COLLECTiEF

ONGOING PERFORMANCE EVALUATION OF THE COLLECTiEF SYSTEM IMPLEMENTED IN THE PILOT CASES (FIRST VERSION M1-M18)

Project acronym: COLLECTiEF

Project title: Collective Intelligence for Energy Flexibility

Call: H2020-LC-SC3-EE-2020-2

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Disclaimer

This document contains a description of the main findings and deliverables of the COLLECTiEF project within the first period of 18 months. COLLECTiEF project has received research funding from European Union's H2020 research and innovation programme under Grant Agreement No 101033683. The contents and achievements of this deliverable reflect only the view of the partners in this consortium and the European Commission Agency is not responsible for any use that may be made of the information it contains.

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Executive Summary

According to the measurement and verification (M&V) protocol developed for the pilot buildings in COLLECTiEF (D5.1), this deliverable reports the progress on the monitoring activities, describes the methodologies applied to assess the performance of the pilots to date, and presents some preliminary analyses using data measured in the buildings and data obtained from calibrated simulations.

This document will be released in 3 updates to report the advancements in the performance assessment in all COLLECTiEF buildings. This first version is thus a partial evaluation that sets the ground for the performance assessment and, using defined key performance indicators (KPIs), provides examples of analyses in some pilots.

The deliverable is structured into five main sections:

1. Smart readiness assessment and indoor environmental quality evaluation criteria
2. Pilot monitoring approach
3. Data management for the evaluation
4. Pilot site modelling and calibration of energy models
5. Simulation based evaluation of pilot performances

The deliverable also presents an annex which shows an overview of the KPIs identified for the assessment, related to the five domains affected by the system implementation (building smartness, energy, indoor environmental quality, climate flexibility and resilience).

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List of Acronyms

AMS	Advanced Measurement Systems
AF	Agility Factor
API	Application Programming Interface
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMS	Building management system
CO_2	Carbon dioxide
CFA	Confirmatory factor analysis
DFF	Demand Flexibility Factor
DSM	Demand Side Management
DR	Demand Response
dTOU	Dynamic Time-Of-Use
EN	European Norm
EFA	Exploratory factor analysis
GOB	Guy Ourisson Building
HDD	Heating Degree Days
HVAC	Heating, Ventilation and Air Conditioning
HAN	Home Area Network
ICC	Intraclass Correlation Coefficient
IEQ	Indoor Environment Quality
ISO	International Standard Organization
KPI	Key Performance Indicators
MV	Measurement and Verification
MS	Member States
P, NREN	Non-renewable primary energy factor
Obj	Objective

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PCA	Principal Component Analysis
PM	Particle Matter
POE	Post-Occupancy Evaluation
PEF	Primary Energy Factor
PCA	Principal component analysis
QoS	Quality of Service
RH	Relative Humidity
RTP	Real time pricing
RQ	Research question
P, REN	renewable primary energy factor
SRI	Smart Readiness Indicator SRI
TOU	Time-Of-Use
VOC	Volatile Organic Compound
WP	Work Package

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1 Introduction

The COLLECTiEF project aims to enhance, implement, test and evaluate an interoperable and scalable energy management system based on Collective Intelligence (CI) that allows easy and seamless integration of legacy equipment into a collaborative network within and between existing buildings and urban energy systems with reduced installation cost, data transfer and computational power while increasing data security, energy flexibility and climate resilience.

The COLLECTiEF system is expected to reach the technology readiness level (TRL) 8, which implies that the system needs to be complete and qualified.

To ensure this achievement, the system will be validated and demonstrated in relevant environments, which include simulation environments, testing and demonstration sites.

In particular, the project plans to test the solutions in a small-scale demonstration site (G2ELAB, France) and 13 large-scale demonstration sites located in three countries characterized by different climatic conditions (Norway, Italy and Cyprus). The chosen pilot buildings have different uses: education, residential, sports, health care, offices and laboratory.

In an effort to evaluate and test the performance of the COLLECTiEF system, several Key Performance Indicators (KPIs) will be calculated using data measured in the pilot buildings and data obtained from calibrated simulations. They will be exploited to assess the impacts deriving from the implementation of the system, which in COLLECTiEF affects five domains: building smart readiness, energy, indoor environmental quality (IEQ), energy flexibility and climate resilience.

According to the Measurement and Verification Protocol developed during the first year of the project and described in deliverable D5.1, the project timeline includes a baseline period from M13 to M24 (before the implementation of the systems) and an assessment period from M25 to M48 (after the implementation). During the two periods, energy and indoor environmental quality data will be measured in the selected thermal zones, where, at the same time, occupants will take part in post-occupancy evaluations by answering questionnaires developed within COLLECTiEF.

The present deliverable reports the progress on monitoring and performance evaluation at M18, describing:

- the status of the installation of the monitoring systems in the demonstration sites;
- the upgrade on the structure and functionality of the data repository;
- the methodological approach used to assess thermal comfort and indoor air quality (IAQ);
- preliminary thermal comfort and IAQ analyses based on available monitored data related to the first months of monitoring;
- the approach used for energy models calibration;
- an example of Smart Readiness evaluation in one pilot building.

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2 Smart readiness and performance evaluation criteria

To evaluate the smart readiness level, the energy and IEQ performance and assess the impacts of the COLLECTiEF systems in the pilot sites several parameters and KPIs, according to literature and international standards, have been identified. They are related to the five domains affected by the system implementation (building smartness, energy, indoor environmental quality, climate flexibility and resilience) and are described in detail in deliverable D5.1. Further details can be found in the Annex 1 of the present deliverable.

The KPIs will be calculated using data measured in the pilot buildings and/or data obtained from calibrated simulations. No measured data are necessary for the assessment of building smartness, since the SRI evaluation is inspection-based. The list of KPIs used to assess the mentioned impacts might be updated throughout the project in relation to the development of the system and to the necessity to better investigate and express its potential.

During the baseline, the KPIs will be used to assess the performance of the pilots before the implementation of the COLLECTiEF systems. After M24, the same KPIs will be calculated and compared to measure the impacts.

Table 1 shows a summary regarding the availability of data collected in the 14 pilots at M18.

Table 1 Collected data in the Pilots at M18

Id	Pilot	Location	Collected Data	Starting date	Notes
B1	Eidet Omsorgssenter	Norway	Sphensor data	2022-08-26	
			POEs	2022-07-02	13 POEs
			Energy data (including data from RES)	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B2	Ellingsøy Idrettshall	Norway	Sphensor data	2022-08-26	
			POEs	2022-07-04	15 POEs
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B3	Flisnes Barneskole	Norway	Sphensor data	2022-08-26	
			POEs	2022-07-04	1 POE
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B4	Hatlane Omsorgssenter	Norway	Sphensor data	2022-08-26	
			POEs	2022-07-15	9 POEs
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B5	Moa Helsehus	Norway	Sphensor data	2022-08-26	
			POEs	2022-07-21	8 POEs
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-09-01	
			Outdoor weather data		API that can call historical data
B6		Norway	Sphensor data	2022-08-26	

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	Spjelkavik Ungdomskole		POEs	2022-07-19	169 POEs
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B7	Tennfjord Barneskole	Norway	Sphensor data	2022-08-26	
			POEs	2022-08-23	305 POEs
			Energy data	2022-06-01	Available through on the portal ElHub
			BMS data	2022-08-05	
			Outdoor weather data		API that can call historical data
B8	Green'ER	France	Sphensor data	2022-08-26	
			POEs	2022-08-26	67 POEs
			- Thermal power metering (supply and return temperatures, flow rates, power and energy), - Electrical power metering - Temperatures and flow rates of air handling unit - PV production	2015	
			Outdoor weather data		High accuracy weather station on the roof of the building. Data is available for COLLECTiEF and will be open data in 2023
B9	Guy Ourisson Building (GOB)	Cyprus	Sphensor data	2022-08-26	
			POEs	2022-07-25	92 POEs records
			Energy data from: - Smart meters: measuring building overall consumption, and consumption at load level (lighting & plugs, HVAC units) - Smart thermostat (only one Ecobee test device is installed)	2022-11-01 (smart meters) 2022-11-15 (smart thermostat)	

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			Outdoor weather data	2021-06-01	- Local weather station (private) - Open API - Meteostat (public)
B10	Graduate School (GS)	Cyprus	Sphensor data	2022-08-29	
			POEs	2022-07-21	8 POEs records
			Energy data from: - Smart meters: measuring building overall consumption, - Smart thermostat (only one Sensibo test device is installed)	2022-11-01 2022-11-15	
			Outdoor weather data	2021-06-01	- Local weather station (private) - Open API - Meteostat (public)
B11	Novel Technologies Laboratory (NTL)	Cyprus	Sphensor data	2022-08-26	
			POEs	2022-07-25	32 POEs records
			Energy data from: - Smart meters: measuring building overall consumption, and consumption at load level (lighting & plugs, HVAC units) - Smart thermostat	2022-11-01 (smart meters) Not connected yet (smart thermostat)	
			Outdoor weather data	2021-06-01	- Local weather station (private) - Open API - Meteostat (public)
B12 B13 B14	Common information for all three Italian pilots: - Valsesia Tower C2 - Valsesia Tower C3 - Valsesia Tower C4	Italy Italy Italy	Sphensor data	2022-08-26	
			POEs	2022-07-08	2 POEs (Tower C2)
				2022-07-07 (QR code distribution)	0 POEs (Tower C3)
				2022-09-28	8 POEs (Tower C4)
			Energy data from: - Heat cost allocators (flat level, daily), and related web portal for data gathering (system and components from company ISTA)	01.06.2022 01.06.2022	

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			- Heat meter (building level, 15 min, one meter per each building) and related software and connection for data gathering (system and components from company COSTER) - Smart plugs - Smart valves Energy bills	not connected not connected requested to the flat occupants, gathering process ongoing	Almost all the smart plugs and the smart valves have been installed, some issues with the WiFi network and their configuration are being tackled by Teicos and R2M, with the support of LSI and E@W.
			Outdoor weather data	01.06.2022	Opt 1. ARPA weather station – Milano Lambrate Opt. 2 Corsico Opt 3. Onsite + outdoor air temperature sensor (data accessible via Coster)

In this deliverable, in the evaluation of performances, we will focus on the assessment of the indoor environmental quality since, at this stage of the project (M18), the data from Sphensors and POEs are already available in the pilots and others are in the commissioning phase.

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2.1 Smart readiness

The smart readiness of buildings is the capability of buildings (or building units) to adapt their operation to the occupant's needs, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility).

The method for calculating the SRI is based on the multi-criteria assessment method defined in Commission Delegated Regulation (EU) 2020/2155, which builds on assessing the smart ready services present in a building. The calculation methodology is structured amongst nine technical domains and seven impact criteria. For each of the services, several functionality levels are defined. A higher functionality level reflects a "smarter" implementation of the service, which generally provides more beneficial impacts to building users or the grid than services implemented at a lower functionality level.

The smart readiness assessment in COLLECTiEF will be carried out following the detailed method B, which is suggested for buildings with a high level of complexity (e.g., large non-residential buildings, large multi-family homes).

At this project stage, we developed the analysis in one of the pilot buildings in Norway, the Eidet Omsorgssenter (B1). The study is reported in chapter 2.1.1.

2.1.1 SRI assessment in Eidet Omsorgssenter, Ålesund, Norway

I. Introduction

The *Smart Readiness Indicator* was born as a consequence of the need for new tools to speed up the building renovation investments and the integration of cutting-edge ICT-based technology to optimize energy efficiency, demand flexibility and improvement of user comfort in the buildings.

II. Building Information

In the present document, Eidet Omsorgssenter has been used as a case of analysis for the SRI methodology. The building corresponds to a healthcare center of 7039 m^2 and four floors, and it is property of Ålesund Municipality. Among the systems that are possible to find in the building, we have a heat pump system (borehole) for heating and sanitary water services supported by solar collectors, decentralized heating through radiators in the patients' rooms, a centralized ventilation system through Air Handling Units (AHU) at a suitable temperature, and PV generation.

a. Assessment Information

Version SRI	4.4
Assessor Name	NTNU
Email address	-
Telephone number	-
Assessment date	05-09-2022

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b. General Information

The selected building type and usage will be used to select the appropriate weighting factors, which can, for example, reflect the differences in the relative importance of domains such as domestic hot water or cooling depending on the use of the building.

For version 4.4, no differentiation has been made in the default weighting factors within a building type (all non-residential buildings currently use the same weighting factors).

Building Name	Eidet Omsorgssenter
Building type	non-residential
Building usage	non-residential - healthcare
Location	Norway
Climate zone:	*North Europe*
Total useful floor area of the building	1.000 - 10.000 m²
Year of construction	> 2010
Building state	Original
Description	-
Address	Trolldalssletta 12, 6264 Tennfjord

III. Methodology

In the present section, a brief explanation of the methodology used in the SRI framework will be explained. For further information, it is recommended to read the support documentation to the Excel sheet calculation: '*Practical Guide Sri Calculation Framework V 4.4*'.

a. Methodology Selection

The user can specify the settings used for the calculation in this part. In some instances, these inputs might be predefined (e.g., the weights).

Selected methodology for the SRI assessment.

Preferred weightings	Default
Preferred services catalogue	B

The domains may be '*Present*', *'Absent-mandatory'* and *'Absent- not mandatory'.*

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Technical systems present in the building.

Domain	Present?
Heating	Present
Domestic hot water	Present
Cooling	Absent – not mandatory
Ventilation	Present
Lighting	Present
Dynamic building envelope	Present
Electricity	Present
Electric vehicle charging	Absent – not mandatory
Monitoring and control	Present

b. Calculation Sheet

In this part, each domain is broken down into different services where the assessment takes place. The methodology applied in the evaluation, considering each service, is the following:

- Define if the service applies to the building.
- Define the functionality level (in most cases, values between 0 to 4, where 0 represents no-smartness and 4 represents the maximum achievable level).
- Specify if a service considers a shared functionality level (in percentage).
- Define the functionality level of the shared service.

For the actual building, the functionality levels for each service and domain are presented in Annex 2, while the expected modifications are shown in Annex 4.

IV. Results

In the present section, the overall results of the SRI assessment are shown for the actual conditions of the building and its expected improvement.

a. Current Status

The total SRI score considers the domain and impact weightings. For this building, the SRI class corresponds to 'E' on a scale of seven letters where 'A' indicates the maximum level of smartness and 'G' the minimum level of smartness.

Overall SRI of the building in the current status.

Total SRI score	38%
SRI Class	E

Regarding aggregated scores (see Annex 3: Scores – Current Status for more details), the current smartness levels are addressed more towards building functionality and user comfort than its integration and flexibility with the electrical grid.

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Key functionality score of the building in the current status.

Key functionality	Score
Building	50 %
User	53 %
Grid	13 %

i. Impact Scores

Considering the impact scores of the buildings, there is room for improvement, in terms of smartness, in all the categories. Still, it is especially noticeable the low score in *'Energy Flexibility and Storage',* where the *COLLECTiEF Project* is targeting its work (see Figure 1).

Impact scores of the current status of the building.

Impact	Score
Energy efficiency	57 %
Energy flexibility and storage	13 %
Comfort	72 %
Convenience	45 %
Health, well-being and accessibility	63 %
Maintenance and fault prediction	42 %
Information to occupants	34 %

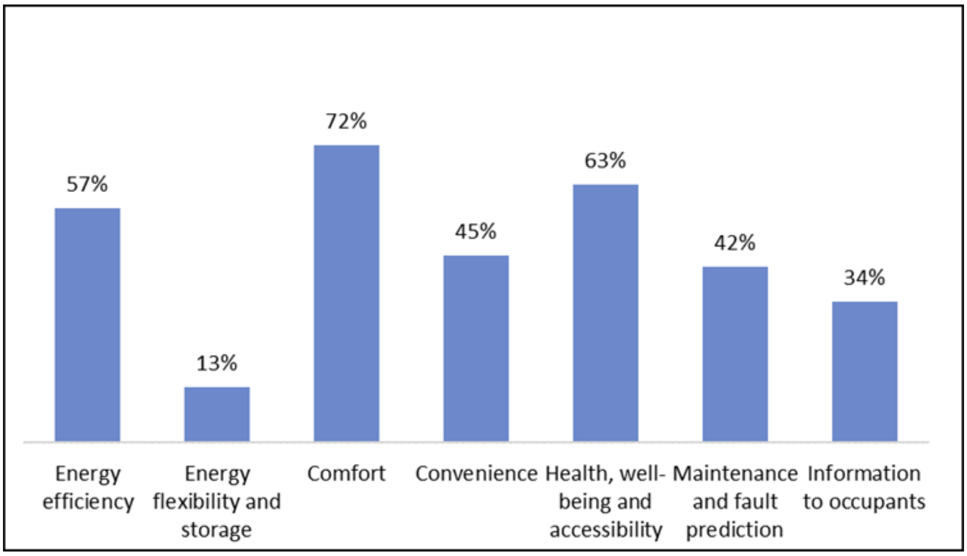

Figure 1 Impact scores of the current status of the building.

ii. Domain Scores

Accordingly, the domain scores show relatively good smartness levels in domains such as *ventilation* and *lighting* but low levels in domains as *heating*, *electricity*, *monitoring and control*. A special case

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is *Monitoring and Control, which* is directly related with the energy flexibility impact score, where *COLLECTiEF* can improve with the development of its work (see Figure 2).

Domain scores of the current status of the building.

Domain	Score
Heating	38 %
Domestic hot water	45 %
Cooling	0 %
Ventilation	68 %
Lighting	83 %
Dynamic building envelope	0 %
Electricity	22 %
Electric vehicle charging	0 %
Monitoring and control	31 %

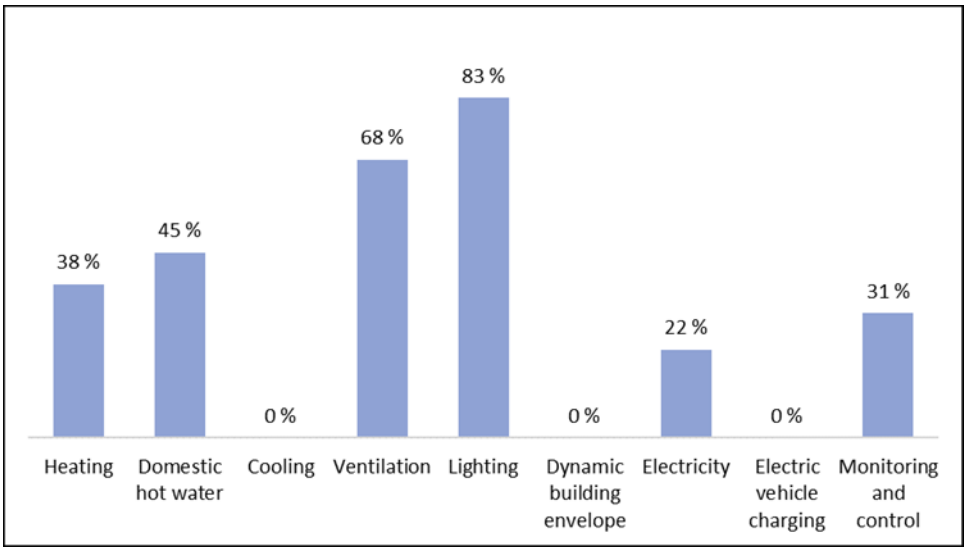

Figure 2 Domain scores of the current status of the building.

b. Expected Results

Considering the possible improvements in the services that *COLLECTiEF project* can achieve (see Annex 5 Scores – Expected Status for further details), the *Total SRI Score* increased from 38% to 59%, which represents an increase of one level in the *SRI class*, from 'E' to 'D'.

Overall SRI of the building with the flexibility measures applied.

Total SRI score	59 %
SRI Class	D

As it is possible to observe in the aggregated scores, building and user functionality shows a slight increase in their score of 7% and 11%, respectively. Moreover, the major impact is in the grid score, when it passes from 13% to 56%, with the measures expected to be applied in the context of this project.

Key functionality score of the building with the flexibility measures applied.

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Key functionality	Score
Building	57 %
User	64 %
Grid	56 %

i. Impact Scores

The detailed *impact scores* increase in all the topics, except *Maintenance and Fault Prediction*, but is noticeable the increase in *Energy Flexibility and Storage*, where the score improves up to 56%, in comparison with the previous 13% with the current conditions of the building (See Figure 3).

Domain scores of the expected status of the building.

Impact	Score
Energy efficiency	62 %
Energy flexibility and storage	56 %
Comfort	76 %
Convenience	67 %
Health, well-being and accessibility	63 %
Maintenance and fault prediction	52 %
Information to occupants	51 %

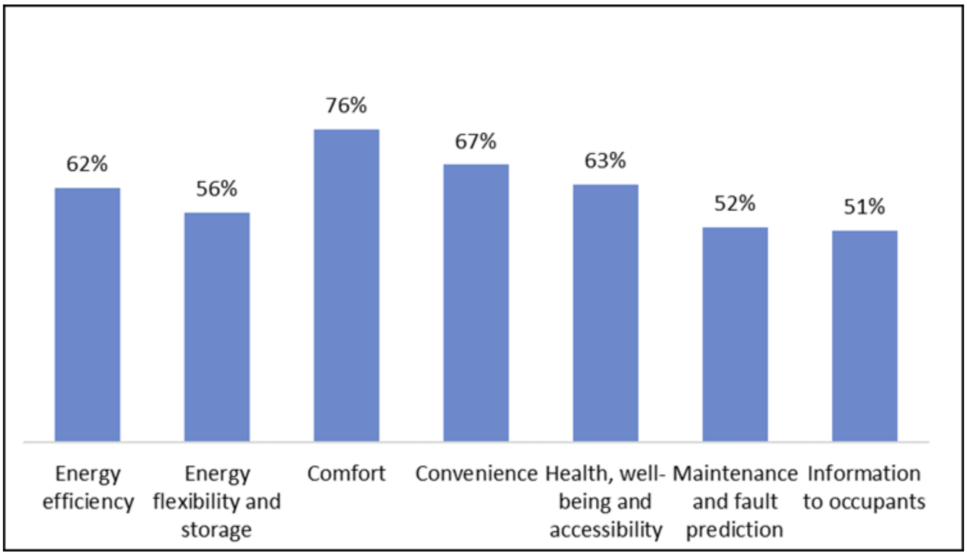

Figure 3 Domain scores of the expected status of the building.

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ii. Domain Scores

The improvement in *Energy Flexibility and Storage* main score is mainly given by the increase in the Monitoring and Control domain score, which passes from 31% to 66% (see Figure 4).

Domain scores of the expected status of the building.

Domain	Score
Heating	53 %
Domestic hot water	45 %
Cooling	0 %
Ventilation	68 %
Lighting	83 %
Dynamic building envelope	0 %
Electricity	54 %
Electric vehicle charging	0 %
Monitoring and control	66 %

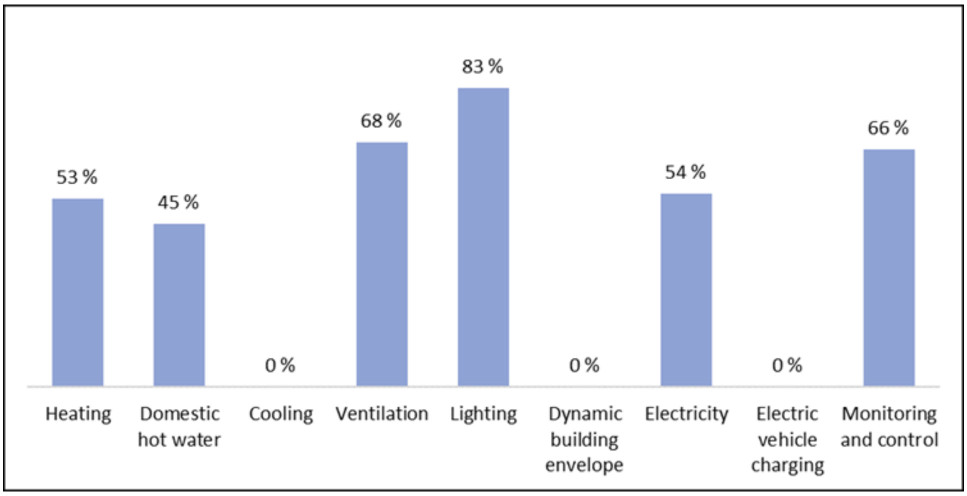

Figure 4 Domain scores of the expected status of the building.

V. Conclusions

The application of the SRI methodology in *Eidet Omsorgssenter* under its current status shows a low smartness level (E score), which has the potential to improve up to one level (D score) after the implementation of the *COLLECTiEF system.*

The lowest points in the impact score of the building correspond to the *Energy Flexibility and Storage* impact score, which are dependent mainly on the *Monitoring and Control* domain score. Thus, the expected improvements primarily shown in the *Monitoring and Control* domain score (from 31% to 66%) have an impact on the *Energy Flexibility and Storage* impact score, increasing from 13% to 56%.

Along the same line, with the expected modifications that can be deployed with the *COLLECTiEF project,* the grid integration score of the building will significantly increase from 13% to 56%, also having the same increase as the *Energy Flexibility* score.

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2.2 Thermal comfort

In COLLECTiEF, the evaluation of indoor thermal comfort, one of the aspects of IEQ, will be based on:

- physical measurements of indoor thermal comfort parameters (indoor air temperature and relative humidity) obtained through the Sphensor units;
- subjective methods based on the occupants' feedback collected through the POE questionnaires developed within the project.

For the thermal comfort assessment, we will consider Fanger's thermal comfort model, often referred to as the PMV/PPD model, the adaptive comfort model, and the ASHRAE Likelihood of Dissatisfaction (ALD) [1].

Starting from the work of Fanger in the 1970s, who used climate chambers to assess the thermal sensation of individuals, a steady-state model is defined that depicts specific ranges of thermal conditions where human beings can feel comfortable. The model employs a heat balance approach, taking into consideration records of metabolic rate, clothing, air temperature, air velocity and humidity. The resulting predicted mean vote (PMV) index represents the average conditions where the majority of a group of people can experience thermal neutrality, without feelings of thermal discomfort. Stemming from the PMV, the predicted percentage of dissatisfied (PPD) can also be calculated, indicating individuals feeling slightly or severely thermally uncomfortable ([2], [3]). In particular, the PMV model considers only indoor conditions and has been used as the basis for international standards such as ISO 7730 [4], EN 15251 [5] , EN 16798 [6], and ASHRAE 55 [7].

Field studies developed after the introduction of the PMV model showed that thermal comfort could be achieved across a broader range of temperatures. This led to a second line of evaluation of indoor thermal comfort, on the principles of adaptive behavior. Based on this approach, when indoor conditions become unfavorable, building users may react to restore their thermal comfort, with actions classified broadly into three categories: behavioral adjustment, physiological adaptation and psychological adaptation [8]. This allows users to feel comfortable at higher or lower temperatures than estimated using the PMV, highlighting the potential of naturally ventilated buildings to offer a higher thermal satisfaction level than air-conditioned buildings [3]. The main difference between the steady-state and adaptive models is therefore the authority afforded to users to adapt their actions, since PMV assumes the passive behavior of occupants. The dynamic nature of this methodology has since been incorporated into international standards, including those mentioned above.

Thermal comfort is subjective to humans; therefore, Post-Occupancy Evaluation (POE) is used to assess the interactions between objective data (spot-measured, monitored) and subjective data (questionnaires, interviews, surveys). These data types are used to draw a comprehensive picture of the actual use and usability of the buildings, perceived as complex and interactive systems, including the physical building attributes, incorporated mechanical and other systems and equipment, and the actual use by their occupants. The POE questionnaires have been developed according to the standard ISO 10551 [9], which describes the subjective judgement scales, as reported in Table 2.

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Table 2 Stress assessment according to EN ISO 10551:2019

	1	2	3	4	5
TYPE OF JUDGEMENT	**Perception**	**Evaluation**	**Preference**	**Personal acceptability**	**Personal tolerance**
Subject under judgement	**Personal state**			**Physical ambience**	
Wording	"How do you feel (at this precise moment)?"	"Do you find it…..?"	"Please state how you would prefer to be now"	"How do you judge this environment (local climate) on a personal level?"	"Is it…..?"
	7 or 9 degrees	4 or 5 degrees	7 (or 3) degrees	2 category statement form or 4 degrees	5 degrees
e.g., for assessing thermal environments	from COLD (or extremely cold) to HOT (or extremely hot)	from COMFORTABLE to very (or extremely) UN-COMFORTABLE	from (much) COLDER to (much) WARMER	"On a personal level, this environment is for me: Acceptable rather than unacceptable; Unacceptable rather than acceptable" From clearly acceptable to clearly unacceptable	from TOLERABLE to INTOLERABLE

Adopting the scales as presented in Table 2, complemented by a set of questions to characterize the occupant, in COLLECTiEF we have developed the POE questionnaires to (i) understand potential differences in thermal comfort perception and/or use of systems (Section 1), (ii) understand if personal factors may affect the thermal response of a person (Section 2), and (iii) assess the thermal indoor environment (Section 3). Table 3 shows an example of a POE questionnaire in the case of an office use case. Specifically, it presents the questions related to each section and the possible options/scales given to the occupant to choose from. In the following link, you can access an online POE questionnaire-type (it is not connected to a particular zone): https://www.collectief-project.com/office-questionnaire_en**.**The questionnaires have been tailored according to the use of each space, which is categorized as follows:

- office or similar,
- health care,
- residence
- school
- sport facility

A dedicated online POE questionnaire, accessible through a unique QR code printed on a poster, has been designed and distributed in each monitored zone in COLLECTiEF pilot buildings.

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Table 3 Post-Occupancy Evaluation (POE) questionnaire: Office use case

			Options						
Section 1	**Q1**	**Age/Sex**	Young 11-24 years (female/male)	Adult 20-64 years (female/male)	Elderly > 65 years (female/male)	Age group only			
	Q2	**Body dimension**	Underweight (< 18.5)	Normal (18.5-24.9)	Overweight (25-29.9)	Obese (30-34.9)	Extremely Obese (35<)	I prefer not to say	
Section 2	**Q3**	**Clothing**	Shorts Clo 0.36	Casual Clo 0.57 – 0.67	Business casual Clo 0.61	Formal Clo 1.04-1.14	Athletic Clo 0.74	Sleepwear Clo 0.96	I prefer not to say
	Q4	**Activity**	Reclining	Seated quiet	Standing relaxed	Typing	Cooking	House cleaning	Dancing
			Tennis	Running					
	Q5	**Alone or not**	Yes	No					
Section 3	**Q6**	**Feel**	I'm healthy and strong	I'm tired	I feel sick				
	Q7	**Temperature preference**	Lower	Without change	Higher				
	Q8	**Temperature judgment**	Clearly unacceptable	Just unacceptable	Just acceptable	Cleary acceptable			
	Q9	**Temperature find**	Extremely uncomfortable	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Comfortable		
	Q10	**Temperature perceive**	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	
	Q11	**Humidity preference**	Lower	Without change	Higher				
	Q12	**Humidity judgement**	Clearly unacceptable	Just unacceptable	Just acceptable	Cleary acceptable			
	Q13	**Humidity find**	Extremely uncomfortable	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Comfortable		
	Q14	**Open/Closed doors and windows**	Yes, they are closed	No, they are open					
	Q15	**Other sources of discomfort**	Air movement is too low	Air movement is too high	Stuffy air	Too much daylight	Lack of daylight	Glare	Temperature is too high
			Temperature is too low	Humidity is too high (damp)	Humidity is too low (dry)	Background noise is too high	Not enough sound privacy	Noise from ventilation systems	

In the following chapters, we report the methodologies chosen for the analysis of the data and we present examples of application in one of the pilot buildings located in Grenoble, France. Table 4 shows the zone information, such as the zone code selected for the COLLECTiEF project (e.g., B[#building]Z[#zone]), actual room id, room type, and the serial numbers of the Sphensor sensors installed in each zone. Figure 5 presents the plan of the G2ELAB, where the zone code labels the zones.

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Table 4 Zone information for the G2ELAB, Grenoble France

Zone code	Room ID	Room type	Sensor serial number
B08Z01	4A015	Shared office	22040312
B08Z02	4A016	Shared office	22040313
B08Z03	4A017	Shared office	22040314
B08Z04	4A018	Shared office	22040315
B08Z05	4A019	Shared office	22040283
B08Z06	4A014	Student Hall	22040316
B08Z07	4A020	Classroom	22040317 22050331
B08Z08	4A013	Laboratory	22040318 22050332

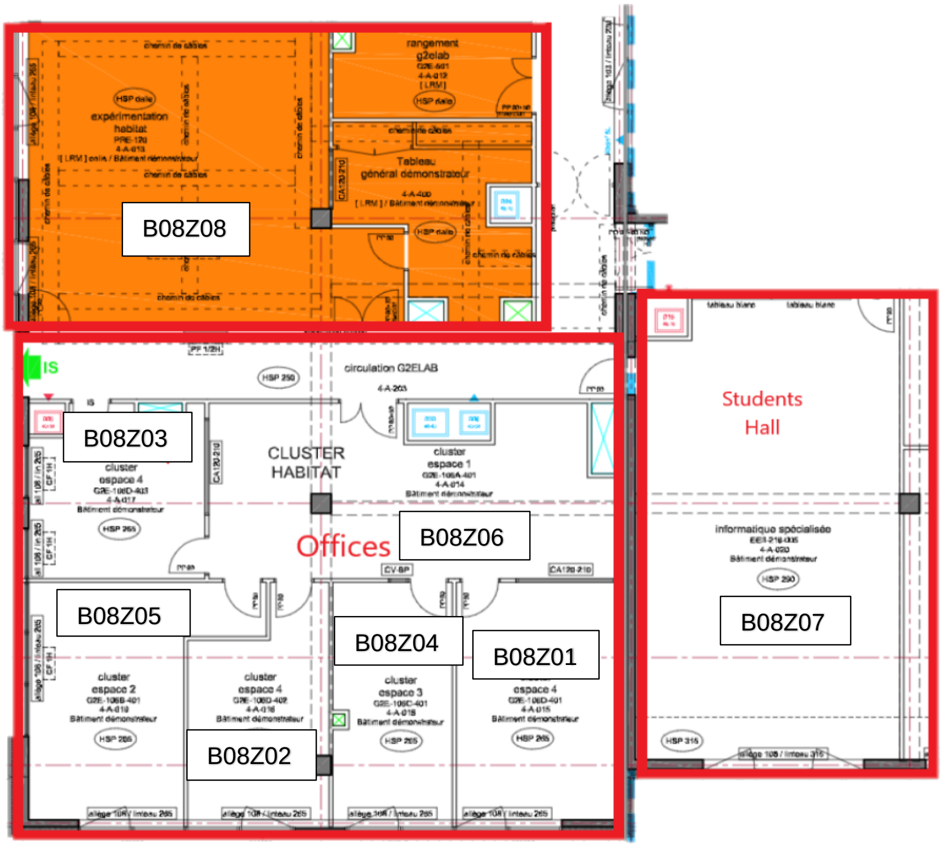

Figure 5 Plan of the G2ELAB

Thermal comfort will be assessed through the following indicators and analyses:

- the PMV/PPD analysis
- the Percentage of time outside a PMV range
- the ASHRAE Likelihood of Dissatisfaction (ALD) analysis
- the Long-term Percentage of Dissatisfaction (LPD) built using both PPD and ALD [10]
- the analysis of thermal acceptability as a result of the POE questionnaires.

It is worth mentioning that for the thermal comfort analysis, we used a portion of G2ELAB zones, i.e., B08Z01-B08Z06; hence, zones B08Z07 and B08Z08 were excluded from the study due to data unavailability.

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2.2.1 PMV/PPD analysis

As described in Chapter 2.2, one of the classical approaches used for analysing the thermal comfort in mechanically heated and/or cooled buildings spaces considers the PMV/PPD indicator. For the subsequent thermal comfort analysis, the *pythermalcomfort* python tool developed by Tartarini and Schiavon [11] is used to calculate the indices PMV and PPD time series. The function that returns the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) calculated in accordance to the main thermal comfort Standards is the following:

pythermalcomfort.models.pmv_ppd(tdb, tr, vr, rh, met, clo, wme=0, standard="ISO"or "ASHRAE")

where

- *tdb* : (float or array-like) dry bulb air temperature, default in [°C] in [°F] if `units` = 'IP'
- *tr* : (float or array-like) mean radiant temperature, default in [°C] in [°F] if `units` = 'IP'
- *vr* : (float or array-like relative air speed, default in [m/s] in [fps] if `units` = 'IP'
- *rh* : (float or array-like relative humidity, [%]
- *met* : (float or array-like) metabolic rate, [met]
- *clo* : (float or array-like) clothing insulation, [clo]
- *wme* : (float or array-like) external work, [met] default 0
- *standard* : {"ISO", "ASHRAE"} comfort standard used for calculation.

For this analysis, the following assumptions and input parameters to the PMV/PPD model are used:

- the room air temperature that is measured by the Sphensors is introduced as the dry bulb temperature (*tdb*) and the radiant temperature (*tr*),
- the relative humidity (*rh*) that is measured by the Sphensors,
- the clothing (*clo*) and metabolic rate (*met*) that are calculated based on the ensembles and activity questions, respectively, reported from the POE questionnaires, and
- the average air speed (*vr*) assumed constant in all rooms, with a value of 0.1 m/s.

Given the aforementioned points, instead of assuming typical levels of activity (met) and typical values of thermal insulation for clothing (clo) as described in EN ISO 7730, the occupant, through the POE questionnaires, provides these parameters asinput information to the PMV/PPD model.

The time period for the thermal comfort analysis is selected based on the current availability of Sphensor and POE questionnaire data given that for the T2.5 of the project, a team is running experiments on the small-scale pilot of the COLLECTiEF that is the G2ELAB (Building no.8) located in Grenoble France. Figure 6 shows the thermal comfort analysis based on the PMV/PDD index for the period 18/09/2022 to 10/10/2022. On the y-axis, the ids of the zones that take part in the experiment, i.e., B08Z01-B09Z06.

