COLLECTiEF

REPORT ON THE SMALL-SCALE EVALUATION OF COLLECTIEF ALGORITHMS AND CONTROL STRATEGIES

Project acronym: COLLECTiEF

Project title: Collective Intelligence for Energy Flexibility

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

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Disclaimer

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Executive Summary

The deliverable describes an evaluation of COLLECTiEF algorithms in the small-scale pilot. This evaluation allows to test the correct functionality and robustness of the algorithms before implementation in the final COLLECTiEF products.

In order to demonstrate a reinforcement learning based algorithm, a test has been carried out in a small-scale pilot. The small-scale pilot comprises of a living-lab, which is a part of G2ELab[1], situated in GreEn-ER2 building in Grenoble, France. The purpose of this living lab is to bring human in the loop of the technological innovation through user engagement and feedback from the end-user side (Delinchant et al., 2016; Twum-Duah et al., 2022; Wurtz & Delinchant, 2017).

The deliverable is divided into 3 main parts:

- Description of the small-scale pilot:
  The pilot building including usage, envelope and energy systems are described in this part.

- Description of the implementation of the intermediate server and data exchange between the algorithms and the pilot energy management system (BEMS):
  In order to be able to connect the COLLECTiEF algorithms to the BEM system in place, an intermediate server had to be set in place and adapted. This is described in this section.

- Debugging the algorithms and their evaluation on correct functionality:
  This is the key objective in this deliverable, to test functionalities of the algorithm in a real building. It is not planned here to evaluate KPI’s of the algorithms but only to check the algorithm of its correct operation.

[1] Laboratoire de Génie Électrique de Grenoble (Grenoble Electrical Engineering Lab, France)

[2] Grenoble énergie - enseignement et recherche (Teaching and Research on energy in Grenoble, France)

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List of Acronyms

API	Application Programming Interface
BRiG	Boarder Router Intelligent Gateway
BIM	Building Information Modeling
D	Deliverable
DIMOSIM	District Modeller & Simulator
DHW	Domestic Hot Water
HTML	HyperText Markup Language
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
MQTT	Message Queuing Telemetry Transport
nDSM	Novel Demand Side Management
POE	Post Occupancy Evaluation
Partner	The beneficiary in the COLLECTiEF Project
SRI	Smart Readiness Indicator
TMY	Typical Meteorological Year
URL	Uniform Resource Locator
WP	Work Package
SG-InterOp	Smart Grid Interoperatability

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1 Introduction

1.1 Description of Task (T2.5 Deployment and testing of algorithms and control strategies at small-scale pilot)

From the Grant Agreement:

"*Based on previous tasks, the Green'ER living lab will be used as a small-scale pilot to integrate, test and validate the successfully simulated COLLECTiEF algorithms and control strategies. Therefore, the algorithms and control strategies will be connected to the real energy system of the pilot via a dedicated API and link to an intermediate server. The strategies will thus be tested in a real energy system and results compared to equivalent zones of the Green'ER building which is fully monitored. To do so, CSTB provides access to Green'ER small scale pilot and facilitates the integration and testing process. Together with ULUND, they ensure successful implementation of COLLECTiEF algorithms and control strategies and share the results and data sets for evaluation and impact assessment (cf. WP5).*"

Remark: The small-scale pilot is hereafter alternatively also referred as G2ELab or living-lab.

1.2 Scope and purpose

This deliverable describes the implementation and test of algorithms and control strategies developed within WP2 in the small-scale pilot.

The deliverable comprises of reporting the following two parts:

1. Implementation of the intermediate server and data exchange principle, which allows the algorithms to modify the control setpoints in the offices of the living lab,
2. Evaluation tests of the COLLECTiEF algorithms in the small-scale pilot.

These developments are carried out by Partners 2, 3 and 9 of the COLLECTiEF project.

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2 Description of the small-scale pilot

2.1 General building description and small-scale pilot characteristics

Location: Green'ER building in Grenoble, France.

The GreEn-ER project is the first PPP (Public-Private Partnership) signed in France as part of the Campus Operation for renewing universities. Led by the University of Grenoble and jointly coordinated by Grenoble INP and CEA, the aim of this project is to bring together, in a single location, the stakeholders of training and research in the field of renewable energy. The building hosts G2Elab (a laboratory) and INP ENSE3 (an engineering school). It also includes a library and university restaurant. The building has 5 floors with a total floor area of more than 22000m². Built in 2015, it has a capacity to accommodate around 2000 occupants (Figure 1).

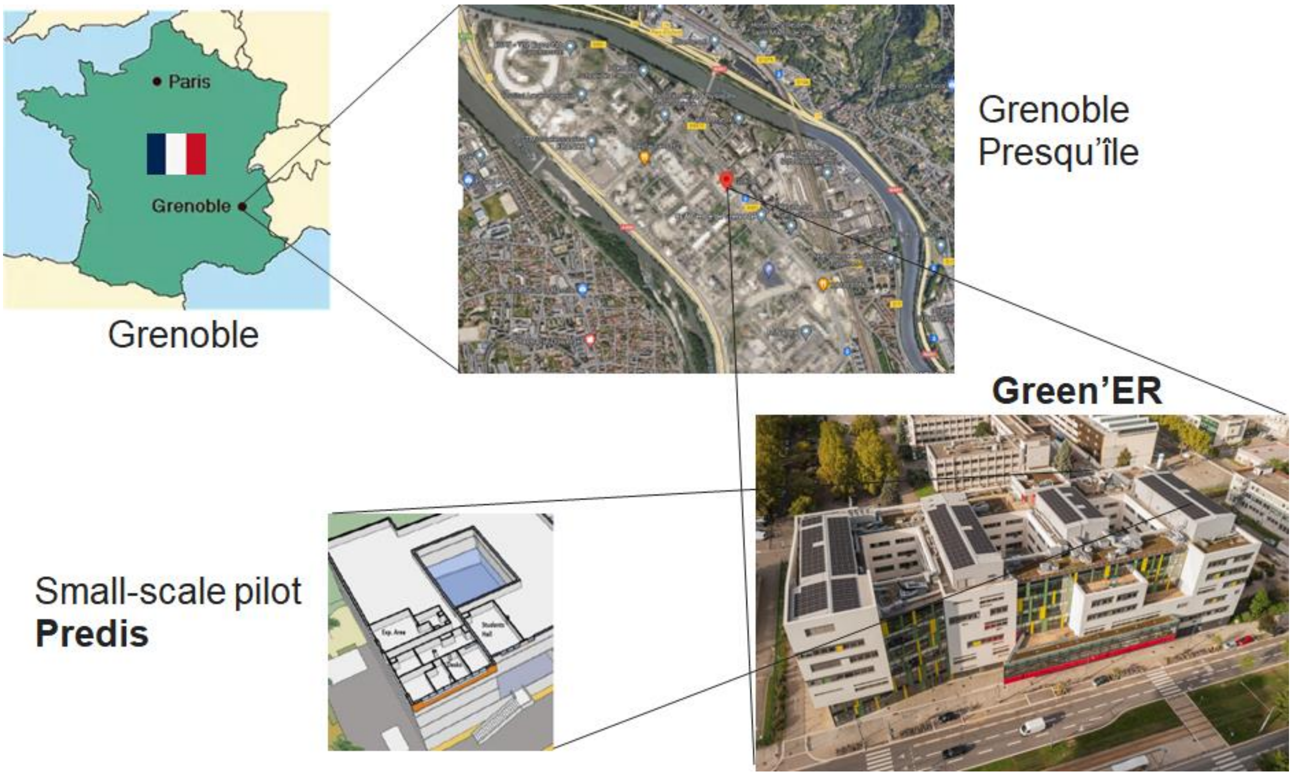

Figure 1 : Geographical location of the Green'Er building and the small-scale pilot

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Figure 2 : The front-view of Green'Er building in which the small-scale pilot is located

The test of algorithm has taken place in the living lab of G2ELab, with access provided by consortium partner CSTB. This living lab allows the evaluation of COLLECTiEF algorithms and control strategies in a real building, before their implementation in the large-scale pilots. The building corresponds to a mix of offices (40%), educational (30%) and research areas (30%). The living lab, in the 4th floor of the building, is equipped with a large number of meters and sensors that will also allow to validate metering and measurement of the COLLECTiEF products. The total surface of the living-lab is 357 m^2, and it consists of 5 offices for professors and researchers, a room for the interns, an experimentation area, and a classroom.

