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Table of Contents

Table of Figures

Table of Tables

1 Executive Summary

The objective of this report is to present the establishment, monitoring, and results of the Swiss demonstrators. The first seven sections are devoted to the four individual case studies of Geneva, their description, monitoring installation, and results, both from monitoring and dynamic modelling.

The four buildings represent the possible situation of multifamily buildings in the Canton: Recently built (2012), recently refurbished (2011), from the past century with no refurbishment project, and from the past century with refurbishment project. Then, the different monitoring solutions chosen for each building are described. The aim was to monitor both energy efficiency and indoor conditions. Some already existing tools were used, like Egain probes. For the two old buildings, gateways with a number of ambient sensors were deployed to monitor the indoor conditions of the apartments in the buildings. From the monitoring data, the buildings' operations are evaluated for energy efficiency and indoor climate conditions. These observations will orientate our analysis for the following months

The modelling of the building is then described with the results from energy demand simulation for both standard and adapted conditions of the building usage. The results are compared to the operative conditions as well as the EPC. Conclusions are drawn concerning the simplification of the model because of simulation time and model complexity.

The second part of the report is devoted to upscaling the E-DYCE policies at the scale of the Canton of Geneva. Starting from monitoring the annual heat consumption of the building, the study aims to decrease the time response of political changes. Different examples and ideas for political actions are enumerated and will be tested.

2 Description of Geneva's case studies

In Geneva, four demo case multifamily buildings were processed using the E-DYCE procedure. They include one recently refurbished according to the Nearly Zero-Energy Buildings (NZEB) standards and a newly constructed NZEB that presents an energy performance gap. The reasons for the performance gap for these two buildings were investigated, which can provide input for measures that can reduce it. The other two buildings consist of a low-energy class building without a planned renovation and an old, not renovated building with a planned renovation. The E-DYCE methodology was applied in these buildings to investigate possible optimizations and define robust renovation roadmaps.

Additionally, Office cantonal de l'énergie (OCEN) analyzed the past and current monitored data to understand better the impact of public energy strategies on sustainability goals. Past public actions were analyzed using measured energy consumption data. Geneva GIS system already provides yearly energy consumption data, and E-DYCE explores added value of analyzing public policies with dynamic energy consumption and simulation. This contributed to the upscaling to the territory level and gave input to implementing dynamic energy labelling.

The following sub-chapters present each demo case in Geneva and its objectives.

2.1 Individual buildings (CS#1-4) description and main object details

The four demo case buildings of the same typology are processed according to the standard E-DYCE procedure. The reasons for the energy performance gap will be analyzed in the two recently refurbished or constructed NZEB buildings, and optimization roadmaps will be developed and implemented. Measurement and monitoring allow quantification of their impact and ability to reach the NZEB performance. A deeper analysis was performed on the old existing buildings. The two cases, with or without refurbishment, allowed for a wide range of options to be explored, ranging from small optimization to a complete renovation roadmap.

2.1.1 Building B1.1 - NZEB deep refurbishment

This building was refurbished in 2011, presenting a very high energy performance gap after commissioning (200%). After several years of optimization, it significantly reduced its energy consumption, but it still consumes 30% more energy than expected. The evolution of the building energy consumption since 1994 is shown in Figure 1, compared to all the canton building stock evolution, using the cantonal GIS energy consumption database. Refurbishment happened in 2011, and optimization took place from 2012 to 2016. The possible technical optimization actions have been almost all tested.

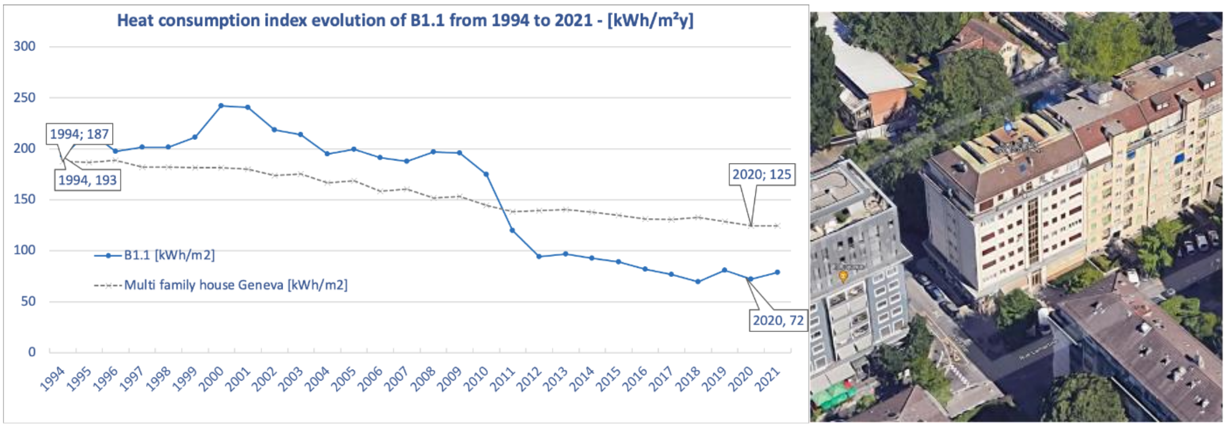


Figure 1: Annual final heat consumption evolution of B1.1

The building's heated floor surface is 2481 m^2. The envelope consists of brick walls with added external insulation in 2011. The technical system is as follows:

An oil heater ensures the building's hot water production for space heating and part of the domestic hot water (DHW). There are thermal solar panels on the roof producing DHW as well. Priority is given to solar panels, and the oil heater is used to cover the DHW demand when solar energy is insufficient.

The inspection protocol was filled for this building and is available here.

2.1.2 Building B1.2 - New building NZEP

Building B1.2 is a new NZEB building recently commissioned but not optimized, and its energy consumption does not meet the high energy performance building expectations. Since its commissioning, there have been efforts to reduce the building's energy consumption to meet the anticipated value. A few installation errors were found in the technical systems that could explain part of it. Since 2018, an optimization system has been installed on the heater, which seems to improve the overall energy consumption, as presented in Figure 2.

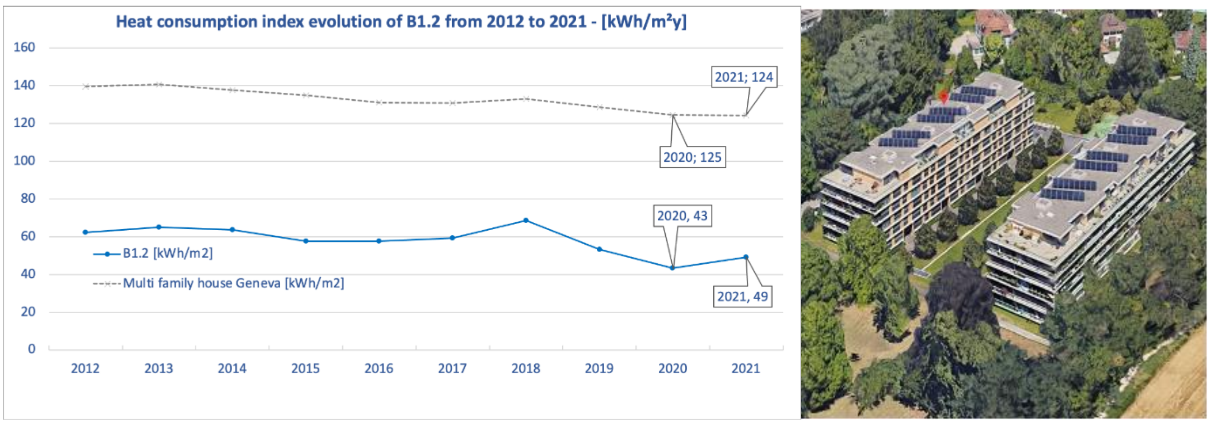


Figure 2: Annual final heat consumption evolution of B1.2

The heated floor surface of the building is 6424 m^2. The heat source for heating is a gas heater, which also produces part of the DHW. There are thermal solar panels on the roof of the building, producing part of the DHW. The priority for DHW production is given to solar panels, and the gas heater is used when the solar system does not meet needs.

We observe that the heat consumption index is way lower than the cantonal average as it is an NZEB. However, this exceeds the initial objective of 40 kWh/m^2·y, including ventilation electricity.

For this building, the inspection sheet could not be filled before the deliverable due date .

2.1.3 Building B 1.3 - Low energy class building

Building B1.3 is a large building from the 1980s with high energy consumption, which will not be renovated during the next 15 years. This building provides a good opportunity to evaluate low-performing buildings and assess simple behavioural changes and their impacts on energy consumption.

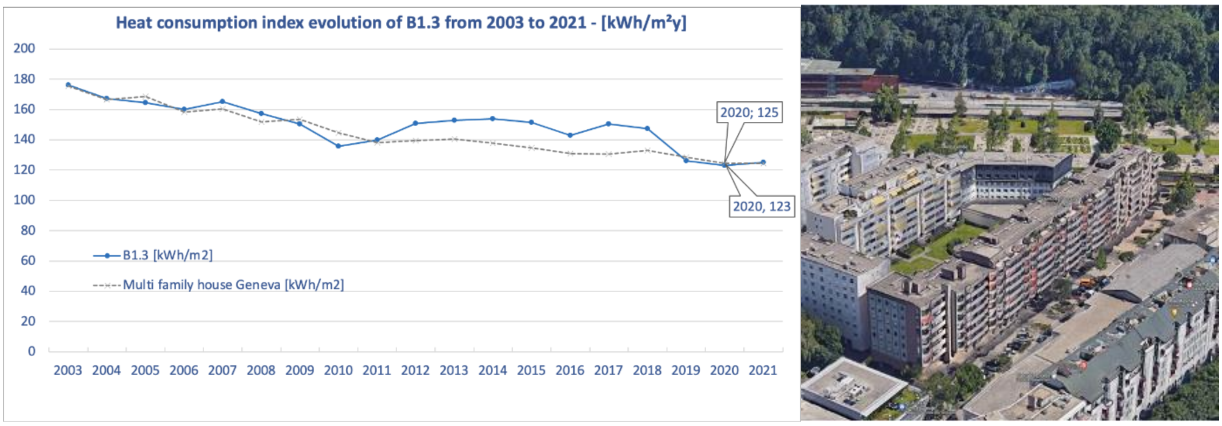


Figure 3: Annual final heat consumption evolution of B1.3

As presented in Figure 3, with data collected from 2003, the heat consumption evolution of this building approximates Canton's average.

The envelope of the building only has a small insulation layer of 2-4cm on the walls and roof. The heat producer is a gas heater for both heating and DHW production. The total heated floor surface of the building is 9788 m^2. The building has six different entrances independent of each other, apart from the fact that they all share the same heating system.

The building ventilation system was initially a simple mechanical extraction with two-speed control and a night stop for some parts of the building. Each building entrance had an independent ventilation system with a nominal power of 1.1 kW. Those ventilation systems were replaced in April 2022 by humidity-sensitive ventilation systems. In this system, the air inlet and exhausts' opening position depends on the room's humidity, allowing the airflow to be adapted to the room's needs. Examples of inlet and exhaust valves are shown in Figure 4.

Figure 4: Humidity-sensitive inlet and exhaust valves installed in B1.3

The extraction ventilator was also changed to match the new airflows in the building.

The inspection protocol of the building can be found here.

2.1.4 Building B 1.4 – Old and not renovated building

Building B1.4 is a typical building of the 1960s, which is not insulated and has a significant energy demand for heating. There is a refurbishment project ongoing on this building. It was initially selected for this reason as it would have been interesting to follow the indoor air quality (IAQ) during the refurbishment work. However, local legislation and constraints delayed the project to 2025, which means that a renovation roadmap can be proposed before the refurbishment work. However, it will not be possible to evaluate if there is a performance gap after the refurbishment before the end of the project.

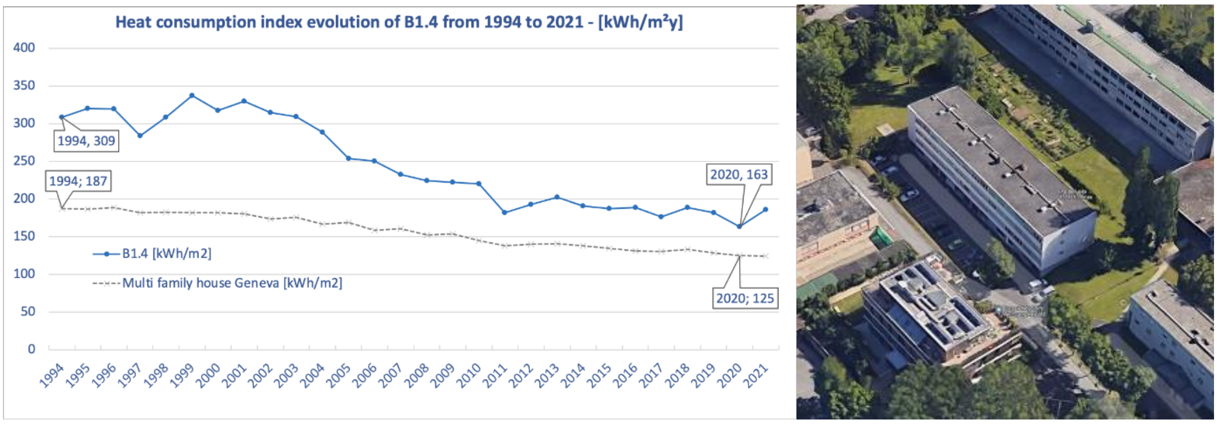


Figure 5: Annual final heat consumption evolution of B1.4

We can see in Figure 5 that the building's heat consumption is well above the mean of multifamily house buildings. This is typical for such old buildings that have not been refurbished yet, which means that the building has a lot of potential for energy savings.