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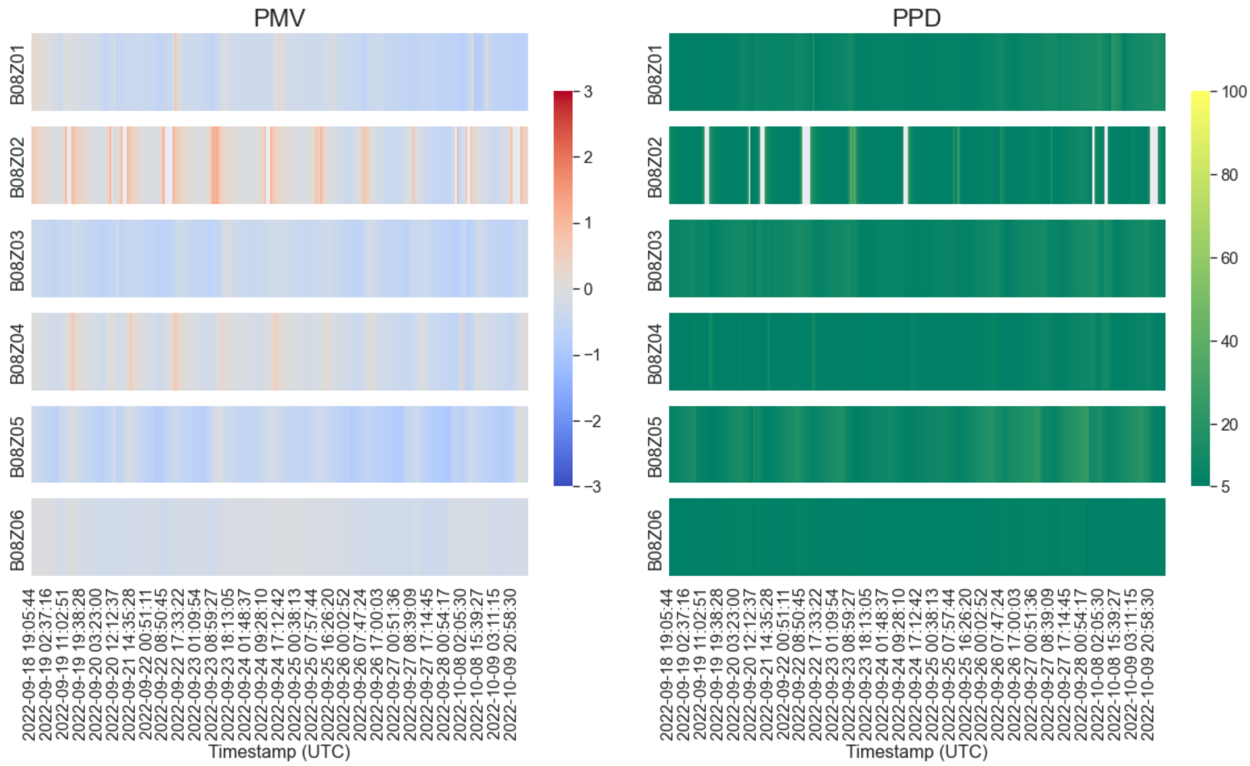

Figure 6 PMV/PDD analysis of the French pilot building located in Grenoble, from 18/09/2022 to 10/10/2022

Based on the assumptions made for the calculation of the PMV/PPD model, for the French pilot building, it can be observed that the model for the majority of the time, estimates that the indoor conditions are orientated mostly on the cold side (i.e., blue colour, negative values) of Fanger's thermal comfort scale. On the right-hand side of Figure 7 , the predicted percentage of dissatisfied (PPD) for the same time period is presented, which estimates the percentage of occupants that are expected to feel thermally uncomfortable.

In the next section, the assessment of the thermal comfort performance based on the PMV/PDD analysis considering the utilization of the space is presented.

2.2.2 Percentage of time outside a comfort range

According to the Method A described in the standard EN ISO 7730:2005 [4], it is necessary to calculate the number or percentage of hours during the hours the building is **occupied**, the PMV or the operative temperature is outside a specified range. When considering the operative temperature ranges, it is possible to apply the Fanger method or the adaptive one. Assuming different criteria for the PPD-PMV, different categories of the indoor environment are established, whose recommended ranges are given in Figure 7. Recommended input values are provided for each of the different categories described in Figure 8.

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Category	Thermal state of the body as a whole	
	PPD %	Predicted Mean Vote
I	< 6	-0.2 < PMV < + 0.2
II	< 10	-0.5 < PMV < + 0.5
III	< 15	-0.7 < PMV < + 0.7
III	< 25	-1.0 < PMV < + 1.0

Figure 7 Recommended categories for the design of mechanical heated and cooled buildings assuming different criteria for the PPD-PMV (source ISO 7730)

Category	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility.
II	Normal level of expectation
III	An acceptable, moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

Figure 8 Description of the applicability of the categories used (EN 16789).

Given the applicability of each category, as presented in Figure 8, the G2ELAB building, whose spaces are mainly used as offices, is assigned to Category II. Therefore for calculating the percentage of time outside of a PMV range we can consider the following condition -0.5<PMV<0.5. Figure 9 illustrates the percentage of time that the PMV/PPD is outside Category II for the French pilot building. Note that for the calculation is assumed that the zones were occupied during the working hours, i.e., 9 am-5 pm, and all PMV time series data beyond that time window were excluded from the calculations.

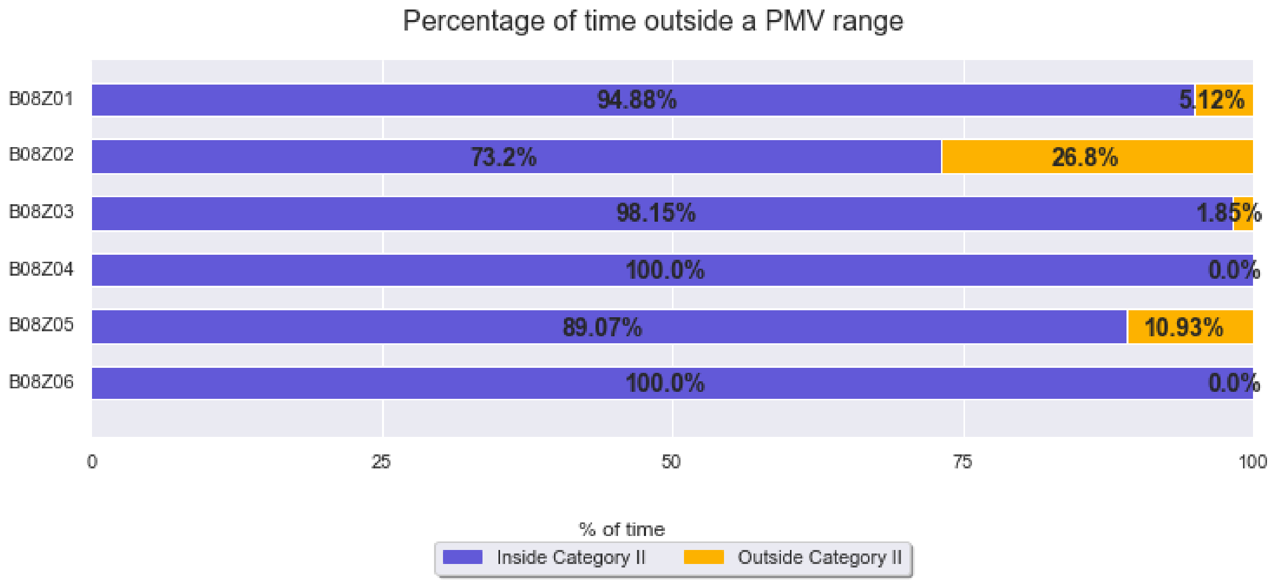

Figure 9 Distribution of percentage of time inside and outside PMV according to the category defined by EN 16789

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From the analysis presented in Figure 9, it can be observed that the zones B08Z01, B08Z03, B08Z04 and B08Z06 show a very good performance with 5.12%, 1.85%, 0% and 0% of the time outside Category II, respectively, while for the remaining zones, i.e., B08Z02 and B08Z05, the performance is lower with percentages varying from 26.8% to 10.93%. This indicator will allow to verify easily the impact of the COLLECTiEF solution on the indoor thermal comfort conditions.

2.2.3 ASHRAE Likelihood of Dissatisfaction (ALD)

The ASHRAE Likelihood of Dissatisfaction (ALD) is a right-here and right-now index based on the ASHRAE adaptive model [1]. It is obtained from a logistic regression of the ASHRAE RP-884 data. The ALD index is validated by the ASHRAE Global Thermal Comfort Database II [12]. Currently, the ASHRAE adaptive thermal comfort model does not have a right-here and right-now index of dissatisfaction, although it does give 80% and 90% acceptability threshold temperatures on either side of the adaptive comfort temperature optimum.

The expression that characterises the ALD index is the following:

$$ALD(\Delta T_{op}) = PPD(\Delta T_{op}) = \frac{e^{\left(-3.057+0.419\Delta T_{op}+0.007\Delta T_{op}{}^{2}\right)}}{1+e^{\left(-3.057+0.419\Delta T_{op}+0.007\Delta T_{op}{}^{2}\right)}}$$

where $\Delta T_{op} = \left|T_{op,in} - T_{ASHRAE}\right|$ is the absolute offset of the indoor operative temperature ($T_{op,in}$) from the ASHRAE optimal operative temperature (T_{ASHRAE}) which is derived from the prevailing mean outdoor air temperature ($t_{pma(out)}$) that is calculated as

$$T_{ASHRAE} = 0.31 \cdot t_{pma(out)} + 17.8$$

The prevailing mean outdoor air temperature ($t_{pma(out)}$) is defined by ASHRAE 55 [13] as the temperature based on the arithmetic average of the mean daily outdoor temperatures over some period of days in accordance with the following:

- It shall be based on no fewer than seven and no more than 30 sequential days prior to the day in question.
- It shall be a simple arithmetic mean of all of the mean daily outdoor air temperatures $T_{mpa(out)}$ of all the sequential days in section A.

Figure 10 shows the outdoor air temperature, the prevailing mean outdoor temperature and the optimal ASHRAE operative temperature for the period between 18th of September and 10^{h} of October at Grenoble, France. Note that for the subsequent analysis the horizon of the 30 sequential days is selected.

Figure 11 shows the calculation of the ALD index for the French pilot building from September 18th to October 10th. It is possible to notice that the rate of dissatisfied people is very low in all the zones, apart from B08Z02. In the next phase of the data analysis we will analyse the results obtained from the calculation of the different KPIs and will compare them with the results coming from the subjective questionnaires.

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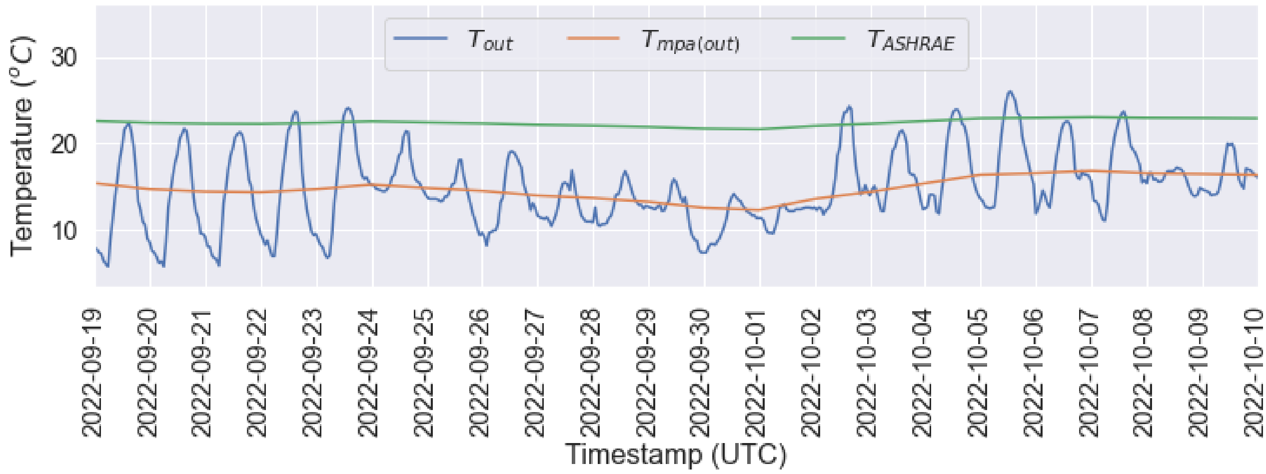

Figure 10 Outdoor air temperature, the prevailing mean outdoor temperature and the optimal ASHRAE operative temperature for the period between 18th of September and 10th of October at Grenoble, France

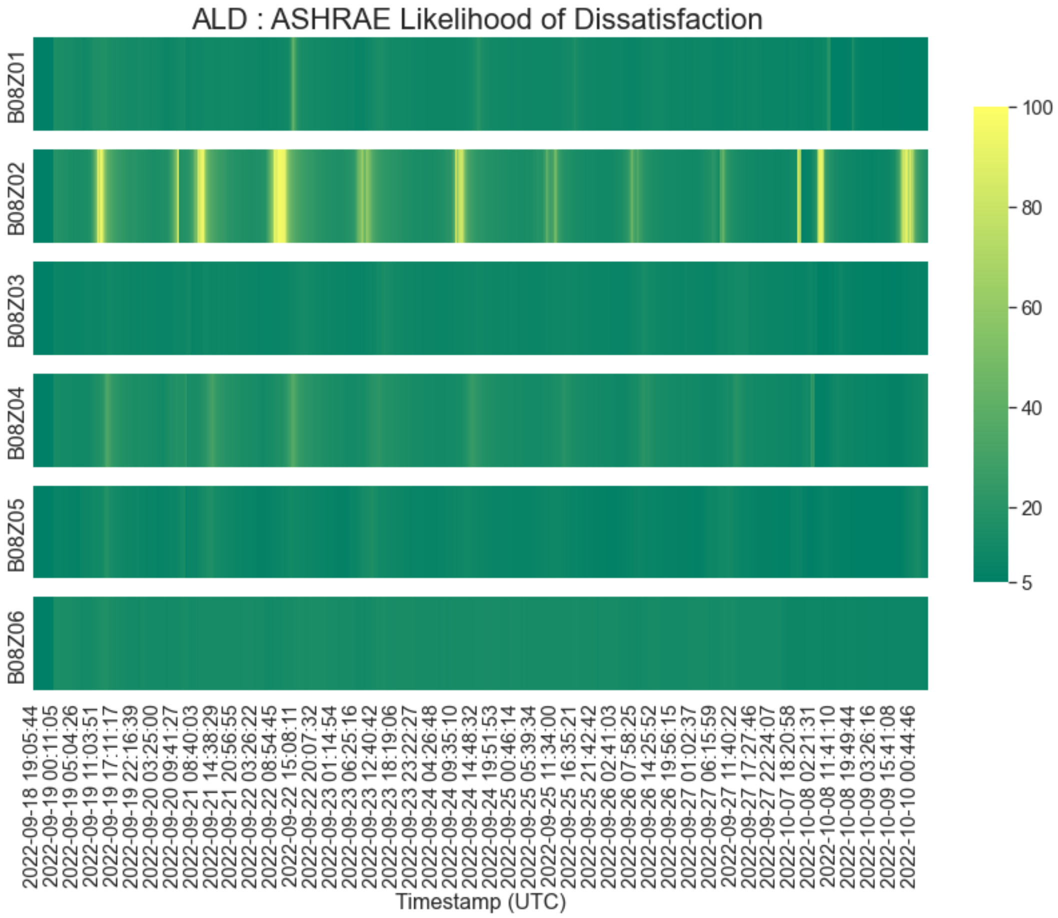

Figure 11 ALD index for the French pilot building for the period from 18th of September to 10th of October

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2.2.4 The Long-term likelihood of dissatisfaction

PPD and ALD are *right-here* and *right-now* metrics useful to assess the specific thermal comfort condition experienced by a large group of people in a given moment and location according to the Fanger and ASHRAE adaptive comfort models, respectively. However, to assess the average performance of a large building in providing comfortable thermal conditions over a longer period of time, long-term thermal discomfort indices should be adopted. For a detailed discussion on this topic, we refer the reader to Carlucci and Pagliano [14]. Furthermore, according to Carlucci [10], a reliable long-term discomfort index should

1. be applicable for both free-running and mechanically cooled buildings, and should be suitable for being used with both the Adaptive and Fanger comfort models (*e.g.,* similarly to *Percentage outside range indices*),
2. reflect the nonlinear relationship between thermal discomfort and the exceedance from the theoretical optimal comfort conditions (*e.g.,* similarly to *Nicol et al.'s overheating risk* and *Average PPD*),
3. evaluate thermal discomfort by putting more focus on the occupants, rather than on building geometry (*e.g.,* similarly to *Exceedance indices*),
4. be applicable to the evaluation of uncomfortable conditions during both summer and winter,
5. allow estimating separately possible uncomfortable conditions due to upper and lower exceedance from theoretical comfort temperature, and
6. be independent of comfort categories.

Moreover, in order to guarantee a reliable thermal comfort assessment, a number of boundary conditions must be clearly specified, like

1. the standard used for the derivation of the operative temperature boundary from *PMV* limits (ISO 7730 or EN 15251), for those indices that use operative temperatures derived from the Fanger model,
2. the method used to calculate the meteorological input data for the ASHRAE optimal comfort temperature in naturally ventilated buildings (monthly or 30-day running mean outdoor air temperature), and
3. the starting and ending days of the calculation period.

To summarize the likelihood of thermal discomfort globally perceived by all occupants (real or hypothetical) of all zones in a building during a certain season, in a single percentage value, the Long-term Thermal Discomfort (LTD) index is adopted. It is a symmetric and comfort-model based index, not depending on comfort categories, and it is applicable to both summer and winter assessments. Its analytical expression accounts for the hourly-predicted Likelihood of Dissatisfied calculated for each zone according to the Fanger, and ASHRAE and European adaptive thermal comfort models, which is weighted for the (actual or design) number of people inside each building zone and is normalized over the total number of the people inside the building and over a specified calculation period.

$$LPD(p,LD) \equiv \frac{\sum_{t=1}^{T}\sum_{z=1}^{Z}\left(p_{z,t}\cdot LD_{z,t}\cdot h_t\right)}{\sum_{t=1}^{T}\sum_{z=1}^{Z}\left(p_{z,t}\cdot h_t\right)}$$

where t is the counter for the time step of the calculation period, T is the last progressive time step of the calculation period, z is the counter for the zones of a building, Z is the total number of the zones, pz,t is the zone occupation rate at a certain time step, LDz,t is the Likelihood of Dissatisfied

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inside a certain zone at a certain time step and ht is the duration of a calculation time step (by default one hour). This index can be used to quantify thermal discomfort during the cold period (C), the warm period (W), or the whole year (Y), due to overheating, overcooling or both, and making reference to the Fanger model, the European adaptive model and the American adaptive model. Its formulations depend on (i) the comfort model, (ii) the calculation period, and (iii) the discomfort type.

Table 5 presents the long-term thermal discomfort using the LPD based on ALD, LPD based on PPD and the percentage of time outside PMV range for the French pilot building.

Table 5 Long-term likelihood of dissatisfaction (LPD)

Zone code	Room type	LPD (%) using ALD	LPD (%) using PPD	Percentage of time outside PMV range
B08Z01	Shared office	9.57	9.26	5.12
B08Z02	Shared office	21.54	21.2	26.8
B08Z03	Shared office	8.65	9.74	1.85
B08Z04	Shared office	12.84	6.5	0
B08Z05	Shared office	8.11	11.57	10.93
B08Z06	Student Hall	12.73	5.89	0

2.2.5 Thermal acceptability analysis through POEs

According to literature [15] and the research developed by Erba within the EU project AZEB [16], it is practice to evaluate thermal acceptability using the following three methods referred to the personal thermal state (Table 2, column 1, 2 and 3):

1. based on ISO 7730 [4], it equals the votes within the central three degrees of the ASHRAE thermal sensation scale (-1: slightly cool; 0: neutral; +1: slightly warm) with 'satisfaction'. This is implicit in the definition of ISO 7730: 'thermally dissatisfied people are those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale'. Thermal acceptability can be thus assessed according to the standard of ASHRAE 55-92, which specifies that the thermal acceptability should be defined as the condition where 80% of occupants vote for the central three categories (−1,0,1).
2. Based on the comfort scale 'evaluation' and following ISO 10551, it assumes that subjects who vote 'comfortable' are satisfied. It has been proposed [17] to extend the acceptability to 'slightly uncomfortable'.
3. It assumes that only subjects who want 'no change' on the 'thermal preference' scale are satisfied with the thermal environment.

In addition, thermal acceptability can be evaluated directly from the answers related to the thermal ambience which investigates the personal acceptability.
Table 6 presents the classification method of the POE voting options followed for the thermal acceptability analysis.

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Table 6 Classification of POE voting options

	Acceptable	Unacceptable
Perceptual (Q10 in the COLLECTiEF questionnaire)	Slightly cool/warm Neutral	Cold, Cool, Warm, Hot
Affective evaluation (Q9 in the COLLECTiEF questionnaire)	Slightly comfortable Comfortable	Extremely uncomfortable Very uncomfortable
Thermal preference (Q7 in the COLLECTiEF questionnaire)	Without change	Lower Higher
Personal acceptability (Q8 in the COLLECTiEF questionnaire)	Just acceptable Clearly acceptable	Clearly unacceptable Just unacceptable

However, the topic is still under investigation to gain a more profound knowledge of the contextual influences affecting the interpretation of thermal perception scales and their verbal anchors [18].

Figure 12 and Figure 13 present the POE data related with thermal comfort for the period between 18th of September and 10th of October for the French pilot building in the form of percentage of observations.

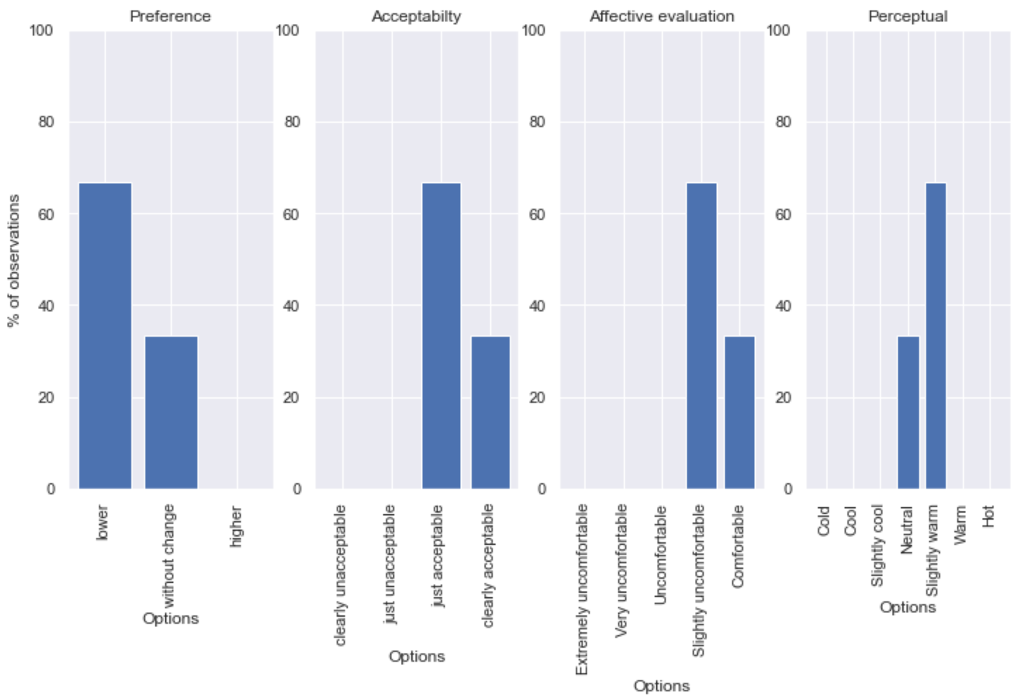

Figure 12 Thermal comfort assessment of zone B08Z01 based on POE data

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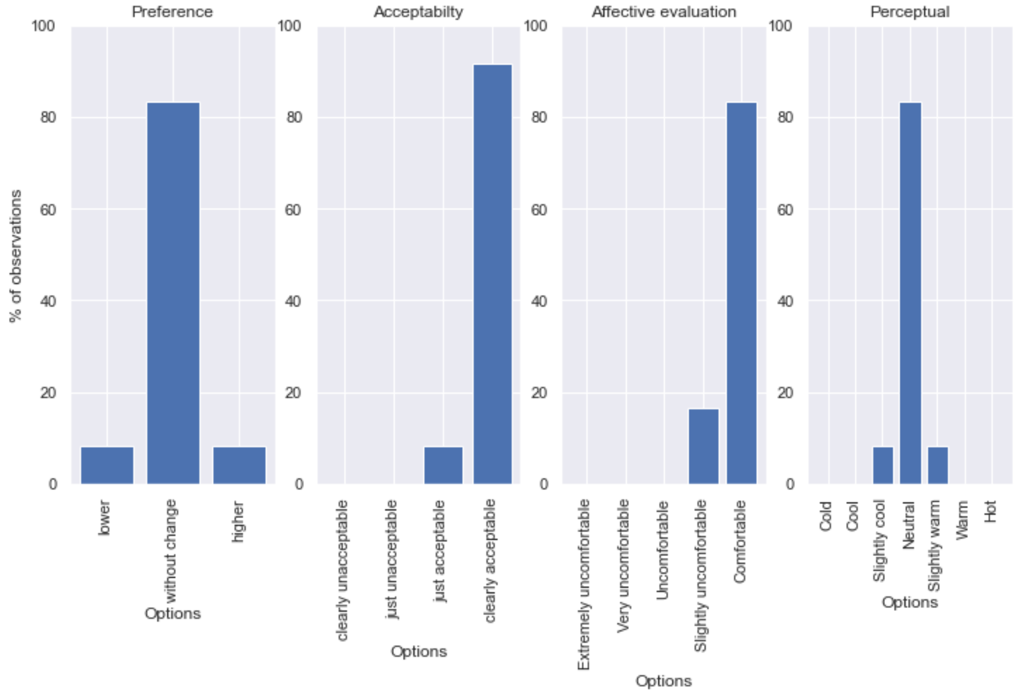

Figure 13 Thermal comfort assessment of zone B08Z04 based on POE data

Figure 14 and Figure 15 show examples of the evaluation of thermal acceptability according to the personal thermal state (thermal preference, perception and evaluation and the thermal ambience (personal acceptability). In this example, the thermal acceptability inferred from perception and evaluation provides the same result as the question investigating thermal ambience, highlighting complete acceptability of the thermal environment. Differently, the feedback collected from the thermal preference shows relevant users' dissatisfaction.

These results highlight that investigating thermal comfort only through one question might not be enough since it might lead to misleading results.

This methodology will be investigated in detail in the following phases to improve the comprehension of the occupants' feedback.

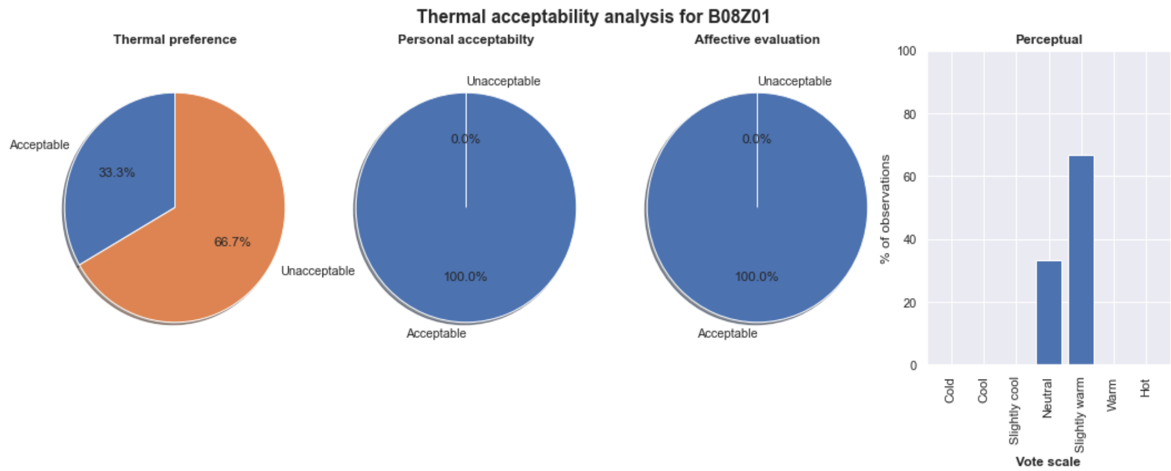

Figure 14 Thermal acceptability analysis for B08Z01

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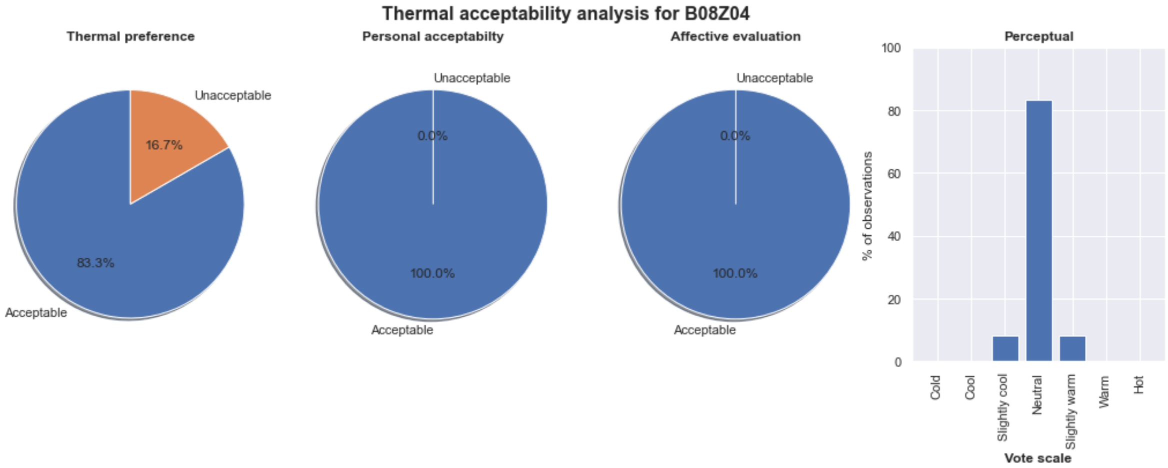

Figure 15 Thermal acceptability analysis for B08Z04

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2.3 Indoor air quality

Indoor Air Quality (IAQ) is the quality of air inside enclosed spaces. It refers to the types and concentrations of airborne contaminants found in buildings that are known or suspected to affect people's comfort, well-being, health, learning outcomes and work performance. The 2020 global Covid-19 pandemic has catalysed attention and awareness of the importance of IAQ.

According to the ANSI/ASHRAE Standard 62.1-2022 [19], acceptable IAQ is the air in which there are:

- no known contaminants at harmful concentrations, as determined by cognizant authorities,
- and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

Health effects from indoor air pollutants may be experienced soon after exposure or years later. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Other health effects may show up years after exposure has occurred or only after long or repeated periods of exposure. These effects, including respiratory diseases, heart disease and cancer, can be severely debilitating or fatal. It is prudent improving indoor air quality even if symptoms are not noticeable.

At the European Community level, the resolution of 13 March 2019 [20] defends "Clean air for everyone", highlighting that people spend almost 90% of their time indoors. Besides, it calls on the Commission and the Member States to support research, development and certification at the EU level for innovative **smart multi-sensor systems** for both indoor and outdoor air quality monitoring, stresses that **smart air quality monitoring systems** can be a viable tool for citizen science, and also of special benefit for people suffering from asthma and cardiovascular diseases.

Indoor air is a complex mixture with typically more than 200-300 pollutants. These pollutants can be classified as gaseous compounds, also called chemical or molecular pollutants (inorganic gases and Volatile Organic Compounds (VOCs)), non-viable particles (Particulate Matter with aerodynamic diameter lower than 10 μm and 2.5 μm - PM_{10} and $PM_{2.5}$ respectively) and bio-contaminants (fungi and bacteria) [21,22].

In COLLECTiEF, the indoor air quality is evaluated through the data measured by the Sphensor units PRMPA0423, which are multiparameter data logger radio sensors which measure carbon dioxide, total volatile organic compounds and particulate matter. Table 7 reports the list of IAQ parameters and related units of measurement, collected in COLLECTiEF pilot buildings.

Table 7 IAQ parameters measured through the Sphensor units PRMPA0423

Name	Acronym	Unit of measurement
Carbon dioxide	CO_2	ppm
Total Volatile Organic Compound	TVOC	ppb
Particulate matter 1	PM1	μg/m^3
Particulate matter 2.5	PM2.5	μg/m^3
Particulate matter 4	PM4	μg/m^3
Particulate matter 10	PM10	μg/m^3

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These sensors are installed only in those rooms where we have either:

- more than one occupant (shared offices, classrooms, meeting rooms);
- fragile persons (self-sufficient elderly and primary school pupils);
- high metabolic activity (sports halls).

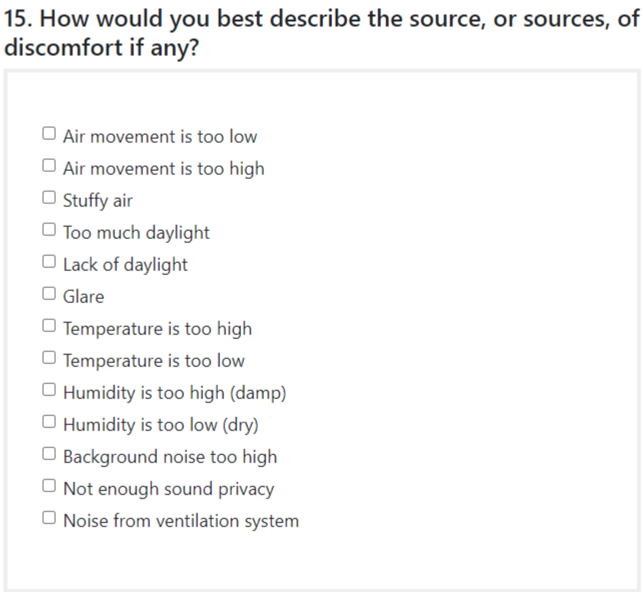
In addition, IAQ is currently being monitored in 5 residential flats (out of 12 apartments) to extend the assessment in private buildings. Monitoring air quality in residential buildings is a less common practice, usually limited to research or demonstration projects.

Relative humidity and temperature are additional parameters that affect the health and perception of IAQ [23]. These parameters are measured by the Sphensors units PRMPB0401 (Table 8).

Table 8 Parameters affecting health and perception of IAQ measured through the Sphensor units PRMPB0401

Name	Acronym	Unit of measurement
Relative Humidity	RH	%
Temperature	T	°C

The evaluation of indoor air quality is also supported by the subjective surveys, which among the questions (mainly related to thermal comfort aspects), ask the occupants to indicate if they perceive "stuffy air" (Figure 16). Additional questions related to IAQ might be proposed to the users in the following stages of the project.


15. How would you best describe the source, or sources, of discomfort if any?

- ☐ Air movement is too low
- ☐ Air movement is too high
- ☐ Stuffy air
- ☐ Too much daylight
- ☐ Lack of daylight
- ☐ Glare
- ☐ Temperature is too high
- ☐ Temperature is too low
- ☐ Humidity is too high (damp)
- ☐ Humidity is too low (dry)
- ☐ Background noise too high
- ☐ Not enough sound privacy
- ☐ Noise from ventilation system

Figure 16 Extract of the subjective questionnaire developed in COLLECTiEF

The information collected both via objective measurements and subjective evaluations will be taken into account in the development of the algorithms which involve the control of the ventilation system and in the definition of specific actions for the occupants (e.g., windows' opening), which will be communicated via the user's platform.

In the following sections are reported guidelines and references related to the assessment of CO_2, TVOC and particulate matter indoor concentrations, providing examples obtained from the analysis of the first data available in the pilot buildings. The next activities will focus on the systematic analysis of the data collected from all the sensors.

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2.3.1 Carbon dioxide CO_2

Carbon dioxide is a colourless and odourless gas. It is a natural component of ambient air, at a concentration in outdoor air, which typically ranges from 400 to 430 ppm (parts per million) depending on the season but can be as high as 600–900 ppm in metropolitan areas [24]. At higher concentrations upwards of 1000 ppm, adverse effects on the general well-being can occur (headaches, fatigue, lack of attention).

The concentration of carbon dioxide is commonly considered a marker of the efficiency of ventilation and air quality when people are in the building. The CO_2 content of the indoor air is thus a direct expression of the intensity of a room's use.

Table 9 reports the effects of different CO_2 concentrations according to REHVA, the Federation of European Heating, Ventilation and Air Conditioning Associations. The upper range of reliable indoor air quality is set at 1000 ppm. Similar thresholds can be found in national guidelines, such as those promoted by the Norwegian Directorate of Health [25] and the Norwegian Working Environment Authority [26], and in literature [23].

Table 9 Effect of different CO_2 concentrations

Concentration	Effect
350 to 450 ppm	Typical atmospheric concentration
600 to 800 ppm	Reliable indoor air quality
1 000 ppm	Upper range of reliable indoor air quality
5 000 ppm	Maximum workplace concentration over 8 hours
6 000 to 30 000 ppm	Critical, only short-term exposure
3 to 8%	Increased breathing frequency, headaches
> 10%	Nausea, vomiting, loss of consciousness
> 20%	Rapid loss of consciousness, death

The standard EN 16798-1 [6] provides the default limit values to calculate the design ventilation rates. These are based on a mass balance formula for the substance concentration in the space, taking into account the outdoor concentration. The standard indicates the categories of indoor environmental quality, which are related to the level of expectations the occupants may have. A normal level would be "Medium". A higher level may be selected for occupants with special needs (children, elderly, persons with disabilities, etc.).

Table 10 EN 16798–1:2019 recommendations for CO_2 concentrations above the outdoor level

	Allowable ppm levels above outdoor levels		
Building use	**Category I**	**Category II**	**Category III**
	High	*Medium*	*Moderate*
School (classroom)	550 ppm	800 ppm	1350 ppm
Office (landscape layout)	550 ppm	800 ppm	1350 ppm
Residential building (bedroom)	380 ppm	550 ppm	950 ppm

The use of the building is relevant on the choice of the CO_2 concentration level. For example, while assembly or conference rooms are, as a rule, only used occasionally and for short periods,

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schoolrooms, in the light of the regular presence of students and teachers over hours, must be viewed as particularly critical regarding the CO_2 concentration in the classroom air.

At this stage of the project, we present, as examples, the preliminary analyses on the data collected in some pilot buildings from September, 18th to September, 28th 2022. The following figures show the measured CO_2 concentrations in the indoor environments and highlight the upper range of reliable indoor air quality (1000 ppm, red line). It is possible to notice the differences between the intended use of the buildings, which are characterised by typical uses of the rooms along the day or the effect of CO_2 controls.

Figure 17 and Figure 18 show the CO_2 concentration in the pilot n°1 (Eidet Omsorgssenter, Norway) in one shared office and in one patient room, respectively. In both cases, the data are always below the limit threshold, due to the presence of controls to CO_2 in the buildings. Differently, Figure 19, which shows the CO_2 concentration in one apartment of the pilot n°12 (Valsesia Tower, Italy), highlights that the 1000 ppm threshold is sometime exceeded. Figure 20 and Figure 21 show the case of two classrooms in the pilot n°6 (Spjelkavik Ungdomsskole, Norway), one during the whole period of analysis (from September, 18th to September 28th 2022) and the other during one single day (September, 23rd 2022), respectively. Also in the case of the school, the CO_2 limit value is exceeded in some events, for several minutes or hours (e.g., about two hours in Figure 21). The registered trend expresses clearly the intensity of the classroom's use along the day.

In the following analyses, we will investigate the correlations with the other measured pollutants, the indoor temperature and relative humidity, the feedback from the occupants' surveys, the outdoor CO_2 level (where available from the weather stations), the differences among the seasons, the ventilation strategies. This information will support the development of the algorithms which involve the control of the ventilation system and will guide the definition of specific actions for the occupants (e.g., windows' opening). Indicators such as the percentage of time above 1000 ppm will be calculated to assess the impact of the implementation of the COLLECTiEF systems on IAQ.