The algorithms will be connected to the energy system in place which are as follow:

- Energy production for the building:
  - Energy for heating is available by a connection to the thermal substation which links the building to the thermal district heating network
  - A 30kW CHP unit that injects electricity to the building electric network (not used at the moment)
  - PV system with battery storage
  - Air/water cooling system
- Energy delivery to the rooms:
  - Radiant hydronic ceiling heating and cooling in all rooms (optional: hydronic floor heating system)
  - Variable air Volume (VAV) system for ventilation and additional heating and cooling via terminal units in the rooms
  - Several unidirectional and bi-directional charging stations for vehicles

The COLLECTiEF solution has been plugged to the living lab and is tested under real conditions.

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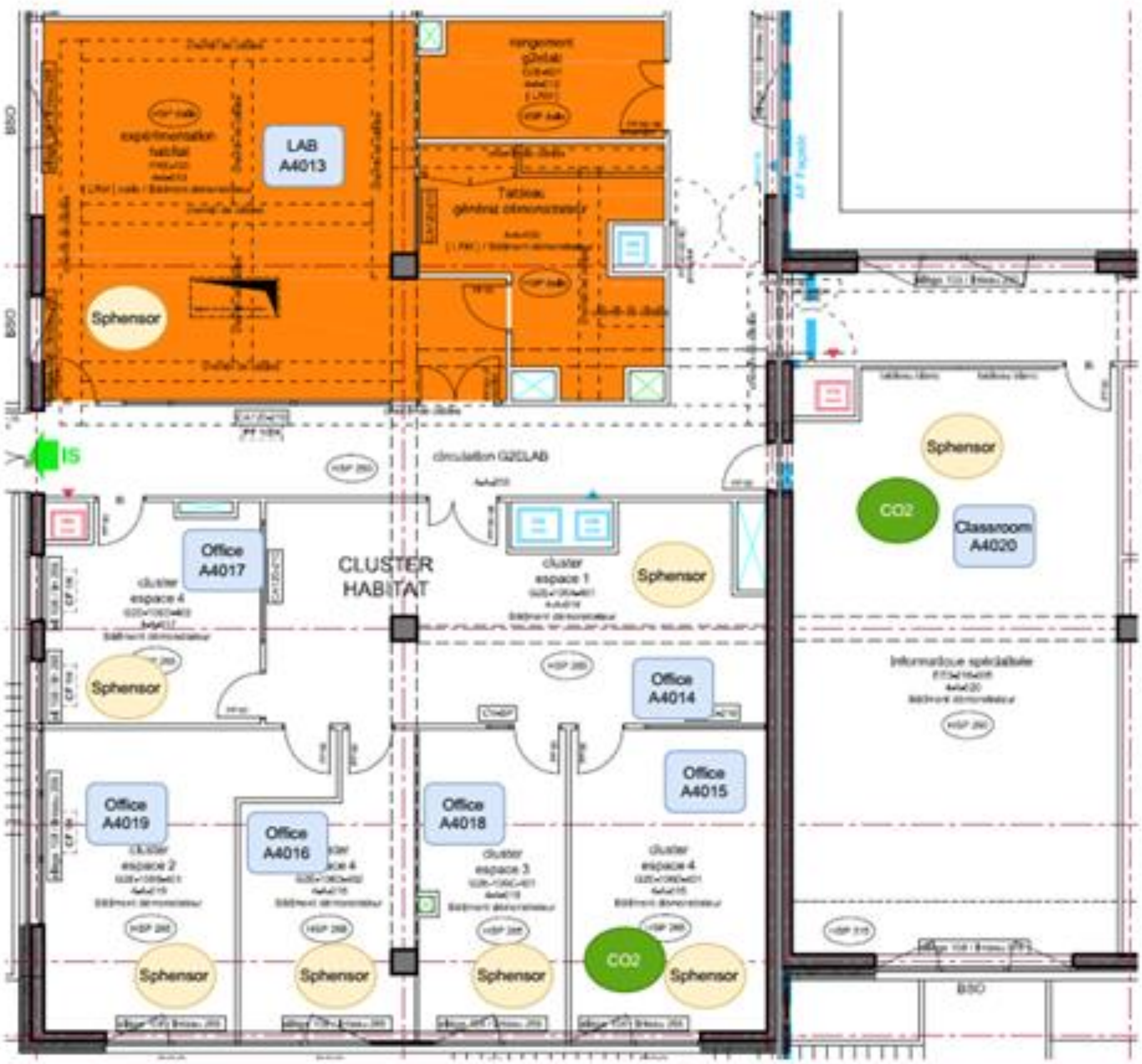

Figure 3 : Rooms included in the small-scale pilot and position of Sphensors

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2.2 Building envelope and energy system characteristics

The previous section enlightened us about the general characteristics, location and plan of the living lab. In this section, the building characteristics including envelope and energy systems in place will be described.

2.2.1 Building envelope

Regarding the building envelope, the interior walls consist of lightweight interior partitions formed by an air gap surrounded by two layers of plaster, with a U-value of 4.2 W/(m².K). For the exterior walls, the composition includes cladding, an air gap, insulation, and a layer of heavy concrete, resulting in a U-value of 0.191 W/(m².K). The ground floor is constructed with insulation and heavy concrete, achieving a U-value of 0.11. The exterior roof is composed of polyurethane insulation and heavy concrete, providing a U-value of 0.135.

In terms of the windows, double-glazed Argon-filled windows are utilized, offering a solar heat gain coefficient (SHGC) of 56% and a visible light transmittance (VLT) of 71%. The window-to-wall ratio exceeds 20%.

These carefully selected building envelope elements enhance energy efficiency, thermal performance, and occupant comfort. The combination of cladding, insulation, and heavy concrete in the exterior walls provides excellent thermal insulation and structural stability.

The incorporation of insulation and heavy concrete in the ground floor and roof helps to minimize heat transfer and increase energy efficiency. The double-glazed Argon-filled windows offer improved insulation properties, reducing heat loss and contributing to overall energy savings.

The blinds used in GreEn-ER are venetian blinds with adjustable angle, controllable through the BMS software. In the summer (cooling season), the blinds are dropped by default to limit the amount of incoming sunlight, contributing to the energy efficiency of the building. Additionally, one room is installed with a motorized window which can open and close on command.

2.2.2 Energy system for heating, cooling and ventilation

The living lab includes the following energy systems for providing heat, cold and ventilation:

- Air handling unit for controlling indoor air quality and pre-conditioning of air to the rooms
- The connection to the district heating network of the district for heating services
- Several air/water heat pumps for cooling in summer

Though the GreEn-ER building is connected with a number of air handling units, yet for this living lab, there is only one air handling unit. This air handling unit is called CTA 05 and it is responsible for the heating cooling and ventilation in the rooms of the living lab. Figure 5 presents the schematic diagram of air handling unit CTA 05.