The heated floor surface of the building is 1984 m^2. The heating system uses an oil heater for both space heating and DHW.

The inspection protocol of the building can be found here.

The building owner plans to refurbish this building in the coming years. A project was initiated in early 2021 in that sense. It is supposed to be a deep refurbishment with the renovation of the whole envelope, a change of HVAC system, and even maybe an addition of an attic. However, local political complications delayed the refurbishment project for 2025. In the meantime, this should allow a better analysis of the foreseen refurbishment actions, as there will be additional inputs from the other case studies. For example, the ventilation system installed in B1.3 , which is supposed to reduce energy consumption, will also be installed in this building. Results will be available before the finalization of the renovation roadmap of B1.4, allowing to modify of this aspect according to the study's results.

The list of refurbishment actions includes:

- Insulation of the envelope so that the U-value of all opaque elements is lower than 0.2 $W/m^2 \cdot K$
- Replacement of all windows with triple glazing windows equipped with humidity-sensitive air inlet valves on their frame
- Connection to the low-carbon district heating for both space heating and DHW
- Energy monitoring of the building before, during, and after refurbishment
- Humidity-sensitive extraction ventilation
- Photovoltaic panels.

2.2 Case Study CS#5 – The Canton of Geneva:

The cantonal energy policy measures aim to promote an adequate, secure, economic, diversified, and environmentally friendly supply of energy to reduce Canton's dependence on fossil and non-renewable energy sources. To achieve this, the Canton of Geneva focuses on energy-saving measures and developing renewable energies. It also promotes the development of efficient energy transformation and distribution systems, in particular by creating heat and cold networks that reduce pollution from fossil heat production facilities by integrating renewable sources (biomass, geothermal, lake heat, etc.).

In the context of the climatic emergency, the cantonal government recently presented its cantonal energy master plan adopted in 2020. The objectives are high: to reduce greenhouse gas emissions compared to 1990 by 60% by 2030 and to achieve carbon neutrality by 2050, reducing by 3.5 times the primary energy consumption per person.

The Canton of Geneva has a unique tool in Switzerland for monitoring the energy consumption of a significant part of its building stock. Since 1994, building owners have been obliged to measure and declare their heat consumption to the cantonal authorities. This instrument makes it possible to identify, for example, the evolution of average and median canton E_{HW} (specific heat consumption for heating and hot water production). The Swiss EPC framework is a more recent instrument, and it has been adopted by the Canton of Geneva only recently.

The annual E_{HW} value is available on the well-documented and rich cantonal GIS public system, an interface of which is presented in Figure 6. Furthermore, GIS services include an extensive range of other information, not only dimensional, like the façade, roof, footprint surface areas of the building, but also energy data, like the boiler size and date of installation, the photovoltaic potential, and thermographic views of roofs, etc. In the framework of the E-DYCE project, two categories of public GIS information are found interesting and relevant:

- Dimensional information, like façade, roof, and heated surface areas
- The building's heat consumption evolution since 2000.

OCEN uses annual heat consumption of buildings or boiler age and size to understand Canton's current energy use by its building stock or to tailor energy policy measures. The energy authorities use this information to set requirements for building owners whose buildings consume too much energy. For instance, buildings of E_{HW}>800 MJ/m²y must undertake urgent measures, and buildings of E_{HW}>600 MJ/m²y must install individual energy metering per apartment or reduce their energy consumption. OCEN would like to exploit this database further and evaluate E-DYCE results and methods for upscaling.

Building owners and managers take action according to their real energy performance and this indicator, as it is compulsory to calculate, becomes a real lever in investment decisions.

Figure 6: Geneva canton 3D cadastre gives surface areas of facades, roofs, or heated reference areas.

The OCEN objectives are:

- Quantify the EPC reliability problems and make EPC labelling more reliable.
- Make predictions of energy-saving measures more reliable.
- Consider low-cost soft optimization measures based on operating conditions modifications in the EPC framework.
- Base energy efficiency policy on actual energy consumption, not theoretical calculations and assumptions.
- Test the real efficiency of public policy actions (evident-based policy)

The E-DYCE case study is working with two building samples: a small sample with four buildings, where the main methodologies and E-DYCE tools are going to be demonstrated in detail, and a large sample of

20 buildings, where policies can be evaluated. The small sample was selected to have the main refurbishment and optimization contexts. The large sample was selected to represent Canton's entire building stock, as demonstrated in Figure 7.

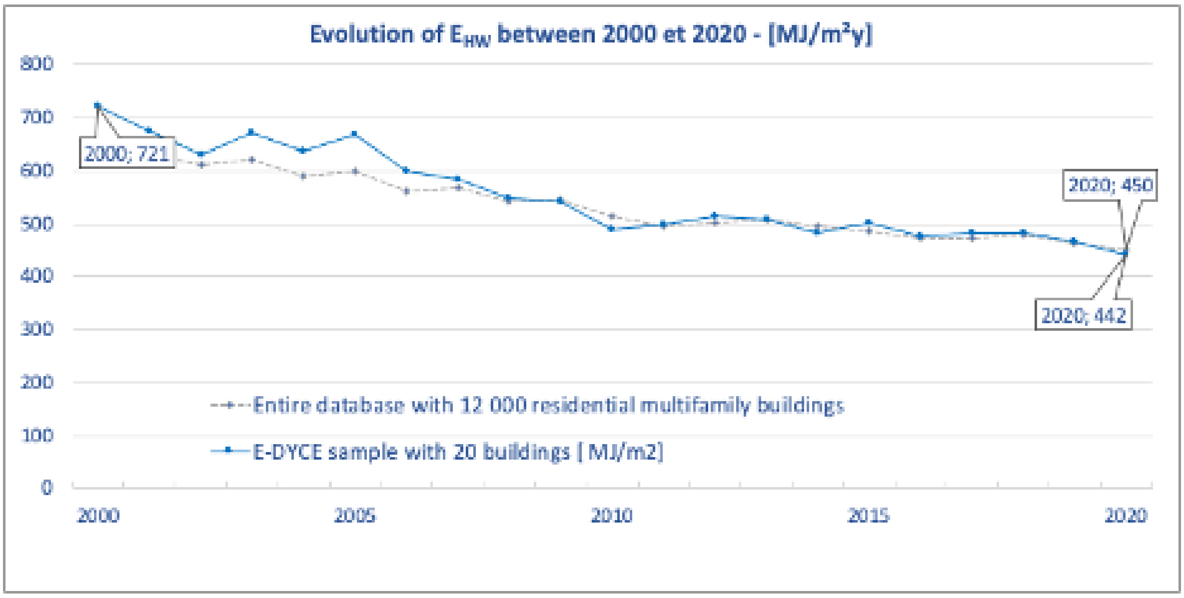


Figure 7: Evolution of the EHW of the E-DYCE sample and the entire Geneva building stock of residential buildings since 2000.

The deeper analysis of the small sample demos are:

- The use of the Dynamic EPC (D-EPC) to understand, anticipate and correct the energy performance gap
- Verify the D-EPC potential for calculating the energy savings of low-cost measures targeting better dynamic operation of the building

In Geneva, it was selected to perform a deep analysis of selected individual buildings and an upscaling to the city scale to verify the feasibility of a political axis centered around actual building performance rather than theoretical certificates.

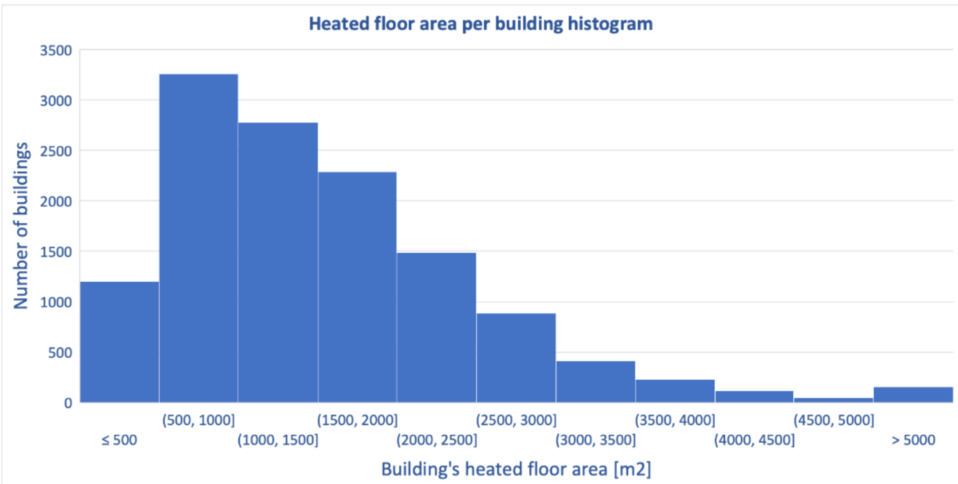


Figure 8: Heated floor surface area per building in Geneva's GIS database

The four individual buildings are typical apartment buildings, which typology represents ~60% of the heated area of the Canton, as observed in Figure 8. The selected cases serve the following main objectives:

- The optimization operation of recently renovated/constructed NZEB buildings presenting a significant energy performance gap,
- The optimization of a building that will not be renovated in the next 20 years but situated in energy class E
- analysis of a typical building of the 60s that should and will be refurbished.

The selected buildings represent a nice sample that will address the above-mentioned objectives and help the energy transition.

Reasons for implementation and E-DYCE activities

The objective of the Geneva case studies is to implement E-DYCE in different individual buildings that have a wealth of background information available. This approach will allow the Consortium to identify patterns related to user behaviour and the performance of buildings of various energy efficiency and smartness levels, such as achieving better dynamic control of the heating system efficiency. The existence of the Geneva cadastre and the accumulated building consumption information will facilitate the refinement of the dynamic simulations and will produce valuable results. Additionally, these demonstration approaches will be conducted to facilitate the scale-up for the region-level implementation as described in CS#5.

3 Monitoring plan

The monitoring of the case studies is the spearhead of the energy efficiency assessment. Without knowing the energy consumption of one building, there is no way to evaluate its performance and identify an energy performance gap. In Switzerland, there is no national obligation to follow a building's consumption. However, as described earlier, the Canton of Geneva has an energy policy that forces the building owners to declare their heating energy consumption each year and developed a GIS database where E_{HW} can be found for part of the building stock.

This yearly data is already an improvement from no monitoring but does not allow a deep understanding of the building's dynamic. However, installing energy counters in all four buildings was not feasible because of the cost and time limitations. In two of them (B1.1 and B1.4), undirect energy counters were already present, so we managed to gain access to this data. For B1.3, we bought and asked for a heat counter installation. Finally, for B1.2, the monthly gas consumption is used.

Concerning the indoor environment, temperature and humidity are monitored in the four buildings. Already existing solutions are here again mainly used. We still needed to evaluate the CO2 levels in some buildings and therefore decided to buy two nomad measurement kits.

3.1 *Monitoring Plan requirements and sensor technologies used in the demonstration*

The different levels of requirements for monitoring the four buildings allowed us to test different monitoring solutions for each building.