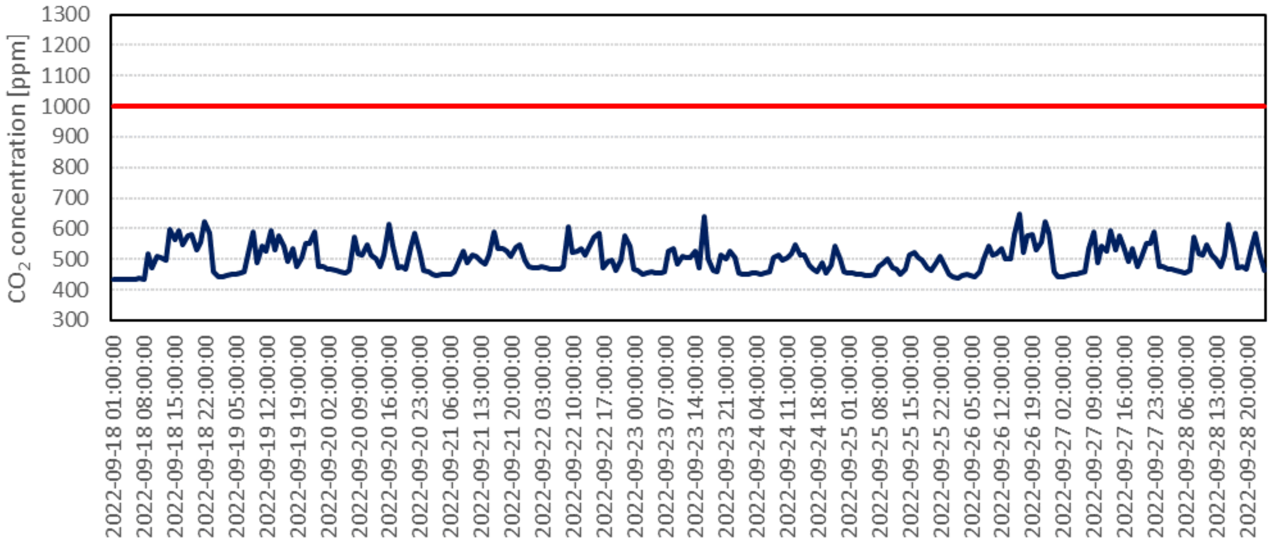

Figure 17 CO_2 concentration from September 18th to September 28th 2022, in one shared office of the pilot n°1 (Eidet Omsorgssenter, Norway)

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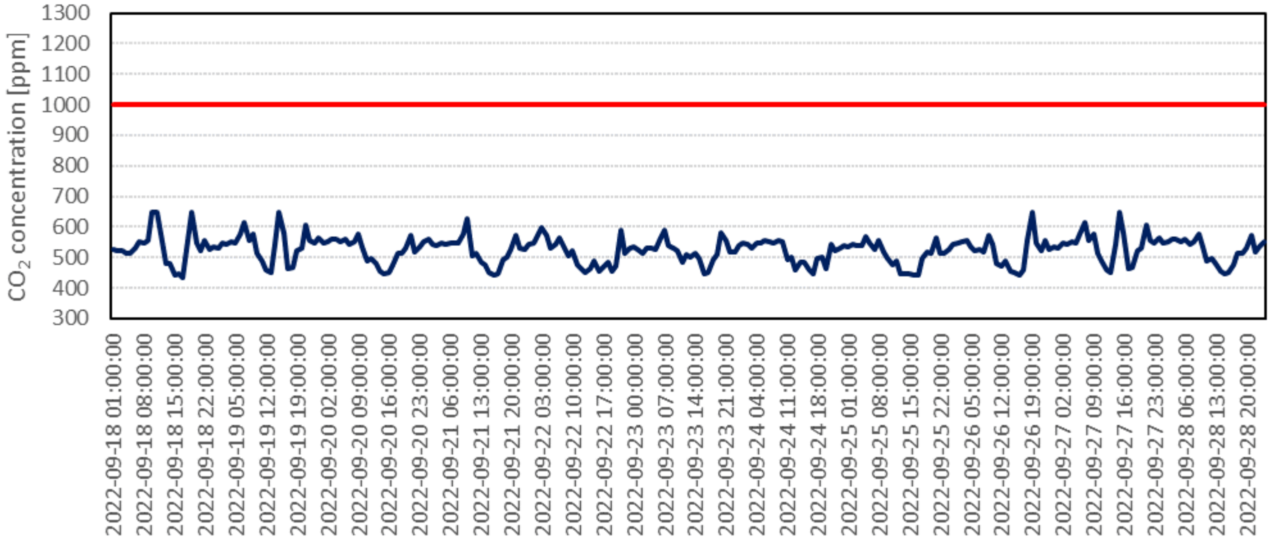

Figure 18 CO_2 concentration from September 18th to September 28th 2022, in one patient room of the pilot n°1 (Eidet Omsorgssenter, Norway)

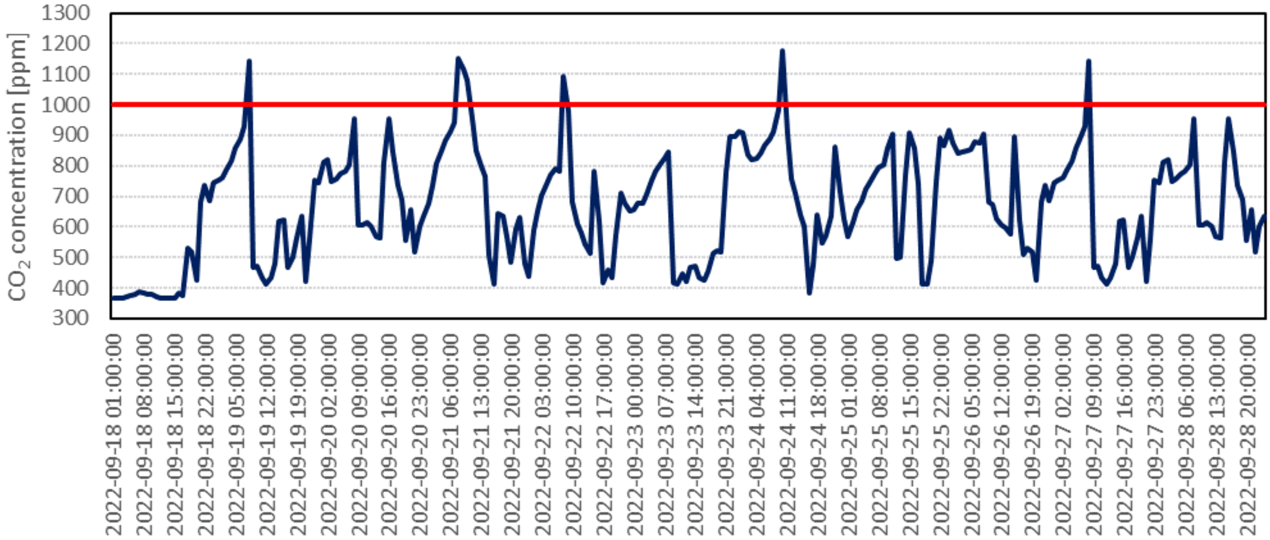

Figure 19 CO_2 concentration from September 18th to September 28th 2022, in one apartment of the pilot n°12 (Valsesia Tower, Italy)

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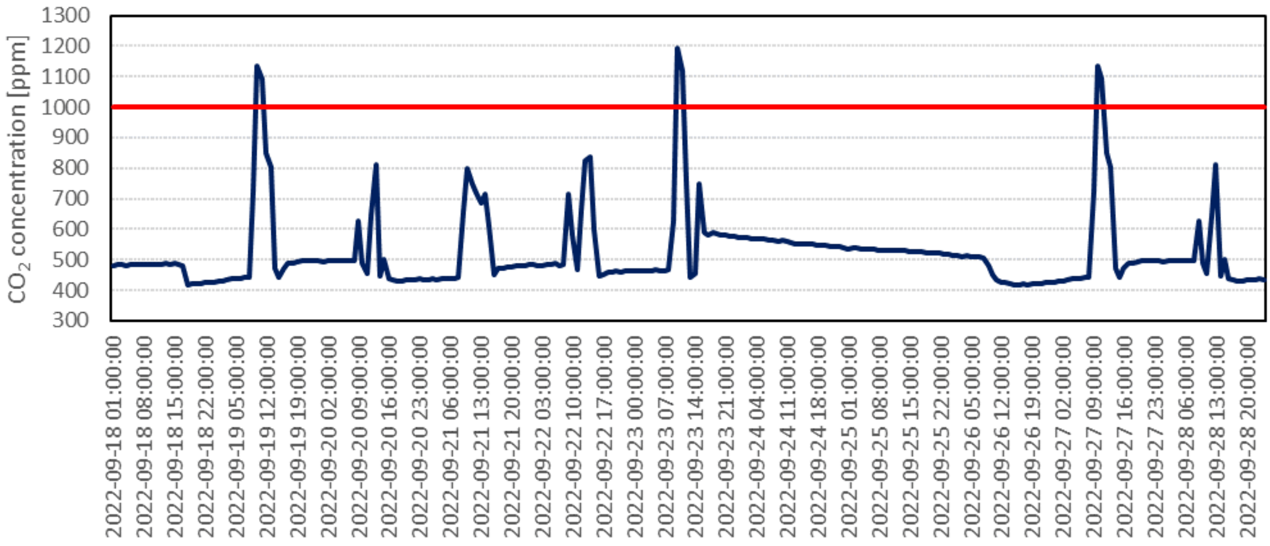

Figure 20 CO_2 concentration from September 18th to September 28th 2022, in one classroom of the pilot n°6 (Spjelkavik Ungdomsskole, Norway)

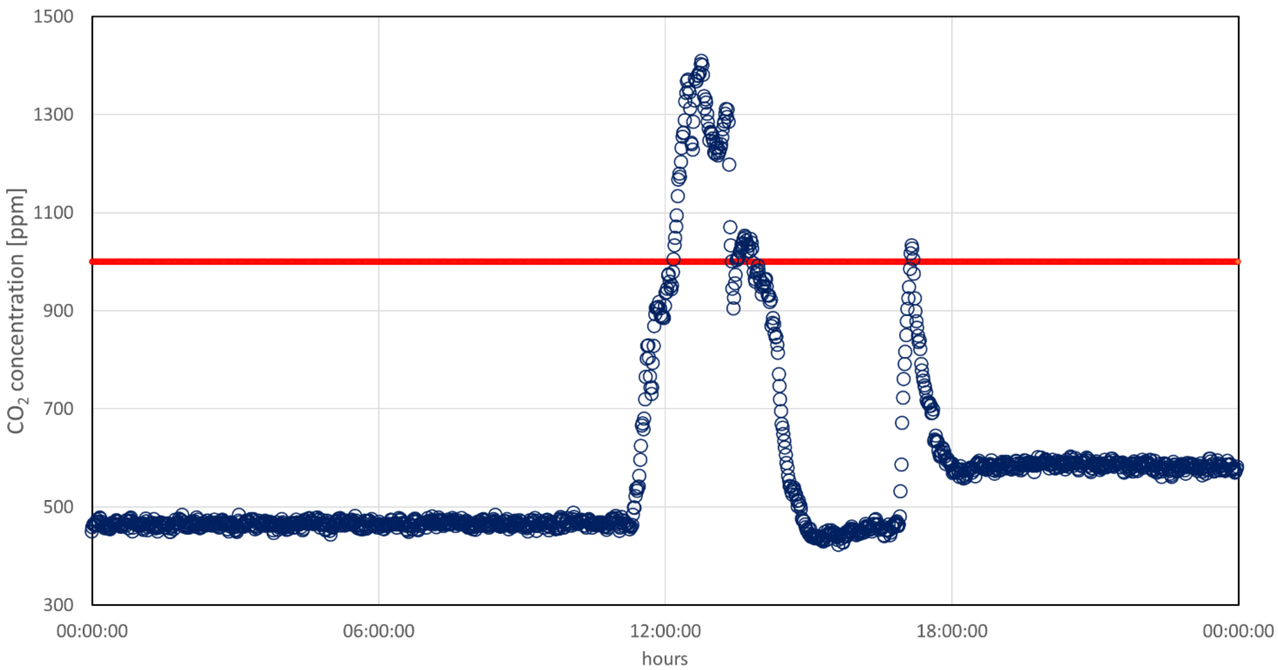

Figure 21 Daily distribution of the CO_2 concentration (September 23rd 2022), in one classroom of the pilot n°6 (Spjelkavik Ungdomsskole, Norway)

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2.3.2 Volatile Organic Compound (VOC)

Volatile Organic Compound (VOC) are molecules containing atoms of carbon and hydrogen (hydrocarbons), and possibly oxygen atoms (carbonyl compounds) or chlorine (halogenated compounds) and having a boiling temperature ranging between 50°C and 250°C at atmospheric pressure.

VOCs are emitted as gases from certain solids or liquids. They include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. The VOC family consists of hundreds of compounds for which emission sources are multiple and have not been completely characterized to date. Examples include paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions. Combustion of all kinds, especially smoking and cooking food, contributes to the emission of VOCs in the air (formaldehyde, acetaldehyde, benzene, naphthalene, etc.) [21].

VOCs concentrations are often assessed by grouping a wide range of organic chemical compounds called Total Volatile Organic Compounds (TVOC). However, the scientific community underlines the importance of also evaluating the different pollutants separately since the health effects related to acute or chronic exposures may be different in kind, intensity and severity depending on the compounds (from respiratory or eye irritation to the development of cancer) [21]. In COLLECTiEF, we have opted for sensors that provide the TVOC concentrations, depending on the available budget.

Few guidelines exist for TVOCs, although several TVOCs may impact our health [23]. The World Health Organization (WHO) released IAQ guidelines for Europe which are classified by means of TVOC concentration values [27]. Different air quality classes and their corresponding class limits in TVOC concentration are listed in Table 11.

Table 11 IAQ levels for Europe according to WHO [27]

Level	Recommendation	TVOC [μg/m^3]	TVOC [ppb]
Outside quality classes	Greatly increased (not acceptable)	>3000	>610
4	Significantly increased (only temporary exposure)	1000±3000	200-610
3	Slightly increased (harmless)	500±1000	100-200
2	Average (harmless)	250±500	50-100
1	Target value	<250	0-50

In Figure 22, Figure 23 and Figure 24 are displayed, as examples, the trends of the TVOC concentration in some rooms of the pilot buildings from September 18th to September 28th 2022. The graphs highlight the 4 ranges according to WHO guidelines [27]: the points which lie above the threshold of 610 ppb (dotted red line) are outside the quality class and describe events which are classified as not acceptable; the points between 610 and 200 ppb (dotted red line and full red line respectively) belong to class 4, for which only temporary exposure is recommended; the points

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between 200 and 100 ppb (full red line and green line respectively) show slightly increased TVOC levels, class 3; the data localised between 100 and 50 ppb (green line and light blue line respectively) are in class 2, considered harmless; finally, when the TVOC concentration is lower than 50 ppb (light blue line) it reaches the target value (class I).

The figures show very different results, which need to be investigated in detail onsite to know the conditions nearby the sensor (e.g., high values can be easily reached if detergents or other alcohol based cleaning products are used near the sensors).

In the following phases of the evaluation process of the building performance based on monitored data, we will calculate the fraction of time in the various TVOC-WHO categories during selected periods in order to assess the impact of the implementation of the COLLECTiEF systems. Besides, we will deepen the correlations between the TVOC concentration and different variables, such as the relative humidity, the indoor air temperature, the seasons, the ventilation strategy, the building location, the house type. The results will support the development of the algorithms which include the control of the ventilation strategies in the pilots, provide valuable insights for improving knowledge about indoor pollutants in real buildings and raise awareness of different stakeholders on the importance of IAQ control.

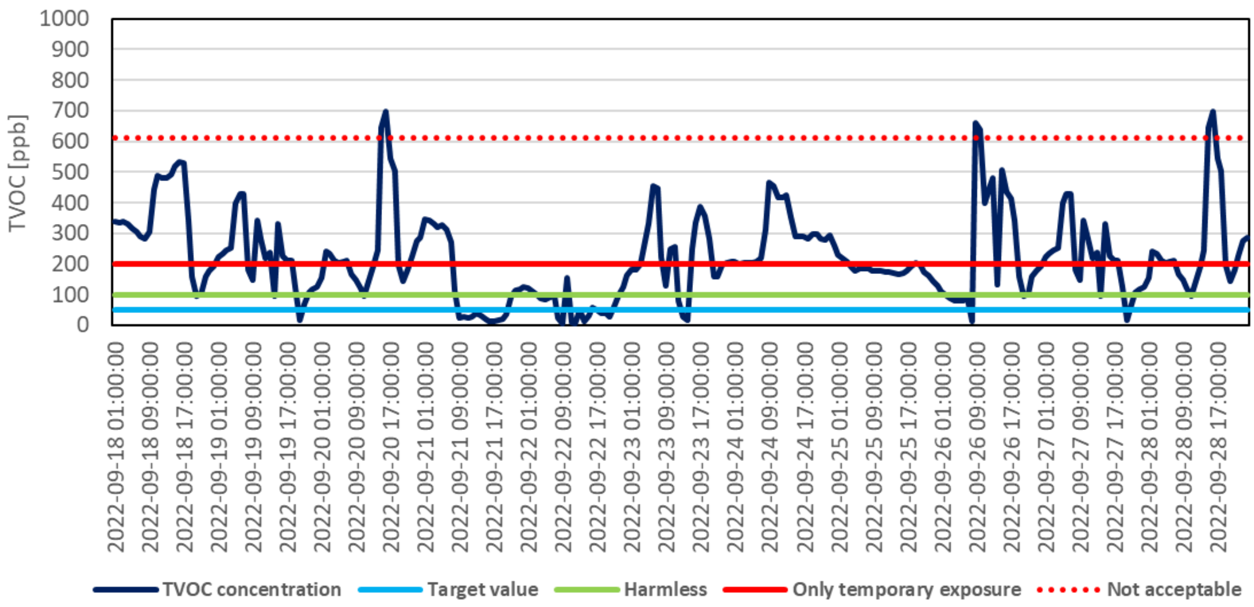

Figure 22 TVOC concentration in the classroom at G2ELAB from September 18th to September 28th 2022

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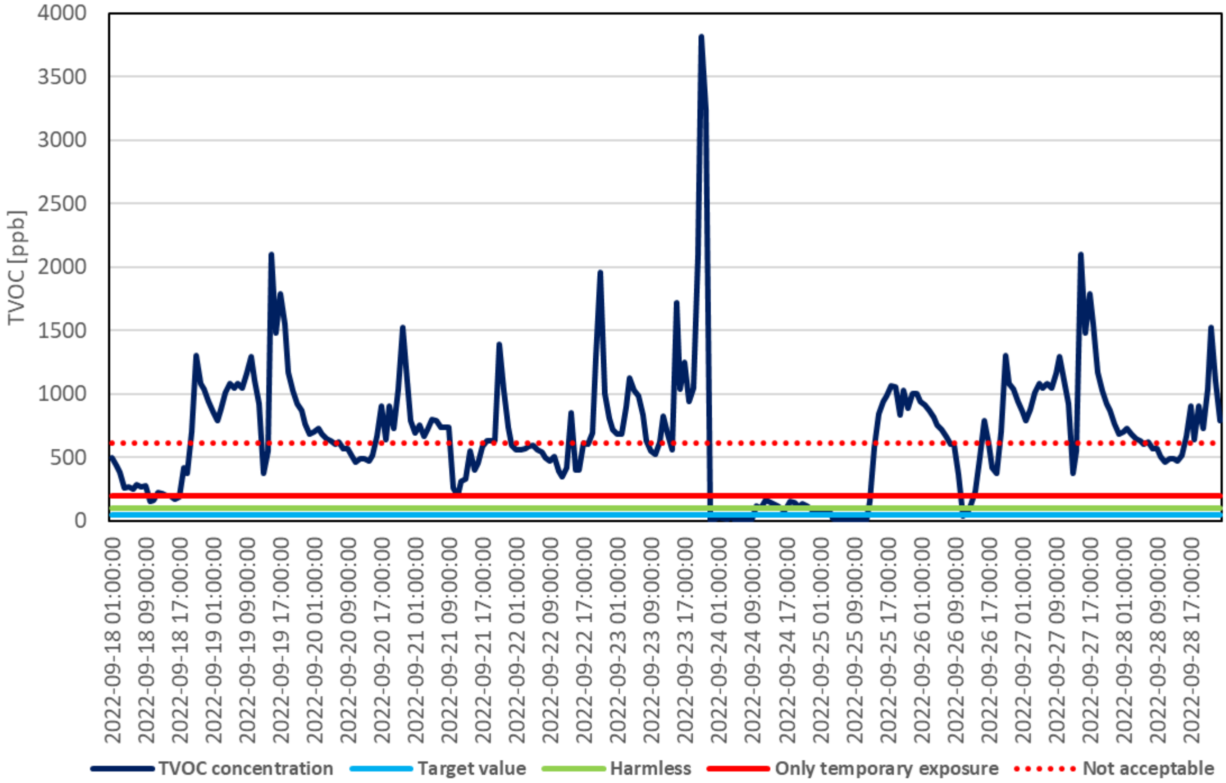

Figure 23 TVOC concentration in one of the residential flats (Valsesia, Italy) from September 18th to September 28th 2022

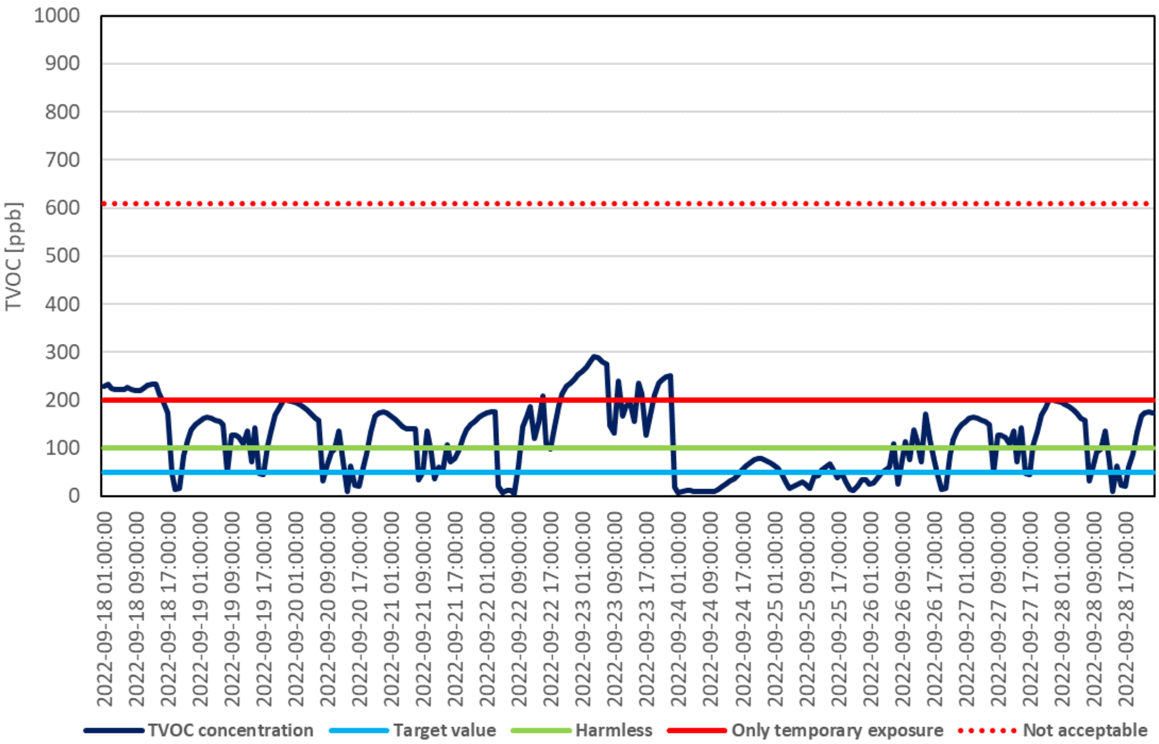

Figure 24 TVOC concentration in one of the classrooms of the pilot building n°8 (Tennfjord Barneskole, Norway) from September 18th to September 28th 2022

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2.3.3 Particle matter PM (1, 2.5, 4, 10)

Particles and fibres can penetrate from outdoor in indoor environments through the building envelope, during airing or because of ventilation of buildings. The primary indoor sources of particles include combustion of all kinds, printing, use of cosmetics (lacquers, sprays), erosion of coating materials, presence of occupants and occupants' activities. The dose of particles inhaled by an individual depends on the concentration and particle size distribution of the aerosol suspended in the air [21] .

Particle pollution includes:

- PM_{10}: inhalable particles, with diameters that are generally 10 micrometers and smaller;
- $PM_{2.5}$: fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller. They are small enough to pass through the upper respiratory tract and reach the lungs;
- PM_1: very fine particles, with diameters that are generally 1 micrometer and smaller. They pass through the alveoli and therefore penetrate deep inside the body;
- $PM_{0.1}$: ultrafine particles, nanoparticles which are used ubiquitously in industrial applications.

In COLLECTiEF we evaluate the concentration of particulate matter through the Sphensor units PRMPB0423, which provide measures of PM_1, $PM_{2.5}$, PM_4 and PM_{10}, expressed in µg/m^3.

The updated WHO guidelines [28] provide the concentrations of PM10 and PM2.5 for long-term exposure (annual) and short-term exposures (24-h), as reported in Table 12. The annual average concentrations of PM_{10} and $PM_{2.5}$ should not exceed 15 and 5 µg/m^3 respectively, while 24-hour average exposures should not exceed 45 and 15 µg/m^3 respectively. Interim targets have been set to support the planning of incremental milestones toward cleaner air, particularly for cities, regions and countries that are struggling with high air pollution levels.

Table 12 Recommended air quality guideline levels for long-term and short-term exposure to PM_{10} and $PM_{2.5}$, according to WHO [28]

Recommendation	PM_{10} (µg/m^3)		$PM_{2.5}$ (µg/m^3)	
	Long-term exposure	Short-term exposure	Long-term exposure	Short-term exposure
Interim target 1	70	150	35	75
Interim target 2	50	100	25	50
Interim target 3	30	75	15	37.5
Interim target 4	20	50	10	25
Air Quality Guidelines	**15**	**45**	**5**	**15**

Figure 25 and Figure 26 show two examples of analysis of $PM_{2.5}$ concentration from September, 18th to September 28th 2022 in one shared office of the pilot n°1 (Eidet Omsorgssenter, Norway) and in one flat of the pilot n°12 (Valsesia Tower, Italy). From the graphs, it's possible to notice that in both the pilots the daily average $PM_{2.5}$ concentration (light-blue line) is always below the short-term exposure threshold (red dotted line). The long-term exposure threshold (red solid line) needs to be considered when analysing the annual average concentrations, however assuming to calculate the average concentration for the selected period (September, 18th to September 28th 2022), we can notice that the average concentration (equal to 6.4 µg/m^3) is already at a critical value regarding the annual limit value. In the subsequent phases of the IAQ analysis, these thresholds will be considered

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for the development of the algorithms which include the control of the ventilation strategies in the pilots and for assessing the impacts of the implementation of the COLLECTiEF systems.

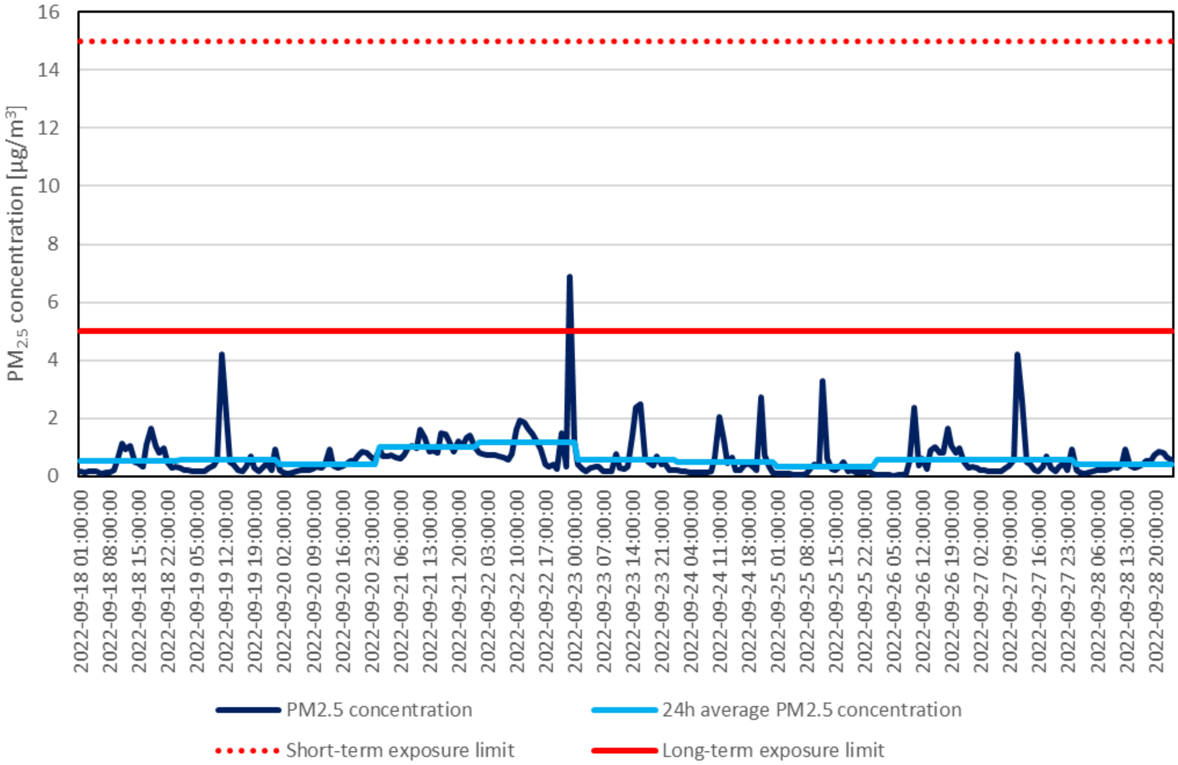

Figure 25 $PM_{2.5}$ concentration from September 18th to October 10th 2022, in one shared office of the pilot n°1 (Eidet Omsorgssenter, Norway)

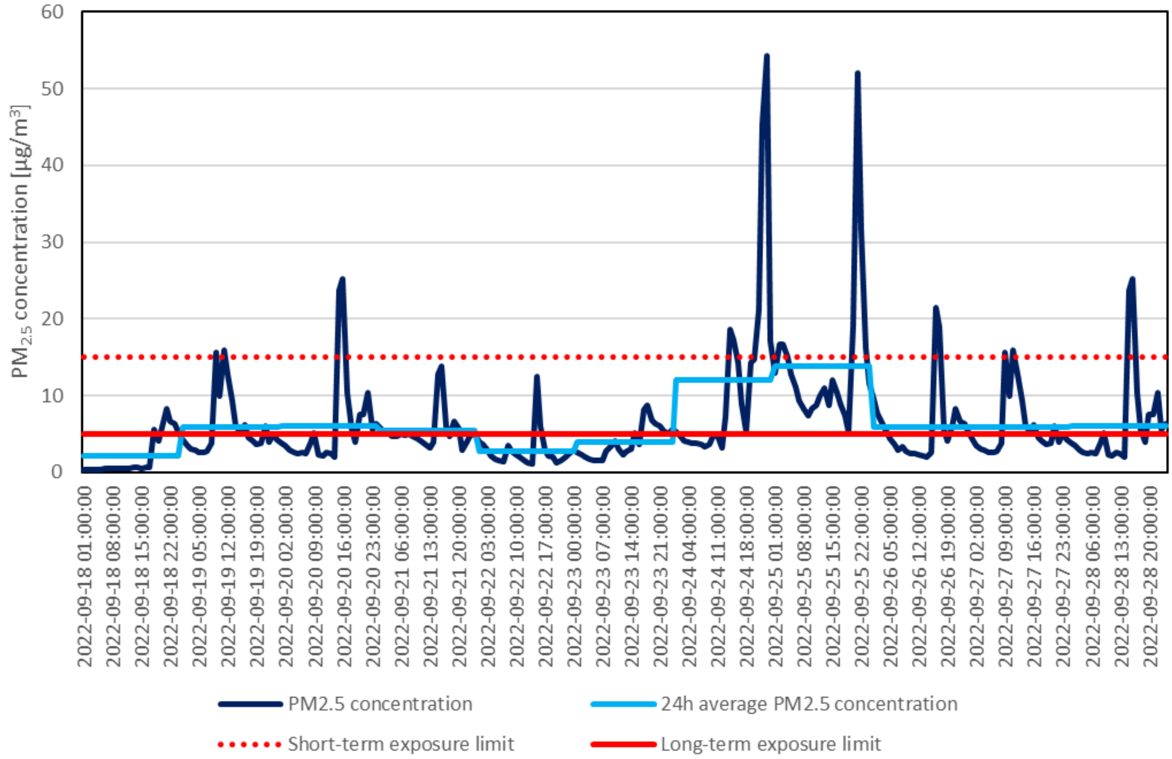

Figure 26 $PM_{2.5}$ concentration from September 18th to September 28th 2022, in one flat of the pilot n°12 (Valsesia Tower, Italy)

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3 Pilot monitoring

The plan of installation in the pilot buildings foresees:

- Sphensors units
- BRIGs
- smart thermostats
- smart plugs and smart valves

For the evaluation of IEQ, the installation of monitoring system including Sphensors, Sphensor Gateway (BRiG) and Repeaters, was initiated on 1st June 2022 and completed by 31st August 2022. The Sphensor Gateway (BRiG) has been installed in each pilot, which activates and monitors the physical connectivity of the Sphensors by accessing the local network. The local network is based on the WiFi standard that offers significant signal coverage for devices installed in the buildings and can be extended through repeaters. It also includes comprehensive security measures to protect the network and ensure privacy.
BRiG provides Border Router functionality for the Thread radio network for the communication with Sphensor units through the Radio module based on Nordic nRF52840 chipset controlled through specific software daemon for OpenThread radio module for the Thread network management via a UDP/IPv6 socket.

Sphensors include **PRMPB0401** (T_{air}, RH, P_{atm}), **PRMPB0402** (T_{air}, RH, P_{atm}, illuminance), **PRMPB0423** (CO_2, VOC, PM1, 2.5, 4, 10):

- The **PRMPB0401** (T_{air}, RH, P_{atm}):
  - In the residences because:
    - these spaces accommodate several functions with different illuminance requirements and do not need strict illuminance control. Furthermore, electric lighting is directly controlled by the occupants.
    - The residential units included in the COLLECTiEF pilot case studies, as the large majority of the existing building stock, do not have a mechanical ventilation system controlled by the concentrations of indoor pollutants like CO_2, VOC or PMx.
  - In the health care center patients' rooms because:
    - these spaces accommodate several functions with different illuminance requirements and do not need a strict illuminance control. Furthermore, electric lighting is directly controlled by the occupants.
  - In the sports center because
    - these spaces accommodate several functions with different illuminance requirements and do not need strict illuminance control.
- The **PRMPB0402** (T_{air}, RH, P_{atm}, illuminance):
  - In both single and shared offices (including the offices in the health care centers, medical center and educational institutes) because the illuminance level has an important role in the users' overall satisfaction with the indoor environment.
  - In the classrooms in primary and high schools and in tertiary institute because the students' overall satisfaction with the indoor environment also depends on the amount of light.
- The **PRMPB0423** (CO_2, VOC, PM1, 2.5, 4, 10) has been installed in those rooms where we have either:
  - **More than one occupant** (shared offices, classrooms, meeting rooms);
  - **Fragile persons** (self-sufficient elderly and primary school pupils);

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- **High metabolic activity** (sports halls);
- In 5 residential flats (out of 12 apartments) to extend the assessment in private buildings.

Figure 27 reports a synthesis of the distribution of the Sphensor units in the different pilots, highlighting the main features of zones under monitoring and the type of Sphensor installed.