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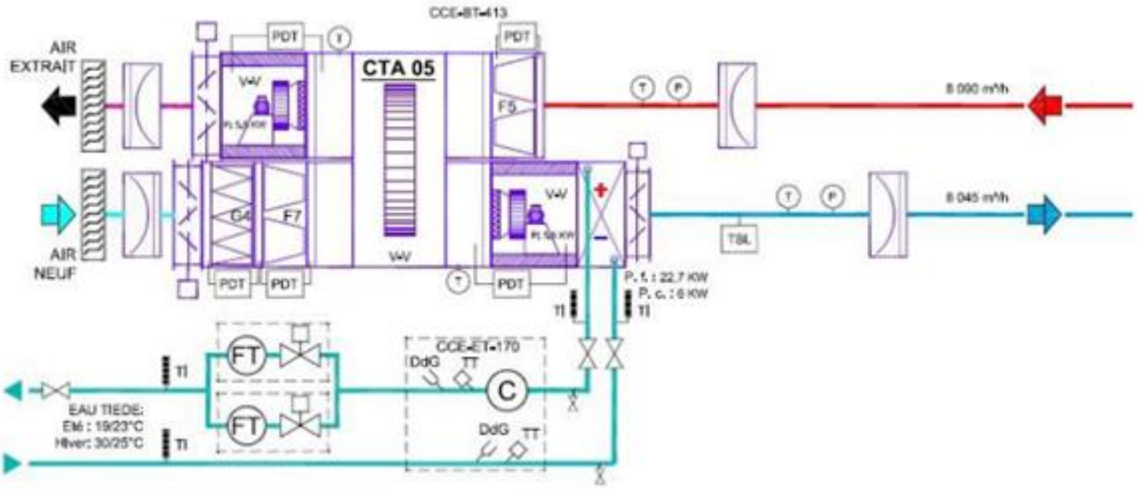

Figure 4 : Air handling unit supplying of the living-lab

Individual room heating/cooling services are supplied using different modules:

- Convective heating based on the air handling unit, with terminal units:
    - The air is preconditioned by a coil on the level of the air handling unit (heating / cooling)
    - Each room disposes of a terminal coil to adjust the air blown to the room, in accordance with the heating or cooling demand, to guarantee the required set point
- Combined convective/radiative heating/cooling services:
    - Each room is equipped with a reversible (hydronic) ceiling, connected to the district heating network (Figure 5) for heating and to the local chillers for cooling in the summer season (Figure 6).

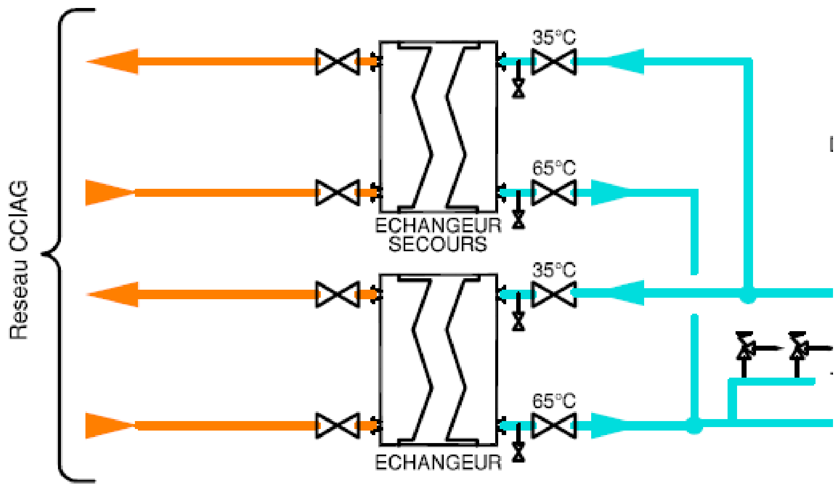

Figure 5 : Energy supply of the building from the district heating network

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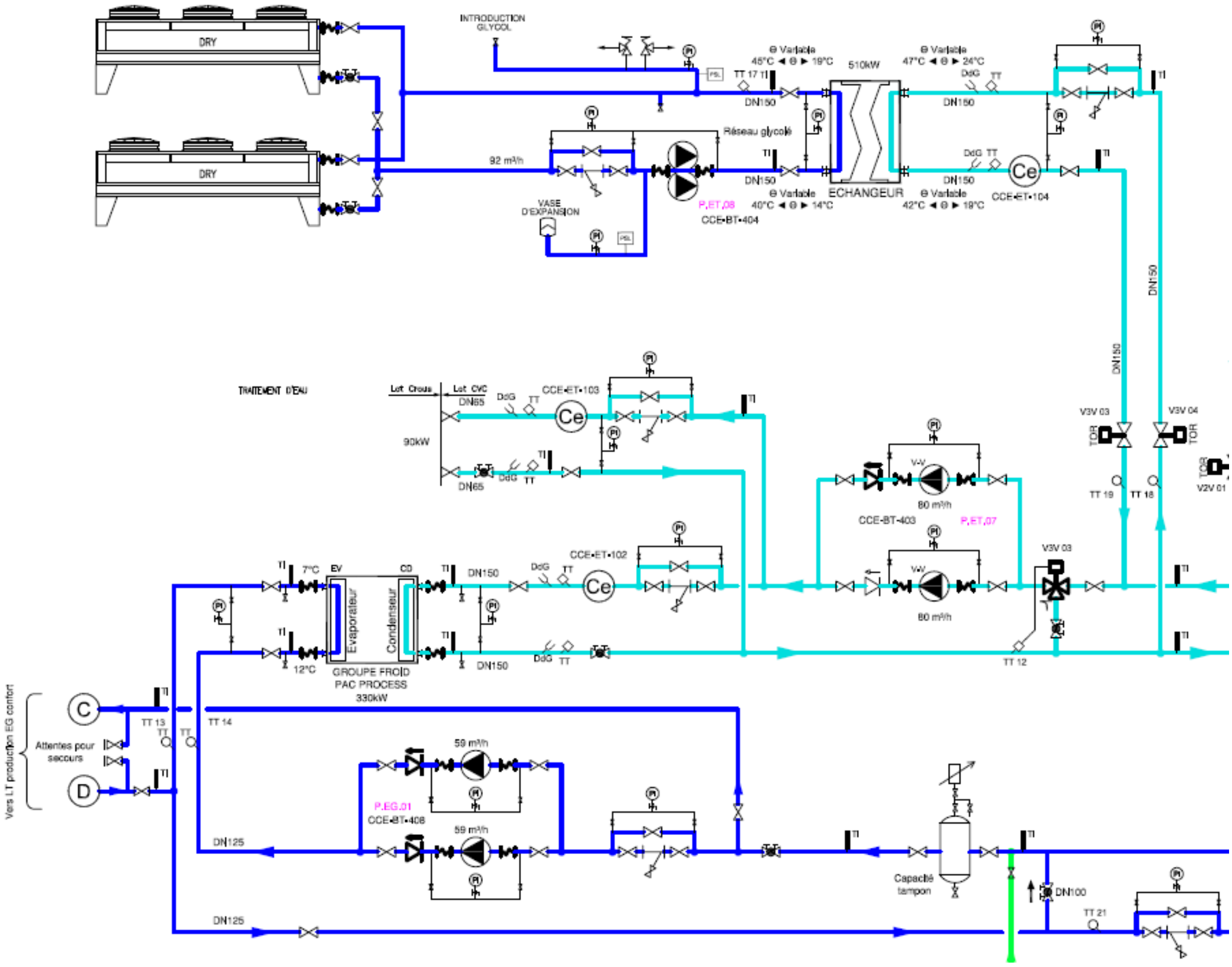

Figure 6 : Energy supply of the building from the thermodynamic cooling system

The occupants of each room can choose according to their preferred way to either heat or cool the room (i.e. air based via AHU with terminal coils or by the radiant ceiling).

Additionally, the set points for room temperature (heating and cooling set points) as well as CO2 set point are adjustable.