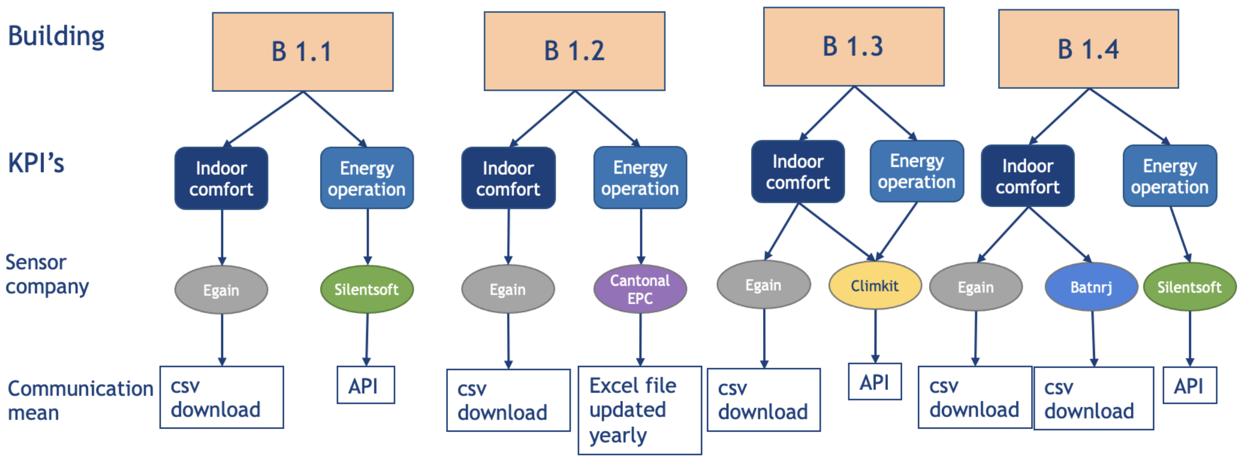


Figure 9: Monitoring quantities and systems for the case studies

The monitored quantities in the different buildings include:

- Thermal Comfort:
  - Air temperature [°C]
  - Relative humidity [%]
- Indoor Air Quality (IAQ)
  - Relative humidity [%]
  - CO2 concentration [ppm]

- Energy Operation:
    - Oil consumption [liters]
    - Gas consumption [kWh]
    - Annual heat consumption [kWh]

The different monitoring solutions visible in Figure 9 are described below:

- Egain is a heating optimization software. It measures the indoor and outdoor temperature and modifies the instructions to the heating system to stay in a defined indoor temperature range[1]. Probes are usually installed in the center of the apartments in a sufficient number of apartments to represent the building well. The probes equally measure the air's relative humidity. Sometimes, Egain contracts also include water temperature in and out of the heating system.

- Batnrj is a platform developed by Pyres Company that allows users to install a Lora Gateway in a building and connect probes to this Gateway. The probes connected to the Gateway are from the same company and allow measuring air temperature, relative humidity, and CO2 concentration. The gateway allows connecting a large number of probes (up to 50) and communicates the data to the platform through 3G communication.

- Climkit is another data visualization platform for building monitoring. It is a Swiss company that allows the connection of different monitoring solutions to the platform and gives a general idea of the building's behaviour. It mostly measures the two following parameters:

    - Indoor comfort: A gateway with LoRa connection to probes from ELSYS allows for monitoring the indoor climate of a building. The gateway communicates through 3G to the platform.

    - Energy operation: Counters installed on the hot water pipes and communicating directly to the platform through 3G allow heat consumption monitoring. In addition, electricity counters can be installed and connected to the platform to account for this aspect.

- Silentsoft is an oil consumption measurement company that installs a pressure sensor inside the oil tank and detects the oil consumption from the pressure measurement. It allows estimation of the oil consumption with an affordable sensor installation for systems already installed without any counting system. Extraction of the data shows that it is highly dependent on the outdoor pressure probe; therefore, the minimum time interval to obtain plausible data is one week (168 hours). Under this time interval, negative energy consumption would occur, showing the bias of the measurement principle.

- Cantonal EPC: In Geneva, there is an obligation to transmit the cantonal energy service heat consumption of buildings. The data are available on the SITG website and can be followed yearly. The heat consumption index has to be entered by an energy professional and is computed over a

[1] https://www.egain.io/

time period of 11 to 13 months. The energy consumption is also standardized with a system of heating days and heating degrees that allow for comparison with a year of reference.

3.2 Building-specific monitoring plan and sensor installation

3.2.1 Building B1.1

The monitoring of B1.1 consists in following the indoor environment with Egain probes (22) and the heat consumption with a Silentsoft probe. This allows following the general consumption for heating and DHW. We are, however, missing the DHW production energy of the thermal solar panels on the roof of the building. This will lead to a lack of information and analysis material.

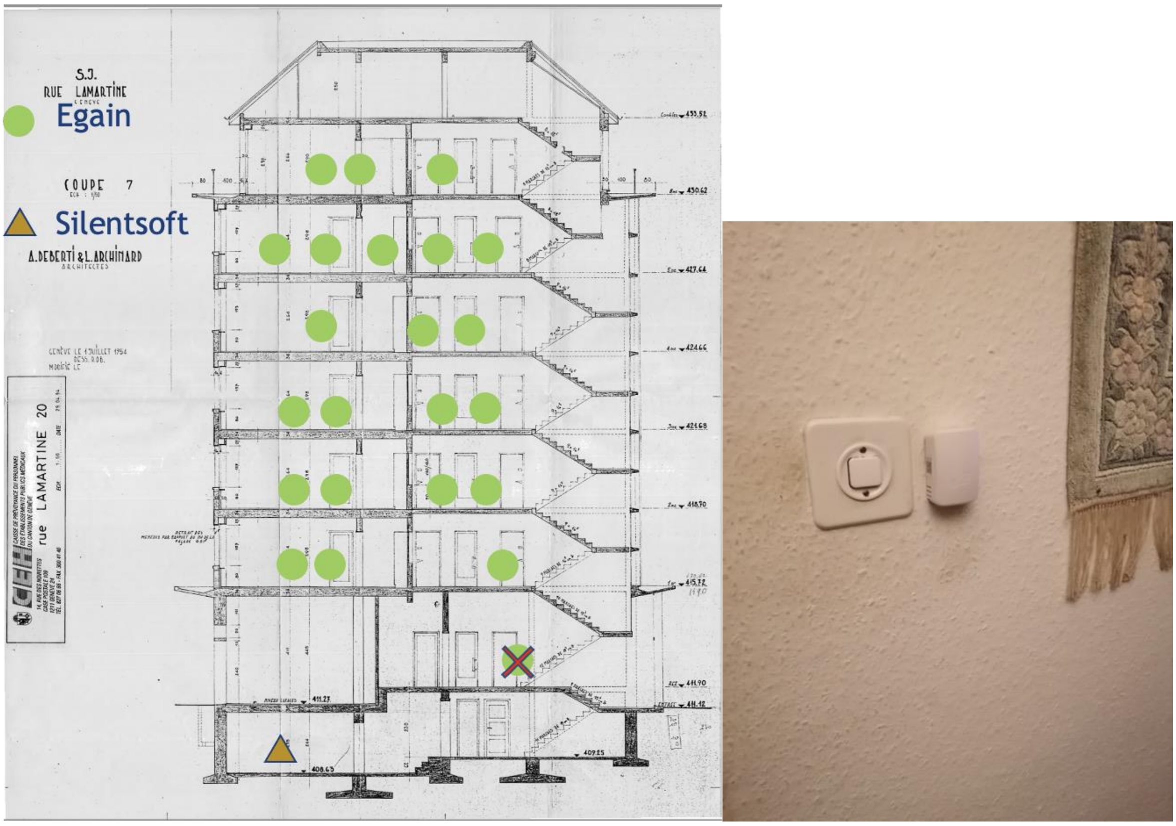


Figure 10: B1.1 (a) Egain probes position in the building and (b) view of a single Egain sensor installed in an apartment

In Figure 10, we observe that the repartition of the probe is sufficient to represent the building's behaviour and allow for adaptation of the dynamic model. Thus, there was no need to add monitoring material to the existing elements.

3.2.2 The detailed monitoring plan of B1.1 can be found in this link. Building B1.2 - New building NZEB

The already existing Egain probes were used to monitor the thermal comfort conditions in B1.2. As the probes also measure relative humidity, they can be used for general analysis of indoor air quality. As presented in Figure 11, almost all apartments were monitored for hygrothermal conditions, so no additional sensors were added.

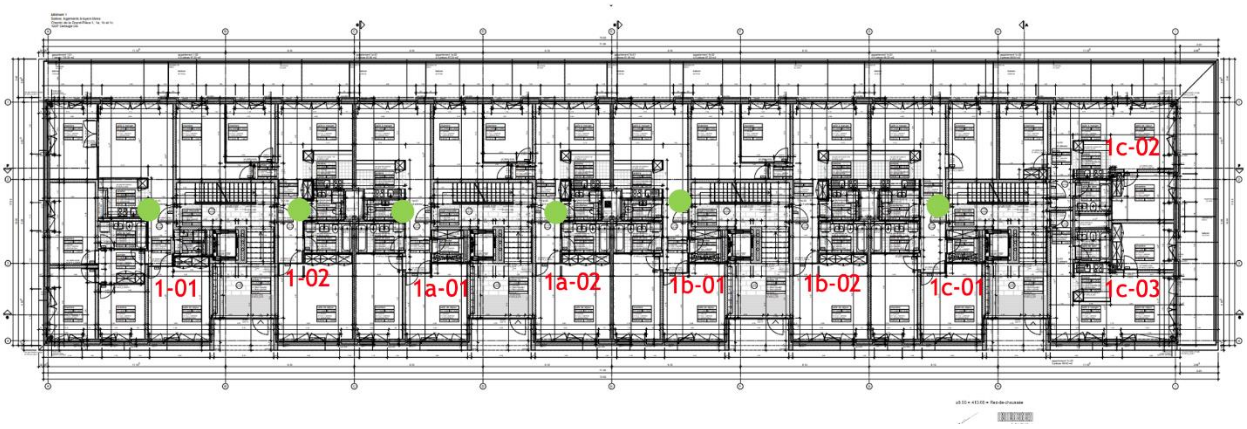


Figure 11: B1.2: Position of Egain probes on a typical floor

Concerning energy consumption, the building owner shared the gas invoices to allow for monthly consumption analysis. The gas heater produces heat for heating and for part of the DHW production. There are also solar thermal panels on the roof producing DHW. Unfortunately, the solar panel production data has not been shared by the company responsible for the overall HVAC system of the building.

The detailed monitoring plan of B1.2 can be found in this link.

3.2.3 Building B1.3 - Low energy class building

This building was the only one that had no monitoring before the beginning of the project. So, to monitor the energy consumption, two heat counters were ordered, one for the total heat production from the heater and one for the DHW production. The delivery of the counter got importantly delayed by the shortage of electrical components. Additionally, the position of the heater (in the second basement of the building) did not allow an adequate internet connection, which delayed the commissioning of the two counters again. Initially ordered in May 2021, the counters' commissioning date was the 6th of May 2022. A view of the installed heat counter is presented in Figure 12.

Figure 12: B1.3: Installed heat counter

Concerning the thermal comfort and indoor air quality, we opted for a nomad monitoring system that could allow us to monitor different places in the building. The selected option is a Climkit sensor Box that communicates with the different Elsys sensors through a LORA antenna, as presented in Table 1. This limits the communication range and, therefore, the possibility of positioning the different sensors.

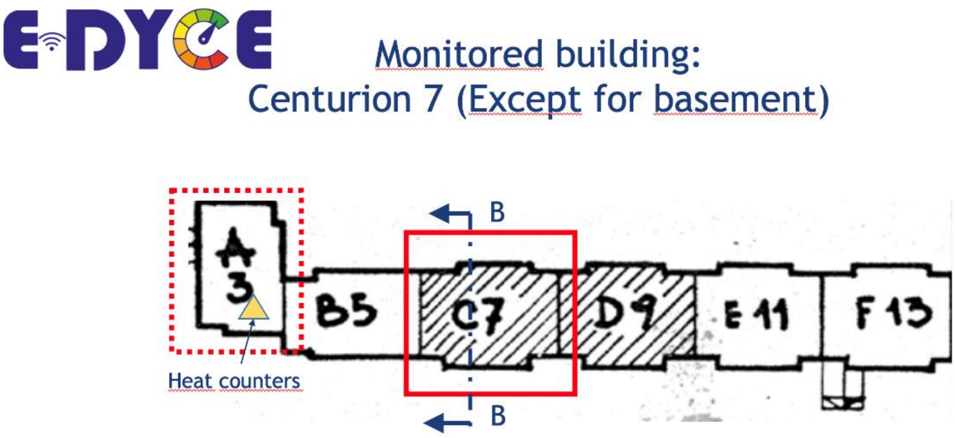
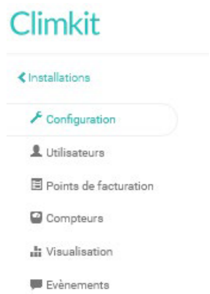


Figure 13: B1.3: Monitored part of the building

The size of the building and the range of the LORA antenna did not allow comprehensive monitoring of many apartments. Thus, we had to focus on the most representative part of the building and settled for the building with entrance number 7, as presented in Figure 13.

Table 1: Monitoring transmission concept

Measure	Transmission	Local data collection	Transmission	Data storage
Elsys (ERS CO-2, ELT-2, ERS VOC)	Radio frequency	By the 'suitcase'	"GSM"	On Climkit server (accessible through API)
	868 MHz		GSM	

There were uncertainties about the range of communication between the different floors. However, when placing the different probes and leaving the gateway on the 3rd floor, we realized that only one sensor (number 8) was not able to communicate, probably due to some default.