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Country	Apartment area (m2)	Occupancy info	Zone area (m2)	Floor number	Nominal number of people	Building number	Zone Number	Type of Sphensors installed	Monitoring parameters
NORWAY	Eidet Omsorgsenter	Patient room, elderlies	21.7	2	1	B01	Z01	423	CO2, VOC, PM1,2.5,4,10
						B01	Z01	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	Z02	423	CO2, VOC, PM1,2.5,4,10
						B01	Z02	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	Z03	423	CO2, VOC, PM1,2.5,4,10
						B01	Z03	401	T_air, RH
		Patient room, elderlies	21.7	2	1	B01	Z04	423	CO2, VOC, PM1,2.5,4,10
						B01	Z04	401	T_air, RH
		Shared office, Nurses	10.9	2	5	B01	Z05	423	CO2, VOC, PM1,2.5,4,10
						B01	Z05	402	T_air, RH, Illuminance
	Ellingsøy Idrettshall	Main Hall (25m* 45m) -futsal, badminton,	1167.3	1	NA	B02	Z01	423	CO2, VOC, PM1,2.5,4,10
						B02	Z01	401	T_air, RH
						B02	Z01	423	CO2, VOC, PM1,2.5,4,10
						B02	Z01	401	T_air, RH
						B02	Z01	423	CO2, VOC, PM1,2.5,4,10
						B02	Z01	401	T_air, RH
		Dance room (98.9 m2) + social room (39.9 m2). They are seperable with folding wall - Aerobic, trim, dance	138.8	2	NA	B02	Z02	423	CO2, VOC, PM1,2.5,4,10
						B02	Z02	401	T_air, RH
						B02	Z02	423	CO2, VOC, PM1,2.5,4,10
						B02	Z02	401	T_air, RH
	Flisnes Barneskole	Classroom, 6-12 years old	?	1	?	B03	Z01	423	CO2, VOC, PM1,2.5,4,10
						B03	Z01	402	T_air, RH, Illuminance
		Classroom, 6-12 years old	?	1	?	B03	Z02	423	CO2, VOC, PM1,2.5,4,10
						B03	Z02	402	T_air, RH, Illuminance
	Hatlane Omsorgsenter	Patient room, elderlies	23.0	2	1	B04	Z01	423	CO2, VOC, PM1,2.5,4,10
						B04	Z01	401	T_air, RH
		Patient room, elderlies	23.0	2	1	B04	Z02	423	CO2, VOC, PM1,2.5,4,10
						B04	Z02	401	T_air, RH
		Patient room, elderlies	23.0	2	1	B04	Z03	423	CO2, VOC, PM1,2.5,4,10
						B04	Z03	401	T_air, RH
		Patient room, elderlies	22.8	2	1	B04	Z04	423	CO2, VOC, PM1,2.5,4,10
						B04	Z04	401	T_air, RH
		Shared office, Nurses	29.4	2	5	B04	Z05	423	CO2, VOC, PM1,2.5,4,10
						B04	Z05	402	T_air, RH, Illuminance
	Moa Helsehus	Shared office, Nurses	21.0	1	3	B05	Z01	423	CO2, VOC, PM1,2.5,4,10
						B05	Z01	402	T_air, RH, Illuminance
		Shared office, Reception	16.4	1	3	B05	Z02	423	CO2, VOC, PM1,2.5,4,10
						B05	Z02	402	T_air, RH, Illuminance
		Shared office, Nurses	?	2	?	B05	Z03	423	CO2, VOC, PM1,2.5,4,10
						B05	Z03	402	T_air, RH, Illuminance
		Break room (checking SBS hypothesis)	27.2	1	NA	B05	Z04	423	CO2, VOC, PM1,2.5,4,10
						B05	Z04	401	T_air, RH
		Individual offices (nurses, doctor, phsychologist,...)		1	1	B05	Z05	402	T_air, RH, Illuminance
		Individual offices (nurses, doctor, phsychologist,...)		1	1	B05	Z06	402	T_air, RH, Illuminance
	Spjelkavik Ungdomsskole	Classroom, 13-15 years old	74.2	2	28 students + 1 teacher	B06	Z01	423	CO2, VOC, PM1,2.5,4,10
						B06	Z01	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	73.6	2	28 students + 1 teacher	B06	Z02	423	CO2, VOC, PM1,2.5,4,10
						B06	Z02	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	71.5	2	28 students + 1 teacher	B06	Z03	423	CO2, VOC, PM1,2.5,4,10
						B06	Z03	402	T_air, RH, Illuminance
		Classroom, 13-15 years old	78.2	2	28 students + 1 teacher	B06	Z04	423	CO2, VOC, PM1,2.5,4,10
						B06	Z04	402	T_air, RH, Illuminance
		Shared office, Teachers	86.0	2	9	B06	Z05	423	CO2, VOC, PM1,2.5,4,10
						B06	Z05	402	T_air, RH, Illuminance
	Tennfjord Barneskole	Classroom, 6 years old	78.0	1	13-25 students + 1 teacher	B07	Z01	423	CO2, VOC, PM1,2.5,4,10
						B07	Z01	402	T_air, RH, Illuminance
		Classroom, 7 years old	55.6	1	13-25 students	B07	Z02	423	CO2, VOC, PM1,2.5,4,10
						B07	Z02	402	T_air, RH, Illuminance
		Classroom, 8 years old	56.3	1	13-25 students	B07	Z03	423	CO2, VOC, PM1,2.5,4,10
						B07	Z03	402	T_air, RH, Illuminance
		Classroom, 9 years old	56.3	1	13-25 students	B07	Z04	423	CO2, VOC, PM1,2.5,4,10
						B07	Z04	402	T_air, RH, Illuminance
		Classroom, 10 years old	56.3	1	13-25 students	B07	Z05	423	CO2, VOC, PM1,2.5,4,10
						B07	Z05	402	T_air, RH, Illuminance
		Classroom, 11 years old	57.0	1	13-25 students	B07	Z06	423	CO2, VOC, PM1,2.5,4,10
						B07	Z06	402	T_air, RH, Illuminance
		Shared office, Teachers	61.0	1	15	B07	Z07	423	CO2, VOC, PM1,2.5,4,10
						B07	Z07	402	T_air, RH, Illuminance
						B07	Z07	423	CO2, VOC, PM1,2.5,4,10
						B07	Z07	402	T_air, RH, Illuminance
France	G2ELab	Shared office	25.0	4	4	B08	Z01	402	T_air, RH, Illuminance
		Shared office	18.5	4	1	B08	Z02	402	T_air, RH, Illuminance
		Shared office	19.0	4	3	B08	Z03	402	T_air, RH, Illuminance
		Shared office	18.5	4	3	B08	Z04	402	T_air, RH, Illuminance
		Shared office	27.5	4	3	B08	Z05	402	T_air, RH, Illuminance
		Student Hall	42.0	4	3	B08	Z06	402	T_air, RH, Illuminance
		Classroom	78.5	4	25-34	B08	Z07	423	CO2, VOC, PM1,2.5,4,10
						B08	Z07	402	T_air, RH, Illuminance
		Laboratory	63.5	4	3	B08	Z08	423	CO2, VOC, PM1,2.5,4,10
						B08	Z08	402	T_air, RH, Illuminance
Cyprus	Guy Ourisson Building (GOB)	Shared office, Post-docs (30-40 y)	25.4	G	5	B09	Z01	423	CO2, VOC, PM1,2.5,4,10
						B09	Z01	402	T_air, RH, Illuminance
		Shared office, Post-docs (30-40 y)	27.6	1	5	B09	Z02	423	CO2, VOC, PM1,2.5,4,10
						B09	Z02	402	T_air, RH, Illuminance
		Shared office, Post-docs (30-40 y)	28.8	1	6	B09	Z03	423	CO2, VOC, PM1,2.5,4,10
						B09	Z03	402	T_air, RH, Illuminance
		Individual office, 40 y	20.4	1	1	B09	Z04	402	T_air, RH, Illuminance
		Individual office, 40 y	19.3	G	1	B09	Z05	402	T_air, RH, Illuminance
		Individual office, 50 y	17.5	G	1	B09	Z06	402	T_air, RH, Illuminance
		Individual office, 50 y	20.4	G	1	B09	Z07	402	T_air, RH, Illuminance
	Graduate School (GS)	Classroom, Graduate studenst and teachers	44.6	G	12	B10	Z01	423	CO2, VOC, PM1,2.5,4,10
						B10	Z01	402	T_air, RH, Illuminance
		Meeting room	28.9	G	7	B10	Z02	423	CO2, VOC, PM1,2.5,4,10
						B10	Z02	402	T_air, RH, Illuminance
		Individual office, Adult - F	13.9	G	1	B10	Z03	402	T_air, RH, Illuminance
		Shared office, PhD students (23-30 y)	79.8	1	16	B10	Z04	423	CO2, VOC, PM1,2.5,4,10
						B10	Z04	423	CO2, VOC, PM1,2.5,4,10
						B10	Z04	402	T_air, RH, Illuminance
		Shared office, PhD Students (23-30 y)	24.3	1	5	B10	Z05	423	CO2, VOC, PM1,2.5,4,10
						B10	Z05	402	T_air, RH, Illuminance
	Novel Technologies Laboratory (NTL)	laboratory activity	112.2	G	18	B11	Z13	423	CO2, VOC, PM1,2.5,4,10
						B11	Z13	402	T_air, RH, Illuminance
		laboratory activity	140.0	2	14	B11	Z14	423	CO2, VOC, PM1,2.5,4,10
						B11	Z14	402	T_air, RH, Illuminance
		Individual office	8.3	1	1	B11	Z15	402	T_air, RH, Illuminance
		Individual office	8.3	2	1	B11	Z16	402	T_air, RH, Illuminance
		Shared office	44.1	1	9	B11	Z17	423	CO2, VOC, PM1,2.5,4,10
						B11	Z17	402	T_air, RH, Illuminance
		Shared office	16.3	G	3	B11	Z18	423	CO2, VOC, PM1,2.5,4,10
						B11	Z18	402	T_air, RH, Illuminance
Italy	C2 Tower, 1A, 86.1	Private apartment, living room	18.2	1	?	B12	Z01	401	T_air, RH
		Private apartment, bed room	18.8	1	?	B12	Z02	401	T_air, RH
	C2 Tower, 3B, 117.5	Private apartment, living room	25.0	5	?	B12	Z01	401	T_air, RH
						B12	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	17.5	5	?	B12	Z02	401	T_air, RH
	C2 Tower, 3C, 89.8	Private apartment, living room	22.1	3	?	B12	Z01	401	T_air, RH
		Private apartment, bed room	15.3	3	?	B12	Z02	401	T_air, RH
	C2 Tower, 3D, 113.9	Private apartment, living room	24.1	3	?	B12	Z01	401	T_air, RH
						B12	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	18.7	3	?	B12	Z02	401	T_air, RH
	C2 Tower, 8A, 86.1	Private apartment, living room	18.2	8	?	B12	Z01	401	T_air, RH
		Private apartment, bed room	18.8	8	?	B12	Z02	401	T_air, RH
	C3 Tower, 1B, 58.8	Private apartment, living room	25.0	1	?	B13	Z01	401	T_air, RH
		Private apartment, bed room	17.5	1	?	B13	Z02	401	T_air, RH
	C3 Tower, 3B, 117.5	Private apartment, living room	25.0	3	?	B13	Z01	401	T_air, RH
						B13	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	17.5	3	?	B13	Z02	401	T_air, RH
	C3 Tower, 5C, 89.8	Private apartment, living room	22.1	5	?	B13	Z01	401	T_air, RH
		Private apartment, bed room	15.3	5	?	B13	Z02	401	T_air, RH
	C3 Tower, 7A, 86.1	Private apartment, living room	18.2	7	?	B13	Z01	401	T_air, RH
						B13	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	18.8	7	?	B13	Z02	401	T_air, RH
	C4 Tower, 1C, 89.8	Private apartment, living room	22.1	1	3	B14	Z01	401	T_air, RH
						B14	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	18.8	1	3	B14	Z02	401	T_air, RH
	C4 Tower, 2B, 117.5	Private apartment, living room	25.0	2	2	B14	Z01	401	T_air, RH
						B14	Z01	423	CO2, VOC, PM1,2.5,4,10
		Private apartment, bed room	17.5	2	2	B14	Z02	401	T_air, RH
	C4 Tower, 4C, 89.8	Private apartment, living room	22.1	4	3	B14	Z01	401	T_air, RH
		Private apartment, bed room	18.8	4	3	B14	Z02	401	T_air, RH

Figure 27 Distribution of the Sphensor units in the different pilots

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3.1 Design and configuration of monitoring system

The design, configuration and installation of environmental monitoring system (Sphensor^{TM}) in the pilots were designed as discussed in Deliverable 5.1, section 3.2 Installation, where the technical feasibility for positioning of sensors and border router was explained. In section 3.2.3 the calibration procedures are detailed.

The installation was done by pilots' managers with technical support from remote by LASTEM. The activities to prepare and deploy the installation are listed below:

- Providing technical tutorials for installation and configuration of the system to people in charge of installation for each pilot building some weeks before the installation date. The video tutorials are openly visible on LASTEM's Youtube channel:

#1 Sphensor Manager Program installation

https://www.youtube.com/watch?v=CBCTziLw9zs&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx

#2 Unbox the Gateway

https://www.youtube.com/watch?v=BQniosmHnGo&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx&index=2

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#3 Unbox the Sphensor sensor

https://www.youtube.com/watch?v=07cMSWfwLdU&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx&index=3

#4 Connection

https://www.youtube.com/watch?v=Rb-NDFUeDkY&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx&index=4

#5 Positioning inside the building

https://www.youtube.com/watch?v=N0njqfix6no&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx&index=5

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#6 Network setup

https://www.youtube.com/watch?v=H7nKcz7JYVU&list=PLz2_T6ih1ej6-nzi757R4PJXsOTOXDcKx&index=6

- Videocall to explain the preliminary steps detailed in the video tutorial to the people in charge of doing the installation.

- Remote support by LASTEM for doubts and questions before the installation.

- Remote support by LASTEM during the installation in order to guide the following activities.

- Verification of sensors operation and accuracy: made in the LSI LASTEM laboratory before shipping

- Verification of communication during installation:

    - Installation of the Border Router and verification of access to its configuration through the MQTT broker installed at Energy @ Work
    - Progressive switch-on of the sensors and check of their connection status and the quality of the radio communication through the indications offered by the SphensorManager program.
    - Interposition of radio repeaters if the quality of the radio signal indicated by SphensorManager program has been less than 10%; in some cases, however, a slightly lower quality was accepted due to the difficulty of inserting repeaters in intermediate positions and also because correct communication with the sensors occurred.

- Installation of the VPN in BRiG to allow remote access in a secure way, in order to have a more direct and in-depth monitoring of the Sphensor network. This required in some pilot sites to open specific communication ports in the computer network where BRiG is connected. On the Italian site was not necessary to operate on the local network as the BRiGs, being connected via the cellular network, had VPN connectivity enabled from the beginning.

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As recommended in D5.1, Section 6.6.1, the Sphensor^{TM} units have been installed as close as possible to the work location of the participants to be capable to characterize the physical environment around the person but mounted in a manner that:

- does not cause any nuisances to the participants and auxiliary people during the execution of their typical activities,
- are away from heat sources (e.g., radiators, computers, lamps) and
- are not exposed to direct solar radiation.

Sensors were also installed and localized in a position comprised between the standing and the seated heights of the hearth. The air quality sensors (**PRMPA0423**) need a power supply; therefore, they have been installed close to an electric socket.

The temperature, humidity and pressure sensors (**PRMPB0401**) do not require a power supply and were delivered with a stainless-steel base, so that they have been easily positioned on a horizontal plane (i.e., the workplane).

The air quality sensors (**PRMPB0423**) require power and were supplied with a stainless-steel base, so that they have been easily positioned on a horizontal plane, close to an electric socket. The repeaters have been installed by means of a screw in the wall in a raised position with respect to the passage of people. However, the installation of repeaters was different pilot by pilot.

In different zones, we have installed the Sphensors using different types of installation, namely resting on a shelf, fixed to the wall, hung by wire.

- Via screw stud

  The MC8111 shank is equipped with an M4 stud screw that allows it to be mounted on a rod/plate with a threaded hole or to a wall by means of the previous positioning of a dowel with a brass metric thread or a self-piercing dowel (in case of plasterboard wall).

- Via stainless steel base

  Using the stainless-steel base is the most convenient solution if you want to place the sensor on a surface, a desk or a table. The weight of the component allows unlimited tilt of the sensor without compromising its stability. The rubber ring below prevents sliding on particularly smooth surfaces and protects any glass surfaces or other delicate surfaces.

- Hung

  If you need to have the sensor hanging, it must be installed with the appropriate component MK5351. The attachment to the ball is the same as that of the stem. Remove from these the M3 nut and place it in the special quarry, then tighten the component with the M3x10 screw supplied.

We have used Sphensor Manager software developed by LASTEM to check the connectivity of the sensors, BRiG and repeaters. We also used Sphensor Manager to configure the sensors and collect the information about each sensor as well as verifying data reception. The Sphensor Manager software needs to communicate with the Sphensor Gateway to display Sphensor sensor data. As an example, the following snapshot is related to a pilot including the information on BRiG, Repeater(s) and Sphensors (Figure 28).

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Serial	Hub	Name	Timesta...	Model	Version	Last Me...	Signal	Battery...	Status	RLOC
22040349										
22050180	22040349	22050180	18/10/...	PRMPA...	1.3.1	diagnostic	23 %	USB	ACTIVE	E01B / ...
22050178	22040349	22050178	18/10/...	PRMPA...	1.3.1	grouped...	12 %	USB	ACTIVE	E097 / ...
22050181	22040349	22050181	18/10/...	PRMPA...	1.3.1	diagnostic	15 %	USB	ACTIVE	6817 / ...
22040278	22040349	22040278	18/10/...	PRMPB...	1.3.3	diagnostic	37 %	100 %	ACTIVE	6821 / ...
22040204	22040349	22040204	18/10/...	PRMPB...	1.3.0	diagnostic	9 %	100 %	ACTIVE	6824 / ...
22050177	22040349	22050177	18/10/...	PRMPA...	1.3.1	diagnostic	12 %	USB	ACTIVE	6820 / ...
22050179	22040349	22050179	18/10/...	PRMPA...	1.3.1	diagnostic	25 %	USB	ACTIVE	E018 / ...
22040215	22040349	22040215	18/10/...	PRMPB...	1.3.0	grouped...	20 %	100 %	ACTIVE	6818 / ...
22040199	22040349	22040199	18/10/...	TXMRB...	1.3.0	diagnostic	30 %	USB	ACTIVE	6800 / ...
22040205	22040349	22040205	18/10/...	PRMPB...	1.3.0	diagnostic	25 %	100 %	ACTIVE	E07F / ...

Figure 28 Snapshot of the Sphensor Manager Software

where:

- *Serial*: is the serial number of the sensor.
- *Hub*: is the serial number of the Sphensor Gateway to which it is "hooked".
- *Name*: is the sensor name. By default, it corresponds to the serial number. You can edit this text using the *Set alias* command of the *Utilities* menu in order to give the sensor a more representative indication (for example its progressive numbering or its location in the environment).
- *Endpoint*: the sensor's IPv6 address.
- *Timestamp*: is the date/time of the last message received from Sphensor Gateway.
- *Model*: is the model of the sensor.
- *Stack*: defines the type of sensor operation (*ftd*: the sensor can also act as a radio repeater; *mtd*: the sensor does not have a radio signal repetition function but, for this reason, it can operate at low power consumption).
- *Version*: is the firmware version of the sensor.
- *Last Message type*: is the type of message received.
- *Signal*: is the value based on RSSI but expressed in positive scale from 0 (absent signal) to 100 (maximum received signal strength). A good operating condition can be achieved with a received signal value greater than 20.
- *RSSI*: is the radio signal strength of the last message received. The indicated value moves within a scale from -100 to 0 (-100 = signal absent; 0 signal at maximum power). Normally the value is around -60...-70.
- *Battery percentage*: battery charge level expressed as a percentage.
- *Battery Voltage*: battery voltage in volts.

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- *Status*: sensor reception status according to the minimum RTM transmission rate:
  - ACTIVE: the sensor/repeater transmits with the expected RTM
  - MISSING: the sensor/repeater does not transmit from at least 2*RTM
  - LOST: the sensor/repeater does not transmit from at least 3*RTM
  - DEAD: the sensor/repeater does not transmit from at least 4*RTM
- *RLOC*: the pair of RLOC belonging to the sensor and to its parent; through these pairs it is possible to reconstruct the hierarchical structure of the devices connected to the PAN.
- *Parent*: the column indicates the serial, if available and known, of the parent device compared to the current device.
- *MCU_ID*: indicates the unique hardware ID of the processor.
- Rx: indicates the reception status of the device:
  - Always on: the sensor is always on active reception and should respond to requests immediately
  - Polling XX: the sensor goes into low power for XX seconds (default 60) and then should respond to requests after at most XX seconds
- *Config*: indicates the ID of the current configuration or Default if it is the factory configuration.

Problems found

After the first pilots' installation, a bug of the Thread communication protocol was found. It determined the disconnection of the sensor from the radio network when it transmits data of dimensions exceeding a certain length. This problem happened only for the Sphensor model equipped with illuminance measurements in addition to those of temperature, relative humidity, pressure and battery level.

To solve the problem, a firmware revision had to be created containing a corrective patch. The patch was installed on site, sensor by sensor, using a specific program provided by the manufacturer of the radio processor. This solution involved reconnecting the sensor to the radio network only when the communication system detects the absence of the sensor in the logical network structure; this condition was affected by a certain latency, and this inevitably produced sporadic data losses downstream of the system.

In the future, with each new release of the communication libraries delivered by the manufacturer of the radio processor, we will proceed to verify the resolution of this specific problem and, if so, we will check with the managers of the pilot sites if it will be convenient to update the Sphensor FW again, considering the benefits of this operation compared to its implementation cost.

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3.2 Deployment of monitoring system in the pilot sites

At this stage of the project, we have installed Sphensors units, Sphensor Gateway (BRiG), Smart plugs, smart valves and POEs in the pilot buildings according to the monitoring plan. The installation procedure was initiated from 1st June 2022 and completed by 31st August 2022. The troubleshooting and fixing of data communication/flow issues have been performed during the month of September.

The activities related to installation and monitoring are continuously supervised and a monthly update is reported by each pilot responsible in a dedicated shared file. In the following sections details about the state of installation in each country at M18 is reported.

3.2.1 Norway

3.2.1.1 State of installation

In Norway, there are seven pilot buildings including three schools, two healthcare centres for elderly, one sports center, one medical center. The total of 32 zones are identified for monitoring in these buildings, out of which 12 are classrooms, 8 are patients' rooms for elders, 6 are shared offices, 2 are individual offices, 1 is a break room and 2 are sports halls. In the classrooms, patients' rooms, shared offices and sports hall, we are monitoring both thermal comfort parameters and IAQ levels. In the individual offices only thermal comfort is monitored. The following table summarizes the status of sensors installation including number of Sphensors and repeaters in the different pilots. No smart plugs nor smart valves will be installed in Norwegian pilots. BRIGs have been installed according to the monitoring plan and posters with QR codes have been distributed in the monitored zones.

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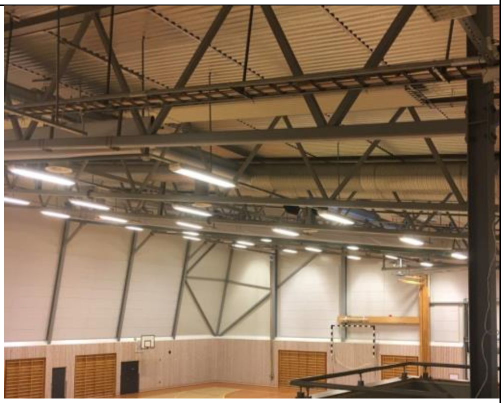
	Buildings	Sphensors	Repeaters	Zone	Completion date	Photograph
B1	Eidet Omsorgssenter	10	1	5	2022-07-25	
B2	Ellingsøy Idrettshall	10	2	2	2022-08-31	
B3	Flisnes Barneskole	6	-	3	2022-08-02	
B4	Hatlane Omsorgssenter	10	2	5	2022-08-28	

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B5	Moa Helsehus	10	-	6	2022-08-28	
B6	Spjelkavik Ungdomsskole	10	3	5	2022-08-30	
B7	Tennfjord Barneskole	14	1	7	2022-08-02	

3.2.1.2 Post Occupancy Evaluation (POE)

The installation process includes the placement of posters containing QR codes, necessary for the post occupancy evaluations (Figure 29). Additional dissemination materials have been distributed. The posters prepared by Geonardo show QR codes which need to be scanned by end-user to be addressed to the dedicated survey for each pilot building. We visited each pilot between June and July 2022 to put up the posters and provide all the necessary information about the involvement of the users in the project. We had meetings with the employees and explained the process they should follow. We received very good and constructive feedback regarding the project and the posters. However, one of the biggest challenges was gathering all the employees in these periods since it was the summer season, and some employees were on holiday. Moreover, we delivered two rollups for the sports hall in Ellingsøy in Ålesund. We visited the sports hall when they gathered for an annual meeting and informed the parents and students who use the halls about COLLECTiEF project and how they can contribute to it. The posters are in place and we are collecting feedback from the users. The activities related to users' engagement, such as the preparation of new dissemination materials, are ongoing to increase the number and frequency of participation.

In schools, we decided to prepare stickers glued on the desks of students. The stickers include the QR Code along with the name of the project. The stickers help students to easily scan the QR code using their iPad without having to search for the poster around the classroom.

Figure 29 POE posters in Norway

In another pilot (Eidet Omsorgssenter), we are using a sticker showing the writing “Venligst Ikke Rør” meaning “please do not touch” on the cables (Figure 30). The main reason is that the cables connected to COLLECTiEF sensors are in the room with all the other cables used by IT people and thus we try to limit any potential power outage.

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Figure 30 Installation of Sphensors in a Norwegian pilot building

3.2.1.3 Lessons learnt and mitigation strategies

- Turning off the light blink signaling some operative condition; this feature was considered too noisy for some users living in the room where the Sphensors are installed. Especially in the offices located in the medical centers and also patients' rooms for elders. We have deactivated the light blink signals for most of the Sphensors and repeaters installed in the Norwegian pilots.
- It is necessary to change the network configuration of a Sphensor or a repeater due to the different site where it is moved or added; this because each site has specific radio network names and protection keys. This operation is quite articulated and supported by the configuration program Sphensor Manager only by a manual step-by-step procedure, not fully automated. For this reason, the remote support was necessary in order to avoid error and difficulties for the local user.
- In some cases, the micro-USB cable disconnected from the repeaters due to the weak connection. We reconnected micro-USB cables and assure the reliable cable connection.
- In Ellingsøy Idrettshall, we have used cage box in order to protect the sensors since this pilot is a sport center and the sensors might be damaged.
- In some pilots, namely Hatlane Omsorgssenter and Spjelkavik Ungdomsskole, the signal connections were very weak due to the lack of communication between BRiG and Sphensors. This was mostly because of long distance of installed Sphensors from the BRiG or obstacles (e.g., concrete walls). We have used extra repeaters to amplify the communication signals.

3.2.2 Italy

3.2.2.1 State of installation

In Italy, there are three residential pilot buildings. In particular, a total of 12 apartments are monitored and for each apartment, one bedroom and one living room areas have been identified, for a total of

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24 thermal zones. The following table summarizes the status of sensors installation including number of Sphensors and repeaters in the Italian pilots:

Buildings		Sphensor	Repeat ers	Zone	Completion date	Photograph
B 1	Tower C2	12	8	10	2022-06-30	
B 2	Tower C3	9	6	8	2022-06-30	
B 3	Tower C4	8	3	6	2022-06-30	

Installation of Sphensors

For each thermal zone, at least one Sphensor that monitors temperature and humidity was installed, and for five apartments, in the living room, was also installed a Sphensor that monitors air quality. The following table summarizes the status of sensors installation for each building:

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Tower C2					
Floor	**Type App.**	**Type sensor**	**Code**	**Sensor number**	**Zone**
1	A	T/RH/P	PRMPB0401	22040227	Living room
		T/RH/P	PRMPB0401	22040229	Bed room
3	B	T/RH/P	PRMPB0401	22040226	Living room
		T/RH/P	PRMPB0401	22040221	Bed room
		CO2/PM/VOC	PRMPA0423	22040394	Living room
3	C	T/RH/P	PRMPB0401	22040223	Living room
		T/RH/P	PRMPB0401	22040228	Bed room
3	D	T/RH/P	PRMPB0401	22040177	Living room
		T/RH/P	PRMPB0401	22040234	Bed room
		CO2/PM/VOC	PRMPA0423	22040397	Living room
8	A	T/RH/P	PRMPB0401	22040224	Living room
		T/RH/P	PRMPB0401	22040222	Bed room

Tower C3					
Floor	**Type App.**	**Type sensor**	**Code**	**Sensor number**	**Zone**
1	B	T/RH/P	PRMPB0401	22040217	Living room
		T/RH/P	PRMPB0401	22040207	Bed room
3	B	T/RH/P	PRMPB0401	22040208	Living room
		T/RH/P	PRMPB0401	22040218	Bed room
		CO2/PM/VOC	PRMPA0423	22040069	Living room
5	C	T/RH/P	PRMPB0401	22040203	Living room
		T/RH/P	PRMPB0401	22040209	Bed room
7	A	T/RH/P	PRMPB0401	22040202	Living room
		T/RH/P	PRMPB0401	22040201	Bed room

Tower C4					
Floor	**Type App.**	**Type sensor**	**Code**	**Sensor number**	**Zone**
1	C	T/RH/P	PRMPB0401	22040242	Living room
		T/RH/P	PRMPB0401	22040232	Bed room
		CO2/PM/VOC	PRMPA0423	22040398	Living room
2	B	T/RH/P	PRMPB0401	22040231	Living room
		T/RH/P	PRMPB0401	22040235	Bed room
		CO2/PM/VOC	PRMPA0423	22040393	Living room
4	C	T/RH/P	PRMPB0401	22040240	Living room
		T/RH/P	PRMPB0401	22040243	Bed room

BRIGs and repeater location identification

To support this sensor network, a series of repeaters supplied by LASTEM, were installed. In order to provide the correct signal to each apartment, we installed a repeater on the landing of each floor. At the moment some sensors are disconnected because the signal is low and probably, we need to increase the number of repeaters. The following table summarizes the status of repeaters installation for each building:

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Tower C2			
Floor	**Type sensor**	**Code**	**Sensor number**
1	Repeater	TXMRB1100	22040158
2	Repeater	TXMRB1100	22040153
3	**Brig**	**TXRGC1001**	**22040352**
	Repeater	TXMRB1100	22040143
4	Repeater	TXMRB1100	22040169
5	Repeater	TXMRB1100	22040170
6	Repeater	TXMRB1100	22040145
7	Repeater	TXMRB1100	22040139
8	Repeater	TXMRB1100	22040159

Tower C3			
Floor	**Type sensor**	**Code**	**Sensor number**
1	Repeater	TXMRB1100	22040156
2	Repeater	TXMRB1100	22040118
3	**Brig**	**TXRGC1001**	**22040369**
4	Repeater	TXMRB1100	22040167
5	Repeater	TXMRB1100	22040157
6	Repeater	TXMRB1100	22040117
7	Repeater	TXMRB1100	22040154

Tower C4			
Floor	**Type sensor**	**Code**	**Sensor number**
1	Repeater	TXMRB1100	22040144
2	**Brig**	**TXRGC1001**	**22040341**
3	Repeater	TXMRB1100	22040152
4	Repeater	TXMRB1100	22040140

3.2.2.2 Post Occupancy Evaluation (POE)

The posters have been prepared by Geonardo and display a QR code that redirects the users after scan to an online questionnaire used to assess indoor environmental quality. In the Italian pilot we delivered, during August and September 2022, two posters for each apartment, one for the living room and one for the bedroom. At the moment all the posters have been delivered except for two apartments. At the time of the delivery of the posters we did the first survey with the users to solve any doubts and encourage the users to do the questionnaires at least weekly.

At the time, to increase the frequency with the surveys, we decided to create a new poster format that was smaller and more user friendly. Below an example of the new pocket-size poster (see Figure 31).

Figure 31 Pocket-size version of the COLLECTiEF poster

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Smart-Valves and plugs location and installation

For the Italian pilot was also planned the use of Shelly's smart plugs and smart valves. At the moment, all equipment has been delivered to users and has been installed in ten apartments. The following table summarizes the status of Shelly's devices installation and position in the apartment for each building:

Tower C2							
User	Floor number	Apartment type	Apartment Id	Smart valves and plugs			
				Type of Shelly to be installed	Code of Shelly to be installed	Zone of apartment/home devices	Shelly Id
C2.1A	1	A	C2.1A	Shelly TRV	TRV	Entry	C2.1A.TRVEntry
tel.				Shelly TRV	TRV	Living room	C2.1A.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C2.1A.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C2.1A.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C2.1A.TRVBedroom2
				Shelly Plug S	PLG		C2.1A.PLG
				Shelly Plug S	PLG		C2.1A.PLG
C2.3B	3	B	C2.3B	Shelly TRV	TRV	Entry	C2.3B.TRVEntry
tel.				Shelly TRV	TRV	Living room	C2.3B.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C2.3B.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C2.3B.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C2.3B.TRVBedroom2
				Shelly TRV	TRV	Bedroom3	C2.3B.TRVBedroom3
				Shelly Plug S	PLG		C2.3B.PLG
				Shelly Plug S	PLG		C2.3B.PLG
C2.							
tel.							
mail.							
qc.ZG							
qc.ZN							
C2.3D	3	D	C2.3D				
tel.							
mail.							
qc.ZG							
qc.ZN							
C2.8A	8	A	C2.8A	Shelly TRV	TRV	Entry	C2.8A.TRVEntry
tel.				Shelly TRV	TRV	Living room	C2.8A.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C2.8A.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C2.8A.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C2.8A.TRVBedroom2
				Shelly Plug S	PLG		C2.8A.PLG
				Shelly Plug S	PLG		C2.8A.PLG

Tower C4							
User	Floor number	Apartment type	Apartment Id	Smart valves and plugs			
				Type of Shelly to be installed	Code of Shelly to be installed	Zone of apartment/home devices	Shelly Id
C4.1C	1	C	C4.1C	Shelly TRV	TRV	Entry	C4.1C.TRVEntry
tel.				Shelly TRV	TRV	Living room	C4.1C.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C4.1C.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C4.1C.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C4.1C.TRVBedroom2
				Shelly Plug S	PLG		C4.1C.PLG
				Shelly Plug S	PLG		C4.1C.PLG
C4.2B	2	B	C4.2B	Shelly TRV	TRV	Entry	C4.2B.TRVEntry
tel.				Shelly TRV	TRV	Living room	C4.2B.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C4.2B.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C4.2B.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C4.2B.TRVBedroom2
				Shelly TRV	TRV	Bedroom3	C4.2B.TRVBedroom3
				Shelly Plug S	PLG		C4.2B.PLG
				Shelly Plug S	PLG		C4.2B.PLG
C4.4C	4	C	C4.4C	Shelly TRV	TRV	Entry	C4.4C.TRVEntry
tel.				Shelly TRV	TRV	Living room	C4.4C.TRVLiving room
mail.				Shelly TRV	TRV	Kitchen	C4.4C.TRVKitchen
qc.ZG				Shelly TRV	TRV	Bedroom1	C4.4C.TRVBedroom1
qc.ZN				Shelly TRV	TRV	Bedroom2	C4.4C.TRVBedroom2
				Shelly Plug S	PLG		C4.4C.PLG
				Shelly Plug S	PLG		C4.4C.PLG

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At the moment, the Shelly devices are not connected to the Internet because the Italian pilot buildings did not have their own WiFi network to connect the equipment. Several attempts have been made to set up a stable network through the use of a repeater for each floor but the desired results have not been reached yet.

Installation of software and modem to gather data on thermal energy use for heating, on heating loops temperatures, and outdoor air temperature

In Italian pilot buildings, a Coster modem is used to verify consumption for each building and allows to access outdoor weather data. Currently Teicos has configured the modem but it has not yet gone into operation because the heating period has not begun yet. Also, it is necessary to discuss with CETMA about how to manage the data that is downloaded from the software.

Access to the web portal for the data of heat cost allocators

We set proper access to the web portal, managed by the manufacturer ISTA, for the data of heat cost allocators, in order to calculate the heating energy use for each radiator in the selected apartments. Data text files can be downloaded from it for each apartments, including daily data. Discussions are ongoing with CETMA to make automatic the process of data acquisition.

Outdoor climate data

Concerning outdoor climate data, at the moment it is possible to download them from the ARPA Lombardia website at the following address:

"https://www.arpalombardia.it/Pages/Meteorologia/Richiesta-dati-misurati.aspx"

The station used is in Milano Lambrate and it can provide the following data:

- Temperature
- Relative humidity
- Wind
- Rainfall
- Global radiation

Below an example for temperature and relative humidity (see Figure 32):

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Sensore	Data-Ora	Medio
05/09/2022	00:00	21.5
05/09/2022	01:00	21.6
05/09/2022	02:00	21.3
05/09/2022	03:00	20.4
05/09/2022	04:00	19.8
05/09/2022	05:00	19.5
05/09/2022	06:00	19.1
05/09/2022	07:00	20.4
05/09/2022	08:00	22.6
05/09/2022	09:00	24.7
05/09/2022	10:00	26.3
05/09/2022	11:00	28.3
05/09/2022	12:00	29.6
05/09/2022	13:00	29.8
05/09/2022	14:00	31.4
05/09/2022	15:00	31.1
05/09/2022	16:00	30.6
05/09/2022	17:00	30.3
05/09/2022	18:00	29.7
05/09/2022	19:00	27.6
05/09/2022	20:00	24.7
05/09/2022	21:00	22.9
05/09/2022	22:00	22.1
05/09/2022	23:00	21.7
06/09/2022	00:00	21.2
06/09/2022	01:00	20.7
06/09/2022	02:00	20.3
06/09/2022	03:00	20.4
06/09/2022	04:00	20.4
06/09/2022	05:00	19.9
06/09/2022	06:00	19.4
06/09/2022	07:00	20.4
06/09/2022	08:00	24.1
06/09/2022	09:00	26.2
06/09/2022	10:00	27.5
06/09/2022	11:00	29.0
06/09/2022	12:00	30.2
06/09/2022	13:00	31.3
06/09/2022	14:00	31.0
06/09/2022	15:00	32.3
06/09/2022	16:00	32.1
06/09/2022	17:00	31.7
06/09/2022	18:00	31.0
06/09/2022	19:00	28.7
06/09/2022	20:00	26.5
06/09/2022	21:00	25.6
06/09/2022	22:00	22.8
06/09/2022	23:00	21.0
07/09/2022	00:00	21.4

Sensore	Data-Ora	Medio
05/09/2022	00:00	75.0
05/09/2022	01:00	74.3
05/09/2022	02:00	75.0
05/09/2022	03:00	78.5
05/09/2022	04:00	80.7
05/09/2022	05:00	81.7
05/09/2022	06:00	84.7
05/09/2022	07:00	79.0
05/09/2022	08:00	70.8
05/09/2022	09:00	63.7
05/09/2022	10:00	58.7
05/09/2022	11:00	53.3
05/09/2022	12:00	48.2
05/09/2022	13:00	44.3
05/09/2022	14:00	39.0
05/09/2022	15:00	38.7
05/09/2022	16:00	41.0
05/09/2022	17:00	41.0
05/09/2022	18:00	42.0
05/09/2022	19:00	46.5
05/09/2022	20:00	56.3
05/09/2022	21:00	63.7
05/09/2022	22:00	68.7
05/09/2022	23:00	71.8
06/09/2022	00:00	75.3
06/09/2022	01:00	78.7
06/09/2022	02:00	80.7
06/09/2022	03:00	81.0
06/09/2022	04:00	81.3
06/09/2022	05:00	82.8
06/09/2022	06:00	83.5
06/09/2022	07:00	79.2
06/09/2022	08:00	64.5
06/09/2022	09:00	56.0
06/09/2022	10:00	52.0
06/09/2022	11:00	48.0
06/09/2022	12:00	45.0
06/09/2022	13:00	41.5
06/09/2022	14:00	41.7
06/09/2022	15:00	37.7
06/09/2022	16:00	36.8
06/09/2022	17:00	37.2
06/09/2022	18:00	39.2
06/09/2022	19:00	44.8
06/09/2022	20:00	52.5
06/09/2022	21:00	57.5
06/09/2022	22:00	77.0
06/09/2022	23:00	86.7
07/09/2022	00:00	88.5

Figure 32 Example of outdoor weather dataset (temperature and relative humidity) extracted from ARPA website

3.2.2.3 Lessons learnt and mitigation strategies

- The sensors make a blue light, and in the case of the Italian pilot, it was very annoying particularly in bedrooms because it caused sleep disturbance. We therefore asked LASTEM to turn off the light emission.
- Some of the sensors and the BRiG occasionally make a strange noise, a buzzing sound, which disturbs users at night. By talking with LASTEM, we understood that the dust may be the cause of this problem, and we paid attention to put the sensors in clean and safe places.
- In some cases, the signal connections is very weak due to the lack of communication between BRiG and Sphensors. This is mostly because of the long distance between the installed Sphensors and the BRiG or obstacles (e.g., concrete walls). Now we still need to solve some problems and probably we need more repeater for each floor.
- Recently, one apartment has withdrawn from the project. At the moment we are working on finding a substitute.
- In one apartment we have not installed yet Shelly equipment due to Covid and vacation reasons. We are working to complete the installations.

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- In two apartments, among those participating in the project, QR codes still need to be delivered.

<u>How to involve the owners and occupants?</u>

A low frequency with which questionnaires are done was found in the Italian pilot. For this reason, two practicable strategies were hypothesized to encourage users to participate more:

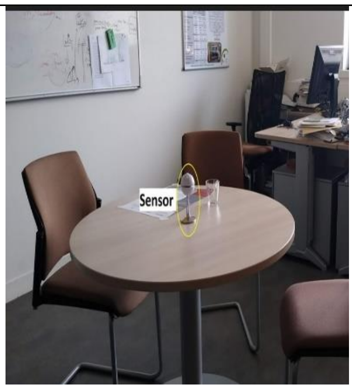
- Organize visits during the month of November and support the users in answering questionnaires.

- Organize a Whatsapp group with users in which each week we send a message as a reminder to take the survey.

3.2.3 France

3.2.3.1 State of installation

In France, there is one pilot building: the Green'er building, hosting the electrical engineering lab of Grenoble University (G2ELAB), on which the study will focus. A total of 8 zones are chosen for monitoring in this building, out of which 6 are shared offices, 1 an experimental zone for the lab and 1 a university classroom. For this pilot, thermal comfort and indoor environmental quality is monitored. In all mentioned spaces, Sphensors have been placed for measuring the indoor air temperature, illuminance, relative humidity and air quality quantities i.e., CO2, TVOC and PM 1, 2.5, 4, 10. The table below summarizes the status of sensors installation that includes the number of Sphensor devices, repeaters and hubs, required for the communication needs in the French pilot.