Figure 7 shows the individual user interface with the following objects:

- Choice of control mode 1-3 as well as set points (left part of the interface)
- Current monitoring data in the room (supply are temperatures for water and/or air, flow rates, damper openings etc. (second left table with values). This module also allows to impose valve or damper opening percentages (in yellow)
- A graph and table with an overview of the office plan and key electric modules with measurement data (plug electric loads and lighting)

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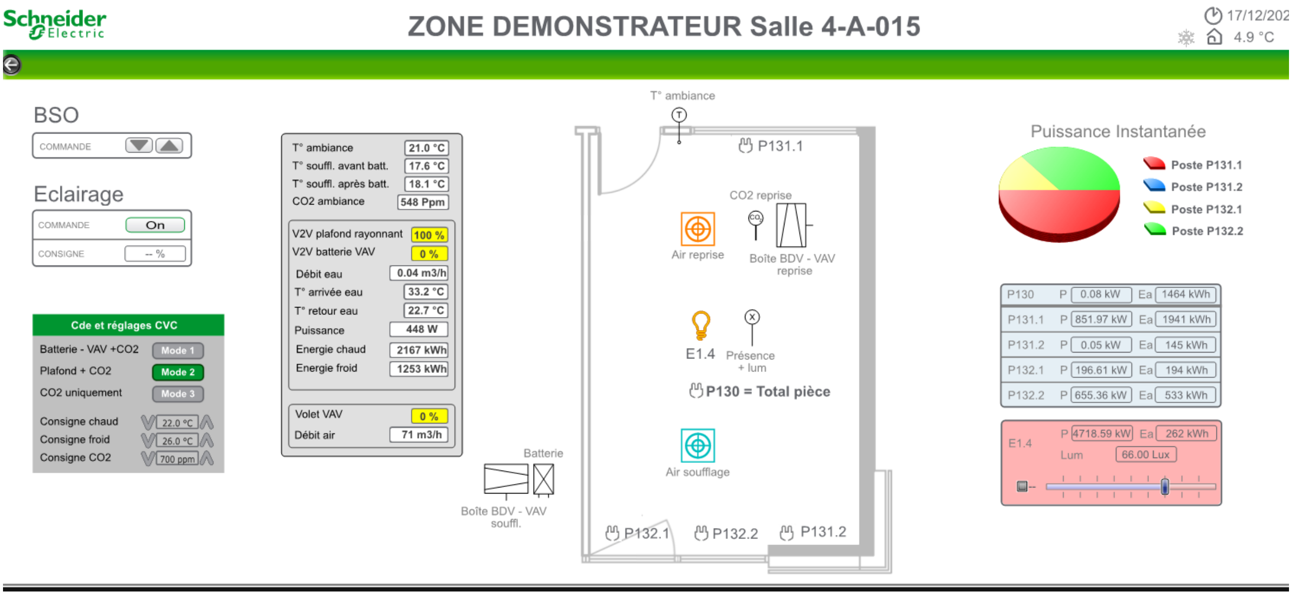

Figure 7 : Room 4A015 user interface with control options

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3 Development and implementation of an intermediate server for data exchange between the small-scale pilot and the COLLETiEF algorithms

3.1 Objectives and main concept

For the purpose of training the model of COLLECTiEF algorithm using reinforcement learning, it is required that the historical data of different variables should be incorporated in the algorithm. The data of these variables is collected from several sensors installed during the construction of GreEN-ER building. For this purpose, the developer of algorithm requested to have access to the historical data of these sensors. However due to security and privacy concerns, the public-private stakeholders of the building do not agree to give a direct access to the building management system. which not only controls different variables in the building but also have a dedicated server to store the data (i.e. the BMS data server). As an alternative, a suggestion was floated to introduce an intermediate platform for sharing the historical data as well as for getting the new control points from the algorithm.

3.2 Data exchange principle

In this regard, an intermediate server (called as SG-InterOp, acronym for smart grid inter-operability) is introduced. Figure 7 is demonstrating data flow through SG-InterOp server. It should be noted that to communicate with SG-InterOp, the algorithm needs to be authenticated through multiple authentication steps, therefore, ensuring the secured flow of data. The working principle of data exchange is as follows:

- For sharing data, an automated script is put in place on the "MHI-SRV" server in G2ELab, which gathers data from building management system and copy it on the SG-InterOp server. A dedicated API is developed in G2ELab and is shared with the developer of algorithm so that this API can be incorporated in COLLECTiEF algorithm. In this way, the COLLECTiEF algorithm has access to the building sensors data indirectly.
- To get new setpoints, the same intermediate server is used. The COLLECTiEF algorithm sends the new setpoints to SG-InterOp server and an automated script running on the "MHI-SRV" server in G2ELab fetches the new setpoints and implement them on the building management system.

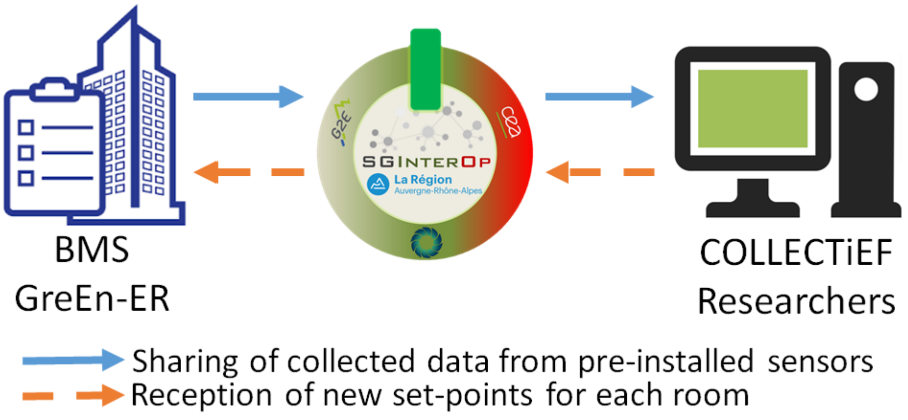

Figure 7 : Schematic diagram of data transfer to and from building management system of GreEN-ER

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It is a significant to enlist here all the variables for which the historical data has been shared to COLLECTiEF algorithm that has been originally recorded on the building management system. This list is given below in tabular form with respect to each room in living-lab. For the sake of convenience, the presence or absence of data for respective variable is colour coded. In the table below the green colour shows that the data is available and is shared with COLLECTiEF algorithm while the red colour shows unavailability of data for the respective variable.

Table 1: The variables for which data is shared to COLLECTiEF algorithm

Sr. No.	Variable Name	Room							
		4A013	4A014	4A015	4A016	4A017	4A018	4A019	4A020
01	Room temperature (°C)								
02	HVAC Power (W)								
03	Heating Energy (kWh)								
04	Cooling Energy (kWh)								
05	Water Flow (m3/h)								
06	Inlet water temperature (°C)								
07	Outlet water temperature (°C)								
08	CO2 Concentration (ppm)								
09	Air Flow (m3/h)								

3.3 Server implementation

It must be noted that the server SG-InterOp is not specifically built as an intermediate platform to share the data outside of G2ELab. In fact, SG-InterOp is a project financed by Auverge Rhone-Alps region of France, with multilateral research purposes in the domain of energy. This includes but is not limited to extraction of energy from a hydro turbine in a hydraulic lab and implementation of a virtual power plant. The objective of this platform is to do cross-sectional research on the inter-operability of the smart grid, ranging from (but not limited to) the electricity production from hydraulic turbines, energy storage, and energy flexibility at the end-user level (Labonne, 2022). In addition to other use cases of SG-InterOp project, sharing of living lab data as well as collecting the news setpoints from COLLECTiEF algorithm is added.

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4 Evaluation of COLLETiEF algorithms in the small-scale pilot

4.1 Overview of algorithms to be evaluated

The algorithm is developed using "Python" language. At this stage, the latest version of the nDSM code is implemented for the test. It applies Reinforcement Learning (RL) approach to learn and control the building indoor conditions. The energy flexibility is activated by a signal.

4.1.1 Algorithm objectives in terms of energy consumption and flexibility

The Novel Demand-Side Management (nDSM) algorithm enables energy flexibility on the demand side. DSM attempts to reduce the energy demand by applying the flexibility measures.

For more detail on the algorithms, please refer to D2.3 (Fine-tuned and feasible control strategies that address user comfort, cost & energy efficiency, climate change mitigation & adaptation (first version).