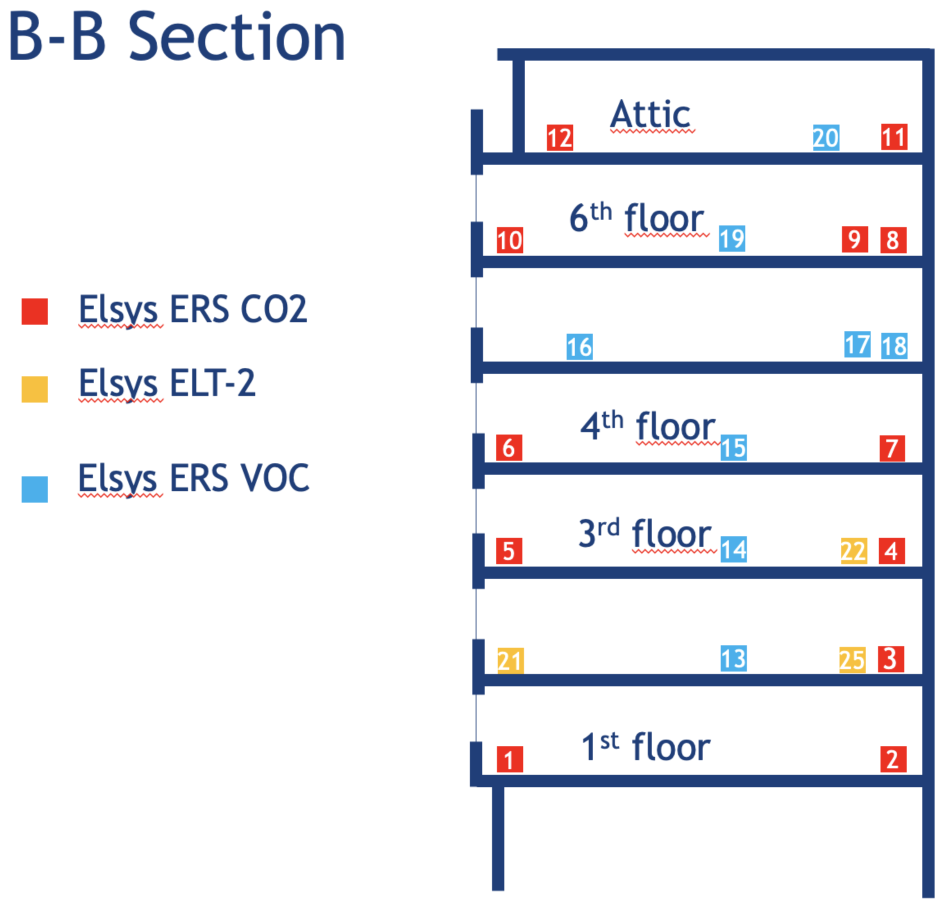


Figure 14: B1.3: Position of the probes in building entrance 7

As presented in Figure 14, various types of sensors were placed to comprehensively analyze the thermal comfort and indoor air quality, mainly in the master bedrooms.

The detailed monitoring plan of B1.3 can be found in this link.

3.2.4 Building B1.4 – Old and not renovated building

The B1.4 was already monitored by the Egain system, allowing a comprehensive thermal comfort analysis. Additionally, a similar system as in B1.1 was already installed for the oil consumption (Silentsoft), meaning that the oil consumption is monitored as well. As there was a plan for the refurbishment of the building during the project time, a decision was taken to install an indoor air quality sensor. This allowed us to analyze the impact on the air quality of refurbishment works and compare the IAQ before and after refurbishment.

Similarly to B1.3, a monitoring solution with a movable gateway was chosen. Although the system is not the same as for B1.3 (BatnrJ and not Climkit), the principle of a gateway communicating to different sensors through LORA is the same. Here again, the range of the LORA antenna did not allow for a clean IAQ monitoring of the whole building. The decision was taken to monitor half of the building, as presented in Figure 15, for IAQ so that probes could communicate with the central gateway.

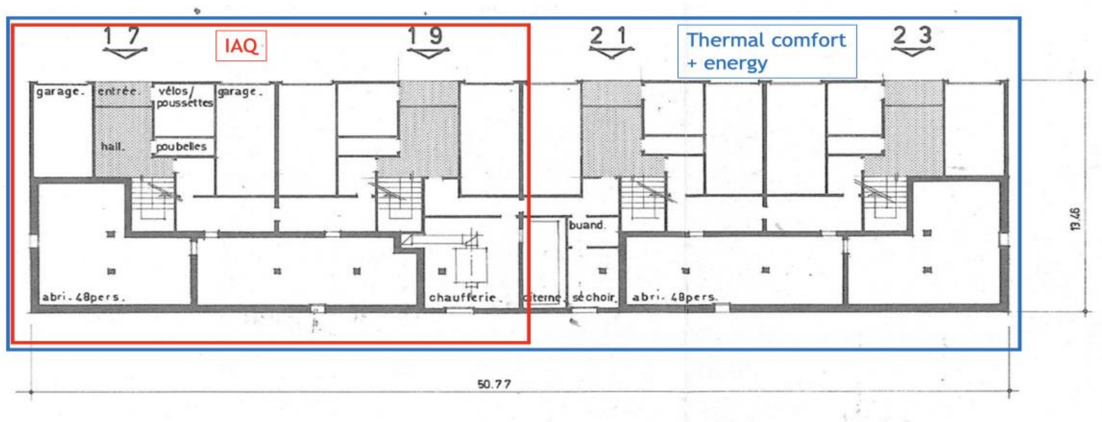


Figure 15: B1.4: Monitored building part

The installed probes allowed monitoring of the CO2 concentration levels at room level. We focused on the master bedrooms as it is the most used spaces in the different flats. The objective was to evaluate if there is a general behaviour and replicability between the different apartment typologies.

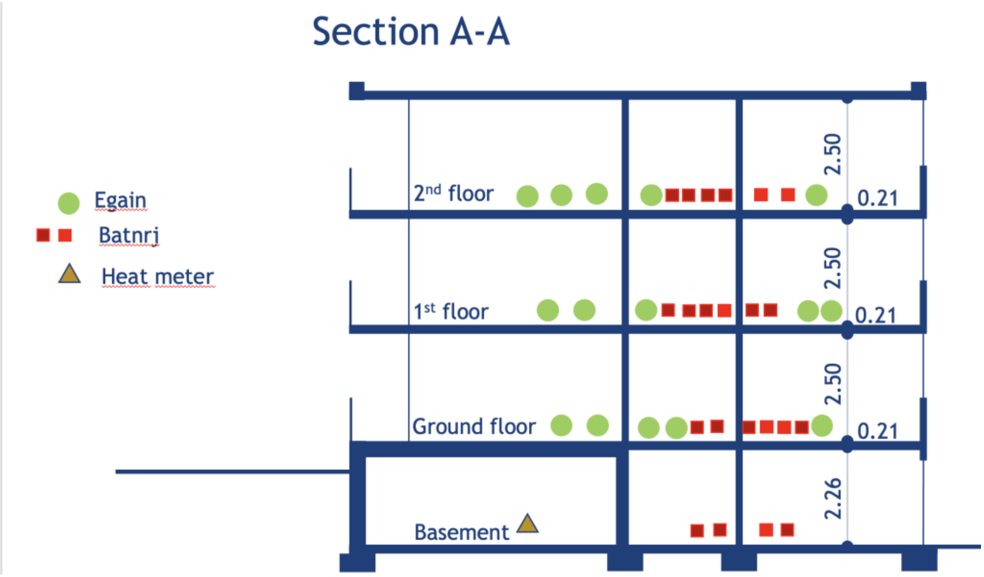


Figure 16: B1.4: repartition of the probes in the building

As presented in Figure 16, two probes were installed in the monitored apartments, one in the master bedroom and one in the living room. This allowed the identification of local discrepancies between the rooms.

Figure 17: B1.4: Batnrj sensor example

As presented in Figure 17, the sensors have a small screen on which the end user can read the measured values. Despite interacting with the tenants during the installation, very few of them showed any interest in understanding the navigation between the different readings.

Concerning the energy efficiency monitoring, a Silentsoft sensor (similar to B1.1) was already installed on site. This allowed monitoring of the oil consumption for heating and DHW production. No additional energy counters were installed. However, after refurbishment, we ensured that a heat counter will be installed in the new heat production plant. However, this refurbishment will not happen during the project; therefore, the Silensoft monitoring will be the only one available for the project period.

The detailed monitoring plan of B1.4 can be found in this link.

3.3 Meteorological data

As installing a robust meteorological station in each building was not economically feasible, it was decided to retrieve weather data from other sources. The official MeteoSuisse [1] station of Genève Cointrin was selected to retrieve the data, as it was close to all case studies. Additionally, supplementary weather data were downloaded from the available online source of NASA POWER [2].

4 Evaluation of the monitored conditions – DEPC-O

4.1 Energy and comparison with the static EPC

In this chapter is presented an evaluation of the performance gap of each building compared to the EPC. This comparison is effectuated between the yearly DEPC-operative consumption and the EPC final energy consumption for heating and DHW (E_{HW}). Additionally, an energy signature showing the daily mean energy consumption against outdoor mean temperature was utilized to better evaluate the reasons for the performance gap. Finally, data from the DEPC operative consumption were used to identify the operative free-running period of each building.

4.1.1 Building B1.1 - NZEB deep refurbishment

As the oil consumption can be read from the Silentsoft sensor, it can be compared to the expected consumption of the EPC. However, we are missing crucial information here, as no data is available for the DHW production from the solar panels.

Despite some parts of DHW production not being taken into consideration, the building consumed more energy than expected by the EPC, as it is shown in Figure 18. The performance gap is, therefore, already visible without adding the DHW production from the solar panels, outlining its importance.

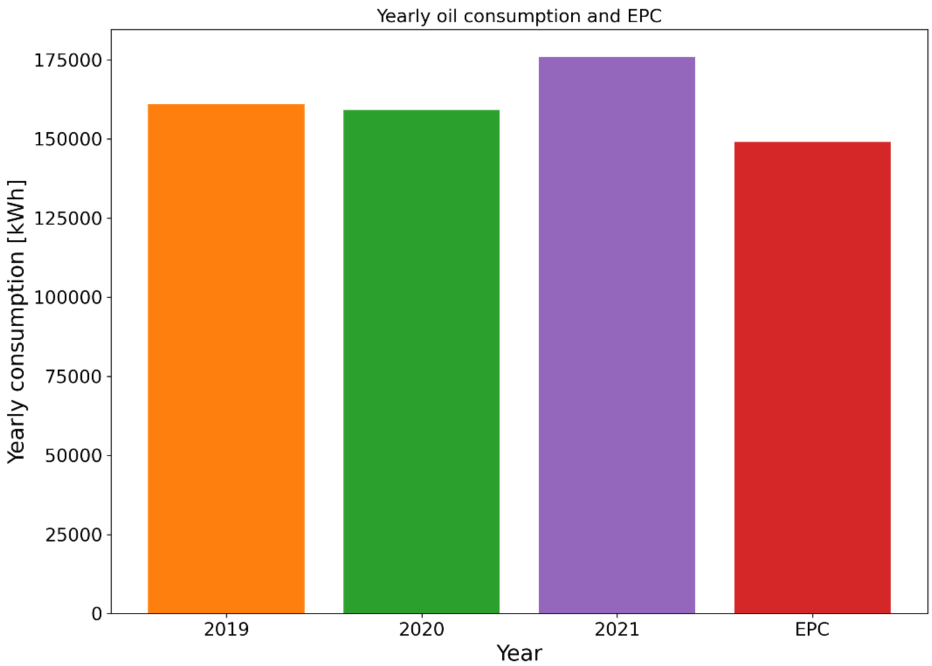


Figure 18: B1.1: Final energy consumption for space heating and DHW from the oil-boiler, compared to EPC final energy estimation

Two interesting results can be identified by observing the energy signature from the oil consumption, presented in Figure 19. First, some DHW production energy from the solar panels is, in fact, missing. The constant part for all three years of data is below the standard value given by the EPC. In most cases (see B1.4, for example), DHW production energy exceeds the standard value. This outlines the lack of information coming from the absence of DHW production from the solar panels.

The second result is visible on the left part of the energy signature, outlining the higher energy need for low external temperature than expected from the EPC. The slope appears to be of the same order, and the difference can therefore be attributed to higher DHW production needs in the cold season when the solar panels are less efficient. However, this does not explain everything. Further analysis should be performed with DHW data.