	Buildings	Sphensors	Repeaters	Zones	Completion date	Photograph
B08	Green'er Building (G2ELAB)	10	1	8	2022-06-17	 

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						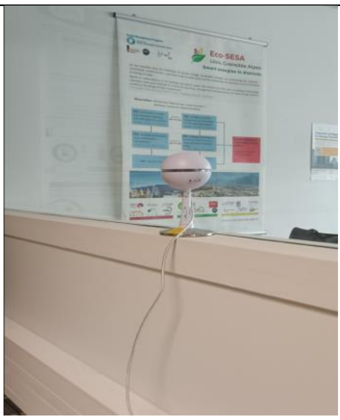

3.2.3.2 Post-Occupancy Evaluation (POE)

In parallel with the installation of monitoring equipment, a set of posters have been placed in the study areas in order to allow the occupants' participation in the Post-Occupancy Evaluation questionnaires. The posters have been prepared by Geonardo and display a QR code that redirects the users after scan to an online questionnaire used to assess user acceptability and perceived indoor environment conditions. At the beginning of installation stage, some participants asked for additional information about the experience and the project in person, thus we had a meeting with the office occupants and explained the process they should follow. The position of posters was chosen according to occupants' opinion, in order to identify a location that can be easily accessible fom them. On each poster, a brief description of the COLLECTiEF project was also added to introduce the program outlines to the users and to improve their participation. Figure 33 shows a picture of the posters in place. The majority of the poster are located close to the offices of users to remind them to complete the questionnaire once they aim to modify the indoor conditions; participants receive also an email every Monday about the experience to improve their participation.

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Figure 33 Picture of POE poster in the French pilot building

An additional sticker is placed beside each device in the shared offices, asking the workers not to touch the Sphensors, to avoid any incidences of the device disconnection or displacement.

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3.2.3.3 Lessons learnt and mitigation strategies

Overall, the level of engagement amongst the participants depends upon their presence in their room during the working day and whether or not they go into the office on a regular basis. A weekly email is sent to the participants with a reminder to complete the questionnaire and researchers established a good practice of reminding each other to scan the QR codes when they are in the office. Moreover, a number of building users has shown interest in knowing more about the COLLECTiEF project and the system we are testing, and we have observed a higher level of engagement with those who participated in an information meeting.

Regarding the researchers, it is observed that those who works regularly in the office are more engaged. However, no check has been made for living room or lecture room.

To encourage more active participation and remind the building users to fill out the questionnaire on a regular basis, new stickers including the QR codes will be created and placed next to the entrance door in each room.

Additionally, an email is sent to all the participants every week to ask for their active participation in the experiment/project.

It might be useful to nudge the participants with a complementary sticker next to the entry door of each room. This sticker can act as a reminder to the researcher whenever the researchers leave the room e.g., for lunch or a break etc.

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3.2.4 Cyprus

3.2.4.1 State of installation

In Cyprus, there are three pilot buildings including one graduate school, and two office buildings, that are mainly part of the Cyprus Institute campus. A total of 18 zones are selected for monitoring in these buildings, out of which 1 is a classroom, 10 are individual offices, and 7 shared offices. In all monitored indoor spaces, Sphensor devices are installed that measure temperature, humidity, atmospheric pressure and illuminance sensor, while in shared spaces, such as classrooms and shared offices, additional Sphensor devices were placed for measuring air quality quantities i.e., PMx, CO2 and TVOC. The table below summarizes the status of the Sphensor installation that includes the number of Sphensor devices, repeaters and hubs, required for the communication needs.

	Buildings	Sphensors	Repeaters	Zone	Completion date	Photograph
B09	Guy Ourisson Building (GOB)	13	1	9	2022-07-25	

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B10	Graduate School (GS)	10	1	5	2022-08-31	 

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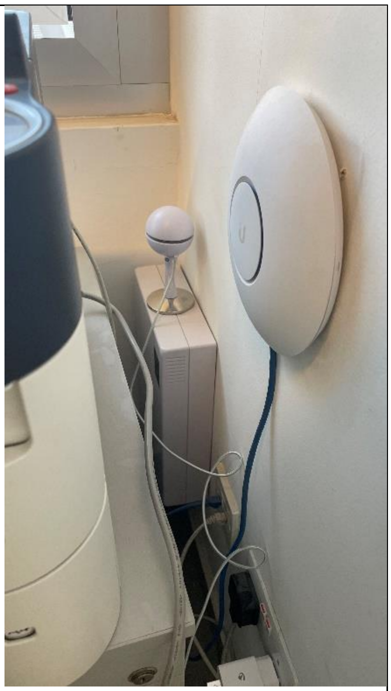
B11	Novel Technologies Laboratory (NTL)	7	1	4	2022-08-02	 

3.2.4.2 Post-Occupancy Evaluation (POE)

During the installation phase of the indoor monitoring equipment, a poster, prepared by Geonardo (GEO), was placed in each selected room of the pilot buildings. The posters, besides project dissemination material, aim to give access to occupants on the Post-Occupancy Evaluation questionnaires through a QR code that redirects them to an online questionnaire designed to evaluate indoor environmental conditions. During the in-person meetings with the room users, a brief description of the COLLECTiEF project is carried out as well. The position of the poster is decided following a discussion with the occupants, in order to identify a location that can be easily accessible for them. Figure 34 shows some pictures of the posters in place. The majority of the posters are located close to the room thermostat to notify them to complete the questionnaire once they aim to modify the indoor conditions, while in other rooms the location was decided based on the user of the room e.g., for individual offices, users decided to keep the posters closed to them for convenience.

Figure 34 Pictures of POE posters at the Cypriot pilot buildings

In addition to the large posters placed across the CyI campus, and as an action to improve user participation in the POE surveys, we decided to prepare smaller laminated flyers. These were placed on desks of students and offices, or at convenient locations where users can readily scan the QR code (Figure 35). The flyers include the unique QR code along with the logo and name of the project and help users to access the POE using their mobile device without having to search for the poster in the room.

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Figure 35 Pictures of position of QR code on office table in the Cypriot pilot buildings

Furthermore, digital tools were employed to remind users to submit their opinions on a weekly basis without leaving their screens. This was done by creating calendar reminders which include the unique QR codes as well as the direct link for online access to the POEs (Figure 36). Users of specific rooms receive calendar invitations twice a week (through Microsoft Outlook), urging them to contribute their opinions.


Dear Colleague,

Firstly, I would like to kindly thank you for your contribution to the H2020 COLLECTiEF project!

We created this **periodic reminder** as an action to inform and involve people to **recurrently complete (at least twice a week)** the Post-Occupancy Evaluation (POE) Questionnaires.

You can access the **POE Questionnaire through the following link:** https://www.collectief-project.com/office-questionnaire?zone=B09Z06
or you can scan via a phone camera the following QR code:

I and Prof. Carlucci are at your full disposal for any technical guidance, questions or clarifications might be needed.

I would like to thank you for your time and hope to work together to enhance our Institute!

With kind regards,

Panayiotis

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Figure 36 Calendar reminders for occupants in the Cypriot buildings

An additional sticker is placed beside each device that is located in a shared space, to avoid any incidences of the device disconnection or displacement (Figure 37).

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Figure 37 Pictures of additional stickers in the Cypriot pilot buildings

3.2.4.3 Lessons learnt and mitigation strategies

Here are some points about the lesson learned and the future actions related to monitoring in the Cypriot pilot buildings:

- Some of the Sphensor units placed in the Guy Ourisson Building (GOB) labelled as B09 are located relatively far from the BRIG and the available repeater. As a result, the battery of them has drop below the 40% in a very short period. CyI proceeded with a purchase of two (2) additional repeaters from Lastem LSI to cover the distance between the Sphensor units and the BRIG and hence, to improve the power consumption of the Sphensor units.
- The BRIG placed at the Graduate School (GS) labelled as B10 is replaced with a new one, since a radio-antenna fault occurred that was forcing the BRIG to stop data transmission that led to intermittent communication.

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4 Data management for the evaluation

Figure 38 shows a flowchart of data flow in the whole process of data collection applied in the COLLETiEF project.

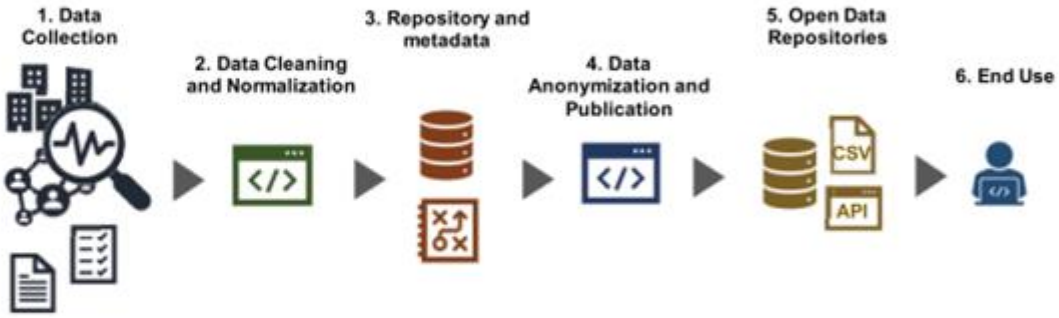

Figure 38 Overview of process for collection, publication and use of open data

- **Data collection:** Information from accessible sources, including information lakes and data warehouses, are collected from different processes. The data might be stored on local sensor storage and then later copied to a repository or transferred to a repository directly via wireless sensors, gateways, building automation systems, or internet-enabled sensors. Data points have to be associated with metadata that explain their origin.
- **Data pre-processing**
  - **Data preparation:** The main reason for this step is to reduce the redundant data (incomplete data or incorrect data) so that we can create a good quality of data for different business purposes.
    - **Data cleaning:** Real-world data contains irrelevant, duplicate, and missing parts. Prior to transferring data into a structured repository, it must be examined in view of **consistency**, **completeness**, and **plausibility**. Data Cleaning is a process by which it guarantees that your information is **right**, **reliable** and **useable**. Data cleaning involves two steps: (a) We exclude unwanted data such as duplicate and irrelevant data. (b) Errors such as measurement errors, data transfer error and many more of this type are fixed during the data cleaning process. Data cleaning involves handling of missing data by ignoring the missing tuples and filling the missing values.
      - **Missing Value in Data**: The idea of missing qualities is critical to understand to effectively oversee information. On the off chance that the missing qualities are not taken care of appropriately by the analyst, at that point he/she may wind up drawing an off-base derivation about the information. Because of ill-advised taking care of, the outcome got by the scientist will contrast from ones where the missing qualities are available.
      - For cleaning **noisy data** different machine learning methods are used like clustering or regression.
  - **Data transformation:** After preparation of data, raw data is converted into an understandable format, and it is made available for storage processing.
    - **Data Standardization:** Data Standardization is information preparing the work process those changes over the structure of dissimilar datasets into a Common Data Format. As a component of the Data Preparation field, Data Standardization manages the change of datasets after the information is pulled from source frameworks and before it's stacked into target frameworks. Hence, Data Standardization can likewise be thought of as the change rules motor in Data Exchange tasks. Data Standardization empowers the

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information customer to investigate and utilize information in a reliable way. Ordinarily, when information is made and put away in the source framework, it's organized with a certain goal in mind that is regularly obscure to the information customer.

- **Data Normalization:** The need for data normalization is required when we are dealing with attributes on different scales. Data normalization is used for mapping data attributes so that it falls under the lower range. At the point when various qualities are there yet characteristics have values on various scales, this may prompt poor information models while performing information mining tasks. So they are standardized to welcome all the traits on a similar scale.

- **Data reduction:** It is used to handle large amounts of data. For this, we use different data reduction techniques like dimensionality reduction or data cube aggregation

- **Repository and metadata association**: Data is transferred to a repository of the collecting organization and made available from here, including metadata (covered in section 6.1). The internal repositories can be constructed in different ways depending on the size and access pattern for data. In a simple setup, the repository might consist of directories of plain files and in an advanced setup, might be a number of databases, e. g., time-series or graph databases.
- **Data anonymization and publication**: Data is published, and the necessary processing is applied, including anonymization. Methods for anonymization to address ethics and privacy protection are covered in section 7.2.
- **Processing**: Processing of data is done by using machine learning algorithms for the manipulation of data so that information or pattern is identified.
- **Interpretation of data**: At this stage, data is being interpreted for final use by the non-data scientist. This stage provides the output of data processing.
- **End use:** The end user can then finally process the data by relevant software tools to do the research of their focus, for example, software analytics combining, and correlating data about occupants, building structure and subsystems to understand how occupants interact with buildings and how buildings respond to occupants' behavior and actions.
- **Data storage:** All the processed data is then stored for future use.

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4.1 COLLECTiEF repository

4.1.1 Data structure on repository

All data collected from COLLECTiEF's pilot building are stored in a relational database located in a server hosted by NTNU. A relational database is a set of information that organizes data into predefined relationships where the data is stored in one or more tables related to each other.

Relationships are logical connections between the different tables, established on the basis of the interaction between them.

Attributes (columns) specify a data type, and each record (or row) contains the value of that specific data type. Usually, all tables in a relational database have an attribute known as primary key, which is a unique identifier of a row, and data from different tables can be put in relation using a foreign key - a reference to a key of another existing table.

The main advantage of the relational database model is that it offers an intuitive way to represent data and allows to easily access related data points.

Using relational databases for data management and storage offers many benefits, including:

- **Flexibility.** It's easy to add, update or delete tables, and relationships, and make other changes to data when necessary, without changing the overall database structure or interfering with existing applications.
- **ACID compliance**. Relational databases support ACID (Atomicity, Consistency, Isolation, Durability) performance to ensure data validity regardless of errors, failures, or other potential incidents.
- **Easy to use**. It is easy to run complex queries using SQL, which allows even non-expert users to learn how to interact with the database.
- **Cooperation**. Multiple people can operate and access data at the same time. The built-in lock prevents simultaneous access to the data being updated.
- **Integrated security**. Role-based security ensures that data access is restricted to specific users.
- **Database normalization**. Relational databases use a design technique known as normalization that reduces data redundancy and improves data integrity.

The main difference between relational and non-relational databases (NoSQL databases) is the way the data is stored and organized. Non-relational databases do not store data in a rule-based tabular format. Instead, they store data as single, detached files and can be used for complex, unstructured data types, such as documents or rich media files.

Unlike relational databases, NoSQL databases follow a flexible data model, making them ideal for storing frequently changing data or for applications that handle different types of data.

The following image shows the structure of the COLLECTiEF Database:

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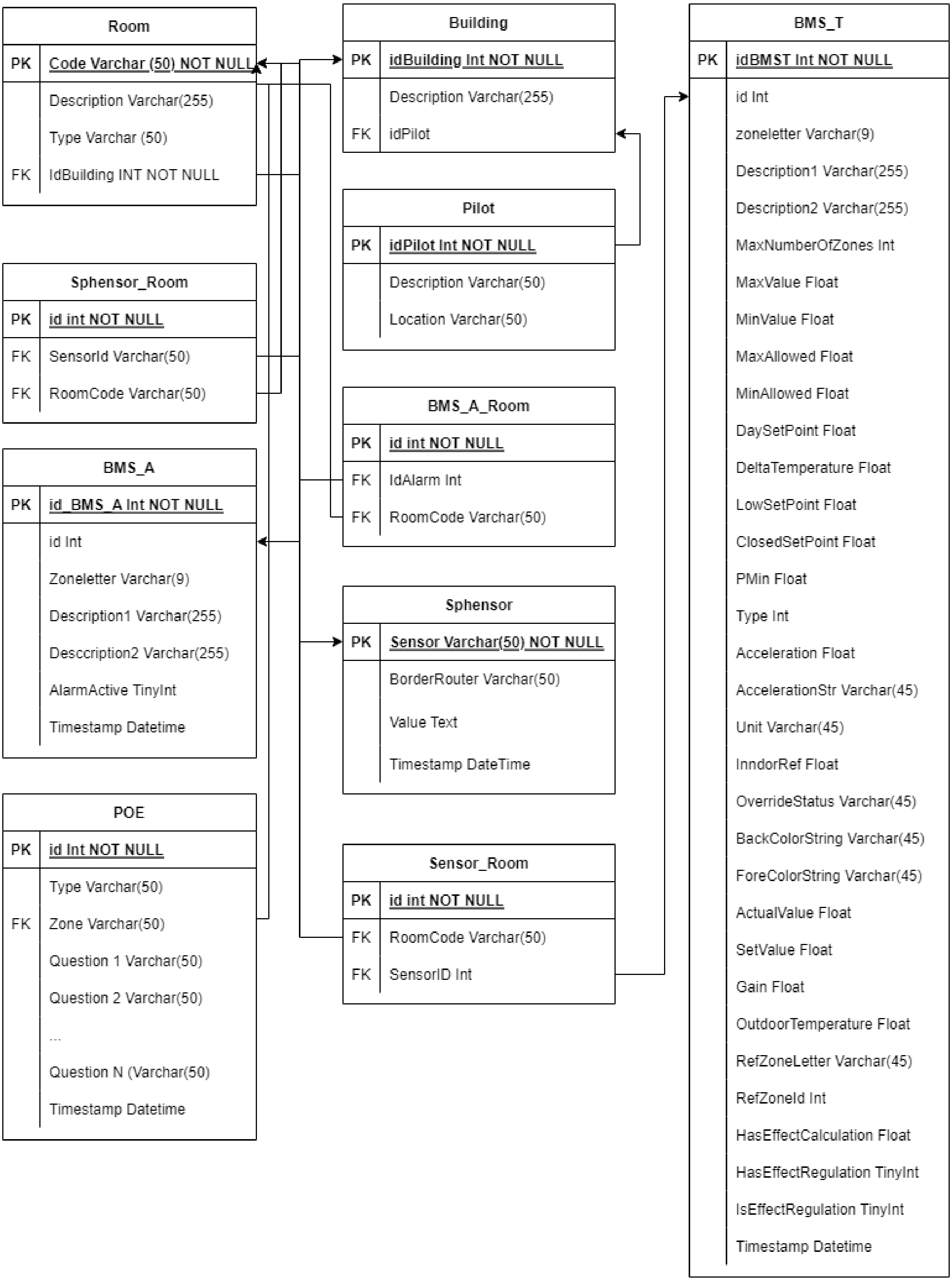

Figure 39 Structure of the COLLECTiEF Database

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A brief description of the main tables and fields is given below:

BMS_T: It represents the data read from BMS for T-zones. The main fields are:

Id:	Identifies what zone the analog values is in the BMS
Zoneletter:	There are different zone types, type T means analog values.
Description1:	Configured description for the analog zone, field 1. This is what the technician has written on site.
Description2:	Configured description for the analog zone, field 2. This is what the technician has written on site.
MaxNumberOfZones:	This field represents how many available zones of this type are in the project. Not all of them are necessarily in use.
MaxValue:	Maximum setpoint.
MinValue:	Minimum setpoint.
MaxAllowed:	Maximum value read.
MinAllowed:	Minimum value read.
DaySetPoint:	Daysetpoint(occupied) for the analog zone. Might not in use and adjustable.
DeltaTemperature:	Used in pref regulations.
LowSetPoint:	Setpoint outside of schedule.
ClosedSetPoint:	Setpoint when there are no scheduled time slots that day.
PMin:	When part of the load shedding, it represents the minimum temperature the zone can go to.
Type:	Type of the analog zone.
Acceleration:	Time it took to reach the day setpoint (last time).
AccelerationStr:	Time it took to reach the day setpoint in text format.
Unit:	Measure unit used.
OverrideStatus:	The current state of the zone.
BackColorString:	Color code of the string.
ForeColorString:	Color code of the string.
ActualValue:	Actual value of the zone as read from the sensor.
SetValue:	Actual working setpoint.
Gain:	Output of the gain.
OutdoorTemperature:	The system's calculated outdoor temperature.
RefZoneLetter:	Reference zone type of the analog value.

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RefZoneId: Reference zone id.

HasEffectRegulation: If the zone is included in a load-shedding scheme, the value is true.

IsEffectRegulation: If the zone is temporarily (by the user) excluded from the load-shedding scheme, this value is false.

Spenshor: it represents all the data received from Sphensors. The fields are:

Id: A unique key used to identify a single record.

BorderRouter: The id of the border router the Sphensor is connected to.

Sensor: The id of the given Sphensor

Value: The data transmitted by the Sphensor. It is a text formatted in JSON format containing all the value read from all the sensors.

There are three different types of Sphensors, that monitor different kinds of data:

- Sphensor type 423, whichmonitors CO2, VOC, PM1, PM2.5, PM4, PM10.
- Sphensor type 401, which monitors T_air, and RH.
- Sphensor type 402, which monitors T_air, RH and Illuminance.

An example of Spenshor transmitted value is given below:

[{"sensor_type": "tvoc", "channel_index": 1, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 208.0}, {"sensor_type": "pm", "channel_index": 0, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 0.29978224635124207}, {"sensor_type": "pm", "channel_index": 1, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 0.34010058641433716}, {"sensor_type": "pm", "channel_index": 2, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 0.3591674566268921}, {"sensor_type": "pm", "channel_index": 3, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 0.3688598871231079}, {"sensor_type": "co2", "channel_index": 1, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 752.0}, {"sensor_type": "battery", "channel_index": 0, "timestamp": "2022-08-26 10:19:29", "result": "ok", "value": 5.0}]

Timestamp: Server datetime at the moment of the message arrival.

BMS_A: Table containing data from A -zones that contain indicators for digital status, such as window contacts, etc. The main fields are described below.

Zoneletter: Zone type. For A-zones the value is ‘A’.

Description1: Configured description for the zone, field 1. This is what the technician has written on site.

Description2: Configured description for the zone, field 2. This is what the technician has written on site.

AlarmActive: Indicates whether the alarm is active or not

Timestamp: DateTime at the moment of the message generation.

POE: Table containing the information about the questionnaires filled in by the zone’s occupants.

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No personal information is stored, only information about the zone, the answers and the timestamp are kept.

4.1.2 Data access to repository for automatic evaluation via API

For external access to the data stored within the NTNU server, after a survey of the possible access methods, the selected methodology was developing an API.

API, which stands for Application Programming Interface, is an intermediate structure that allows different applications to communicate with each other. The main role of APIs is taking care of exposing some data to the outside, and making possible to share information and procedures to the applications that request it.

Among the possible approaches, the most widespread is called RESTful or Rest, which is a sort of "extended" standard to adhere, to which certain structural constraints is required (e.g. the manipulation of resources through representations or self-description messages).

The REST architectural approach is defined by the following six constraints:

- ***Uniform Interface***: A key constraint differentiates between a REST API and Non-REST API. A uniform way of interacting with a server is given, which does not depend on the device or application used.
- ***Stateless***: The necessary state to handle the request is contained within the request itself and server would not store anything related to the session. In REST, the client must include all information for the server to fulfill the request whether as a part of query parameters, headers or URL. Statelessness enables greater availability since the server does not have to maintain, update or communicate that session state. There is a drawback when the client needs to send too much data to the server, so it reduces the scope of network optimization and requires more bandwidth.
- ***Cacheable***: every response should include whether the response is cacheable or not and for how much duration responses can be cached at the client side. Client will return the data from its cache for any subsequent request and there would be no need to send the request again to the server. A well-managed caching partially or completely eliminates some client–server interactions, further improving availability and performance.
- ***Client-Server***: REST application should have a client-server architecture. A Client is someone who is requesting resources but not concerned with data storage, which remains internal to each server, and server is someone who holds the resources and are not concerned with the user interface or user state. They can evolve independently. Client does not need to know anything about business logic and server does not need to know anything about frontend UI.
- ***Layered system***: An application architecture needs to be composed of multiple layers. Each layer does not know anything about any layer other than that of immediate layer and there can be lot of intermediate servers between client and the end server. Intermediary servers may improve system availability by enabling load-balancing and by providing shared caches.
- ***Code on demand***: It is an optional feature. According to this, servers can also provide executable code to the client.

When an architecture respects all these constraints, it is called RESTful.

REST APIs offer four main benefits:

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1. **Integration**. APIs are used to integrate new applications with existing software systems. This increases the speed of development because each feature doesn't have to be written from scratch. You can use the APIs to leverage existing code.
2. **Innovation**. With the arrival of a new app, entire sectors can change. Businesses need to respond quickly and support the rapid implementation of innovative services. They can do this by making API-level changes without having to rewrite the entire code.
3. **Expansion**. APIs represent a unique opportunity for companies to respond to customer needs across multiple platforms.
4. **Ease of maintenance**. The API acts as a gateway between two systems. Each system is obliged to make internal changes so that the APIs are not affected. This way, any future code changes on one side will not affect the other party.

The various types of API requests most common today correspond to 5 possible HTTP predicates typical of the REST architectural approach:

- GET: the application requests information from another;
- POST: the creation of new information is requested;
- PUT: it is requested that the information be replaced in its entirety;
- PATCH: modification of part of the information is required;
- DELETE: the application requests that information is deleted.

The main elements that characterize an API call are:

- **Endpoint**: it is the "physical" address of the API, the point from which the REST server is listening, waiting for requests. Generally the endpoint describes its function.
- **Method**: method is the type of request that can be formulated through the HTTP verbs GET, POST, PATCH, etc .;
- **Headers**: these are details that applications exchange for communication purposes, both in the request phase and in the response phase. Among the most common headers in calls is "host", which requires the IP from which the request originates;
- **Data**, or **message body**: it is the content of the interaction between applications, it contains the information that you intend to pass from one program to another. This option is only used with the verbs POST, PUT, PATCH.

At the moment the API is still under development, but it is possible to provide some of the methods that will be used to access the data.

Get Sphensor data by serial number

A first method allows access to the data received from a specific Sphensor through the following endpoint:

api/mqtts/getSphensorbyId

The parameters needed to carry out the search are:

• serial of the Sphensor in question

• search start date

• search end date

The data is returned in JSON format with the following structure:

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```
[
    {
      "id": 0,
      "Sphensor": "string",
      "borderrouter": "string",
      "sensor": "string",
      "value": "string",
      "timestamp": "2022-10-30T11:07:30.904Z"
    }
]
```


Figure 40 shows an example of a search using this method.

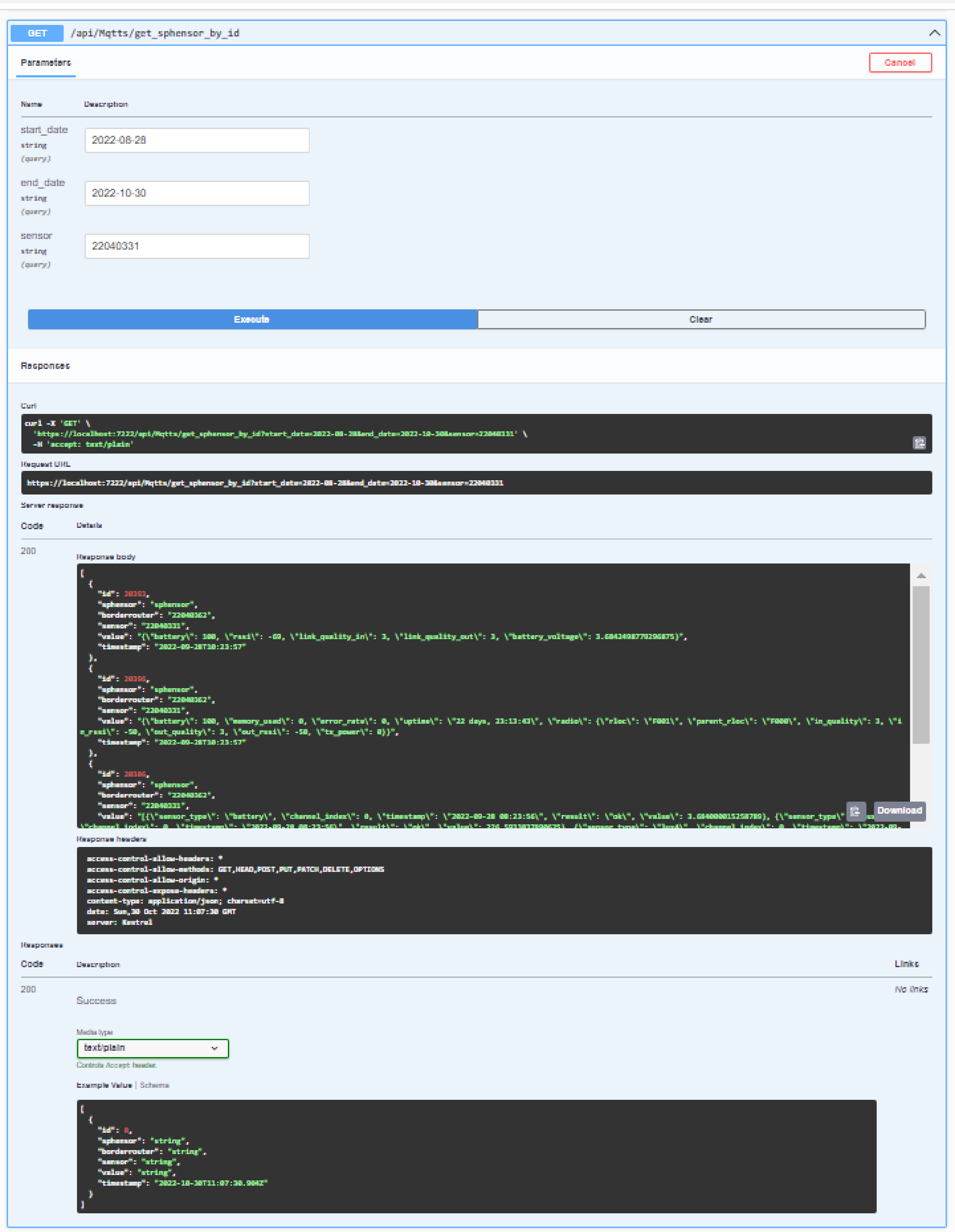

Figure 40 Example of a search of Sphensor by serial numbe

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Get Sphensor data by Room

A further method of searching for the data produced by the Sphensors consists in the aggregation of all data from a specific zone.

The endpoint used is:

api/mqtts/getSphensorbyRoom

The input parameters needed to perform this method are:

- search start date
- search end date
- zone identifier

An example of how this method works is shown in Figure 41.

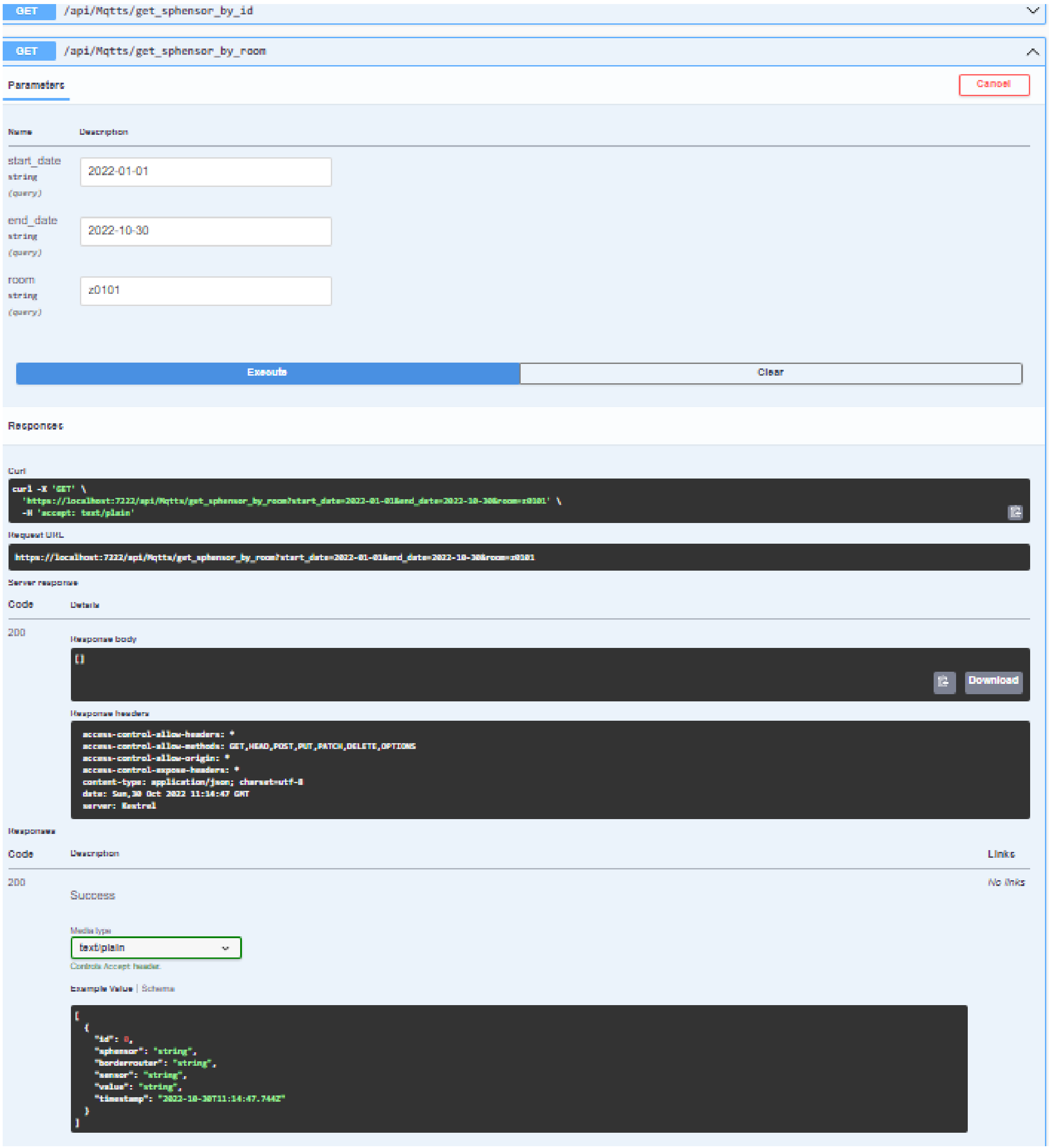

Figure 41 example of a search of Sphensor by room

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The structure of the returned data is the same as the previous method, that is:

```
[
  {
    "id": 0,
    "Sphensor": "string",
    "borderrouter": "string",
    "sensor": "string",
    "value": "string",
    "timestamp": "2022-10-30T11:14:47.744Z"
  }
]
```

Get Sphensor Data by Building

It is also possible to aggregate all the data from the Sphensors present inside a building.

The operating method is the same as seen above, the endpoint used is:

api/mqtts/getSphensorByBuilding

This method requires the insertion of the following parameters:

- search start date
- search end date
- building identifier

The data is returned in JSON format using the following structure:

```
[
  {
    "id": 0,
    "Sphensor": "string",
    "borderrouter": "string",
    "sensor": "string",
    "value": "string",
    "timestamp": "2022-10-30T11:26:09.649Z"
  }
]
```

An example of a request is shown in Figure 42.

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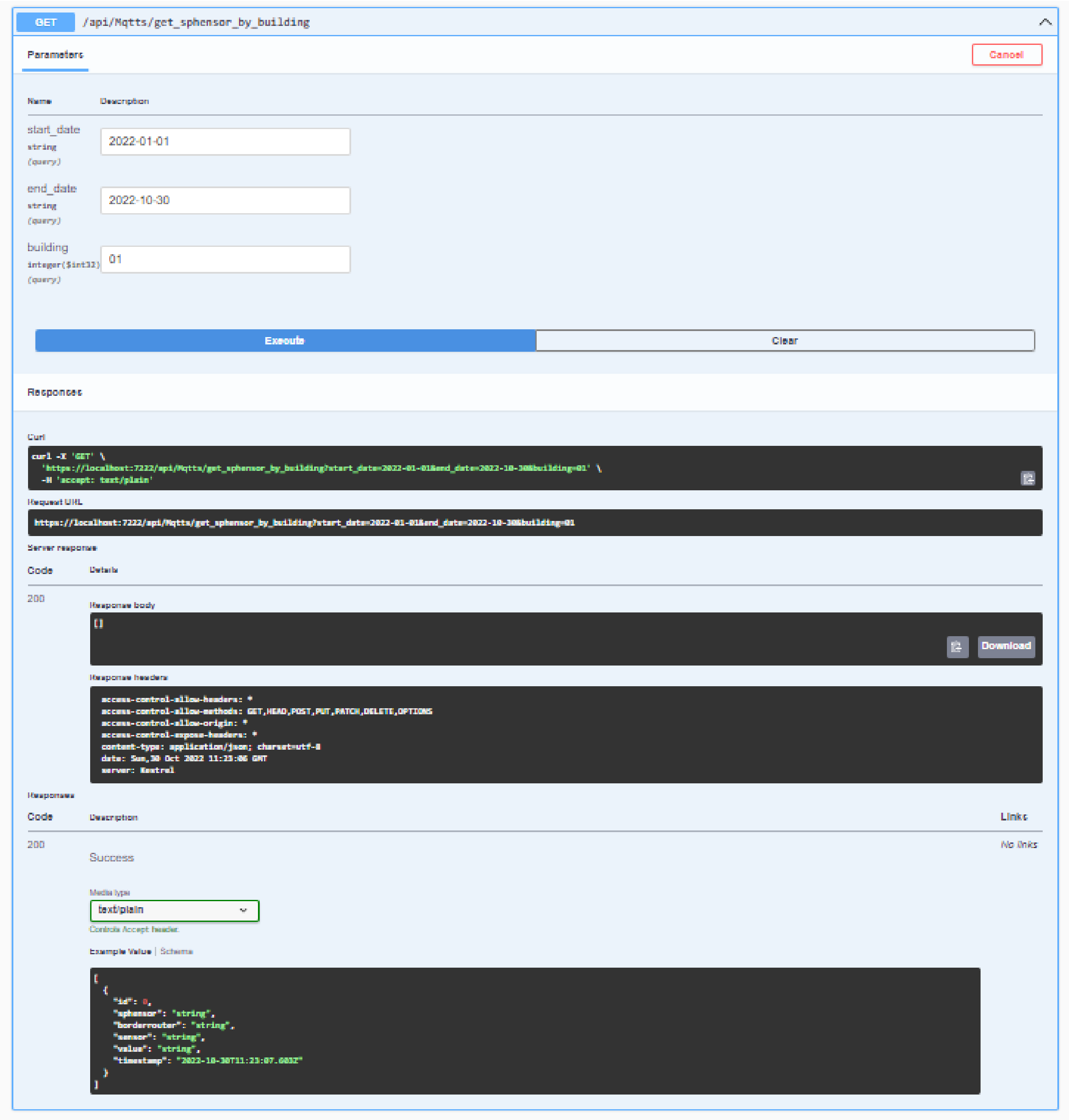

Figure 42 Example of a search of Sphensor by building

In the same way, it is possible to access the other main classes of data available, data from the analog zones of the BMS, data from the alarm zones and data relating to POEs.

As for the alarm zones, the following endpoints are provided:

api/getBmsAlarmsby_id

Allows you to access the data generated by the alarms using the following parameters:

- sensor id
- search start date
- search end date

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api/getBmsAlarmsby_room

allows you to access the data generated by the alarms by aggregating all the data available for a specific zone. The parameters required to use this function are:

- zone id
- search start date
- search end date

api/getBmsAlarmsby_building

allows you to access the data generated by the alarms by aggregating all the data available for a specific building. The parameters required to use this function are:

- building id
- search start date
- search end date

The data returned by the previous methods are in JSON format having the following structure:

```
[
  {
    "idbms": 0,
    "id": 0,
    "zoneletter": "string",
    "description1": "string",
    "description2": "string",
    "alarmActive": 0,
    "timestamp": "2022-10-30T12:04:38.068Z"
  }
]
```

An example call for alarm data is shown in Figure 43.

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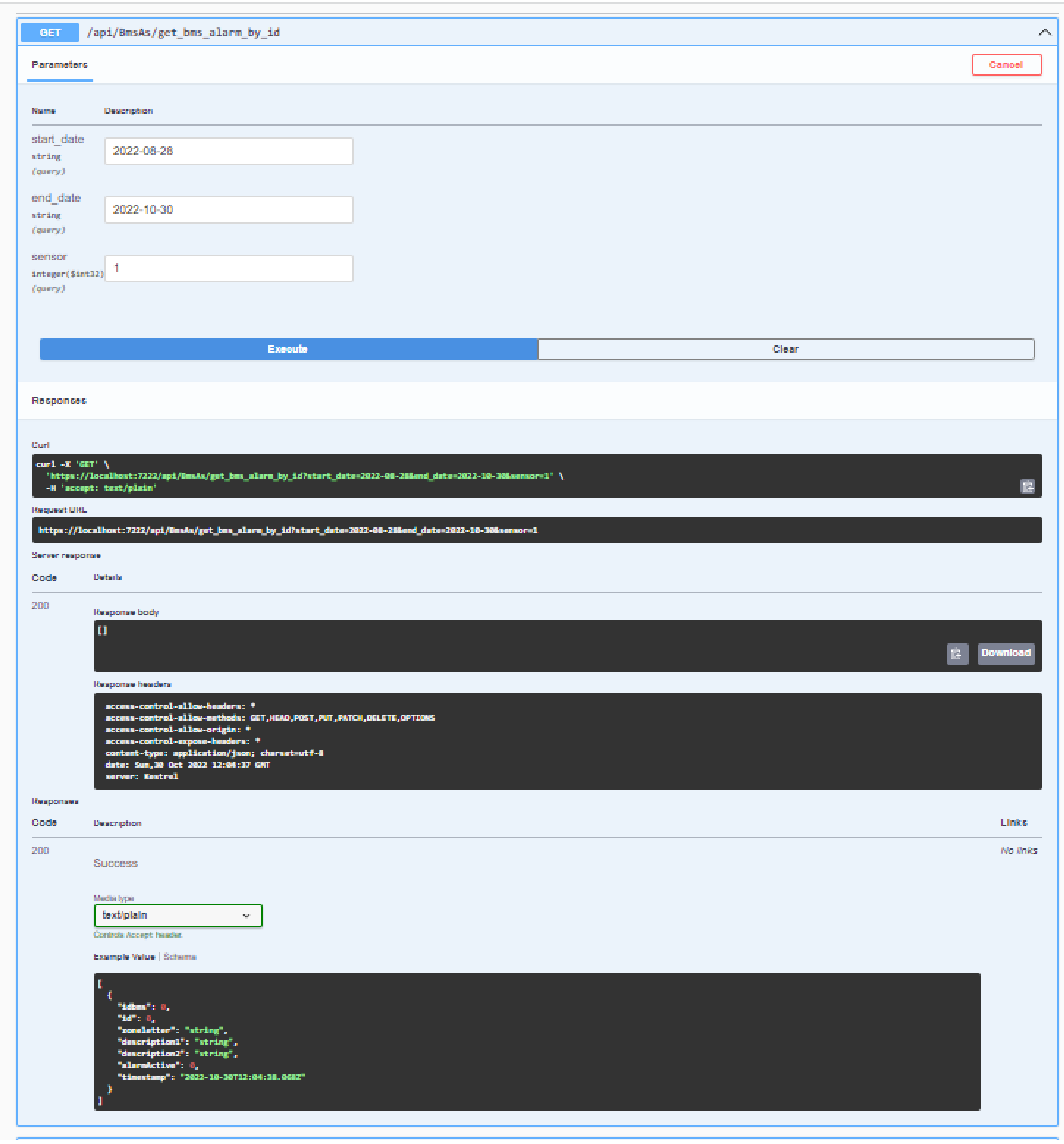

Figure 43 example call for alarm data

In the same way, access to data relating to the analog zones of the BMS is provided.

The following methods are available:

api/getBmsDataBy_id

It allows you to access the data generated by the sensors using the following parameters:

- sensor id
- search start date
- search end date

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api/getBmsDataBy_room

allows you to access the data generated by the sensors by aggregating all the data available for a specific area. The parameters required to use this function are:

- zone id
- search start date
- search end date

api/getBmsDataBy_building

allows you to access the data generated by the sensors by aggregating all the data available for a specific building. The parameters required to use this function are:

- building id
- search start date
- search end date

The data returned by the previous methods are in JSON format having the following structure:


```
[
  {
    "id": 0,
    "zoneletter": "string",
    "description1": "string",
    "description2": "string",
    "maxnumberofzones": 0,
    "maxValue": 0,
    "minvalue": 0,
    "maxallowed": 0,
    "minallowed": 0,
    "daysetpoint": 0,
    "deltatemperature": 0,
    "lowsetpoint": 0,
    "closedsetpoint": 0,
    "pmin": 0,
    "type": 0,
    "acceleration": 0,
    "accelerationstr": "string",
    "unit": "string",
    "inndorref": 0,
    "overridestatus": "string",
    "backcolorstring": "string",
    "forecolorstring": "string",
    "actualvalue": 0,
    "setvalue": 0,
    "gain": 0,
    "outdoortemperature": 0,
    "refzoneletter": "string",
    "refzoneid": 0,
    "haseffectcalculation": 0,
    "haseffectregulation": 0,
    "iseffectregulation": 0,
    "timestamp": "2022-10-30T12:25:00.228Z"
  }
]
```


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An example of a call to obtain data related to the analog zones of the BMS is shown in Figure 44.

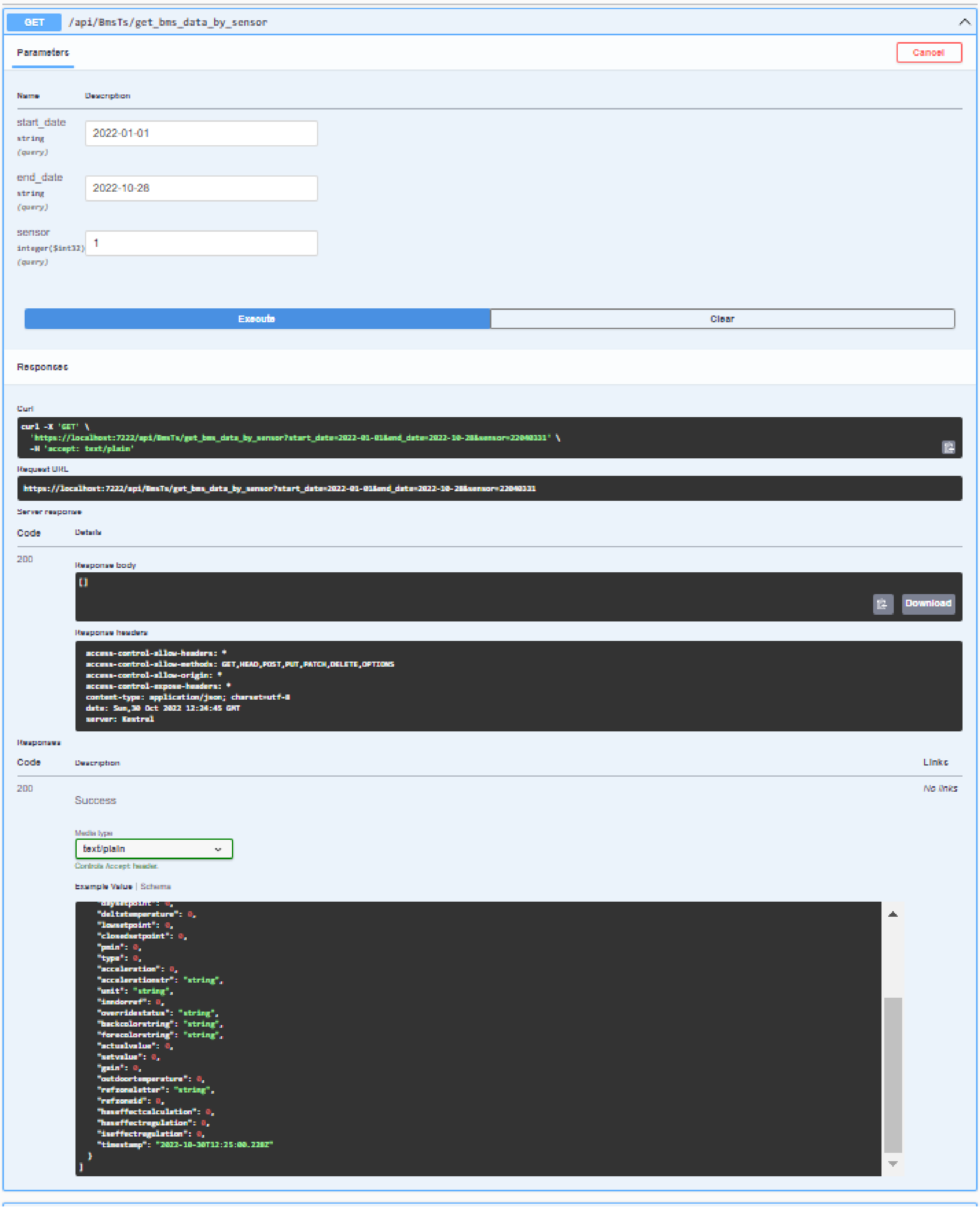

Figure 44 Example of a call to obtain data related to the analog zones of the BMS

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For a first evaluation of data quality and processing, Eidet Sphensor data has been selected.

Below is an initial assessment[1] of the temperature values concerning the Eidet building for the last month obtained from the 4 Sphensor (ID: 22040204, id 22040205, 22040214, 22040215). The dataset reported is a time series with a total of 127,096 float64 observations. The reference period is 27 September to 27 October 2022. The date time index is expressed in this form Year-month-day Hour:Minute:Seconds. In Table 13, some descriptive statistics are provided and the distribution in quartiles is shown to give an initial idea of the shape of the data distribution.

Table 13 - Eidet - Descriptive statistics sensor data

Value	**Sensor ID 22040204**	**Sensor ID 22040205**	**Sensor ID 22040214**	**Sensor ID 22040215**
count	38,642	40,942	6,951	40,561
mean	23.377638	23.596008	23.266047	23.232627
std	0.371657	0.284994	0.386627	0.381233
Min	21.889999	22.740000	22.360001	21.820000
25%	23.270000	23.370001	23.090000	22.990000
50%	23.480000	23.590000	23.260000	23.200001
75%	23.559999	23.799999	23.549999	23.510000
Max	24.370001	24.620001	24.549999	24.209999

In the period considered the number of observations for each sensor is reported:

1. **Sensor ID 22040204** has 38,642 observations,
    - **Start**: the first observations were sent on 2022-09-29 at 08:15:12
    - **End**: the last observations were observed on 2022-10-27 at 21:59:35

2. **Sensor ID 22040205** has 40,942 observations,
    - **Start**: the first observation was sent on 2022-09-27 at 22:00:13
    - **End**: the last observation was observed on 2022-10-27 at 21:59:21

3. **Sensor ID 22040214** has 6,951 observations (has not sent data from 3 October 2022)
    - **Start**: the first detection was sent on 2022-09-27 at 22:00:14
    - **End**: the last observed detection is on 2022-10-03 at 06:07:46

4. **Sensor ID 22040215** has 40,561observations,
    - **Start**: the first detection was sent on 2022-09-27 at 22:00:21
    - **End**: the last observed detection is on 2022-10-27 at 21:59:19

[1] This analysis is made by python software. There are some methods built-in or in the library (es. Missingno), for post-processing data in their environment (resampling Datetime index in minutes, hours, days and so on, checking NA/NULL values in a precise point of date time index, sum the value NA/NULL, interpolation methods for NA/NULL values, etc.) that easily made the analysis of raw data in the database.

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The mean value is within a range from a minimum of 23.23 (Sensor ID 22040215) to a maximum of 23.59 (Sensor ID 22040205). The standard deviation is within a range with a minimum of 0.284 (Sensor ID 22040205) and a maximum of 0.3866 (Sensor ID 22040214).

No duplicate or null values are recorded during the period considered. The number of observations differs between the different sensors because the reference time period is different (e.g. the first observation of sensor ID 22040204 was recorded with DateTime index 2022-09-29 08:15:12, while the first observation of sensor ID 22040205 was recorded with DateTime index 2022-09-27 22:00:13, therefore with a time difference of about 2 days). This difference explains the difference in the number of observations between the different sensors. At the level of the temporal resolution with which the data is sent, the sensors send readings every minute, but over time the sending does not have regular intervals (e.g. Sensor ID 22040204 starts on 2022-09-29 08:15:12 and ends 2022-10-27 21:59:35). At the DateTime index level, resampling is important to provide a precise frequency to the DateTime index of the series, in order to make some techniques of post-processing and analysis possible.

The time distribution of the raw data recorded and sent by each sensor according to its time index is shown below.

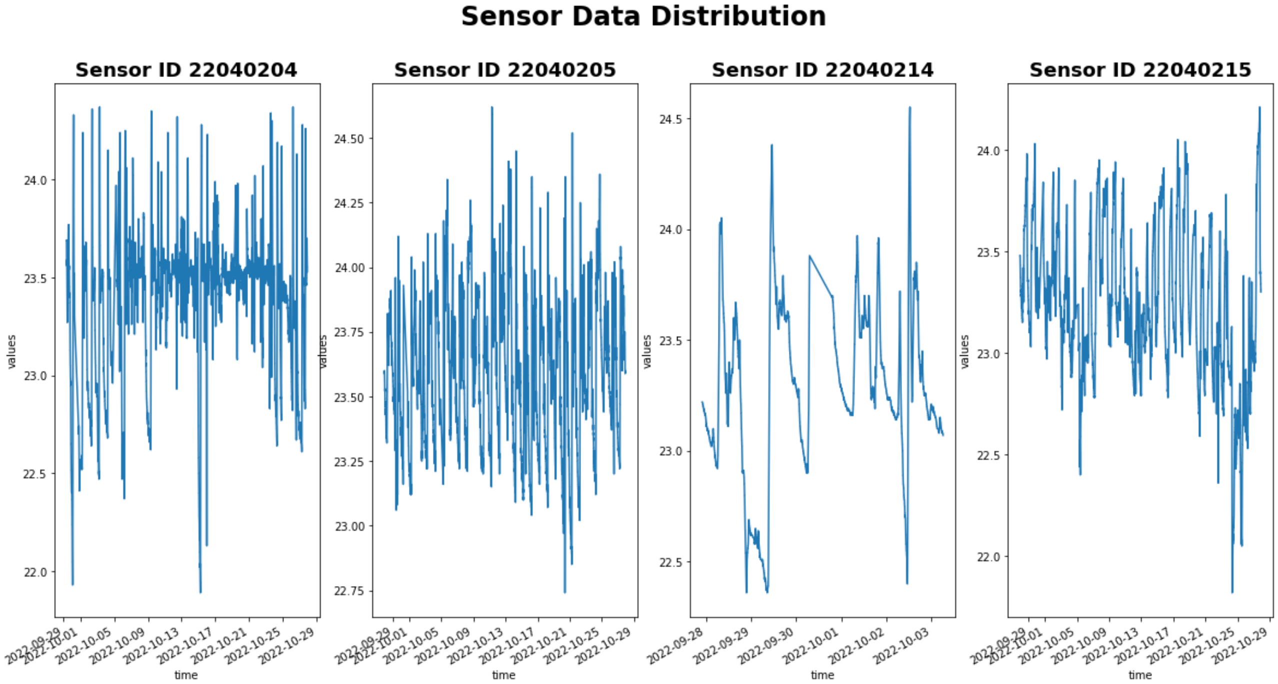

Figure 45 Eidet Omsorgssenter - distribution of sensor values by time index

Regarding handling outliers, outlier detection methods in data can take many forms. The basic point was their ability to detect outliers generally through threshold values and statistical conditions. These thresholds could be determined directly from the technical specifications of the sensors, or it is possible to use methods based on parametric statistics, where it is necessary to model the data using a statistical distribution. Another way is to use non-parametric methods based on a well-defined notion of distance to measure the separation between a pair of data objects (e.g., distance-based, density-based, cluster-based).

For the treatment of null values, it is necessary to assess their nature, i.e., complete missing at random (MCAR), missing at random (MAR) or missing not at random (MNAR). Missing value estimation methods based on past and future values can be applied, such as Last

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Observation Carried Forward (LOCF), Next Observation Carried Backward (NOCB), moving average (simple, weighted, exponential) and interpolation-based methods, such as time-based, linear, polynomial, spline, akima, etc.

If data are missing and are concentrated in specific time intervals, the handling of missing values becomes more complicated. The larger the period with missing values within it, the more uncertain the interpolation methods become. The handling of this type of situation obviously depends on the presence of certain characteristics and specific properties of the time series (stationarity, autocorrelation, partial autocorrelation, etc.). If certain properties are observed, one can try to bridge a time interval in which values are absent by using past time. Predictive methods can then be tried (e.g., ARMA, LSTM neural networks, etc.). However, it must be considered that the further away in time the predictions are, the more uncertain they are. For the implementation of these solutions, in addition to verifying certain characteristics of the temporal series, it is necessary to have as much historical data as possible to train the model. When a large historical base is not available, the period over which forecasts are stable and reliable is very limited.

The criterion for choosing between the different methods could be the one that does not alter the original distribution and statistical properties of the data.

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4.2 Development of common evaluation routines

It is planned to implement several routines for data check and correction of data. This will be presented in the next update of this deliverable once more monitoring data is available for testing.

A list of rules for data cleaning and filling that will be implemented for the different measurement types is as follow:

- Check value coherence and corrections
- Check for blank periods and filling
- Resample to common time step for evaluation

These routines will be applied specifically to the following measurement data type:

- States: Temperatures, humidity, CO2 etc.
- Powers: thermal power, electric power, gas power
- Energy: thermal energy, electric energy (active), gas energy
- Flows: water and air flow rates

4.3 Lessons learnt

At the moment the data flow from the field/pilot building involves an MQTT server developed by E@W which acts as a bridge between the LASTEM server and the NTNU database managed by CETMA. During the company summer holidays, from the evening of 4 August to the early morning of 23 August, the data was lost, due to an extraordinary power outage in the Puglia region of Italy. Unfortunately, although the E@W bridge server remained switched on during the entire time of the power outage, the VM on which the MQTT E@W server resides no longer connected to the Internet after losing its connection to the network, causing the loss of data during the above-mentioned time interval.

The current data flow manifested vulnerability problems at the physical integrity level (the power outage in August affected the functionality of the E@W bridge server, effectively causing the loss of data).

With the aim of eliminating the E@W bridge server and considering sending the data from the LASTEM server directly to the NTNU server managed by CETMA, the MQTT broker will be installed on the NTNU server (VM with the E@W SW) by October, and communication with the various nodes will be tested, prevent the loss of data in the future.

The NTNU server is a protected server and well protected against such risks; therefore, it does not seem reasonable to send the data first to E@W and then to the NTNU server. The solution that will be implemented consists of eliminating this node and considering sending the data directly to the NTNU server. This procedure consists of installing the MQTT broker on the NTNU server (VM with the E@W SW) and testing the communication with the various nodes, to avoid similar problems and allow CETMA to continue collecting data in the same way.

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5 Pilot site modelling and calibration of energy models (CSTB)

5.1 Modelling approach based on DIMOSIM

DiMoSim (District Modeller and Simulator) is a building, district and city-level, bottom-up, object-oriented, simulation platform. By providing two dependency management mechanisms (for one-way and two-way dependencies between models) as well as generic utilities (support for several input file format, result aggregation and plotting, object-tree data queries), it allows a fast prototyping of new models and their integration in an inter-dependent simulation chain. Below is a schematic describing the main types of available models and their dependencies:

- HVAC systems
- Thermal heating and cooling networks
- Residential user behaviour
- Electricity distribution network
- Flexibility systems

DIMOSIM can be used as a locally installed package, in a docker or over http via a REST API. The DIMOSIM API has been used for simulation and calibration of the pilot projects. The input data required includes a weather data file, simulation parameters such as the timestep duration and buildings characteristics file including building geometry and energy systems included in the building. The API allows for easy access to complete simulations including access to modify and customize a large part of the simulation parameters.

The workflow for models developed with DIMOSIM is below:

- Collect building envelope and occupant related characteristics
- Model the energy demand of the building envelope
- Collect building energy system characteristics
- Calculate electric and natural gas load of buildings considering energy system characteristics
- Calibrate models based on measured energy consumption data provided by each pilot

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5.2 Pilot model calibration methodology

5.2.1 General layout of calibration methodology

CSTB has developed a generic calibration package (Python) for the calibration of building energy simulation tools, CALIENTE (**CALI**bration for **EN**ergy consump**T**ion in **E**xisting buildings). In the COLLECTiEF project, this package has been adapted and updated for the DIMOSIM simulation tool. The calculation core is an independent method that can be connected to any Building Energy System (BES) as long as some tools data converters are developed (see Figure 46). The standardisation of input and output data are mandatory to run the calibration core. Therefore, the calibration can be done with measured data or with precise simulation data from other tools, at an aggregated level (annual results) or dynamic level (monthly, hourly or sub-hourly time series). Nevertheless, CALIENTE has been tested for now only for physical models and not black box models (the core was only tested for detailed models).

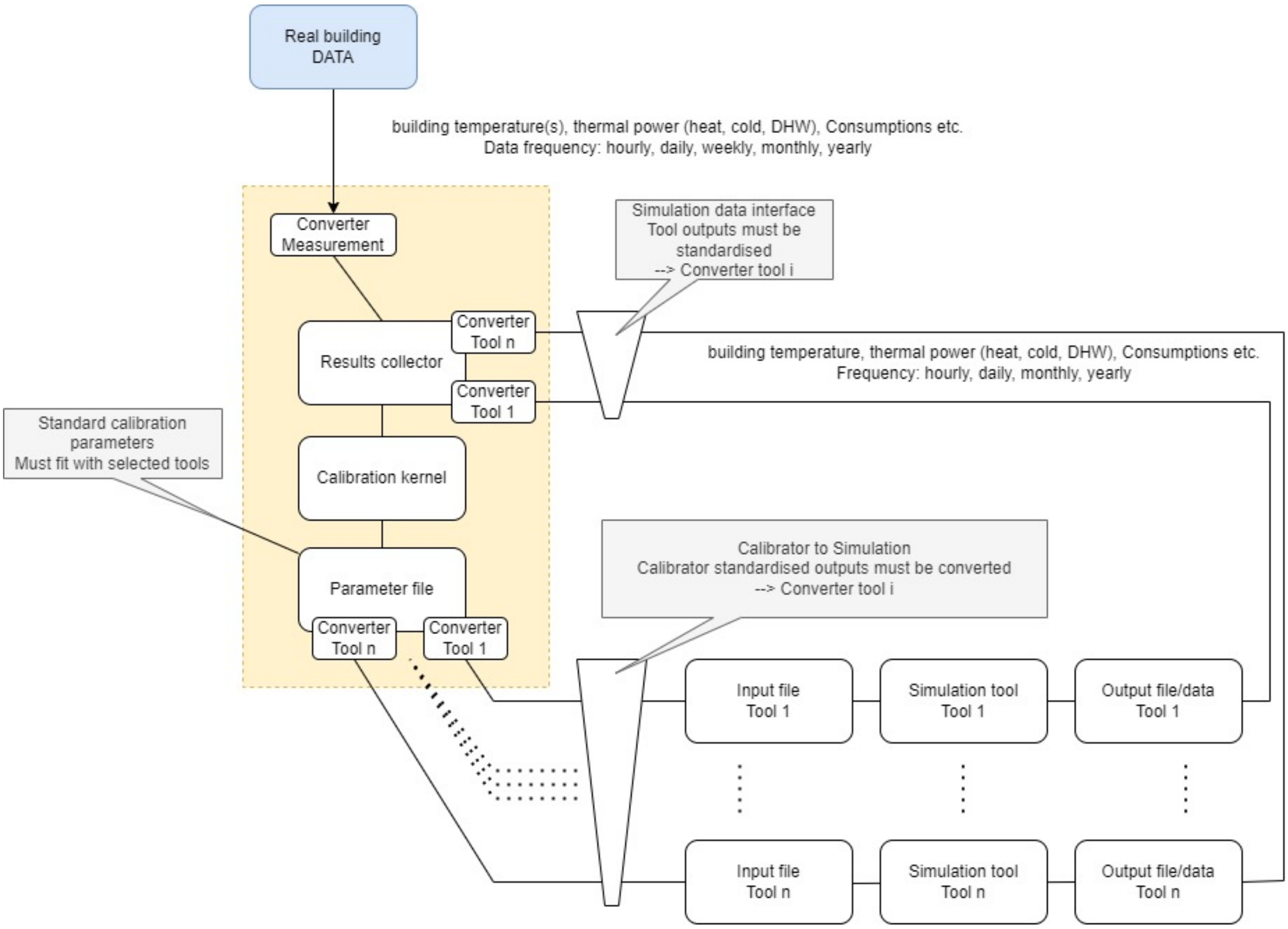

Figure 46 General methodology of the CALIENTE calibration tool

5.2.2 Global calibration methodology

The calibration of buildings parameters can be done in several steps (optional and mandatory):

1. ***Building physical model***: The building characteristics e.g., the geometry, the thermal parameters, the construction year, etc, must be gathered.
2. ***Baseline timeseries data***: Weather and building measured data (e.g., consumption, air temperature, etc.) are cleaned and disaggregated if possible, to be used for calibration. The

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analysis of these data can be useful to determine some building parameters (e.g., heating set point temperatures, etc.)

3. ***Building sensitivity analysis***: This analysis is used for choosing the right parameters for the calibration. It is not mandatory but is useful to reduce the number of parameters for the calibration and thus it accelerates the identification process.
4. ***Model calibration***: The calibration is done on a set of parameters to obtain a BES result close to the baseline reference data. The calibrated parameters are proposed to the user at the end.

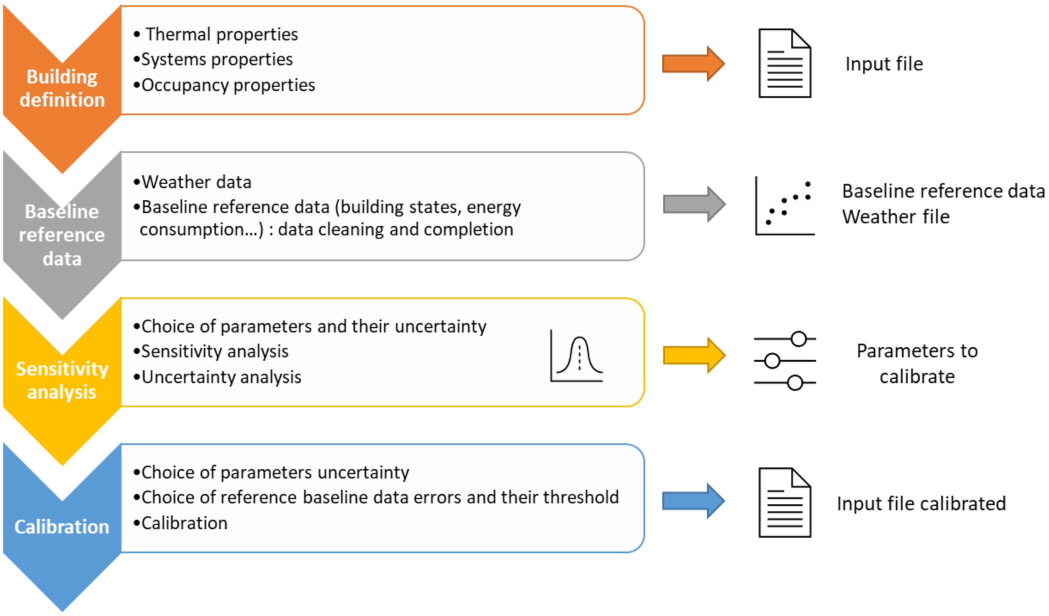

Figure 47 General calibration methodology

5.2.2.1 Building physical model

The building physical description is one of the most important parts to create a first model that is as close as possible to the reality and estimate the uncertainty associated with all building characteristics. The parameters can be:

- Thermal envelop parameters: u-values of the boundaries, window share, infiltration rate and all thermal properties of the opaque and windows boundaries.
- Systems parameters: parameters linked to the HVAC systems as the ventilation efficiency or the type of heating system.
- Occupancy: The type of occupancy with the given profiles must be described. The usage of the building must be known as well as the set point temperatures, the internal gains of occupant and equipment or air change rates.

The type of input file is linked to the BES used.

5.2.2.2 Baseline reference data recovery

The baseline reference data must be recovered from the building. In order to be used in the calibration process, all the data must be the same length (used for the simulation) and must be cleaned and without missing data.

The data must be in a csv format. Two files are used: one for aggregated data (annual data) and one for time-series data (monthly or hourly, but all the data must be in the same format). The calibration can be done on both data types.

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5.2.2.3 Building sensitivity analysis

Sensitivity and uncertainty analysis are useful for calibration as they allow to detect the most influential parameters and thus facilitate the calibration process and the building results comprehension. The calibration will then only be done on the selected parameters allowing savings in time effort.

Two parts of this analysis can be done: a sensitivity analysis and an uncertainty analysis. The sensitivity analysis detects the parameters that are the most influential and the least influential on the building consumption profile and the uncertainty analysis evaluates the reliability of the results by showing their distribution instead of a fixed value.

The sensitivity analysis includes several methods that allow to explore the parameter space and propose indicators to show the main effect and inter-effects of the parameters. Two main methodologies can be distinguished: Local sensitivity analysis and global sensitivity analysis. The local sensitivity varies only one parameter at a time while the others are fixed, whereas the global sensitivity analysis changed all the parameters values to detect how the uncertainty of the results are distributed to different source of uncertainty in the input parameters. It is this last methodology that is implement in CALIENTE through different methods [29–31]:

- Morris: Screening method that measures the rank of each parameter and that can work with a large number of input parameters. Cannot be used for uncertainty analysis.
- Sobol: Variance-based method that consider main and interaction effects between the parameters with a high computation cost.
- Experimental design: Screening method that create all the parameters combinations. To not use with a lot of parameters.
- EASI RBD-FAST: Variance-based method that consider main and interaction effects between the parameters with a reasonable computation cost. The parameter space is evenly sampled.

The sensitivity analysis is done in several steps whatever method is used:

- Choice of the input parameters of interest for the uncertainty or sensitivity analysis. The choice of bounds and probability distributions are crucial for the analysis to be meaningful: they must reflect the actual state of uncertainty from the expert's point of view.
- Creation of the input parameter samples: depending on the sensitivity method chosen, a different sampling method is applied. The number of samples must be cautiously chosen: too few could strongly bias the analysis, too many burdens the computational cost. Run the BES for each sample, i.e. each set of input parameters and, if applicable, post-process the simulated data to save the simulated output of interest for the analysis. Apply the sensitivity analysis on the simulated output of interest

The sensitivity analysis provides first-order sensitivity indices (or importance measures depending on the method) for each input parameter. The larger the index, the larger the influence of the input parameter alone on the variability of the BES output of interest. The uncertainty of the sensitivity indices can also be evaluated to critically analyse the results.

The results of the sensitivity analysis can be presented with graphs, for example the Figure 48 shows the sensitivity results for the cooling demand of a building with random values for the input parameters. The figure shows that the window share of exterior walls is one of the most influential parameters for the simulation.

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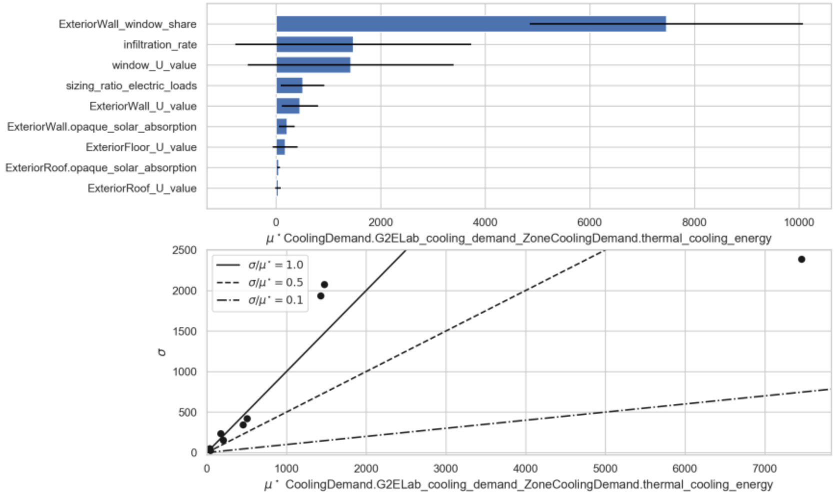

Figure 48 Example of Morris results for 9 parameters

The uncertainty analysis can be done with the sensitivity analysis or independently. The analysis gives the distribution of the results and shows the uncertainty of model output following the model inputs. Figure 49 shows the distribution of the heating demand with the kernel density estimate.

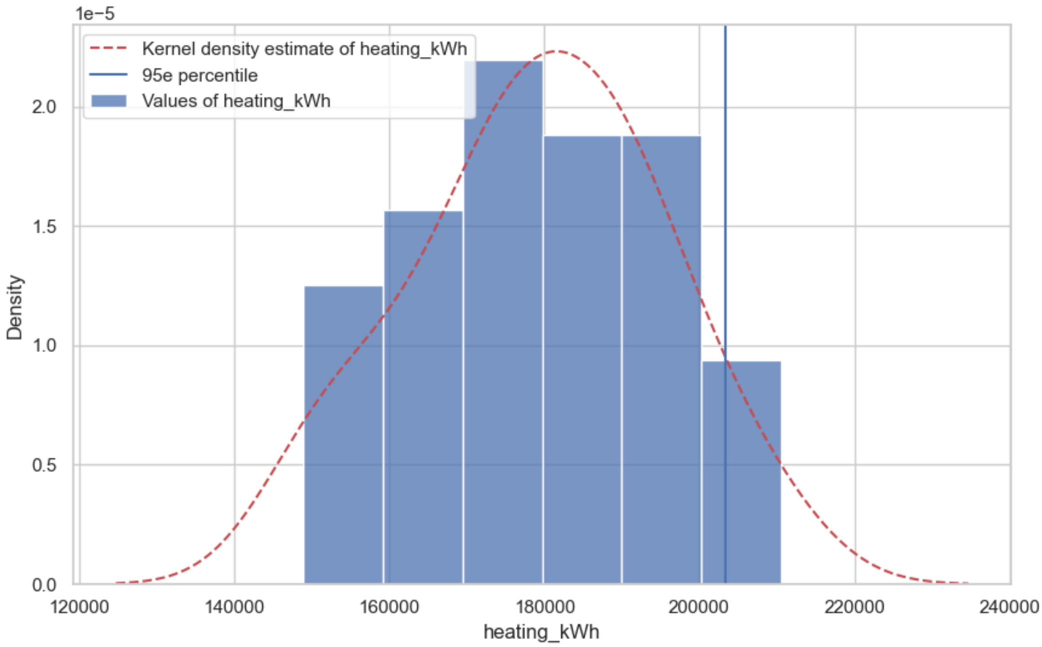

Figure 49 Distribution of the heating demand of a random building

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5.2.2.4 Calibration of model

Methods overview

The objective of the calibration is to reduce the uncertainty in the input parameters and tune them to have simulation results close to the baseline reference data (either measured or detailed simulation data). Three different methods are available in CALIENTE to do a calibration:

- Simple calibration: the module creates a sample with the distribution for all wanted parameters, all simulations are run with the BES (connected to the package or independently) and the best errors is picked.
- Simple coupled calibration: the module creates a sample with distribution for all the wanted parameters, the simulations are run with the BES and are stopped when the errors on the results are under a given threshold. This method needs a connection to the BES.

Genetic calibration: the module applies a genetic evolutionary algorithm with parameters sample evolution and stops the simulation when the errors are under a given threshold. This method needs a connection to the BES.

Baseline comparison

Different standardized statistical indices can be used for the calibration, depending on the type of results to be evaluated and the objectives of the calibration.

The indices can be the Percentage Error (PE), the Absolute Percentage Error (APE) to avoid errors cancellation, the Mean Bias Error (MBE) or the Root Mean Square Error (RMSE) for time series. The ASHRAE guidelines [32], the International Performance Measurement and Verification Protocol (IPMVP) and the Federal Energy Management Program (FEMP) propose also several indices such as the Normalized Mean Bias Error (NMBE), the Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) and the Coefficient of Determination R^2. All these indices are described as:

- Percentage Error: Simple comparison between the simulated values and the baseline reference values at an aggregated scale. It indicates an over or underestimation.

$$PE(Y) = \frac{Y - \hat{Y}}{\hat{Y}} * 100\ (\%)$$

- Absolute Percentage Error: It is the absolute value of the percentage error where the over or underestimation is not taken into account, only the absolute difference is studied.

$$APE(Y) = \left|\frac{Y - Y_{ref}}{\hat{Y}}\right| * 100\ (\%)$$

- Mean Bias Error: This error can be applied on the entire time series where the difference is calculated and averaged over the whole time series. It only gives the average difference between the two series with the data unit.

$$MBE(Y) = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}$$

- Root Mean Square Error: It is the equivalent of the standard deviation of the MBE, allowing to visualize the standard deviation of the time series to the baseline reference.

$$RMSE(Y) = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}$$

- Coefficient of Variation of the Root Mean Square Error: It is the normalisation of the RMSE

$$CV\big(RMSE(Y)\big) = \frac{RMSE(Y)}{\bar{Y}} \cdot 100\ (\%)$$

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- Normalized Mean Bias Error: It is the normalisation of the MBE

$$NMBE = \frac{MBE}{\bar{Y}} \cdot 100\ (\%)$$

- Coefficient of Determination: It represents the quality of the linear regression with respect to the reference

$$R^2(Y) = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

With Y the simulated annual value (y_i the simulated value at time step i) and $\hat{Y}$ the baseline reference annual value ($\hat{y}_i$ the baseline reference value at time step i) and $\bar{Y}$ the baseline reference mean value, and n the number of data points (simulation duration).

For each error the user must indicates a threshold under which the calibration is considered as enough. The ASHRAE, IPMVP and FEMP propose threshold values following the results time scale, monthly or hourly, and the error used. It is gathered in Table 14. In CALIENTE the user can choose its own threshold.

Table 14 Error threshold from ASHRAE, IPMVP and FEMD

Standard	Monthly		Hourly	
	NMBE (%)	CV(RMSE) (%)	NMBE (%)	CV(RMSE) (%)
ASHRAE	5	15	10	30
IPMVP	20	-	5	20
FEMP	5	15	10	30

Methods description

The calibration protocol aims to improve the accuracy of the energetic simulation of BES by calibrating the input parameters that have a significant impact on the building performance. The unknown and/or uncertain parameters are tuned to find their best value for the model simulation compared to baseline reference data.

Therefore, a first step is to choose the input parameters and their uncertainty. Then, with the input data adapted for each BES, the calibration core can be run to find the calibrated input data that fit the baseline reference data.

Choice of input parameters and creation of parameter combinations

A sensitivity analysis can be done before the calibration process to reduce the number of parameters to calibrate. When the input parameters are selected, it is necessary to assess their reliability. Following the type of data recovery, some parameters can be defined as reliable whereas some can be considered as uncertain or totally unknown with the use of default values. The parameter uncertainty is directly correlated to a higher possible range of values. The user must be careful when choosing the value range. If the parameter is deduced from detailed measurement, it can be considered as certain and put aside for the calibration.

The input parameters must be described for the calibration procedure by a statistical distribution: uniform, normal, discrete, triangular, beta or log-normal. For each type of distribution several characteristics are needed (mean and standard deviation error for normal distribution, min and max value for uniform…). This distribution can be taken as a multiplying scalar or as the value of the parameter. Other characteristics for each parameter can be added depending on the BES.

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A list of simulations with varying parameter combinations is created from the csv file:

- Simple calibrations: A given number of samples must be indicated to create the whole sample with a given sample method (monte carlo, lhs or full experimental design). If the full experimental design is used, the number of parameter grid level must be also indicated.
- Genetic calibration: The sample is updated for each generation.

For now, the parameters are considered independent, there is no relation between them.

Calibration protocol and choice of the best combination

Once the sample is created it is possible to run the calibration core. The 3 methods are presented in Figure 50. For each calibration method, the BES simulation must be run to retrieve the wanted results to calibrate. For each result (annual or time series) the discrepancy to the baseline reference data is calculated, and this, for each combination of input parameters.

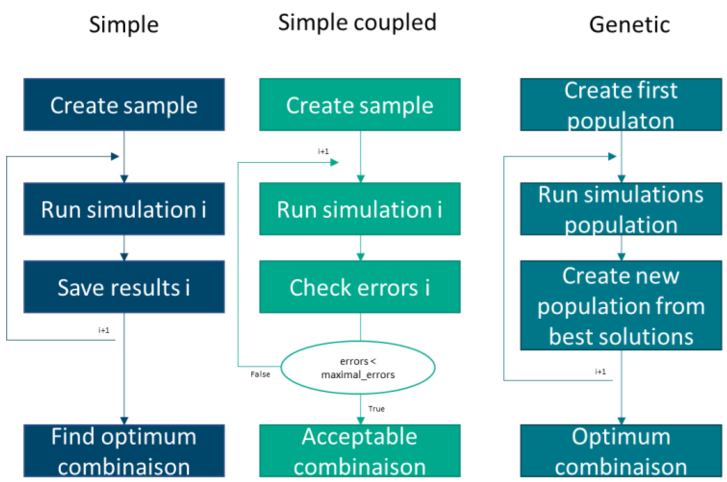

Figure 50 Overview of the 3 calibration methods of CALIENTE

For the simple calibration, all the combinations in the sample are run and the best combination of parameters is selected. This combination is found by taking the smallest error. If the calibration is done on multiple results, the optimum is taken as the minimum of the sum of errors. Therefore, the user must be careful when choosing to calibrate with different types of errors. This part will be improved in the future.

For the simple coupled calibration, the simulations are stopped when the errors calculated are below the threshold indicated by the user. If several results are calibrated, the simulations are stopped only when all the results errors are under their threshold.

For the genetic algorithm, the simulations are stopped in the same way as the simple coupled calibration. However, the threshold for the genetic algorithm can only be unique. Therefore, the threshold is calculated as the inverse of the sum of the error thresholds. If the sample population do not achieve to be under the error threshold, then a new sample population is created based on the best combinations of the parent sample. A simulation limitation is given by the user to stop the simulations even if the optimum is not found.

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5.2.3 Adaptation to DIMOSIM

In order to run CALIENTE with DIMOSIM, a tool converter was developed to transform the CALIENTE input parameter sample into DIMOSIM input data, and DIMOSIM output results into data that can be read by CALIENTE to apply the calibration core.

5.2.3.1 Workflow

The DIMOSIM calibration workflow is composed as follow:

1. Files input load:
    a. Load of the initial DIMOSIM files
    b. Load of the calibration parameters files
    c. Load of the baseline reference data files
2. Choice of calibration method
3. Creation of the calibration sample
4. Transform and link the DIMOSIM and calibration data to the exact calibration objects in the right format
5. Launch of the calibration:
    a. Change the values in DIMOSIM parameter files to consider a new parameter combination
    b. Launch DIMOSIM API server with the changed files
    c. Recover the simulation results specified in DIMOSIM parameter file
    d. Store the DIMOSIM results into the calibration object with the right format
    e. Calculates the errors for each DIMOSIM results stored
    f. Find the optimum combination based on the wanted errors
6. Creation of DIMOSIM input files from the calibrated parameter combination

5.2.3.2 Inputs

Several files are needed to run calibration:

- DIMOSIM files:
    - Thermal zone file with the geometry and the mandatory parameters: json or geojson file
    - Specific parameters to add to all the thermal zones and systems: json file
    - Scenario file (time series) to apply to different object in DIMOSIM: json file
    - Weather file with the right weather consistent with the reference baseline data: EPW file
- Calibration file:
    - Input parameter file with the parameter names, the object name and the DIMOSIM file where to change the parameter value: csv file
    - Calibration file with the characteristics of the calibration method and the results specifics (maximal error, zone group…): json file
    - Baseline reference files, one for aggregated results and one for time series results: csv files

5.2.3.3 Outputs

The calibration process creates 2 types of files:

- Calibration file: csv file with all the parameters combinations and the results errors linked to it, and the indication of the optimal combination.
- DIMOSIM files: the production of the input DIMOSIM files completed with the right calibrated parameters.

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5.3 Pilot models and their calibration

5.3.1 G2ELAB building

The G2ELAB building acts as living lab in the COLLECTiEF project. It is equipped with a huge number of sensors and meters, for single zones and also for groups of zones.

5.3.1.1 Levels of detail (s) of G2ELAB building model

Three levels of detail (LOD) of modelling have been prepared for the project.

Models	*Geojson file name*	*Thermal Zones*
Basic Model (One zone model for the lab)	G2elab.geojson	4 main thermal zones: -Greener 0: The three floors below the Lab -G2eLab: The whole lab as one thermal zone -Greener 1: The rest of fourth floor -Greener 2: the fifth floor above the lab
Edge Node Mode (two zones model for the lab:edge node+lab)	G2eLab_EdgeNode.geojson	5 thermal zones: (The G2elab is splitted to 2 zones: the office 4A015 and the rest of lab) -Greener 0: The three floors below the Lab -G2eLab: The whole lab without the office 4A015 -EdgeNode: The office 4A015 -Greener 1: The rest of fourth floor -Greener 2: the fifth floor above the lab
Detailed Model (each office is a thermal zone)	G2eLab_All_EdgeNodes.geojson	12 thermal zones: (The G2elab is splitted to 9 zones: one for each office) -Greener 0: The three floors below the Lab -offices in G2eLab: 4A013-14-15-16-17-18-19-20+4A400 -Greener 1: The rest of fourth floor -Greener 2: the fifth floor above the lab

Figure 51different LOD's of building modelling applied to the G2ELAB living lab - description

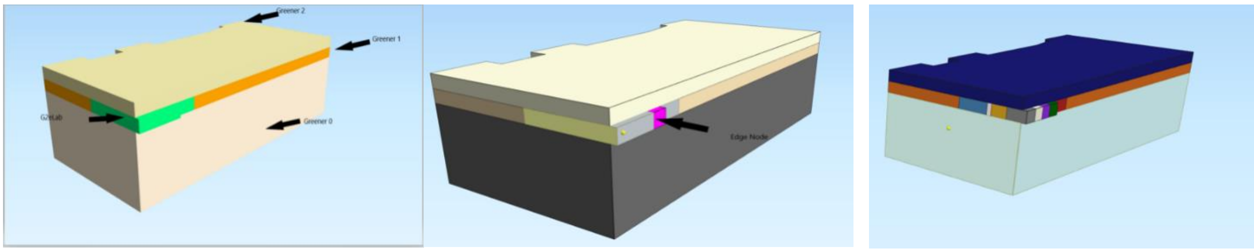

Figure 52 different LOD's of building modelling applied to the G2ELAB living lab – 3D view (left: living lab as single zone, middle: one edge node zone and living lab, right: multizone model)

The detailed model corresponds to the highest LOD since all rooms are modelled individually.

In this report, the calibration of the basic model and the detailed model are presented. The calibration might be updated in the update of this deliverable since the monitoring data that is available is very detailed and the calibration process has allowed to clean and validate measurement data progressively. It is also planned to publish measurement data as open data, available to other researchers. This will help to increase the quality of data. Updates of data treatment processes will thus require to rerun calibration in the future, to consider any correction of measurement inconsistency that has not yet been recognised.

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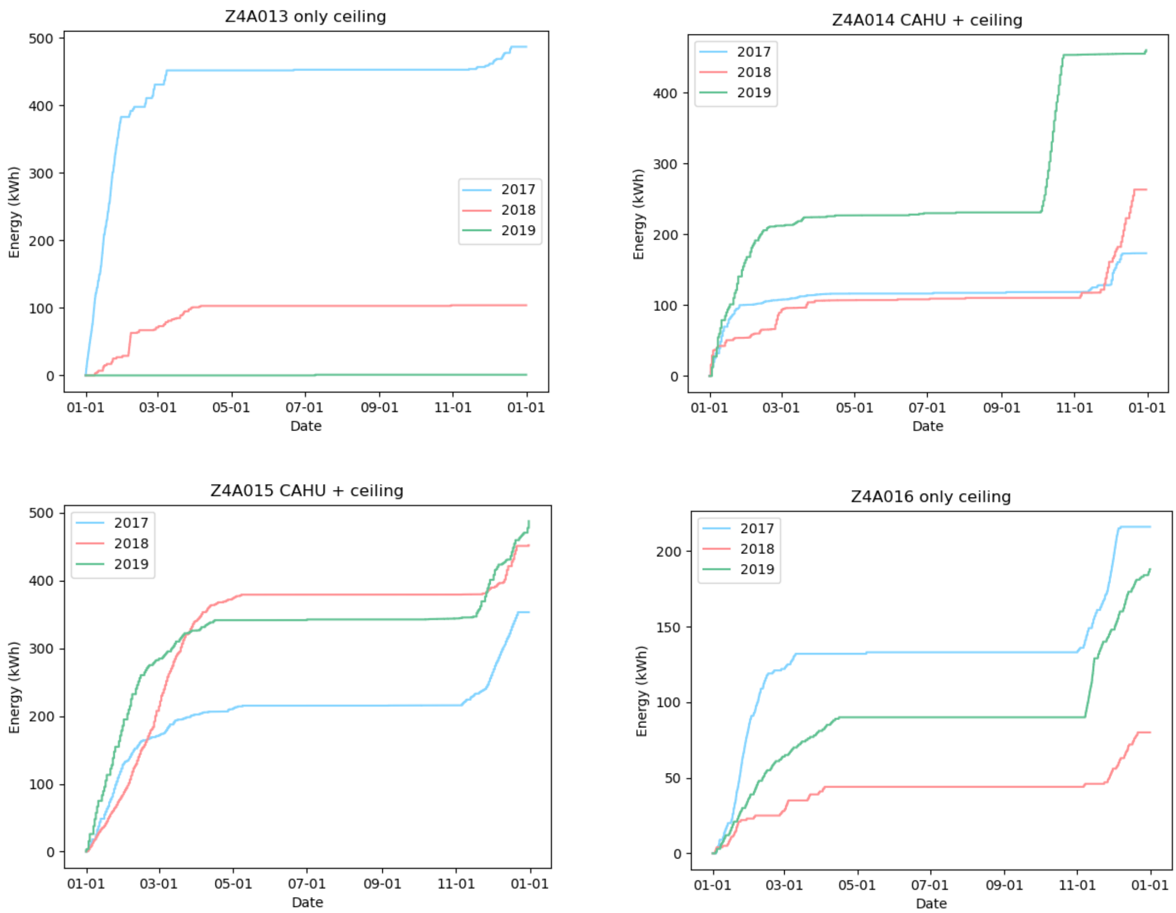
5.3.1.2 Available monitoring data of G2ELAB used for calibration

The data available in relation to the heating and cooling measured load spans a 7-year period with data measurements starting in June of 2015. Measured data includes the total heating and cooling load of the centralized air handling unit (CAHU) as well as heating and cooling loads of reversible hydronic ceiling panels in each zone.

Air flow rates per hour per zone have also been provided in order to estimate the amount of heating provided to each zone by the CAHU. These air flow rates have not been provided by all the zones of interest and data is missing from the data logs of provided zones. This implies that an estimation of the percentage of energy provided by the CAHU to each zone is difficult to calculate with high accuracy.

The total measured heating and cooling load of each zone is therefore the cumulated energy provided by the CAHU and the hydronic ceiling panels. Figure 53 shows the total heating load for the 8 zones of interest. These graphs allow for the comparison of three years of data (not including COVID years where use of the building could be significantly different).



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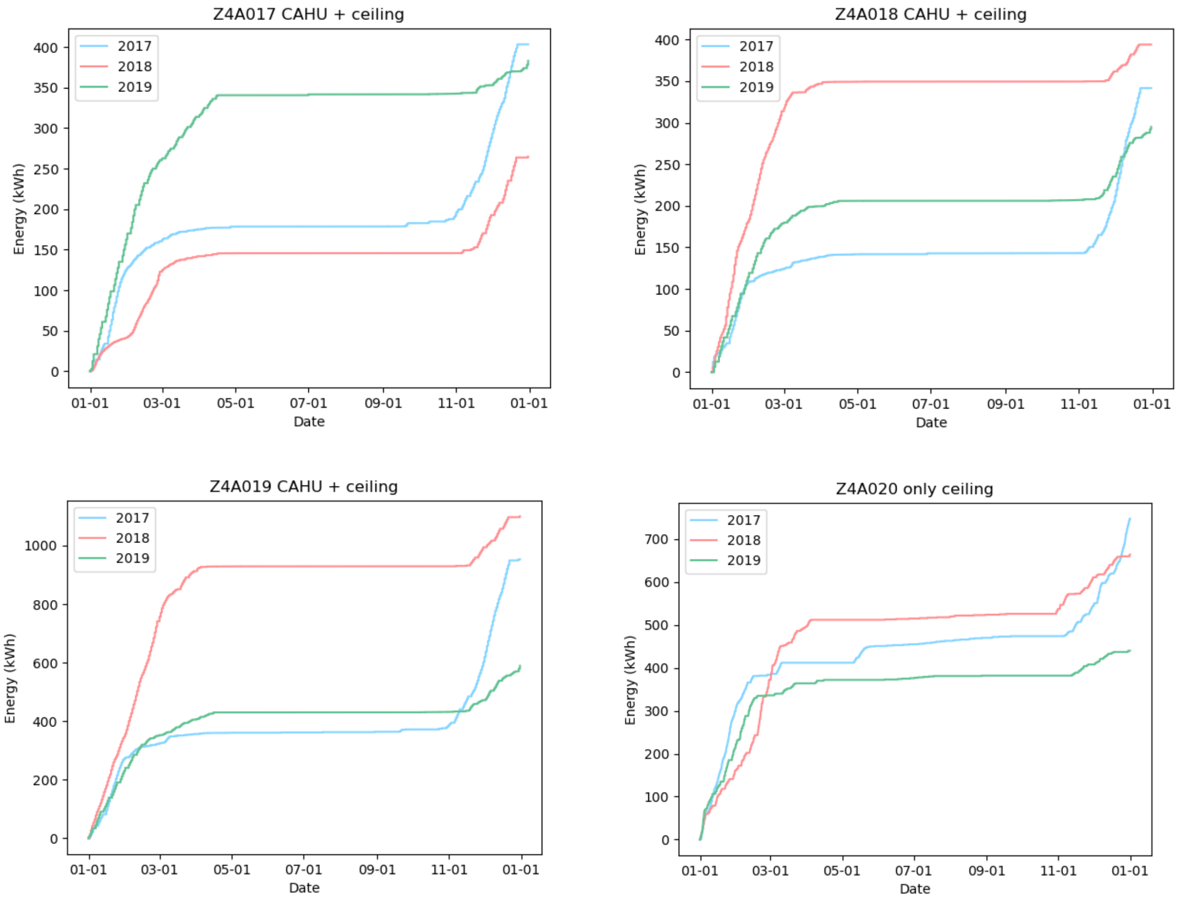

Figure 53 Cumulated energy consumption for each zone of the living lab for 2017, 2018 and 2019

The graphs above show a significant variability in the heating load depending on the year. The annual consumption is doubled and sometimes tripled depending on the year. This large variability cannot be explained only by variable weather from one year to another. Additionally, no correlation of increased consumption for one year in comparison to another is present for all zones. For example, the zone 19 has an annual consumption two fold during 2018 in comparison to 2019 while zone 17 has a significantly higher consumption in 2019 in comparison to 2018.

This implies that other factors that are not considered here may have a significant impact on the energy load profile such as occupancy. Further analysis of the high variability of the load profile from one year to another should be completed and other significant factors should be taken into account for the final calibrated models.

An initial calibration of the models was therefore completed with the heating and cooling load data of 2019. Further work could include calibrating the model for each year and attempting to calibrate a model considering multiple years of measured data.

5.3.1.3 Calibration of the G2ELAB monozone building model

An initial simple calibration of the DIMOSIM building model G2ELAB building was completed. This model is simplified because it is a single zone model.

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Therefore, the model does not consider multiple zones within the building and variable zone conditions or consumption. The calibration was performed in a dynamic way on the total thermal heating and cooling load of the building.

The model has considered the G2ELAB building but also surrounding buildings to properly calculate the solar irradiation exposure due to shading of surrounding buildings.

Model parameters identified for calibration:

A sensitivity analysis was performed to identify the modelling parameters with the most significant impact on calibrating the heating and cooling demand. The parameters identified are below:

Parameter name	Units	Minimum value	Maximum value
Infiltration rate	air change per hour	0.1	0.2
Exterior Wall U value	W/m2K	0.15	0.25
Unoccupied hours heating set point	°C	17	18
Occupied hours heating set point	°C	20	22
Occupied hours cooling set point	°C	25	27
Unoccupied air change set point rate	volume per hour	0	1
Occupied air change set point rate	volume per hour	0.1	3.2

A simulation combination file is generated by selecting combinations of parameters that are feasible in relation to the physical limits of the modeled building. The cumulated energy consumption for a one-year period can be seen below with an example simulation of 15 variants of parameter combinations.

Results of calibration procedure:

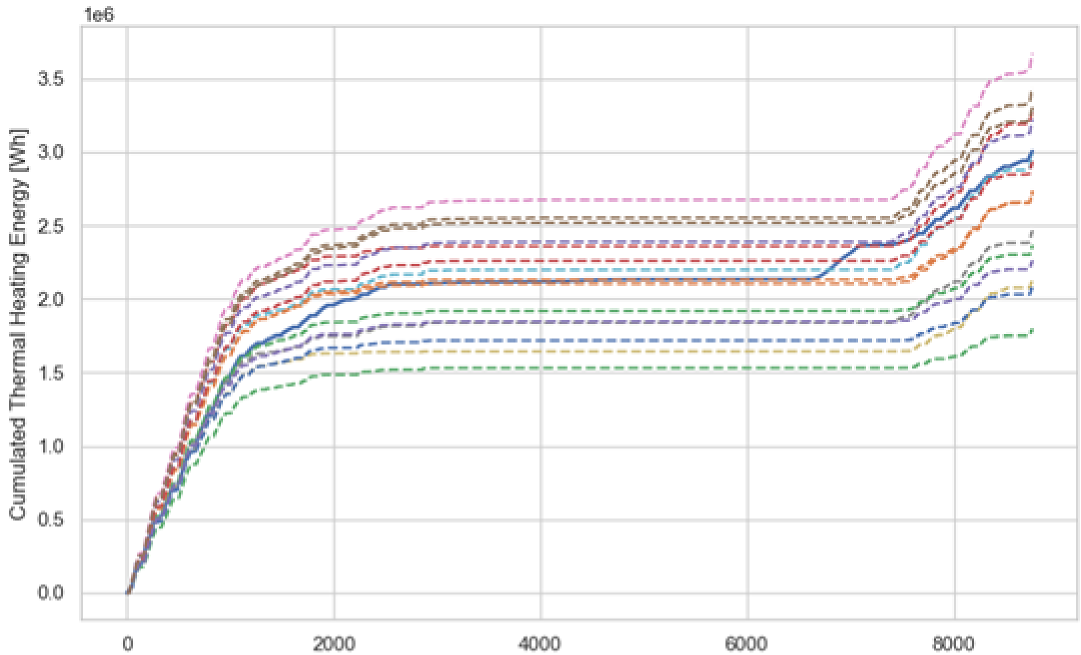

Figure 54 TG2ELAB monozone - total thermal heating demand in comparison to DIMOSIM simulations with variable parameters

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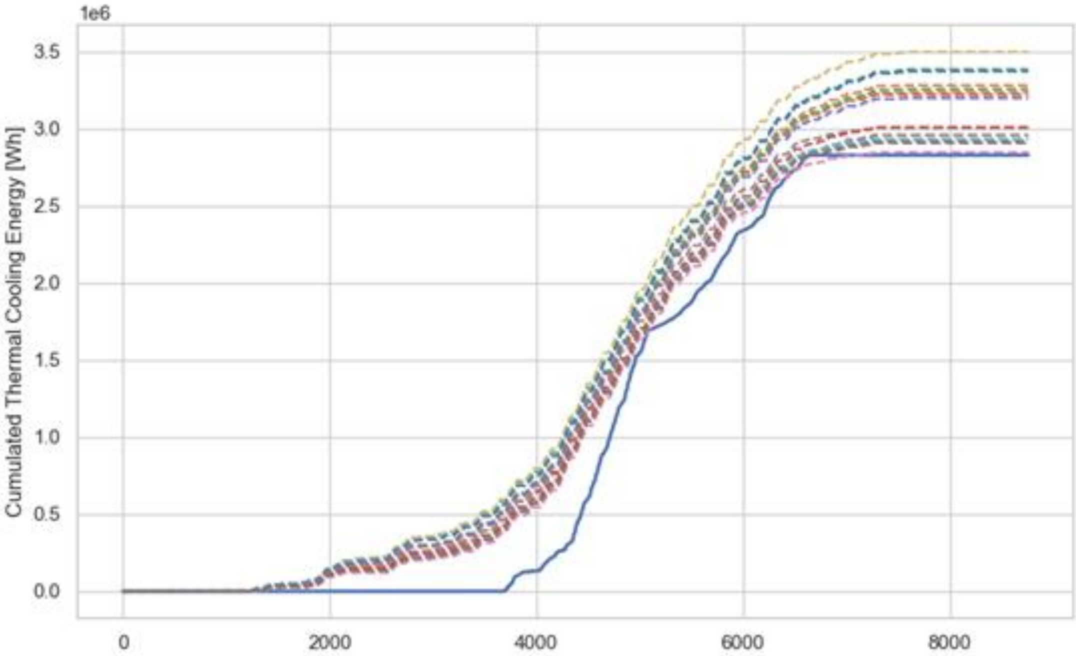

Figure 55 G2ELAB monozone - total thermal cooling demand in comparison to DIMOSIM simulations with variable parameters

To take into account internal mass such as furniture, internal walls, etc that have not been simulated in the single zone model, an internal mass was added to the zone in order to improve calibration results. However, the single zone doesn't realistically take into account the internal inertia or the effects that a multi-zone model could more accurately consider. These effects are seen in the simulation results where the building is slightly too sensitive to external conditions (using more energy than necessary to heat the building in winter and less energy than necessary to heat during the springtime). An energy consumption peak around autumn is also poorly represented by our model. This could be an effect of a certain part of the building with minimal sun exposure needing to start heating their zones earlier than the rest of the zones in the building. Since only a single zone is modelled, these effects are not calculated by the model. This will be improved in the future with a more detailed multi-zone model.

<u>Calibration model performance</u>

For the calibration of the G2ELAB model, the NMBE for the heating demand was calculated to be -2.56% and the NMBE for the cooling demand was calculated to be -13.99%.

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5.3.1.4 Calibration of the G2ELAB multizone building model

This second LOD corresponds to the case where all rooms have been modelled individually.

The model has considered the G2ELAB building but also surrounding buildings to properly calculate the solar irradiation exposure due to shading of surrounding buildings.

Model parameters identified for calibration:

A sensitivity analysis was performed to identify the modelling parameters with the most significant impact on calibrating the heating and cooling demand. The parameters identified are below:

Parameter name	Units	Minimum value	Maximum value
Infiltration rate	air change per hour	85%	115%
Exterior Wall U value	W/m2K	0.15	0.25
Unoccupied hours heating set point	°C	17	18
Occupied hours heating set point	°C	19	23
Occupied hours cooling set point	°C	28	30
Unoccupied air change set point rate	volume per hour	0	1.0
Occupied air change set point rate	volume per hour	0.1	3.2

A simulation combination file is generated by selecting combinations of parameters that are feasible in relation to the physical limits of the modeled building. The cumulated energy consumption for a one-year period can be seen below with an example simulation of 10 variants of parameter combinations.

Results of calibration procedure:

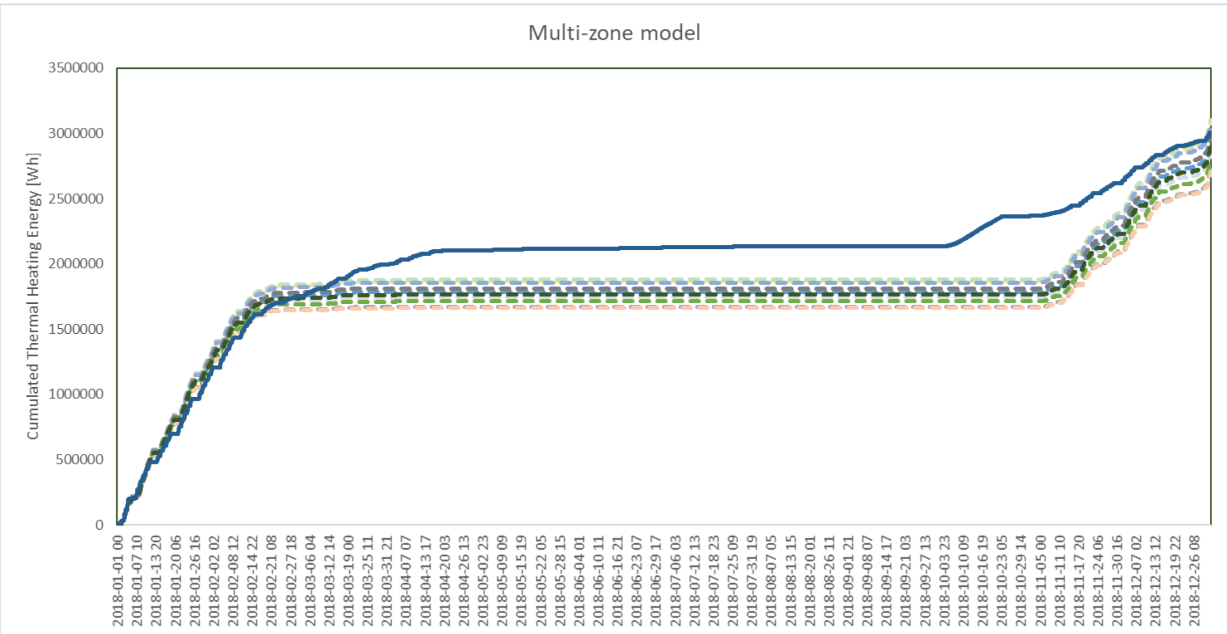

Figure 56 G2ELAB multizone: total thermal heating demand in comparison to DIMOSIM simulations with variable parameters

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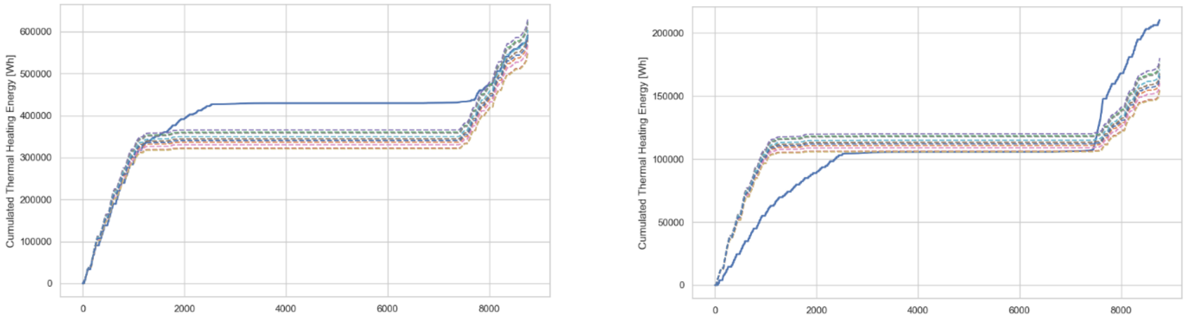

Figure 57 G2ELAB multizone example of individual zone model calibration. Zone Z4A018 (left) successful calibration and Z4A016 (right) unsuccessful calibration

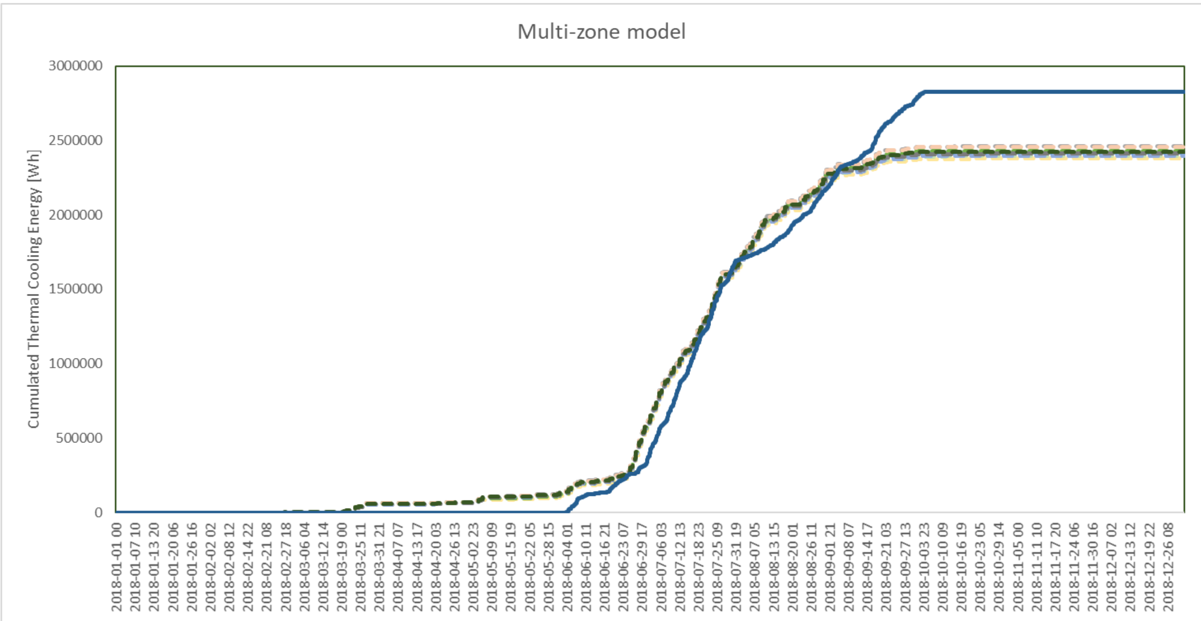

Figure 58 G2ELAB multizone: total thermal cooling demand in comparison to DIMOSIM simulations with variable parameters

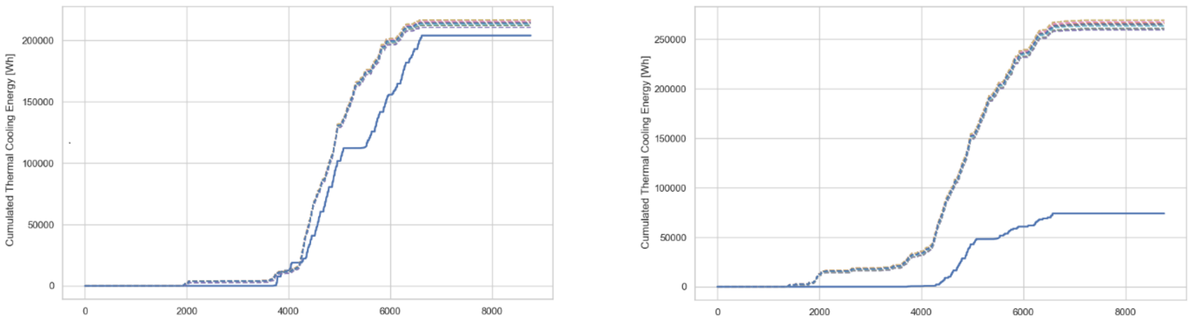

Figure 59 G2ELAB multizone example of individual zone model calibration. Zone Z4A018 (left) successful calibration and Zone Z4A016 (right) unsuccessful calibration

<u>Calibration model performance</u>

For the calibration of the G2ELAB model, the NMBE for the heating demand was calculated to be -7.1% and the NMBE for the cooling demand was calculated to be 5.75%.

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5.3.2 EIDET building

A mono-zone model of the Eidet building has also been calibrated. The data available for this building extended from September 2021 to April 2022, i.e. during the heating season. This Eidet building is equipped with electric convective heaters and a ground source heat pump for auxiliary heating. A simplified version of the heating systems has been implemented in the building model. The cooling systems have not been implemented so far because the data available does not cover summer period. This will be included in a further step.