4.1.2 Algorithm objectives in terms of occupant comfort

The algorithm aims to improve occupants' comfort in actual operational conditions by increasing their satisfaction and productivity. The backbone of the algorithm is the state-of-the-art thermal comfort models, which are presented analytically in D2.3 - Fine-tuned and feasible control strategies that address user comfort, cost & energy efficiency, climate change mitigation & adaptation (first version) and D2.5 - Verified and working control strategies that maximise the occupant comfort and integration of renewable energy generation, working for current and future climate.

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4.2 Test preparation and implementation

In order to calculate the reward function at any instance, the algorithm needs the real-time as well as historical data of certain monitoring points. In this regard, the data is provisioned either by the building management system or through the project-specific sensors (known as sphensors). The following monitoring points are considered to monitor the indoor conditions and learn from the actions.

1. Room air temperature (°C)
2. Room CO2 level (ppm)
3. Inlet water temperature (°C)
4. Outlet water temperature (°C)
5. Water flow (m3/h)
6. HVAC power (W)

The algorithm is developed by the researchers in ULUND[3]-Sweden and NTNU[4]-Norway in collaboration with the researchers of CYI-Cyprus and G2ELab-France. To execute the algorithm in a secured way, the algorithm is scheduled to run every 15 minutes on "MHI-SRV (Monitoring intelligent habitat)" server located in G2ELab. The version controlling of the algorithm is enabled thanks to a remote git repository, hosted by UGA -France. Any modification made by the developers located in NTNU or CYI is validated and pulled on MHI-SRV manually. The automation of this process is still under consideration. The steps of realization of the algorithm are as follows. It should be noted that the algorithm is scheduled to be self-executed every 15 minutes on MHI-SRV.

1. The monitored data is fetched from BMS and Sphensors and is stored in SQL databases in G2ELab and NTNU, respectively.
2. With a 2 minutes delay after data fetching from BMS and Sphensors, the nDSM code executes on MHI-SRV. During each execution,
    a. The monitored values are fetched from the database via an API (get_sensors).
    b. After processing in the nDSM kernel, the values for the actuators are sent to the BMS through another API (post_actuators). The post_actuator function includes a module that check the values to be within a certain limit to avoid any damage or corruption. Figure 1 demonstrates the schematic diagram of the implementation of algorithm. The flowchart of the code is presented on top right of the picture. The G2ELab's dashboard is used to visualize the data (i.e. sensor and actuator values) in real-time.

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[3] Lund University

[4] Norges teknisk-naturvitenskapelige universitet (Norwegian University of Science and Technology)

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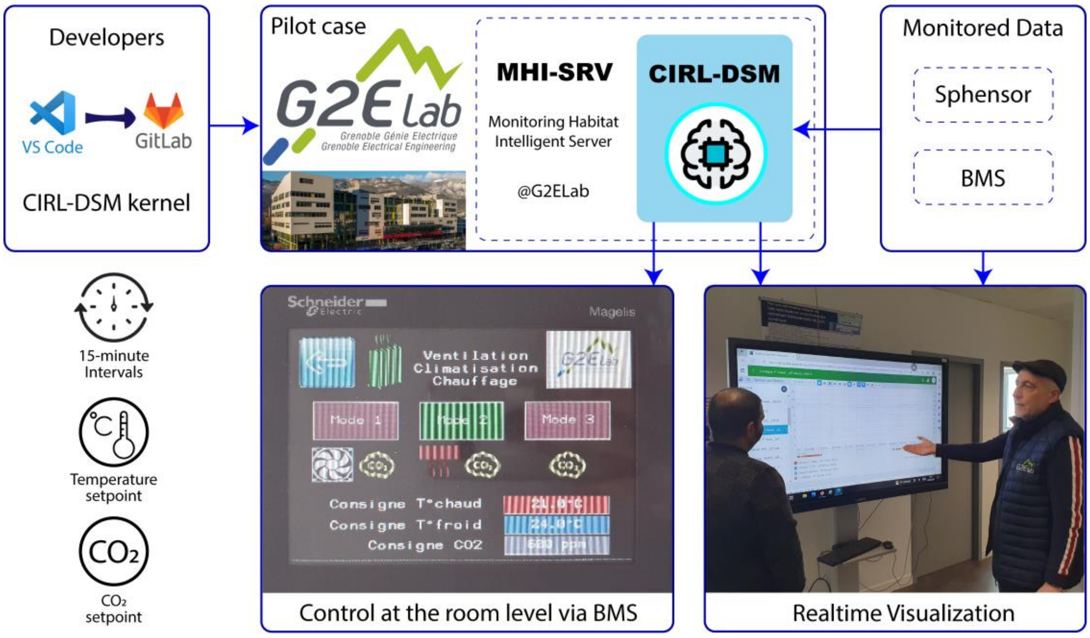

Figure 8 : Workflow of the small-scale test in G2ELab. bottom-left: BMS panel in the rooms, top-right: flowchart of the developed algorithm, bottom-right: real-time visualization platform to demonstrate the performance of the code.

The occupants can manually override the temperature and CO2 concentration setpoint values through the MAGALIS screens installed in each room. There is also possibility to fill a POE which is stored with the timestamp in the SQL server. This POE data can be correlated to the sensor and actuator values to evaluate the performance of the algorithm regarding indoor environment quality.

The building is also equipped with smart plugs and dimmable lights; however, controlling these loads is not authorized yet by the stakeholders of the public-private partnership that manages the GreEn-ER building. The developed pipeline is capable to get more actuators and sensors if they are available in the system. Also, by adapting the “get_sensor” and “post_actuator” functions to another API, it is possible to integrate the code with other buildings with slightest modifications. If the measured values are transmitted by the Sphensors, then there is no need to modify the functions in the algorithm.

It is expected to have the effects of the algorithm in the warmer months, since by definition, the algorithm is to enable energy flexibility under extreme conditions. Figure 9 illustrates the monthly temperature distribution over cooling months (i.e. May, June, July, August) from 2018 to 2022. The monthly average temperature over the past five years are 21.4, 26.7, 29.9, 28.8 °C showing fairly lower temperature in May. The average temperature in May 2023 (until May 25th) is measured equal to 15.6 °C. These values show that the best conditions for algorithm performance evaluation is in July and August. In June, considering a bit higher temperature, it is planned for debugging and fine tunning.

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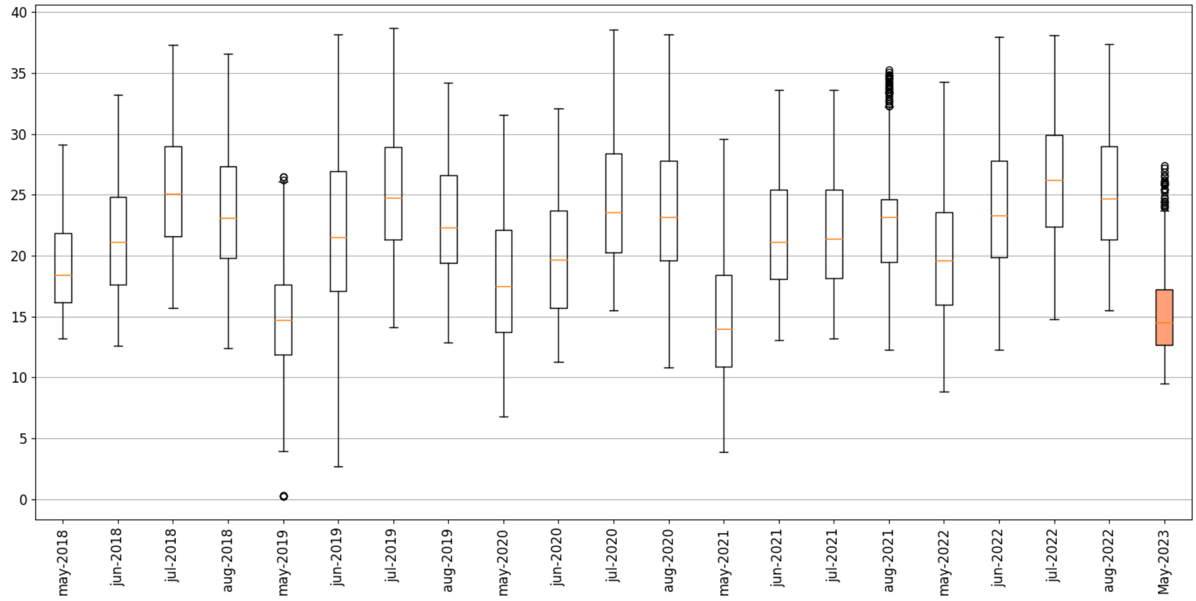

Figure 9: Monthly summer period historic outdoor temperature from 2018.