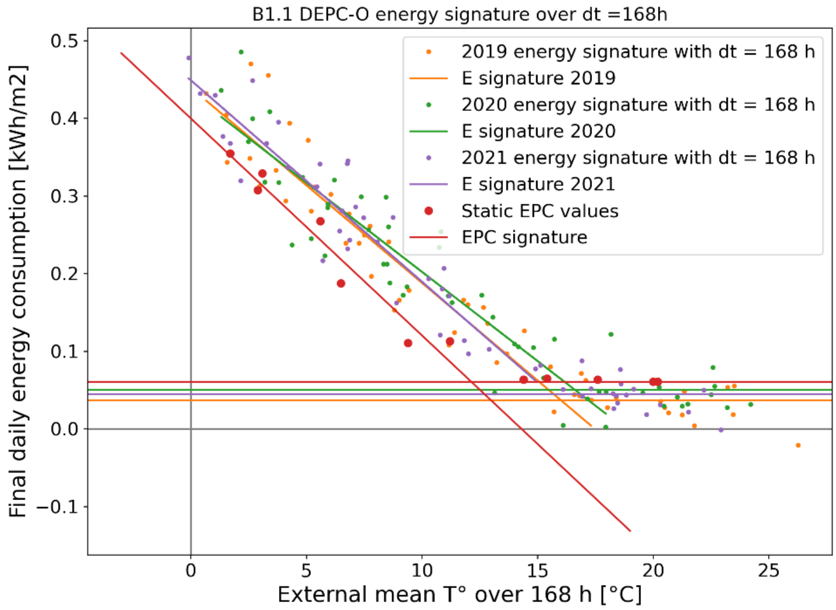


Figure 19: B1.1: Energy signature for final energy consumption of the oil-boiler over 168h time interval. The y axis was normalized to daily consumption/m2 of floor heated surface area of the building

Figure 20 presents the evolution of oil consumption over the weeks of the year. It can be observed the free-running period of the building is between weeks 20 and 37 of the year.

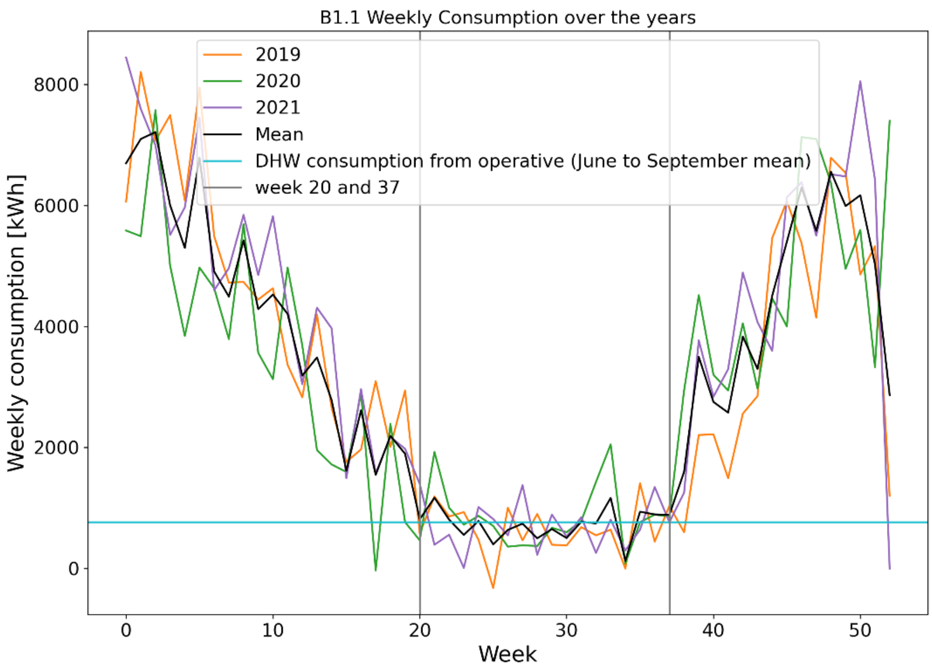


Figure 20: B1.1: Weekly final energy consumption for the oil boiler over the years

In conclusion, the performance gap of the building is visible despite the missing information about DHW production from the solar panels. The next steps will be to gather information about DHW production from the solar panels and include it in the global energy analysis.

4.1.2 Building B1.2 - New building NZEB

Building B1.2 showed a substantial performance gap from its commissioning in 2012-2013. However, since 2019, its energy consumption has been reduced, as observed in Figure 21. The energy consumption data are coming from the monthly gas delivery invoices. The SIG (gas deliverer for Geneva city) already translates the gas in kWh.

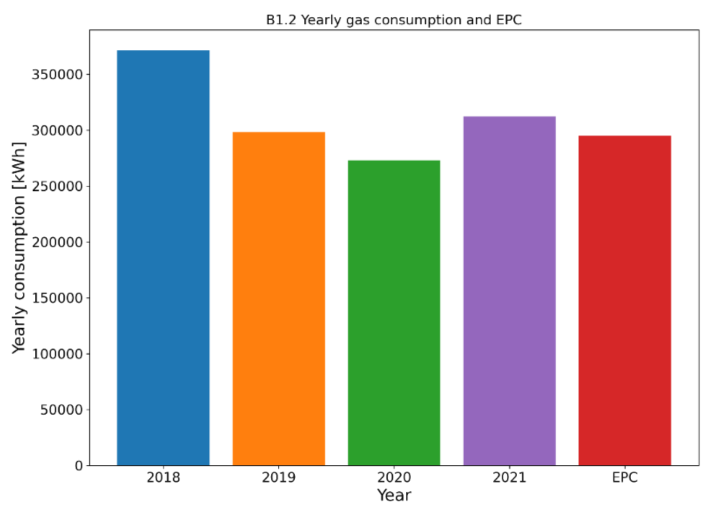


Figure 21: B1.2: Final energy consumption for space heating and DHW from the gas-boiler, compared to EPC final energy estimation

Just like B1.1, we are missing the DHW production data of the solar panels. This energy should be added to the consumption compared with the EPC. From the energy signature presented in Figure 22, we can evaluate that at least half of the DHW production is done by the solar panels, at least during summer.

When observing the energy signatures over the different years, an important difference between 2018 and the following years is visible. The reason for this gap is still uncertain and is subject to investigation. However, several HVAC companies have been in charge of the building over the years, and the information takes time to recover.

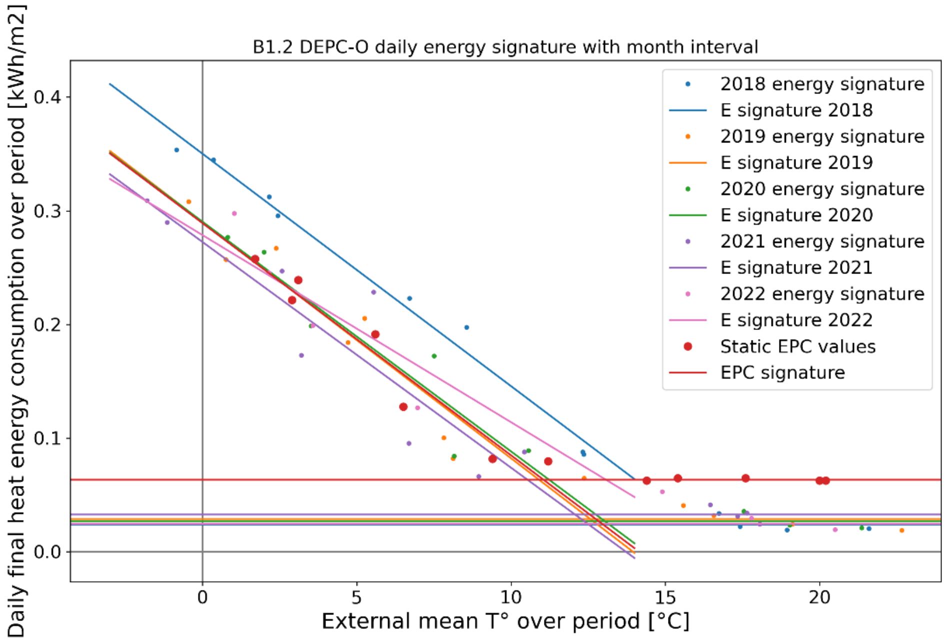


Figure 22: B1.2: Energy signature for final energy consumption of the gas-boiler over 168h time interval. The y-axis was normalized to daily consumption/m2 of floor heated surface area of the building

The different hypotheses to explain such abrupt changes in energy signature are:

- Installation of the Egain system in May 2018
- Intervention on the heater between 2018 and 2019
- Optimization of the DHW production by the solar thermal panels

Similarly to B1.1, the missing data about solar panels production makes the analysis harder to perform precisely, and conclusions can hardly be drawn.

The possible optimization actions taken on the building will be investigated, and results will be used to identify efficient actions and develop an optimization roadmap.

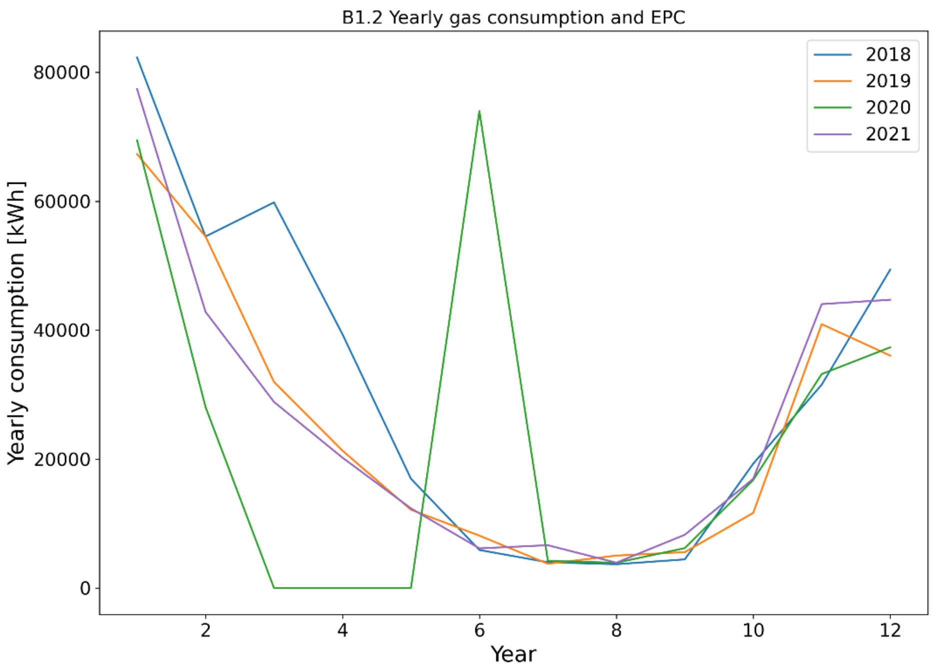


Figure 23: B1.2: Monthly final energy delivery for the gas boiler over the years.

To identify the operative free-running period with the buildings consumption data, this model's temporal definition is quite poor. As only monthly data are available, the free-running period is harder to define precisely. From Figure 23 is visible that months 6 to 9 (June to September) are free-running months. As for May and October, the monthly consumption data tend to show that the free-running period extends in some parts of both months. The COVID-19 pandemic explains the peak in June 2020 and the billing of the last four months (March to June) being done in June.

4.1.3 Building B1.3 - Low energy class building

Energy consumption for building B1.3 for the past three years also came from the gas delivery invoices. This building's heating system consists of a gas heater producing hot water for both heating and DHW. There is no secondary heat production system. Therefore, the gas consumption readings are equal to the final energy consumption of the building for both heating and DHW.

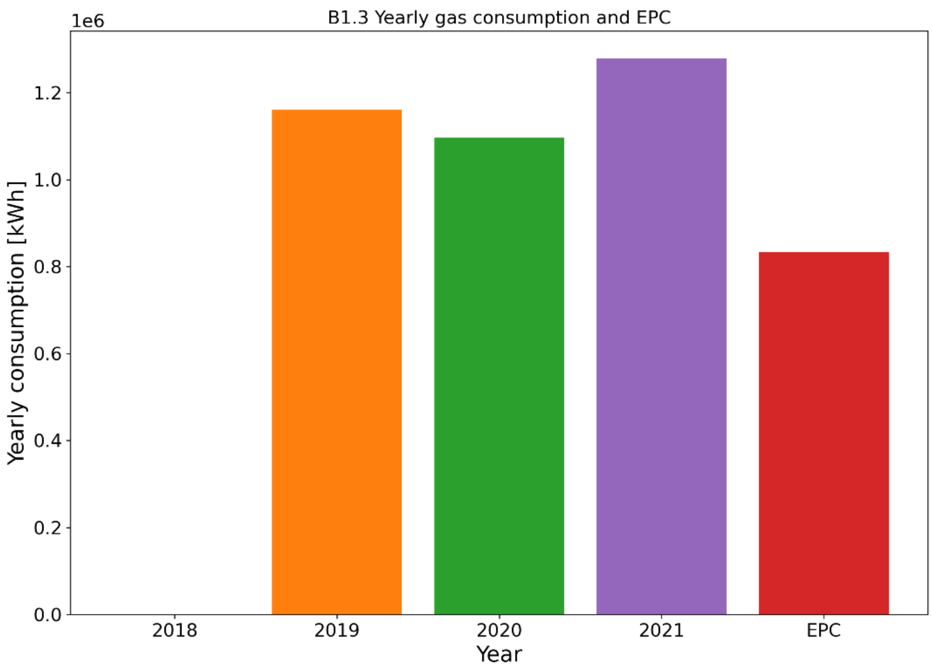


Figure 24: B1.3: Final energy consumption for space heating and DHW from the gas-boiler, compared to EPC final energy estimation

In Figure 24, we observe a significant performance gap in the heating system. As the building's heated floor surface is significant, the order of magnitude of E_{HW} is equally significant. The following graphs are presented with a ponderation of the building's surface for comparison purposes.