A 31-day data subset has been selected for the calibration process. As can be seen in the figure, day and night temperature setpoints can be assumed and are valid throughout the entire heating season.

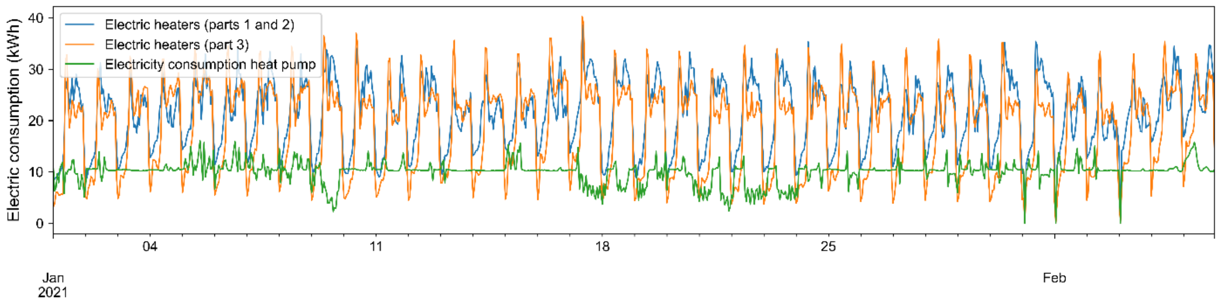

Figure 60 Monitoring results from the Eidet pilot building in Winter 2021

The building itself has been built in 2017 and its envelope composition is known to be as good as the 2017 Norwegian thermal regulation. The model assumes therefore default values for the envelope thermal performance. A sensitivity analysis on the most uncertain parameters has been implemented to get a sense of the influence of the default values on the overall electric consumption for heating. Parameters included in the sensitivity analysis are therefore the U values of walls, roof and floor (with around 10% variability) as well as day-time temperature setpoint, night-time temperature setpoint and air change rate by ventilation (system implemented is a heat recovery AHU, efficiency 80%). The bounds for day-time and night-time temperature setpoints have been set according to measured data available that suggested values around 24°C during the day and values around 23,5 during the night. Table 21 shows the input parameters for the sensitivity analysis with their bounds.

Table 15 Inputs for the sensitivity analysis of pilot Eidet

Parameter	Unit	Minimum value	Maximum value
Walls U-value	W/K/m²	0.11	0.13
Floor U-value	W/K/m²	0.08	0.1
Roof U-value	W/K/m²	0,07	0,09
Day-time temperature setpoint	°C	23,4	24,5
Night-time temperature setpoint	°C	22	23,2
Air change rate	h^{-1}		

The EASI RBD-FAST analysis has been used, based on a Latin Hypercube sampling of 200 samples to ensure convergence of the analysis. The analysis, in Figure 61, shows that the most influential

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parameter is the day-time temperature setpoint which explains around 80% of the overall variability in electricity consumption for heating. The other parameters have non-significant first order indices. The results also suggest interaction effects between parameters, since the first order effect of parameters do not explain the entire variability of the output. As can be seen in Figure 62Figure , the U-value of the wall interacts with the day-time temperature setpoint. Therefore, although its sensitivity index seems non-significant, it should be included in the calibration process.

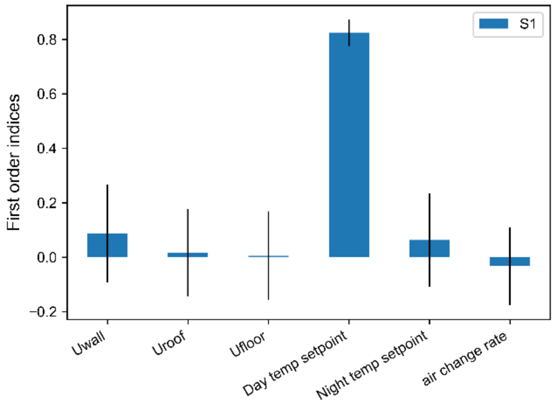

Figure 61 Sensitivity of the Eidet model to the key model parameters

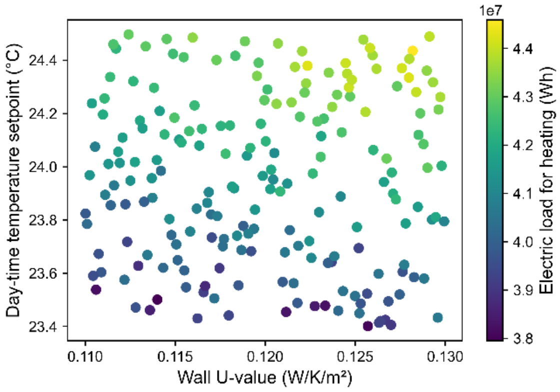

Figure 62 Impact of wall U-value and Comfort indoor temperature set point on electric load of heating system

The calibration procedure focuses then on minimizing the error between predicted overall electric load of all heating systems with the reference values over the 31-day period.

The best result, as can be seen in Figure 63Figure , shows a general good agreement with the reference, although a slight drift can be seen towards the end of the dataset. The NMBE is around 6.2% with however a CVRMSE of almost 100% which confirms an inconsistency in the calibrated fit to the data. Looking at a daily summed electric consumption in Figure 64, it is clear that part of the thermal dynamic is indeed not properly caught so far in the model. It seems to be correlated to outdoor temperatures. Whether it is due to thermal bridges, inaccurate U-values or higher air change rates is yet to be investigated.

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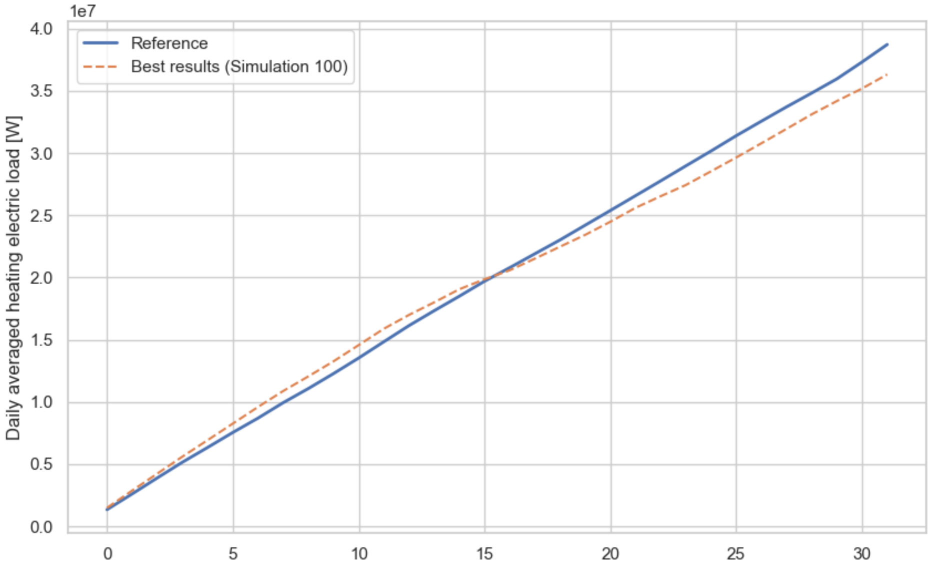

Figure 63 CALIENTE output of the cumulated electric load of all heating systems compared to the reference

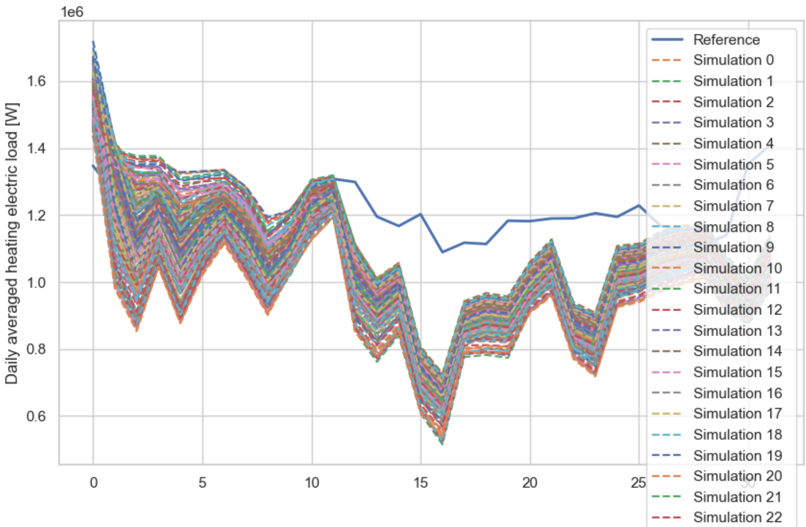

Figure 64 Daily summed electric load of heating systems in the Eidet pilot compared to reference

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6 Simulation based evaluation of pilot performances

6.1 Pilot Eidet

Eidet Omsorgssenter (care center) is located in Ålesund, Norway. The pilot building is a five-story elderly care center with 110 private residential units and fully equipped with Energy Management System (EMS). The EMS controls and monitors the heating, cooling, and ventilation system. The building is supplied by different energy sources including (1) grid electricity, (2) Photo Voltaic panels (PV), and (3) Solar collector. Additionally, a Borehole thermal Storage System (BTES) stores heat during summer (from solar collector and chillers) to be exploited in winter.

The photovoltaic (PV) system are installed on the roof with a capacity of 7 kWh which generated around 105 MWh in 2020. PV generation is used with electricity grid as the main source of energy. Solar collector provides domestic hot water. Accordingly, the pilot building is a prosumer which can be a proper case study for energy flexibility; therefore, it has been investigated in [https://ieeexplore.ieee.org/document/9898453] with a flexible Demand-Side Management (DSM) algorithm.

The objective is to maximize the electricity use from PV through demand shifting or shedding. Therefore, when PV generation is lower than the building electricity demand the excess demand from the production is to be curtailed or shifted.

6.1.1 Presentation of methodology

Based on the available technical information of the building, a Building Energy Model (BEM) is developed in EnergyPlus and calibrated against measured energy demand. The PV system is modeled with TRNSYS. The flexible DSM is applied to the building model under future weather conditions, over an extreme warm summer to evaluate the performance of the cooling system. The analysis period is a July under future climate conditions. (For more information about future weather data see https://ieeexplore.ieee.org/document/9898453)

The flexible DSM algorithm kernel is a decision tree extracted from the regression analysis of the historic measure values. The regression model consists of the significant variables in the model including outdoor temperature, occupancy, hour of the day, day of the week, etc. The predefined decision tree makes the algorithm light and quick enough to run on a single board computer, while provide enough accuracy.

The key point of this study is that the residents of the building (elderly people) are quite sensitive to indoor climate variation. According to EN 16798-2:2019, elderly occupants expect a high level of indoor environmental quality (IEQI).

In this study, temperature setpoint, ventilation rate, and plug load are the sources of flexibility. Energy demand is the total electricity use for running heating, cooling, ventilation, appliances, and lighting

6.1.2 KPI evaluation

According to the objective, the performance of the algorithm is evaluated based on the energy demand, peak power, Self-Consumption Rate (SCR), and Load Match Index (LMI), indoor thermal comfort.

Since the analysis period is cooling season; therefore, it is expected to have the high PV generation at the same time with the high cooling peak load. Consequently, peak curtailment is estimated to be a proper indicator. Reducing energy demand is not the main objective of the algorithm; however, it

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is meaningful when the battery is added to the system. SCR and LMI can describe adequately how the algorithm could increase grid independency. Hence, they are included in the evaluation. To assess the indoor thermal comfort, the overheating hours based on the operative temperature is selected with respect to mentioned indicators in EN 16798-2:2019 (Operative temperature > 26.3 ℃).

The results show 22% and 20% peak and demand reduction, respectively. SCR and LMI does not show significant change when system does not include battery. The overheating hours are reduced by 22% over the analysis period.

6.1.3 Next steps

The aforementioned progress is the primitive development of the algorithm where not all the building's energy system components are included. Further ongoing work is to develop the model of the existing storage systems in the building (i.e., water tanks, BTES) in addition to improvement of the decision-making process.

6.2 Pilot G2ELAB

6.2.1 Presentation of methodology

The building energy model is developed in DIMOSIM simulation platform. The building model consists of the entire Green'ER building and G2ELAB is modelled as a separate zone on the 3rd floor. Building energy model is calibrated against measured energy demand and room temperatures. DIMOSIM provides the ability to modify the building and system setting at each timestep from an external algorithm.

A flexible DSM algorithm is developed for this building based on a Reinforcement Learning (RL) algorithm. The RL-DSM enhance the decision-making progress compared to decision tree, while no prediction or heavy computation is required. The algorithm applies flexibility measures based on the current state and the reward. Thus far, reward is calculated based on the energy demand curtailment and indoor temperature reduction.

The stimulus of the RL-DSM is a signal from 0 to 5 (integer values) based on the energy demand of the entire building. In another word, signal is universal and generated from the environment. Signal in this case is defined based on the historic total energy demand as presented in Figure 65. This signal functions for summertime when the source of energy is electricity. The thresholds for signal generating at the moment are arbitrary values and still under investigation. The signal 5 represents a critical condition in which energy system are in the risk of malfunction or black out. This condition introduces Resilient Mode for the RL-DSM which allows the algorithm to cross the thresholds for thermal comfort keeping it in a margin yet. This helps the system to avoid power outage and be able to maintain indoor condition close to the desired conditions. To be noted that signal is generated from environment like grid or power plant and can be generated based on the grid conditions.

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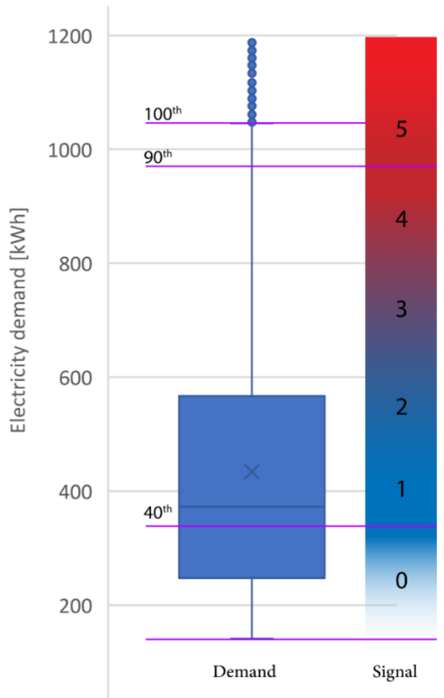

Figure 65 Signal generator thresholds based on the historic demand data

The RL-DSM maintains the operative temperature in a proper range according to the standard. The threshold is based on the signal and in response to the demand target. The operative temperature threshold is illustrated in Figure 66.

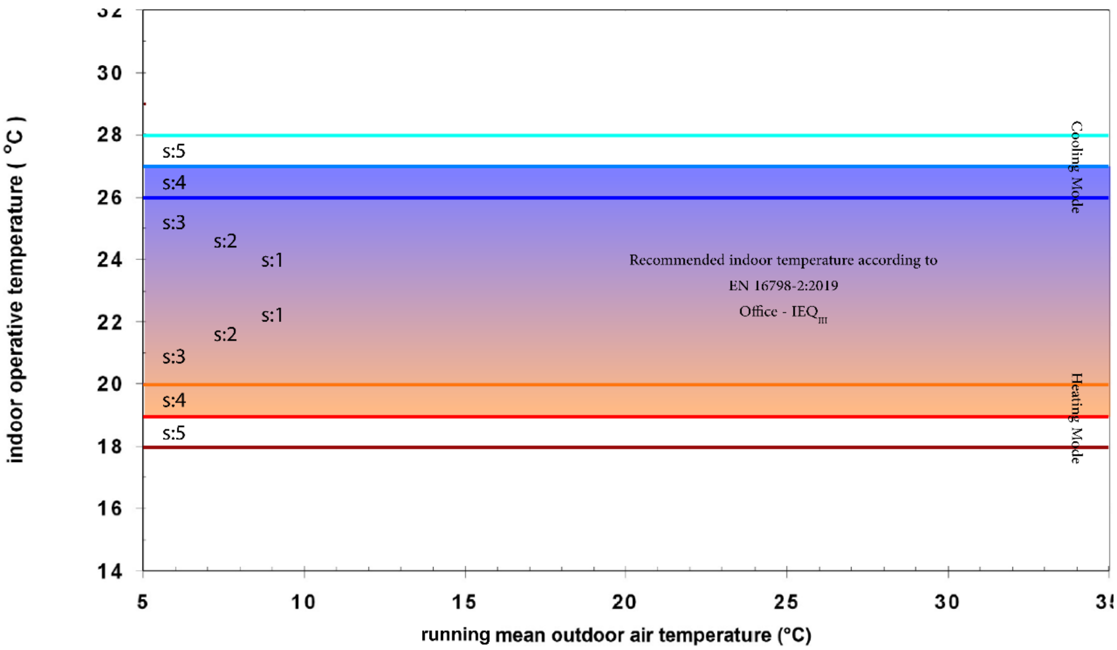

Figure 66 Operative temperature thresholds based on the signal

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6.2.2 KPI evaluation

The KPIs for this assessment are firstly, energy indicators including demand and peak power, and secondly, thermal comfort including operative temperature. The primitive results show reduction of 28% in energy demand and 17% in peak power.

It is planned to add more thermal comfort KPIs such as users satisfaction and PMV to assess the indoor comfort comprehensively.

6.2.3 Next steps

In the next step, the assessment is to be done over a heating season as well, where the major source of energy is district heating. Moreover, building modelling includes all rooms (zones) in G2ELAB and the shaders and lightings will be added to the model. More studies are in progress to generate the signal in a cluster level with an overall knowledge from the whole grid/cluster.

The temperature threshold, in the other RL-DSM criteria, is following the adaptive comfort model to increase the flexibility of the algorithm. Also, user feedbacks for indoor thermal comfort are being developed to consider a more realistic user conditions while the RL-DSM is running. Afterwards, user feedback will be included in the reward function.

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7 Conclusion

According to the measurement and verification (M&V) protocol developed for the pilot buildings in COLLECTiEF (D5.1), this deliverable reports the progress on the monitoring activities, describes the methodologies applied to assess the performance of the pilots to date, and presents some preliminary analyses using data measured in the buildings and data obtained from calibrated simulations.

Since this document will be released in 3 updates to report the advancements in the performance assessment in all COLLECTiEF buildings, this first version describes the general methodology which is adopted for those parts that can be carried out in respect to the available data.

This first version is thus a partial evaluation that sets the ground for the performance assessment and, using defined key performance indicators (KPIs), provides examples of analyses in some pilots.

These examples are important to allow to improve any analysis for the next versions of the report with more data available.

The deliverable has allowed to demonstrate the project progress in five main sections:

1. Smart readiness assessment and indoor environmental quality evaluation criteria
   After the definition of the methodology, it has been applied to the Eidet Omsorgssenter in Norway.
2. Pilot monitoring approach
   After a summary of started and ongoing monitoring of pilot sites, a description of all pilots is given in this part.
3. Data management for the evaluation
   The developed data repository has been detailed and API's to access date has been described. This will be helpful for the next steps in the analysis of data.
4. Pilot site modelling and calibration of energy models
   Since the KPI's shall be calculated also based on numerical simulation, the DIMOSIM simulation tool has been briefly presented. To ensure the validity of simulation results, all pilot models have to be calibrated using a robust calibration method. The method as well as its application to the G2ELAB living lab is shown to illustrate the approach.
5. Simulation based evaluation of pilot performances
   For two pilots, Eidet Omsorgssenter and G2ELAB, some first illustrations are provided on the evaluation of pilot performances.

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8 References

[1] Carlucci S, Erba S, Pagliano L, de Dear R. ASHRAE Likelihood of Dissatisfaction: A new right-here and right-now thermal comfort index for assessing the Likelihood of dissatisfaction according to the ASHRAE adaptive comfort model. Energy Build 2021;250:111286. https://doi.org/10.1016/j.enbuild.2021.111286.
[2] van Hoof J. Forty years of Fanger's model of thermal comfort: comfort for all? Indoor Air 2008;18:182–201. https://doi.org/10.1111/j.1600-0668.2007.00516.x.
[3] Rupp RF, Vásquez NG, Lamberts R. A review of human thermal comfort in the built environment. Energy Build 2015;105:178–205. https://doi.org/10.1016/j.enbuild.2015.07.047.
[4] International Organization for Standardization. ISO 7730:2005 – Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria 2005.
[5] European Committee for Standardization. EN 15251:2007 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. 2007.
[6] European Committee for Standardization. EN 16798-1:2019. Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6. 2019.
[7] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ANSI/ASHRAE Standard 55-Thermal Environmental Conditions for Human Occupancy. 2017.
[8] de Dear RJ, Brager GS. Towards an adaptive model of thermal comfort and preference. ASHRAE Transactions 1998;104 (1):145–67.
[9] ISO. BS EN ISO 10551-2019--Ergonomics of the physical environment - Subjective judgement scales for assessing physical environments. 2019.
[10] Carlucci S. Thermal Comfort Assessment of Buildings. Milano: Springer Milan; 2013. https://doi.org/10.1007/978-88-470-5238-3.
[11] Tartarini F, Schiavon S. pythermalcomfort: A Python package for thermal comfort research. SoftwareX 2020;12:100578. https://doi.org/10.1016/j.softx.2020.100578.
[12] Földváry Ličina V, Cheung T, Zhang H, Dear R, Parkinson T, Arens E, et al. Development of the ASHRAE Global Thermal Comfort Database II. Build Environ 2018;142:502–12. https://doi.org/10.1016/j.buildenv.2018.06.022.
[13] ANSI/ASHRAE. Standard 55-2020. Thermal Environmental Conditions for Human Occupancy. 2020.
[14] Carlucci S, Pagliano L. A review of indices for the long-term evaluation of the general thermal comfort conditions in buildings. Energy Build 2012;53:194–205. https://doi.org/10.1016/j.enbuild.2012.06.015.
[15] Pagliano L, Zangheri P. Comfort models and cooling of buildings in the Mediterranean zone. Adv Build Energy Res 2010;4:167–200. https://doi.org/10.3763/aber.2009.0406.
[16] Erba S. D4.7 - Guideline for interviewing end-user. AZEB (Affordable Zero Energy Buildings). 2019.
[17] Brager G, Fountain M, Benton C, Arens EA, Bauman F. A Comparison of Methods for Assessing Thermal Sensation and Acceptability in the Field 1993.
[18] Schweiker M, Abdul-Zahra A, André M, Al-Atrash F, Al-Khatri H, Alprianti RR, et al. The Scales Project, a cross-national dataset on the interpretation of thermal perception scales. Sci Data 2019;6:289. https://doi.org/10.1038/s41597-019-0272-6.
[19] ANSI/ASHRAE. Standard 62.1-2022. Ventilation and Acceptable Indoor Air Quality 2022.

This project has received funding from the European Union's H2020 research and innovation programme under Grant Agreement No 101033683

[20] European Union. European Parliament resolution of 13 March 2019 on a Europe that protects: Clean air for all (2018/2792(RSP)). n.d.

[21] AIVC Contributed Report 17. Indoor Air Quality Design and Control in Low-energy Residential Buildings - Annex 68 | Subtask 1: Defining the metrics 2017.

[22] Kakoulli C, Kyriacou A, Michaelides MP. A Review of Field Measurement Studies on Thermal Comfort, Indoor Air Quality and Virus Risk. Atmosphere 2022;13:191. https://doi.org/10.3390/atmos13020191.

[23] Justo Alonso M, Moazami TN, Liu P, Jørgensen RB, Mathisen HM. Assessing the indoor air quality and their predictor variable in 21 home offices during the Covid-19 pandemic in Norway. Build Environ 2022;225:109580. https://doi.org/10.1016/j.buildenv.2022.109580.

[24] FSIS -ESHG. Carbon Dioxide Health Hazard Information Sheet 2010.

[25] Helsedirektoratet. Indoor Air Quality n.d.

[26] Arbeidsmiljøtilsynet. Indoor Air Quality in working spaces n.d.

[27] WHO. Air Quality Guidelines for Europe 2000.

[28] World Health Organization. WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide 2021.

[29] Saltelli A, Ratto M, Andres T, Campolongo F, Cariboni J, Gatelli D, et al. Global Sensitivity Analysis. The Primer. Chichester, UK: John Wiley & Sons, Ltd; 2007. https://doi.org/10.1002/9780470725184.

[30] Herman J, Usher W. SALib: An open-source Python library for Sensitivity Analysis. J Open Source Softw 2017. https://doi.org/10.21105/joss.00097.

[31] Campolongo F, Cariboni J, Saltelli A. An effective screening design for sensitivity analysis of large models. Environ Model Softw 2007;22:1509–18. https://doi.org/10.1016/j.envsoft.2006.10.004.

[32] ASHRAE. ANSI/ASHRAE/IES Standard 90.1-2019 -- Energy Standard for Buildings Except Low-Rise Residential Buildings 2019.

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9 Annexes

Annex 1: KPI methodology and calculation methods

To align with COLLECTiEF project goals, 6 categories of KPIs are defined:

- Smart readiness indicator (quantitative) - ratio between the smart readiness of the building compared to the maximum smart readiness
- Energy – measured energy reduction
  - Energy savings (electrical and natural gas) - the savings resulting from the project implementation
  - Energy cost savings - the cost savings resulting from the project implementation
- Primary energy savings
- Self-consumption
- Comfort
- Flexibility

I. Smart Readiness Indicator (SRI)

The SRI will be performed on each pilot. This indicator is based on common EU methodology and is a percentage ratio between the smart readiness of the building compared to the maximum smart readiness. The indicator will be calculated before and after implementation of the project. The SRI evaluation is inspection-based and no measured data are necessary, therefore no specific plan for monitoring has to be defined.

GOAL : upgrade existing pilot with at least one level of smartness

Indicator will take into account domain weightings and impact weightings :

1.1. Impact scores: the impact scores for each impact criterion, taking into account domain weightings.
1.2. Domain scores: the domain scores for each domain, taking into account impact weightings.
1.3. Detailed scores: the detailed scores for each domain and each impact criterion, which results in a matrix for 9 domains and 7 criteria.
1.4. Aggregated scores: the aggregated scores for 3 key functionalities.

II. Energy

The energy savings or increased consumption resulting from the project is calculated for the duration of the measurement plan following project implementation. The energy savings are calculated by comparing the measured consumption to a baseline consumption for each pilot project. The baseline consumption is calculated based on measurements collected before the implementation of smart control and optimization strategies. If the baseline data collection is not sufficient to calculate a reliable baseline for all further data collection periods, calibrated models will be used to estimate the baseline. The measured or simulated baseline consumption will be adjusted to account for variable

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weather condition in relation to the baseline data collection period and the project implementation phase.

a. Energy savings

Description: Total energy savings due to project implementation

GAOL : 9%-27% relative energy reduction

Inputs:

- $P_{baseline}(t)$: Baseline energy consumption either measured or simulated for each energy vector in (kW)
- $P_{measured}(t)$: Measured energy consumption after implementing project for each energy vector (kW)
- $T_{ext,b}(t)$: External temperature during baseline energy consumption measurement period (°C)
- $T_{ext,m}(t)$ External temperature during measurement collection after project implementation (°C)
- s: period of 6 months classified as a semester of a given year

Outputs:

- $E_{savings}$: Total energy savings achieved over evaluation period (kWh)

Calculation method:

Heating degree days (ISO-15927-6-2007)

$$DD_{heat} = \frac{1}{n}\sum_{0}^{n} T_{diff}$$

Hourly temperature data available –

$$T_{diff} = T_{base} - T_{ext} \; if \; T_{ext} < T_{base}$$

$$T_{diff} = 0 \; if \; T_{ext} > T_{base}$$

$$DD_{ratio} = \frac{DD_{heat,measured}}{DD_{heat,baseline}}$$

Daily max and min temperature data available –

$$T_{diff} = T_{base} - 0.5 \times (T_{ext,max} + T_{ext,min})$$

$$if \;\; T_{ext,max} < T_{base}$$

$$T_{diff} = 0.5 \times (T_{base} - T_{ext,min}) - 0.25 \times (T_{ext,max} - T_{base})$$

$$if \;\; T_{ext,max} > T_{base}$$

$$(T_{ext,max} - T_{base}) < (T_{base} - T_{ext,min})$$

$$T_{diff} = 0.25 \times (T_{base} - T_{ext,min})$$

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$$if \quad T_{ext,min} < T_{base}$$

$$(T_{ext,max} - T_{base}) > (T_{base} - T_{ext,min})$$

Total energy savings

$$E_{savings} = \sum_{0}^{S} \left(P_{baseline}(s) \times DD_{ratio} - P_{measured}(s)\right)$$

This calculation will be performed on total building electric consumption, total electric consumption of specific building zones or specific electric usage categories as detailed in deliverable 5.1 table 22 depending on available data for each pilot project.

b. Energy costs

Description: The calculation of energy cost savings will be calculated from the total energy savings calculated in section 2.1 and the prices found in the electric and natural gas tables for each country. Electricity pricing tables can be found in project deliverable 5.1 Table 9, 10, 11, 12. Gas pricing tables can be found in project deliverable 5.1 Table 13, 14, 15, 16.

GOAL : 0.2-3 €/m² annual energy cost savings

Inputs:

- $E_{elec}(s)$: Total electric energy savings achieved over evaluation period (kWh)
- $E_{gas}(s)$: Total natural gas energy savings achieved over evaluation period (kWh)
- $P_{elec}(s)$: Price of electricity per semester for each country (€)
- $P_{gas}(s)$: Price of natural gas per semester for each country (€)
- s: period of 6 months classified as a semester of a given year

Outputs:

- C_{elec}: Total cost electrical energy savings achieved over evaluation period (€)
- C_{gas}: Total cost natural gas energy savings achieved over evaluation period (€)

Calculation method:

$$C_{elec} = E_{elec}(s) \times P_{elec}(s)$$

$$C_{gas} = E_{gas}(s) \times P_{gas}(s)$$

III. Primary energy savings

GOAL : 16% reduction in primary energy

Description: The primary energy savings will be calculated using the total energy savings achieved and primary energy factor tables specific to each country. A summary of the most common energy factors that will be used are below:

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Country	Natural gas	Electricity from grid	District heating/cooling	PV production self-consumption	PV production injected into grid
Italy	1.05	2.42			
France		2.3	1	2.58	1
Norway		1.2	1.5		
Cyprus		2.7			1

Inputs:

- E_{elec}: Total electric energy savings achieved over evaluation period (kWh)
- E_{gas}: Total natural gas energy savings achieved over evaluation period (kWh)
- $E_{district}$: Total district heating/cooling energy savings achieved over evaluation period (kWh)
- $E_{PV,sc}$: Total self-consumption of photovoltaic local production achieved over evaluation period (kWh)
- $E_{PV,grid}$: Total photovoltaic local production injected into the grid over evaluation period (kWh)
- F: energy factors for each type of energy

Outputs:

- $E_{primary}$: Total primary energy savings achieved over evaluation period (kWh)

Calculation method:

$$E_{primary} = E_{elec} \times F_{elec} + E_{gas} \times F_{gas} + E_{district} \times F_{district} + E_{PV,sc} \times F_{PV,sc} + E_{PV,grid} \times F_{PV,grid}$$

IV. Self-consumption indicator

GOAL: Up to a certain increase in self-consumption rate (percentage)

Description: To quantify the energy self-consumed during the pilot project, the supply cover-factor method will be deployed. This method takes into account instantaneous consumption of onsite renewable energy production, instantaneous load and also includes onsite consumption of stored energy in electrical storage systems such as batteries if the energy used to charge the battery originated from renewable sources.

Inputs:

- E_g: onsite renewable energy generation (kWh)
- E_s: net energy flowing in or out of the onsite storage systems (kWh)
- E_{loss}: energy losses including inverter conversion losses, storage system conversion losses, building system energy losses and load energy losses (kWh)
- E_{load}: energy load (kWh)
- s: period of 6 months classified as a semester of a given year
- t: data resolution of 1h, analysis resolution for self-consumption indicator calculation

Outputs:

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- $\gamma_{supply}(s)$: supply cover factor calculation per semester representing the percentage of on-site generation that is used by the building

Calculation method:

$$\gamma_{supply}(s) = \frac{\int_0^T min\left[E_g(t) - E_s(t) - E_{loss}(t), E_{load}(t)\right]dt}{\int_0^T E_g(t) - E_s(t) - E_{loss}(t)\, dt}$$

V. Comfort analysis

GOAL: increasing user satisfaction with respect to some of the components of the indoor physical environments by at least 15%

a. Percentage of time outside a temperature range (percentage of hours in relation to number of occupied hours that the temperature is outside of comfort range)

Inputs:

- t: inside air temperature
- T_{min}: minimum temperature of comfort range
- T_{max}: maximum temperature of comfort range
- T_{occ}: total time that building or building zone is occupied

Outputs:

- P_{cold}: percentage of time where inside temperature is below the minimum comfort zone temperature in relation to total occupied time
- P_{hot}: percentage of time where inside temperature is above the maximum comfort zone temperature in relation to total occupied time

Calculation method:

$$P_{cold} = \frac{1}{T_{occ}} \sum_0^T t \;\; if \; t < T_{min}$$

$$P_{hot} = \frac{1}{T_{occ}} \sum_0^T t \;\; if \; t > T_{max}$$

b. Degree-hours calculating the time and magnitude of temperature deviation outside of comfort range

Inputs:

- t: duration of time that the temperature is outside the defined comfortable temperature range
- T_{min}: minimum temperature of comfort range
- T_{max}: maximum temperature of comfort range
- T_{sp}: setpoint temperature

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- wf: weighting factor to take into account the magnitude of temperature deviation from optimal value

Outputs:

- DH_{cold}: degree hours weighted by temperature deviation from setpoint when temperature drops below the minimum comfort temperature
- DH_{hot}: degree hours weighted by temperature deviation from setpoint when temperature is above the maximum comfort temperature

Calculation method:

$$DH_{cold} = \sum_{0}^{T} \left[1 + \frac{T_{min} - t}{T_{sp} - T_{min}}\right] \times t \ if \ t < T_{min}$$

$$DH_{hot} = \sum_{0}^{T} \left[1 + \frac{t - T_{max}}{T_{max} - T_{sp}}\right] \times t \ if \ t > T_{max}$$

c. Percentage of time outside a PMV range (percentage of hours during the occupied hours that PMV is outside of acceptable range)

Inputs:

- t: duration of time outside of PMV acceptable range
- PMV_{min}: minimum PMV acceptable value
- PMV_{max}: maximum PMV acceptable value
- T_{occ}: total time that building is occupied

Outputs:

- P: percentage of time outside of PMV acceptable range

Calculation method:

$$P = \frac{1}{T_{occ}} \sum_{0}^{T} t \ if PMV_{max} < PMV(t) < PMV_{min}$$

VI. Flexibility analysis

GOAL : increase the demand flexibility between 24% to 58% and the agility of the system between 27% to 40%

a. Demand response (DR) event KPI (Implicit and explicit cumulated)

i. Peak power reduction during event (kW and %)

Inputs:

- $P_{base}(t)$: simulated or calculated baseline consumption profile, expected normal consumption during demand response event

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- $P_m(t)$: measured consumption profile during demand response event

Outputs:

- P_f: average difference of baseline profile and measured consumption during demand response event (kW)
- $P_{f,\%}$: average difference of baseline profile and measured consumption during demand response event (%)

Calculation method:

$$P_f = \frac{1}{T}\sum_{0}^{T} P_m(t) - P_{base}(t)$$

$$P_{f,\%} = \frac{P_f}{\frac{1}{T}\sum_0^T P_{base}(t)}$$

ii. Energy savings during demand response event (kWh and %)

Outputs:

- E_f: cumulated energy savings achieved during demand response event (kWh)
- $E_{f,\%}$: cumulated energy savings achieved in relation to baseline energy consumption during demand response event (%)

Calculation method:

$$E_f = \sum_{0}^{T} P_m(t) - P_{base}(t)$$

$$E_{f,\%} = \frac{E_f}{\frac{1}{T}\sum_0^T P_{base}(t)}$$

iii. Self-consumption energy increase based on supply cover factor (%)

Inputs:

- E_g: onsite renewable energy generation (kWh)
- E_s: net energy flowing in or out of the onsite storage systems (kWh)
- E_{loss}: energy losses including inverter conversion losses, storage system conversion losses, building system energy losses and load energy losses (kWh)
- E_{load}: energy load (kWh)
- t: data resolution of 1h, analysis resolution for self-consumption indicator calculation
- $\gamma_{supply,base}$: supply cover factor for baseline scenario during demand response event (%)
- $\gamma_{supply,m}$: supply cover factor for measured data during demand response event (%)

Outputs:

- E_{DR}: onsite generated energy use increase or decrease during demand response event (kWh)

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- γ_{DR}: supply cover factor percentage increase or decrease during demand response event (%)

Calculation method:

$$E_{DR} = \int_0^T min[E_g(t) - E_s(t) - E_{loss}(t), E_{load}(t)]dt$$

$$\gamma_{DR} = \gamma_{supply,m} - \gamma_{supply,base}$$

iv. Primary energy balance (kWh)

Inputs:

- $E_{primary,base}$: primary energy use of baseline scenario either measured or simulated (kWh)
- $E_{primary,m}$: primary energy use of measured consumption during demand response event (kWh)

Outputs:

- $E_{primary,DR}$: difference in primary energy use resulting from demand response event (kWh)
- $P_{primary,DR}$: percentage difference in primary energy use resulting from demand response event (%)

Calculation method:

$$E_{primary,DR} = E_{primary,base} - E_{primary,m}$$

$$P_{primary,DR} = \frac{E_{primary,base} - E_{primary,m}}{E_{primary,base}}$$

b. Climate resilience and flexibility (Demand Flexibility Factor)

Inputs:

- A: set of controllable appliances available for demand response events
- P_a: nominal power of controllable load (kW)
- $P_{cont,a}$: power increase or decrease available for demand response events for each appliance (kW)

Outputs:

- P_{FF}: power available considering all controllable loads for a demand response event (kW)
- FF: percentage of the total load that is controllable during a demand response event (%)

Calculation method:

$$P_{FF} = \sum_0^A P_{cont,a}$$

$$FF = \frac{\sum_0^A P_{cont,a}}{\sum_0^A P_a}$$

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Annex 2: Calculation Parameters – Current Status

Table 16 Heating catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
H-1a	*Heat emission control*	Yes	Yes	3	100 %	-
H-1b	*Emission control for TABS (heating mode)*	No	No	-	-	-
H-1c	*Control of distribution fluid temperature* [1]	Yes	Yes	1	100 %	-
H-1d	*Control of distribution pumps in networks*	Yes	Yes	3	100 %	-
H-1f	*Thermal Energy Storage (TES) for building heating* [2]	No	No	-	100 %	-
H-2a	*Heat generator control (all except heat pumps)*	Yes	Yes	0	100 %	-
H-2b	*Heat generator control (for heat pumps)*	Yes	Yes	1	100 %	-
H-2d	*Sequencing in case of different heat generators*	Yes	Yes	0	100 %	-
H-3	*Report information regarding heating system performance*	Yes	Yes	1	100 %	-
H-4	*Flexibility and grid interaction*	Yes	Yes	1	100 %	-

Table 17 Domestic hot water catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
DHW-1a	*Control of DHW storage charging* [3]	Yes	Yes	1	100 %	-
DHW-1b	*Control of DHW storage charging (using hot water generation)*	No	No	-	-	-
DHW-1d	*Control of DHW storage charging* [4]	Yes	Yes	3	100 %	-
DHW-2b	*Sequencing in case of different DHW generators*	Yes	Yes	0	100 %	-
DHW-3	*Report performance information*	Yes	Yes	1	100 %	-

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Table 18 Cooling catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
C-1a	*Cooling emission control*	No	No	-	-	-
C-1b	*Emission control for TABS (cooling mode)*	No	No	-	-	-
C-1c	*Control of distribution network* [5]	No	No	-	-	-
C-1d	*Control of distribution pumps in networks*	No	No	-	-	-
C-1f	*Interlock* [6]	No	No	-	-	-
C-1g	*Control of Thermal Energy Storage (TES) operation*	No	No	-	-	-
C-2a	*Generator control for cooling*	No	No	-	-	-
C-2b	*Sequencing of different cooling generators*	No	No	-	-	-
C-3	*Report performance information*	No	No	-	-	-
C-4	*Flexibility and grid interaction*	No	No	-	-	-

Table 19 Ventilation catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
V-1a	*Supply air flow control at the room level*	Yes	Yes	4	100 %	-
V-1c	*Air flow or pressure control at the air handler level*	Yes	Yes	4	100 %	-
V-2c	*Heat recovery control: prevention of overheating*	Yes	Yes	1	100 %	-
V-2d	*Supply air temperature control at the air handling unit level*	Yes	Yes	2	100 %	-
V-3	*Free cooling with mechanical ventilation system*	Yes	Yes	2	100 %	-
V-6	*Reporting information regarding IAQ*	Yes	Yes	1	100 %	-

Table 20 Lighting catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
L-1a	*Occupancy control for indoor lighting*	Yes	Yes	2	100 %	-
L-2	*Control artificial lighting power based on daylight levels*	No	No	-	100 %	-

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Table 21 Dynamic building envelope catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
DE-1	*Window solar shading control*	No	No	-	-	-
DE-2	*Window open/closed control, combined with HVAC system*	No	No	-	-	-
DE-4	*Report performance information*	No	No	-	-	-

Table 22 Electricity catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
E-2	*Reporting information regarding local electricity generation*	Yes	Yes	2	100 %	-
E-3	*Storage of (locally generated) electricity*	No	No	-	-	-
E-4	*Optimizing self-consumption of locally generated electricity*	Yes	Yes	0	100 %	-
E-5	*Control of combined heat and power plant (CHP)*	No	No	-	-	-
E-8	*Support of (micro)grid operation modes*	Yes	Yes	0	100 %	-
E-11	*Report storage information*	No	No	-	-	-
E-12	*Report consumption information*	Yes	Yes	2	100 %	-

Table 23 Electric vehicle charging catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
EV-15	*EV Charging Capacity*	No	-	-	-	-
EV-16	*EV Charging Grid balancing*	No	-	-	-	-
EV-17	*Report charging / connectivity information*	No	-	-	-	-

Table 24 Monitoring and control catalogue

Code	Smart ready service	Affects score?	Service applicable ?	Functionality level	Shared level	Shared functionality level
MC-3	*Run time management of HVAC systems*	Yes	Yes	1	100 %	-
MC-4	*Detecting faults of technical building systems* [7]	Yes	Yes	1	100 %	-
MC-9	*Occupancy detection: connected services*	Yes	Yes	1	100 %	-
MC-13	*Central reporting of TBS performance and energy use*	Yes	Yes	1	100 %	-
MC-25	*Smart Grid Integration*	Yes	Yes	0	100 %	-
MC-28	*Report demand performace information*	Yes	Yes	0	100 %	-
MC-29	*Override of DSM control*	Yes	Yes	0	100 %	-
MC-30	*Single platform* [8]	Yes	Yes	2	100 %	-

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Annex 3: Scores – Current Status

Detailed Scores

Table 25 Detailed scores of the current status of the building

Domain\Impact	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	47 %	11 %	50 %	63 %	67 %	50 %	33 %
Domestic hot water	56 %	38 %	0 %	60 %	0 %	50 %	33 %
Cooling	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Ventilation	79 %	0 %	90 %	88 %	78 %	50 %	33 %
Lighting	67 %	0 %	100 %	100 %	0 %	0 %	0 %
Dynamic building envelope	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Electricity	50 %	0 %	0 %	0 %	0 %	25 %	67 %
Electric vehicle charging	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Monitoring and control	50 %	11 %	67 %	35 %	25 %	36 %	22 %

Aggregated Scores

Table 26 Aggregated scores of the current status of the building

Domain \ Key Functionality	Building	User	Grid
Heating	49 %	53 %	11 %
Domestic hot water	53 %	47 %	38 %
Cooling	0 %	0 %	0 %
Ventilation	64 %	72 %	0 %
Lighting	67 %	100 %	0 %
Dynamic building envelope	0 %	0 %	0 %
Electricity	38 %	33 %	0 %
Electric vehicle charging	0 %	0 %	0 %
Monitoring and control	43 %	37 %	11 %

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Annex 4: Calculation Parameters – Expected Status

Table 27 Changes made in the functionality level to calculate the expected level of SRI in the building

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Domain	Code	Smart ready service	Actual functionality level	Expected functionality level
Heating	H-4	*Flexibility and grid interaction*	1	3
Electricity	*E-4*	*Optimizing self-consumption of locally generated electricity*	0	2
Electricity	*E-8*	*Support of (micro)grid operation modes*	0	1
Monitoring and control	*MC-25*	*Smart Grid Integration*	0	2
Monitoring and control	*MC-28*	*Report demand performance information (DSM)*	0	2
Monitoring and control	*MC-29*	*Override of DSM control*	0	4

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Annex 5: Scores – Expected Status

Detailed Scores

Table 28 Detailed scores of the expected status of the building

Domain\Impact	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	53 %	44 %	60 %	88 %	67 %	50 %	33 %
Domestic hot water	56 %	38 %	0 %	60 %	0 %	50 %	33 %
Cooling	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Ventilation	79 %	0 %	90 %	88 %	78 %	50 %	33 %
Lighting	67 %	0 %	100 %	100 %	0 %	0 %	0 %
Dynamic building envelope	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Electricity	50 %	67 %	0 %	57 %	0 %	25 %	67 %
Electric vehicle charging	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Monitoring and control	63 %	89 %	67 %	59 %	25 %	55 %	56 %

Aggregated Scores

Table 29 Aggregated scores of the expected status of the building

Domain \ Key Functionality	Building	User	Grid
Heating	51 %	62 %	44 %
Domestic hot water	53 %	47 %	38 %
Cooling	0 %	0 %	0 %
Ventilation	64 %	72 %	0 %
Lighting	67 %	100 %	0 %
Dynamic building envelope	0 %	0 %	0 %
Electricity	38 %	62 %	67 %
Electric vehicle charging	0 %	0 %	0 %
Monitoring and control	59 %	52 %	89 %

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[1] (Supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks

[2] Excluding TABS

[3] With direct electric heating or integrated electric heat pump

[4] With solar collector and supplementary heat generation

[5] Chilled water temperature (supply or return)

[6] Avoiding simultaneous heating and cooling in the same room

[7] And providing support to the diagnosis of these faults

[8] That allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals

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