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4.3 Test results and analysis

4.3.1 Overview on types of tests

This section provides a description of the experimental design prepared to test and evaluate COLLECTiEF control algorithms in the small-scale pilot. This lab is already equipped with state-of-the-art building management system (BMS) that allows the development of interfaces capable to test building control algorithms. Apart from the exciting monitoring equipment included in the BMS of the G2Elab, COLLECTiEF project provided a number of additional IEQ sensors, called Sphensors, installed at the room level and measure quantities such as air temperature, relative humidity, illuminance, CO2 concentration, PM 1, 2.5, 4, 10 and atmospheric pressure.

The following experimental design emphasizes on testing building control algorithms *that aim to improve occupants' comfort in indoor spaces*. Occupants' comfort is related to indoor environmental quality (IEQ); which corresponds to thermal comfort, indoor air quality, and sound visual quality. Since thermal comfort has a dominant role in human comfort and it's the main control variable for HVAC systems that is mainly responsible for the enormous energy use in buildings.

To evaluate and verify the effectiveness of the Edge Node control algorithms, in terms of both humans' thermal comfort, health, and energy savings for cooling and heating, a set of experimental scenarios were designed and presented in the following sections. Table 1 summarizes the schedule of experiments at the G2Elab.

Table 1 Timetable of the experiments at the G2Elab

	Leader	Year 2022															
		Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52
Experiments	**CYI**																
Scenario 1 Assessment of the thermal comfort models																	
Scenario 2 Evaluation of the health improvement model																	
Scenario 3 Energy performance/savings comparison																	

4.3.1.1 Scenario 1: Assessment of the thermal comfort models in terms of user acceptability and perceived indoor conditions

Post-Occupancy Evaluation (POE) questionnaires were designed as part of the D5.1 *Performance Measurement & Verification Protocol –Concepts and methods for performance evaluation of COLLECTiEF solutions*. Here, POE questionnaire data are used to assess user acceptability and perceived indoor conditions of the two thermal comfort models under investigation; Fanger's model and adaptive thermal comfort model. Furthermore, for comparing the two models in relation to the personalized perceived thermal comfort, we decided to split rooms into groups and repeat the experiment for each thermal comfort model in order to avoid any source bias.

Hence, for Week 37, Fanger's model applied in Group A0 and Adaptive thermal comfort model applied in Group B0. For Week 38, the models reversed. The same scenario repeated for Weeks 43 and 44 for Groups A1 and B1. Here are the details about the experiment: The overall testing period: lasted for four (4) weeks and here are the dates selected for this test scenario:

- Week 37 – 12/09/2022 - 16/09/2022
- Week 38 – 19/09/2022 - 23/09/2022
- Week 43 – 24/10/2022 - 28/10/2022
- Week 44 – 31/10/2022 - 04/11/2022

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The rooms in test formed into the following groups:

- GROUP A0: Shared Office 4A015
- GROUP B0: Shared Office 4A018
- GROUP A1: Shared Office 4A015, 4A016, Classroom 4A020
- GROUP B1: Shared Office 4A018, 4A019, 4A014,

Note that rooms 4A017 and Laboratory 4A013, were not included in the test, since for those two rooms the BMS system was not designed to comply with the API communication.

Since, the application of the Adaptive thermal comfort model requires historical weather data, an open-access API data source i.e., *Meteostat* is used to collect outdoor air temperature records for calculating the prevailing mean outdoor temperature as it is indicated with blue dots in Figure 10. Furthermore, indoor environment measurements from Sphensor devices were used to monitor and evaluate the indoor environmental quality in terms of thermal comfort. The control command corresponds to the daily modification of the temperature set point at room level. For the indoor thermal comfort assessment, a sufficient completion rate of POEs was needed, therefore an email communication was activated in a weekly basis to inform people about their feedback requirement. Note that for this scenario the completion of POEs is set to be at 4 times per day per person. Moreover, the clothing insulation information was neglected for the first hour in order to consider the acclimation period, and the metabolic activity is related to the type of building, room use.

4.3.1.2 Scenario 2 Evaluation of the health improvement model

For testing the health improvement model, we had to exclude the effect of weather conditions; hence, a number of weekdays with similar weather conditions need to be considered.

Therefore, the testing period was selected for Week 39 with a duration of three (3) days i..e, 27/09/2022 - 29/09/2022, and the test rooms were selected as follows:

- Shared office A4018 - Adaptive thermal comfort model
- Shared office A4015 - Adaptive thermal comfort model & Health improvement signal

Since the health improvement modification (see D2.3 – *Fine-tuned and feasible control strategies that address user comfort, cost & energy efficiency, climate change mitigation & adaptation (first version)*) requires a sinusoidal modification of the temperature set point in a daily basis i.e., an hourly modification of the temperature set point at room level was applied. Hence, for capturing the short-term and periodical indoor temperature variation, the completion of POEs was set to be 7 times per day per person during 10am – 4pm at the following suggested time instances: 10am, 11am, 12pm, 1pm, 2pm, 3pm, 4pm.

4.3.1.3 Scenario 3: Energy performance/savings comparison of the thermal comfort models

The adaptive thermal comfort model calculates the daily optimal operative temperature based on the weighted average mean outdoor temperature. To show the potential of energy savings of the adaptive thermal comfort model in comparison to the Fanger's model, we had to pick a period of time in which the mean outdoor temperature creates a significant difference of the indoor operative temperature, otherwise the two models will give similar results.

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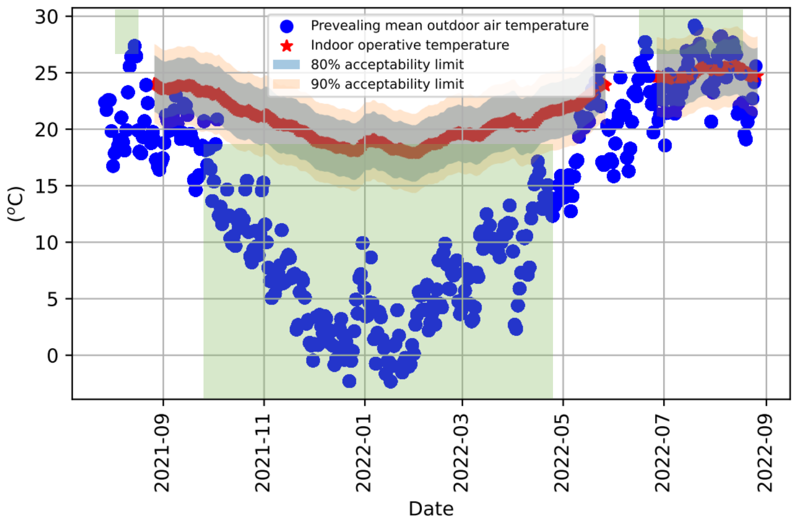

Figure 10 The calculation of the adaptive thermal comfort model for the G2Elab for one year (September 2021 to August 2022).