From the energy signature presented in Figure 25, it appears clearly that the DHW production energy is higher than expected from the EPC. This difference explains most of the gap between the EPC curve and the operative ones in the heating season part of the graph. The slopes of the heating curves are similar and show a general building behaviour as expected by the standard model. The vertical shift between the two curves can also be explained by the lower energy efficiency of the heating system.

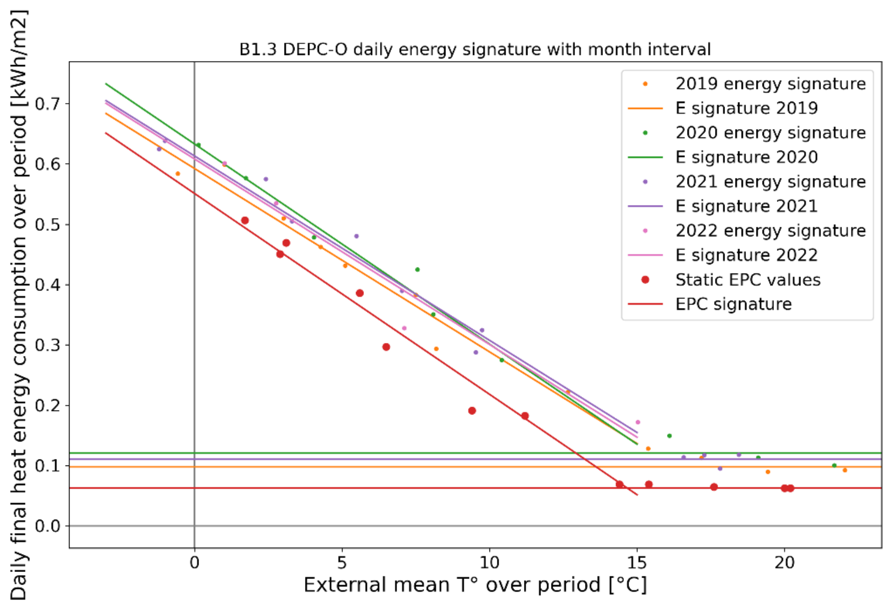


Figure 25: B1.3: Energy signature for final energy consumption of the gas-boiler over 168h time interval. The y-axis was normalized to daily consumption/m2 of floor heated surface area of the building

Again, only monthly consumption data are available, allowing less precision for identifying the operative free-running. From Figure 26 is visible that months 6 to 8 (June to August) are in free-running. September seems to depend on the year and can be partially included in the free-running period. Just like for B1.2, the peak in June 2020 is explained by the COVID-19 pandemic and the delivery of the last four months (March to June) being done in June.

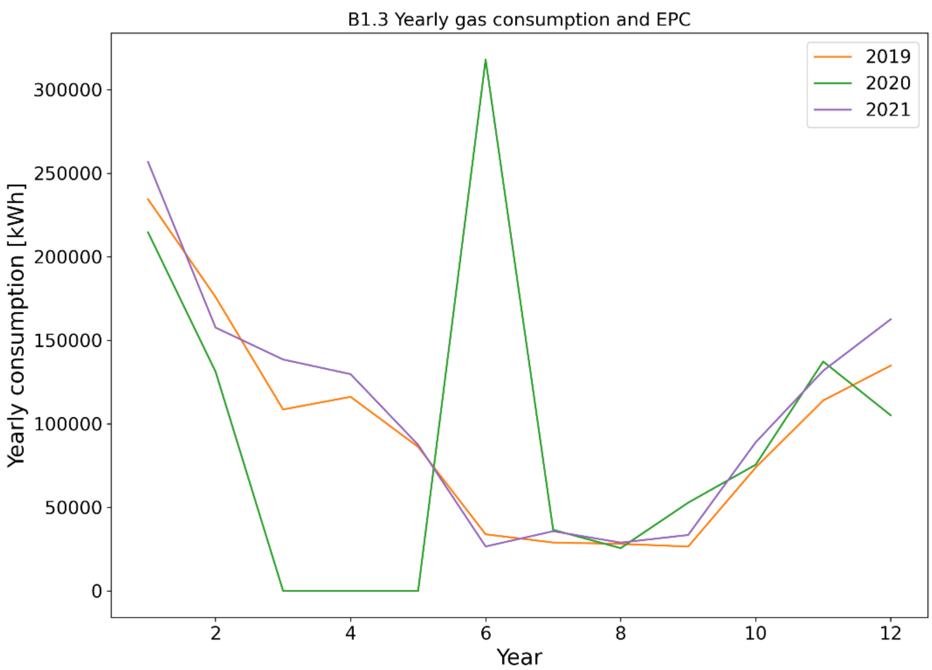


Figure 26: B1.3: Monthly final energy delivery for the gas boiler over the years.

There seems to be a performance gap due to DHW production in the building. As two heat counters were installed before the summer period of 2022, a more precise analysis of the separation between the production of DHW and heating will be made during the next winter period.

In addition, as the ventilation system was changed over April 2022, an analysis of this action's impact on the heat demand will be performed.

4.1.4 Building B 1.4 - Old and not renovated building

Building B1.4 was built in the 60s, and no significant renovation action has been done so far. This building is a nice example of a negative performance gap. In fact, in Figure 27, we observe that the operative final energy consumption is lower than what is expected from the reading of the EPC:

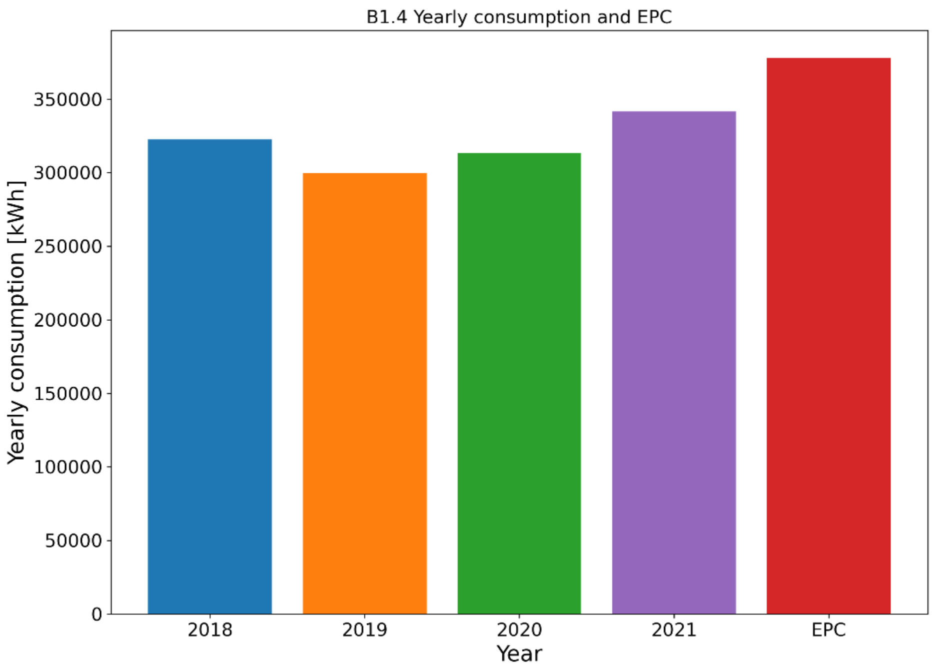


Figure 27: B1.4: Final energy consumption for space heating and DHW from the oil-boiler, compared to EPC final energy estimation

This comparison over different years does not represent well the building characteristics as it lacks the dependency on the outdoor air temperature. For this purpose, an energy signature with respect to the outdoor temperature is shown in Figure 28. This allowed us to evaluate if the building performs differently with respect to the outdoor condition as it was anticipated in the EPC:

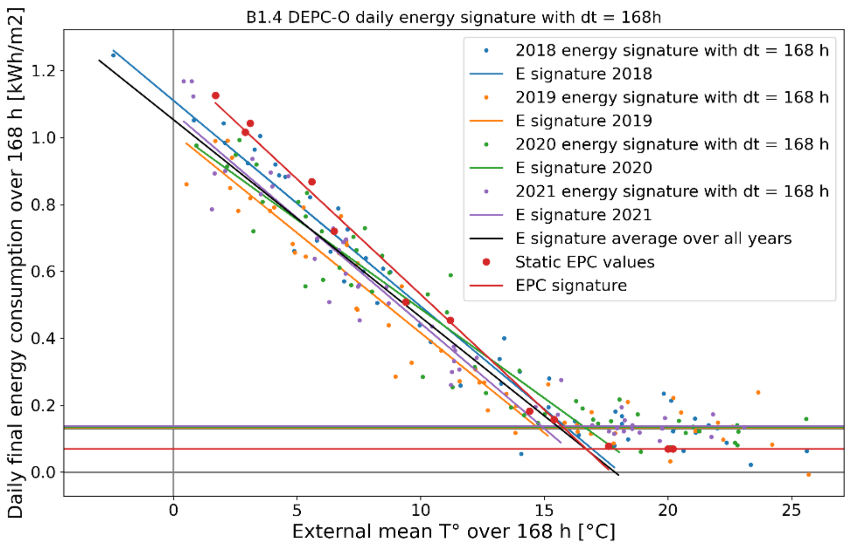


Figure 28: B1.4: Energy signature for final energy consumption of the oil-boiler over 168h time interval. The y axis was normalized to daily consumption/m2 of floor heated surface area of the building

We observe that the building behaves better at low outdoor temperatures than expected by the EPC. Additionally, we observe that the DHW consumption is higher than anticipated by the EPC. This shifts the whole curve vertically. The slope of the linear fit can be used to compare the EPC and consumption. The black curve (average over 2018-2021) shows a smaller slope than the red curve coming from the EPC data. This is typical behaviour of a negative performance gap, but the DHW overconsumption reduces its importance.

Finally, by observing the operative energy consumption per week, in Figure 29, it is possible to identify the free-running period of a building:

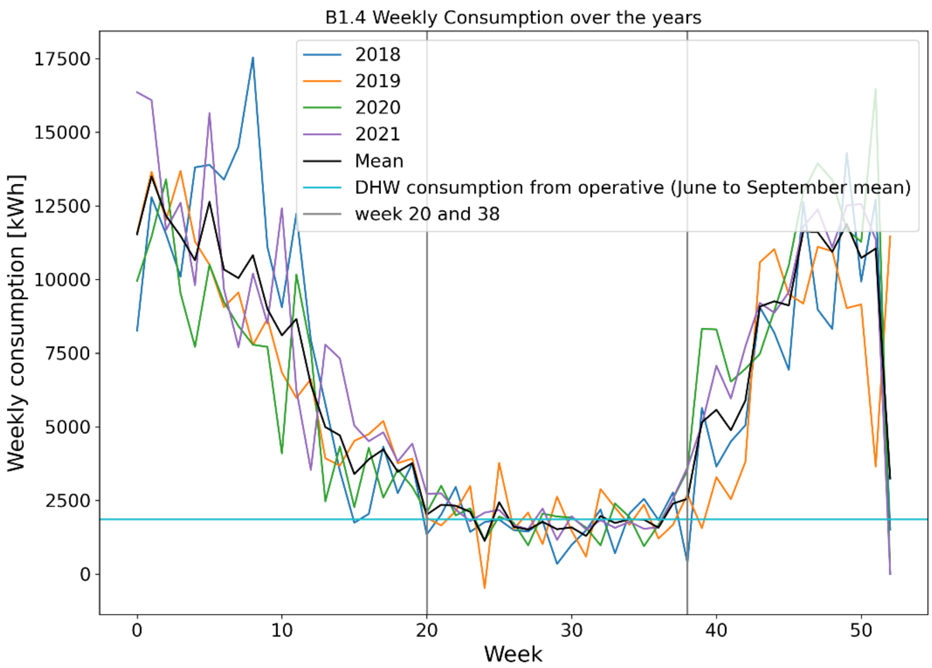


Figure 29: B1.4: Weekly final energy consumption for the oil boiler over the years

4.2 Thermal comfort

Thermal comfort was evaluated through the analysis of heat maps or carpet diagrams of all the available sensors. The heatmap shows the thermal comfort class observed for one hour with a coloured box. This allows showing the whole year's behaviour of each apartment. On the left side of the diagram, the hours of the day are used on the y-axis. On the x-axis are the days of the year. This type of visualization allows for identifying time periods or repetition of events. In this chapter, individual extreme apartments will be shown for each building. The analysis and aggregation will be performed in D5.6.