For illustrating the potential energy savings by applying the temperature setpoints based on the adaptive thermal comfort model instead of the temperature setpoints based on the Fanger's model the experimental period should be selected in a period of time in which the prevailing mean outdoor temperature (blue dot) is expected be outside the Fanger thermal comfort limits i.e., lower than 19 degrees and higher than 26 degrees. Hence, taking into consideration last years historical weather data for Grenoble, as illustrated in Figure 10, a suitable experimental period for the winter season could be a period between October 2022 and May 2023. With green color are highlighted the periods in which the aforementioned condition is satisfied. As you can see the summer in Grenoble is quite mild, hence it might not be suitable for comparing the two temperature control approaches. Therefore, the experiment period for this scenario is set to be at Week 40 that corresponds to the period between 03/10/2022 and 07/10/2022. The rooms taking part in this experiment are the following:

- Fanger's model: Shared offices A4018, A4016
- Adaptive thermal comfort model: Shared offices A4015, A4017

Again, weather data are used from the open-access API provided by Meteostat and control commands were applied daily by modifying the room setpoint temperature in the associated rooms. For the thermal comfort assessment, the completion of POEs for this scenario was set at 1 time per day per person.

4.3.2 Results

4.3.2.1 Experimental results for the occupant-centric control algorithm

This section presents some of the results made during the small-scale demonstration. Specifically, the analysis emphasizes on the assessment of thermal acceptability based on the user feedback given through the Brief post-occupancy evaluation (POE) questionnaires.

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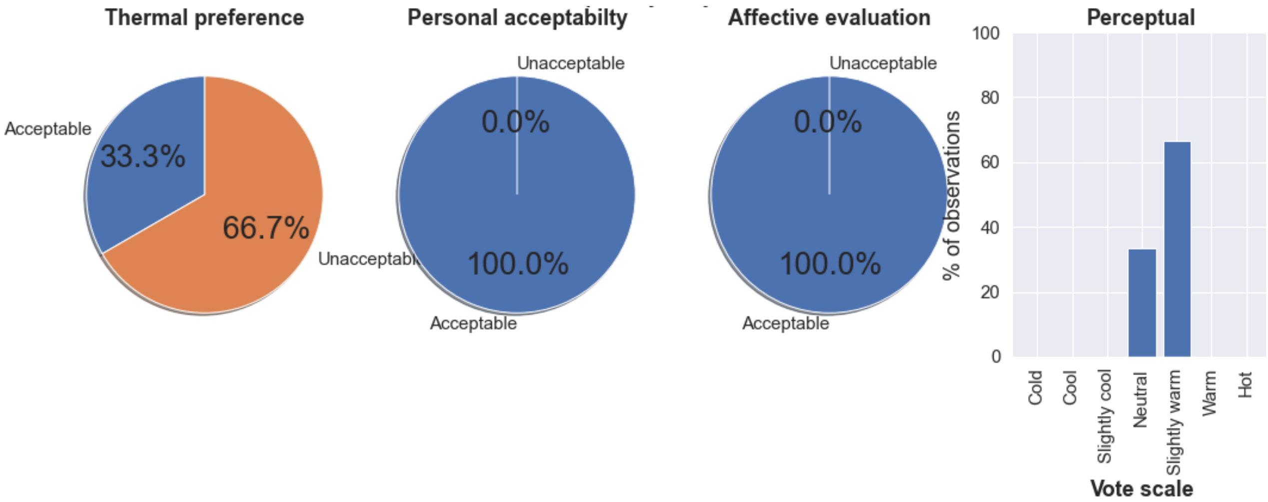
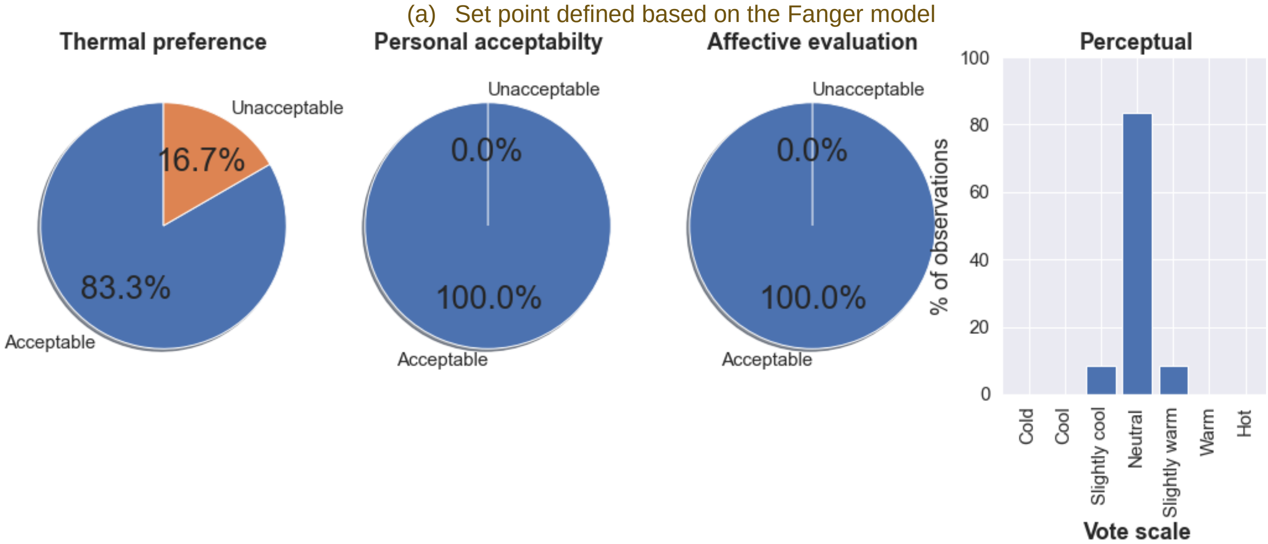


(a) Set point defined based on the Fanger model



(b) Set point defined based on Adaptive thermal comfort model

Figure 11 Thermal acceptability assessment for Scenario 1 applied on Week 38, 2022

Figure 11 shows that the use of temperature set point based on the adaptive thermal comfort model as presented in subfigure (b) can provide an improved or similar thermal comfort assessment will the temperature set points based on the Fanger's model. Specifically, in the case of the Fanger model, it can be shown that in the questions addressing the thermal preference (i.e., preference on lower, higher or on change in temperature) 66.7% of the times the occupants would prefer lower or higher temperature, in comparison to the adaptive model that gives only 16.7%. Moreover, on the perceptual scale for the Fanger model 30% of occupants perceive conditions to be neutral, while this percentage for the adaptive thermal comfort model reaches more that 80%. Therefore, from a thermal comfort perspective, the adaptive thermal comfort can create satisfactory conditions for occupant.

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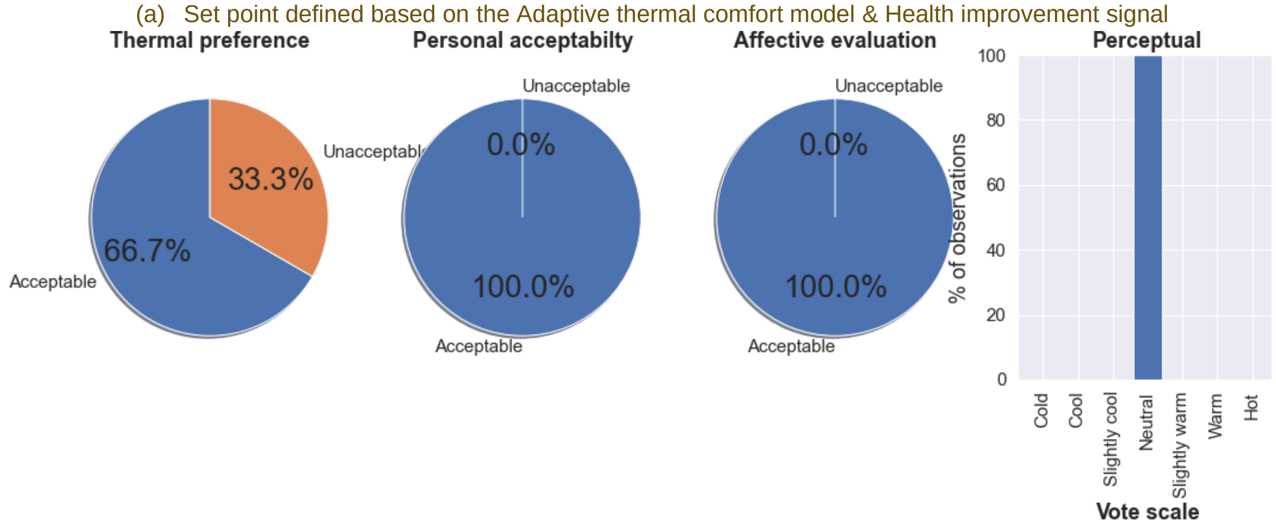
(a) Set point defined based on the Adaptive thermal comfort model & Health improvement signal