The comfort classes proposed by standard EN16798-1 [1]were utilized to perform the analysis. The different comfort classes are presented in Table 2:

Table 2: Thermal comfort classes definition from EN 16798-1 [1]

	Lower limit	Upper limit
Category 1	$0.33T_{rm} + 18.8 + 2$	$0.33T_{rm} + 18.8 - 3$
Category 2	$0.33T_{rm} + 18.8 + 3$	$0.33T_{rm} + 18.8 - 4$
Category 3	$0.33T_{rm} + 18.8 + 4$	$0.33T_{rm} + 18.8 - 5$
Category 4	All not in cat. 3	All not in cat. 3

With T_{rm} being the running mean of the outdoor temperature.

4.2.1 Building B1.1 - NZEB deep refurbishment

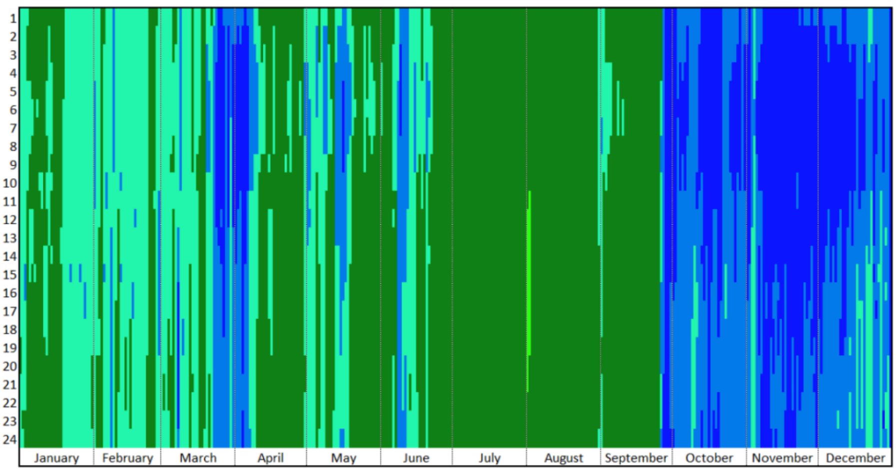
To analyze the global thermal comfort of a building, aggregation of results was performed, as shown in Table 3.

Table 3: Aggregated results of thermal comfort for B1.1 during the year 2020

	No. of flats	Surface area (m^2)	% of flats	% of area
Class 1	1	55,1	4,3%	3,6%
Class 2	10	705,9	43,5%	46,2%
Class 3	8	510,8	34,8%	33,4%
Class 4	4	255,8	17,4%	16,7%

The thermal comfort class of an apartment is defined according to the time that the indoor temperatures comply with this thermal class limit. If the indoor temperatures in an apartment comply with class limits for 95% of the time, it is classified as this comfort class. As an example, the apartment with a carpet diagram presented in Figure 30 is in class 4, as the indoor temperatures are in this class for more than 5% of the time.

From Table 3, we observe that the discrepancies inside the building are high. This should lead to identifying the extreme flat locations in the building and individual dynamic simulation of these extreme cases.



	Répartition Heure totale	Répartition Heure Occupation (SIA 2024)
Out range	0,0%	0,0%
Class 3	0,0%	0,0%
Class 2	0,2%	0,1%
Class 1	43,3%	42,9%
Class 2	23,8%	23,9%
Class 3	18,2%	18,3%
Out range	14,4%	14,8%

Figure 30: B1.1: Carpet diagram of thermal comfort for an extreme apartment location (5th floor)

The example shown here allows identifying the time period of the year when heating can be shut too early or start too late, at least for extreme flats. These periods are easily identified in the above carpet diagram. The end of March and early April seems to be a good example of an early decrease in space heating for the building. However, the cold zones from October to December can possibly be explained by the fact that the apartment is more exposed to exterior conditions, and maybe its radiators do not work optimally. The striking aspect of this carpet diagram is the transition from class 1 comfort to class 4 at the end of September.

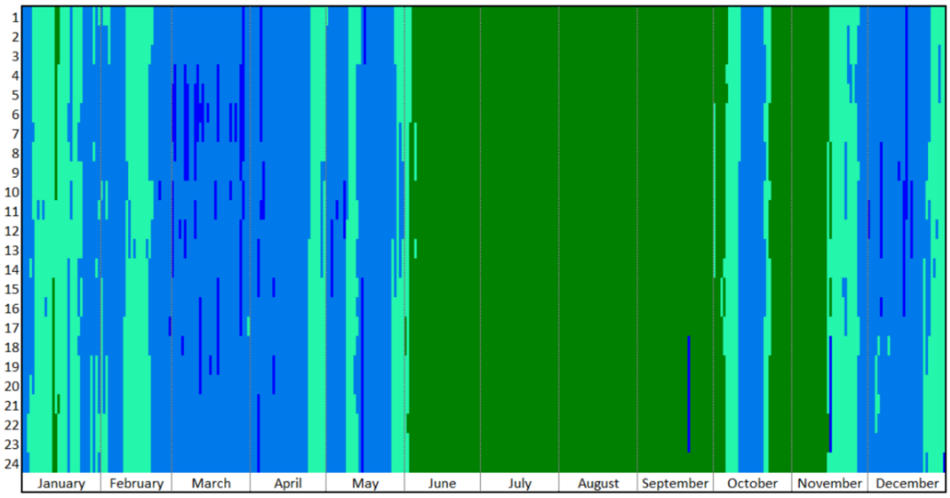
4.2.2 Building B1.2 - New building NZEB

Aggregation of the individual building probe is performed similarly to B1.1. The result table shows an average comfort of class 2, but the number of flats in class 3 is important compared to the total of monitored flats.

Table 4: Aggregated results of thermal comfort for B1.2 during the year 2021

	No. of flats	Surface area (m^2)	%. of flats	% of area
Class 1	2	233,7	8,3%	9%
Class 2	14	1527,8	58,3%	58,9%
Class 3	7	721,5	29,2%	27,8%
Class 4	1	110,7	4,2%	4,3%

When looking closely at one *class 3* flat in Figure 31, observation can be made that the heating seems to be minimalist during the heating season. The comfort class oscillates between 2, 3, and sometimes 4 during the whole heating season. The behaviour is constant and shows a fine-tuning of the heating system to obtain the lower comfort limit, at least in the more exposed flat.



	Répartition Heure totale	Répartition Heure Occupation (SIA 2024)
Out range	0,0%	0,0%
Class 3	0,0%	0,0%
Class 2	0,0%	0,0%
Class 1	40,7%	40,8%
Class 2	19,3%	19,5%
Class 3	38,0%	37,9%
Out range	2,0%	1,9%

Figure 31: B1.2: Carpet diagram of thermal comfort for an extreme apartment location (ground floor)

The building seems to work at optimal conditions to allow strict comfort, thanks to the heating optimization of Egain.

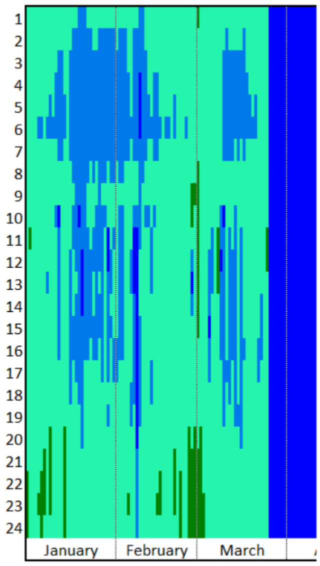
4.2.3 Building B 1.3 - Low energy class building

In Building 1.3, probes were only installed in one of the 6 sub-buildings to monitor its indoor temperature and air quality. As the monitoring started in December, only the start of the year is shown in the carpet diagrams. Data were retrieved until the 25th of March. The comfort is evaluated during this short period. As presented in Table 5, the t majority of apartments are in thermal class 3.

Table 5: Aggregated results of thermal comfort for B1.3 during the beginning of the year 2022

	No. of flats	Surface area (m²)	% of flats	% of area
Class 1	1	67,5	6,7%	5,4%
Class 2	1	104,3	6,7%	8,4%
Class 3	13	1073,9	86,7%	86,2%
Class 4	0	0	0%	0%

When we look closer at an apartment in Figure 32, we observe that the majority of the hours are in class 2, but there are too many class 3 hours to allow for classification in class 2. We can observe the night heating reduction effect between 2 and 8 a.m. in January and March.



	Répartition Heure totale	Répartition Heure Occupation (SIA 2024)
Out range	0,0%	0,0%
Class 3	0,0%	0,0%
Class 2	0,0%	0,0%
Class 1	3,6%	4,5%
Class 2	71,9%	72,9%
Class 3	23,2%	22,1%
Out range	1,3%	0,5%

Figure 32: B1.3: Partial carpet diagram of thermal comfort for an extreme apartment location (1st floor)

Also, it seems that class 1 is more often reached during the evening, probably when the tenants are at home, increasing the internal loads by their activity and equipment. The comfort will be re-evaluated in the framework of D5.6 to examine if the replacement of the ventilation system has an impact.

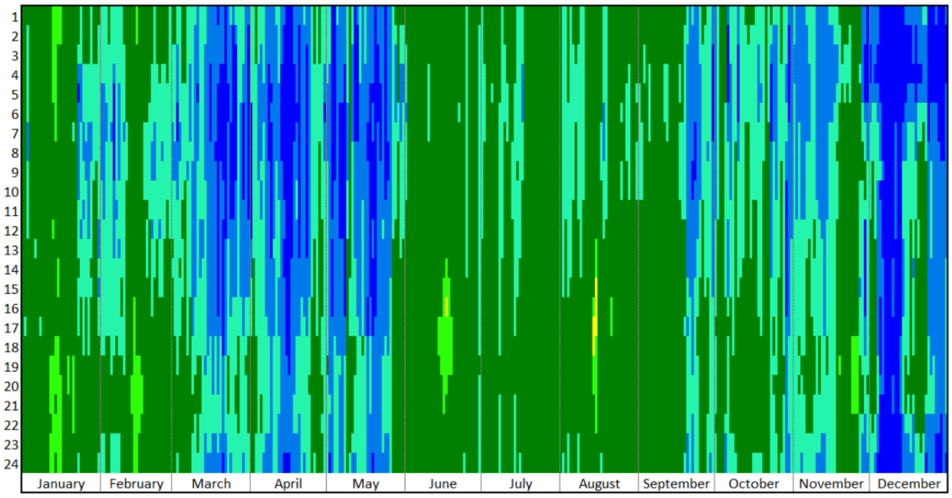
4.2.4 Building B 1.4 – Old and not renovated building

For the old, and not yet refurbished building B1.4, thermal comfort is expected to be low, especially for apartments with extreme locations in the building (such as the top or ground floor facing North). The low thermal comfort is visible in the Table 6, as no apartment is of class 1. Some are even showing very low thermal comfort and are of class 4.

Table 6: Aggregated results of thermal comfort for B1.4 during the year 2021

	No. of flats	Surface area (m²)	% of flats	% of area
Class 1	0	0	0%	0%
Class 2	6	447,3	40%	40%
Class 3	6	447,3	40%	40%
Class 4	3	223,7	20%	20%

Low thermal comfort can be explained by the combination of 2 factors: the non-insulated envelope of the building, combined with a dynamic heat optimization of Egain system. This system continuously reduces energy consumption for space heating to find the optimal minimum comfort. This minimum comfort is set by the building owner. In the B1.4 case, the range that the system tries to attain is 21.5 °C to 22.5°C of indoor temperature on average for all flats. This leads to discrepancies and local discomfort, visible in Figure 33.



		Répartition Heure totale	Répartition Heure Occupation (SIA 2024)
	Out range	0,0%	0,0%
	Class 3	0,1%	0,0%
	Class 2	1,5%	1,7%
	Class 1	48,1%	47,2%
	Class 2	26,1%	25,8%
	Class 3	16,7%	17,0%
	Out range	7,5%	8,4%

Figure 33: B1.4: Carpet diagram of thermal comfort for an extreme apartment location (1st floor, North)

We can observe a lack of space heating in this flat for the spring season upon the end of the heating season. This is probably due to the disequilibrium between the indoor temperature of the apartments, leading the heating system to work at lower power because of the Egain system. In December, the cold temperatures could be attributed to holiday departure or a general lack of space heating in the building.

4.3 Indoor Air Quality

Similarly to the thermal comfort evaluation, the IAQ evaluation is performed with carpet diagrams. The carpet diagrams are done with either CO2 or relative humidity values, depending on available data from monitoring.

For relative humidity, according to EN 16798-1 [1], the different classes are:

Class 1: between 30% and 50%

Class 2: between 25% and 60 %

Class 3: between 20% and 70%

The CO2 measurements are interpreted using the ICONE protocol, presented in **Fejl! Henvisningskilde ikke fundet.**. This protocol is used in France to evaluate the confinement index in school classrooms. it gives a score from 0 to 5, according to the level of stuffiness of the air [4].