(b) Set point defined based only on the Adaptive thermal comfort model

Figure 12 Thermal acceptability assessment for Scenario 2 applied on Week 39, 2022

For Scenario 2, it can be observed that the health improvement modification may reduce the overall thermal comfort performance, but this feature could benefit the health of people by stimulating their metabolic activity in an indoor environment and increasing the blood circulation. For more information, on the design and impact of the health improvement modification is availalble in D2.3 - *Fine-tuned and feasible control strategies that address user comfort, cost & energy efficiency, climate change mitigation & adaptation (first version).*

4.3.2.2 Results in terms of energy consumption

The primitive results from the implementation are gathered to firstly, assess the functionality of the workflow and debugging, and secondly, evaluate the performance of the algorithm. As it is expected from the historic weather data (see 4.2), the generated signal is mostly 0 and barely goes up to 2. Thus, no significant impact from the algorithm is anticipated. Figure 13 presents the major environmental and energy variables from one of the zones over one-week in May. In the figure, the x-axis represents the timeline which is shared in all the sub-graphs. From top: (1) shows the outdoor air temperature (blue) and global solar radiation (orange) on the secondary y-axis, (2) demonstrates

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the thermal energy for heating and cooling system (blue) including hydronic and ventilation systems and, on the secondary y-axis, flexibility signal is presented in integer values from 1 to 5 (red dots), (3) presents the indoor measured air temperature (solid red) and temperature setpoints for heating (dashed red) and cooling (dashed blue), and (4) shows the measured value (solid blue) and setpoint (dashed blue) for CO_2.

Graph 2 shows that, as it is expected, the generated signal over this period is only 1 and 2 since the weather conditions are pretty mild and there is almost no energy use. During the events of the signal 1 and 2 there is manipulation in the temperature setpoints that is presented in Graph 3. Even though, the setpoint modification is limited to 1 °C at each timestep, it can be seen that this happens up to 4 °C. This could be due to an unknown bug in the operation or modification of the setpoint by the occupants. By definition, CO_2 setpoint is involved in the flexibility algorithm when the signal is 3 or more; hence, there is no change in it in this period.

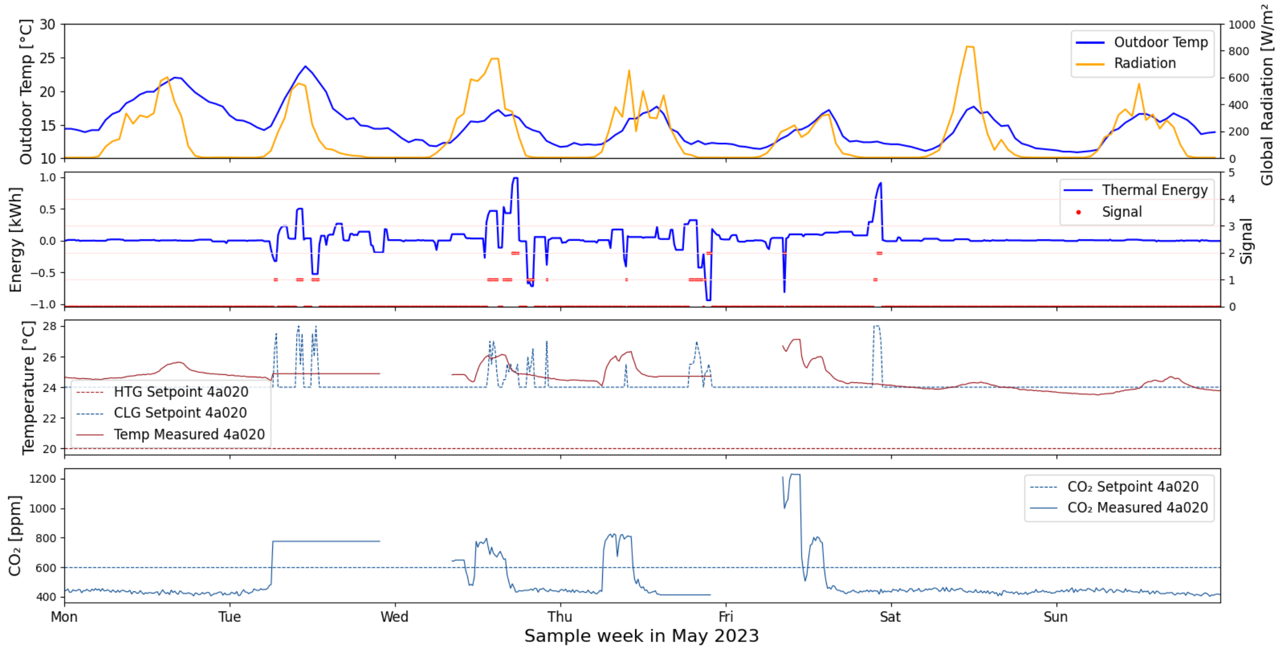

Figure 13: Environmental and energy systems variables in the algorithm over a one week in the test period. From top: (1) Outdoor air temperature (blue) and global solar radiation (orange), (2) Thermal energy for heating and cooling system (blue) and flexibility signal in integer values (red dots), (3) Indoor measured air temperature (solid red) and temperature setpoints for heating (dashed red) and cooling (dashed blue), (4) CO_2 measured (solid blue) and setpoint (dashed blue)

4.3.3 Further progress

It is planned to replace the thermal comfort module in the reward function with more indicators, taking into account more advanced thermal comfort indicators that can provide additional energy flexibility and optimize occupant satisfaction Also, the algorithm will be running until the cooling season to evaluate its performance in summer. Moreover, signal function will generate the signal based on the PV production to maximize the on-site generation. (For more information check the previous study on Eidet Omsorgssenter (Hosseini et al., 2022)).

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5 Conclusion

The deliverable has shown the test of COLLECTiEF algorithms in the small-scale pilot. This evaluation has allowed to test the correct functionality and robustness of the algorithms before implementation in the final COLLECTiEF products and large-scale pilots.

The small-scale pilot comprises of a living-lab, which is a part of G2ELab[5], situated in GreEn-ER[6] building in Grenoble, France. The purpose of this living lab is to bring human in the loop of the technological innovation through user engagement and feedback from the end-user side.

The deliverable is divided into 3 main parts:

- Description of the small-scale pilot
- Description of the implementation of the intermediate server and data exchange between the algorithms and the pilot energy management system (BEMS)
- Test of the algorithms and their evaluation on correct functionality

The testing period was divided in two key parts: Implementation of the intermediate server functionalities necessary to exchange date between the algorithms and the BEMS in the pilot as well as the test and debugging of the whole algorithm in a real environment (different to a simulated environment).

Some tests are still ongoing for additional functionalities, but this work has allowed to ensure the correct operation in a real-world building, before deploying the products in the large-scale pilots with a higher risk of user non-satisfaction in case of failure.

[5] Laboratoire de Génie Électrique de Grenoble (Grenoble Electrical Engineering Lab, France)

[6] Grenoble énergie - enseignement et recherche (Teaching and Research on energy in Grenoble, France)

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