In the next sub-chapter, the extreme cases of each building will be shown.

4.3.1 Building B1.1 - NZEB deep refurbishment

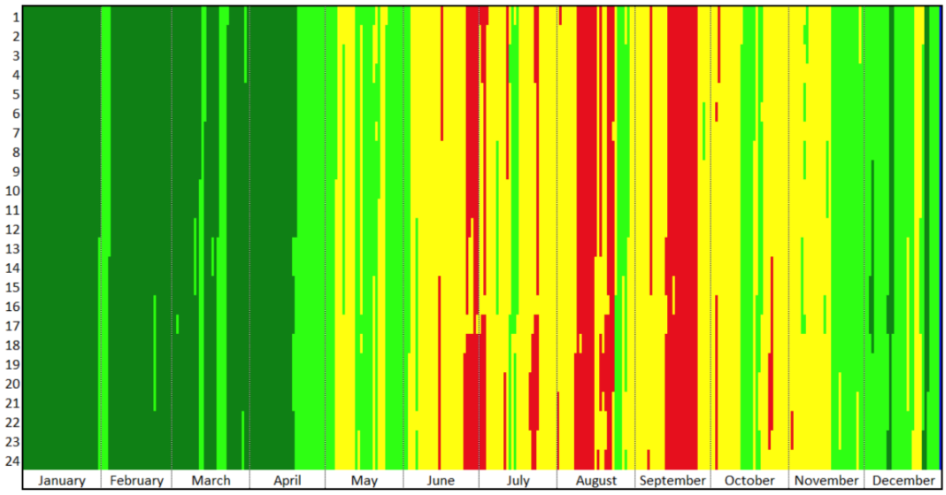
In building B1.1, as only Egain probes are available, the visualization of indoor air quality will be performed with the relative humidity data.

Table 7: Aggregated results of IAQ from humidity sensor for B1.1 during the year 2020

	No. of flats	**Surface area (m²)**	**% of flats**	**% of area**
Class 1	1	79,2	4,3%	4,8%
Class 2	18	1185,4	78,3%	77,6%
Class 3	3	217,1	13%	14,2%
Class 4	1	52,2	4,3%	3,4%

According to aggregated data presented in Table 7, indoor air quality is acceptable for this building. Some apartments show higher average humidity levels, but the overall building seems to work well.

When looking at the only *class 4* apartment presented in Figure 34, during the year 2020, the highest relative humidity values are reached during summer. Some time periods could be associated with the home office during the hot season, increasing the relative humidity consequently. There is no information available to confirm this hypothesis.



	Répartition Heure Totale	Répartition Heure Occupation (SIA 2024)
Out range : > 70%	9,8%	10,4%
Class 3 [60% ; 70%]	35,8%	35,4%
Class 2 [50% ; 60%]	26,2%	26,0%
Class 1 [30% ; 50%]	28,0%	27,9%
Class 2 [25% ; 30%]	0,0%	0,0%
Class 3 [20% ; 25%]	0,0%	0,0%
Out range : < 20%	0,3%	0,3%

Figure 34: B1.1: Carpet diagram of relative humidity for an extreme apartment location (1st floor)

This apartment is the only one showing such high relative humidity values, and it cannot be linked to its location in the building. Further analysis of individual indoor air quality should be performed to try and explain this kind of behaviour.

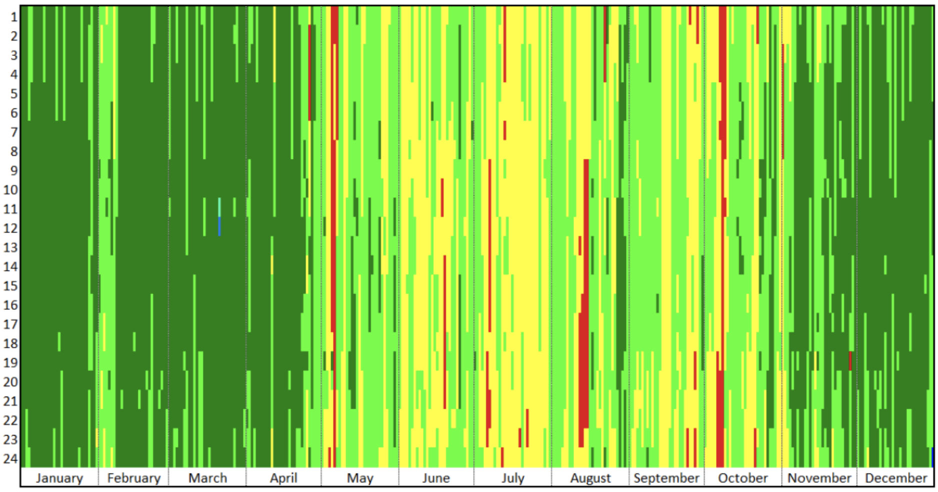
4.3.2 Building B1.2 - New building NZEB

In building B1.2 as well, only Egain probes are present, allowing us to measure relative humidity and draw a carpet diagram as for B1.1. The aggregated results are shown in Table 8.

Table 8: Aggregated results of relative humidity for B1.2 during the year 2021

	No. of flats	Surface area (m²)	%. of flats	% of area
Class 1	0	0	0%	0%
Class 2	7	693,3	29,2%	26,7%
Class 3	17	1900,5	70,8%	73,3%
Class 4	0	0	0%	0%

The indoor air quality is globally of class 3 with respect to relative humidity. No apartments were ranked class 4, which is a good sign of a functioning ventilation system. However, it seems that no apartment is in class 1 either, meaning that the relative humidity tends to vary significantly during the year. This is expected as no humidity regulation system is installed in the building.



	Répartition Heure Totale	Répartition Heure Occupation (SIA 2024)
Out range : > 70%	2,3%	2,4%
Class 3 [60% ; 70%]	21,7%	22,8%
Class 2 [50% ; 60%]	35,7%	36,3%
Class 1 [30% ; 50%]	40,3%	38,4%
Class 2 [25% ; 30%]	0,0%	0,0%
Class 3 [20% ; 25%]	0,0%	0,0%
Out range : < 20%	0,0%	0,0%

Figure 35: B1.2: Carpet diagram of relative humidity for an extreme apartment location (4th floor)

When looking at the extreme individual apartment in **Figure 35**, we observe no evident tendencies for indoor air quality. Most values seem influenced by the outdoor air humidity rather than the building's technical installation.

4.3.3 Building B 1.3 - Low energy class building

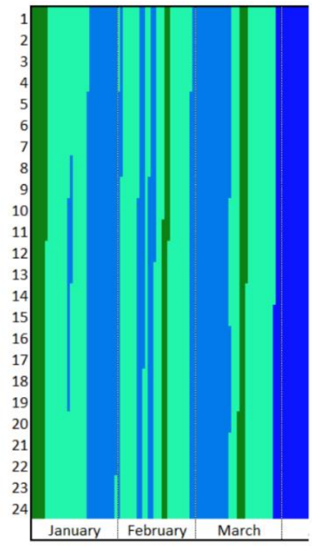
In B 1.3, Elsys sensors were installed to monitor indoor air quality. Most of them have relative humidity readings, and some have CO2 readings as well. Both data are shown here.

Concerning relative humidity, aggregated results for the winter period (January to 25th of March) are shown in Table 9. Globally, the air quality in sub-building with entrance 7 is adequate, with the majority of apartments ranging in class 2 and none in class 4 during the period.

Table 9: Aggregated results of relative humidity for B1.3 during the beginning of the year 2022

	No. of flats	Surface area (m²)	% of flats	% of area
Class 1	1	83,9	6,7%	6,7%
Class 2	8	696,2	53,3%	55,9%
Class 3	6	465,6	40%	37,4%
Class 4	0	0	0%	0%

Looking at an individual flat of class 3 in **Figure 36**, we observe that the relative humidity level is low and ranges from 20 to 50% during the whole period. This is a surprising result as no humidity control is being performed on the building. Even more surprising is the fact that the probe is in a bedroom, where the humidity level should rise at night due to the presence of occupants. Possible explanations for such behaviour would be an empty bedroom or an overventilation of the apartment during the cold season.



		Répartition Heure Totale	Répartition Heure Occupation (SIA 2024)
	Out range : > 70%	0,0%	0,0%
	Class 3 [60% ; 70%]	0,0%	0,0%
	Class 2 [50% ; 60%]	0,0%	0,0%
	Class 1 [30% ; 50%]	11,7%	11,9%
	Class 2 [25% ; 30%]	52,3%	53,1%
	Class 3 [20% ; 25%]	36,0%	35,0%
	Out range : < 20%	0,0%	0,0%

Figure 36: B1.3: Partial carpet diagram of relative humidity for a central apartment location (3rd floor)

As some of the installed sensors are also measuring CO2 levels, Table 10 shows the aggregated results for the winter period.

Table 10: Aggregated results of ICONE indexes for the beginning of the year 2022 in B1.3

ICONE (during standard occupancy)	No. of flats	% of flats
0	9	90%
1	0	0%
2	0	0%
3	1	10%
4	0	0%
5	0	0%

The air quality, according to the CO2 sensors, is good. It is in fact, surprising to obtain such small stuffiness indexes. An explanation could come from user habits of opening their window at night and over-ventilating their apartment. Both humidity and CO2 measurements corroborate the significant outdoor airflow in the apartment. It will be interesting to observe how the new ventilation system will influence the IAQ.

4.3.4 Building B 1.4 – Old and not renovated building

In B1.4, two different monitoring solutions were used to determine indoor air quality. Relative humidity readings from the Egain and CO2 measurements from the BatNRJ probes installed in entrances 17 and 19 of the building (half north of the building).

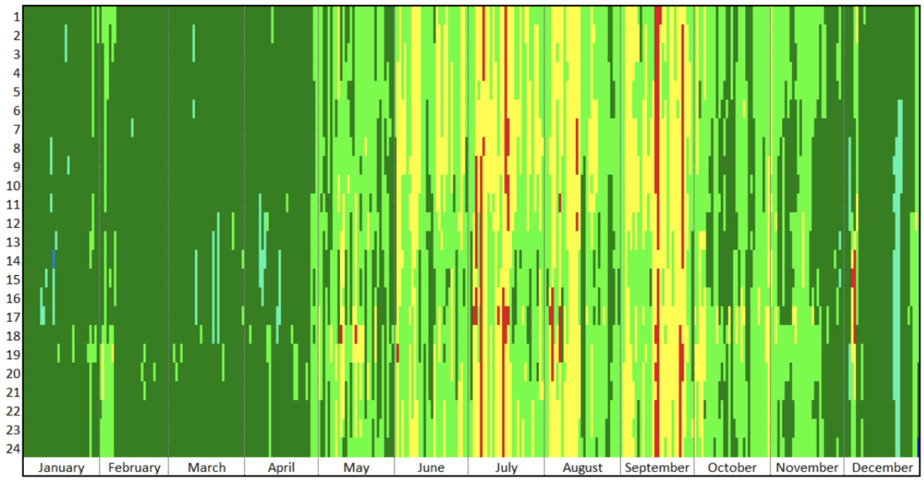
Regarding relative humidity measurements, the aggregated data are shown in Table 11. According to these results, the building's indoor air quality is acceptable, but most apartments are in class 3, at least in 2021.

Table 11: Aggregated results of relative humidity for B1.4 during the year 2021

	No. of flats	Surface area (m²)	%. of flats	% of area
Class 1	0	0	0%	0%
Class 2	5	372,8	33,3%	33,3%
Class 3	10	745,6	66,7%	66,7%
Class 4	0	0	0%	0%

Observing the particular sensor in Figure 37, most of class 3 (and even 4) measurements are during the summer period.

The ventilation system with two different exhaust air flow speeds is not visible on the carpet diagram. As ventilation schedules are unknown, the system is probably working at the highest speed for the whole day all year long.



	Répartition Heure Totale	Répartition Heure Occupation (SIA 2024)
Out range : > 70%	1,6%	1,5%
Class 3 [60% ; 70%]	16,0%	16,7%
Class 2 [50% ; 60%]	32,9%	33,9%
Class 1 [30% ; 50%]	48,1%	47,0%
Class 2 [25% ; 30%]	1,3%	0,9%
Class 3 [20% ; 25%]	0,0%	0,0%
Out range : < 20%	0,0%	0,0%

Figure 37: B1.4: Carpet diagram of relative humidity for an extreme apartment location (4th floor)

Table 12 shows the aggregation of the ICONE index results of the different room sensors installed in B1.4. IAQ is acceptable as no apartment has an index higher than 3.

Table 12: Aggregated results of ICONE index for B1.4 during the beginning of the year 2022

ICONE (during standard occupancy)	No. of flats	% of flats
0	9	50%
1	4	22%
2	2	11%
3	3	17%
4	0	0%
5	0	0%

Interestingly, when observing local ICONE indexes, we can observe that the standard occupancy is not the real occupancy for some rooms, as it is presented in Figure 38. A deeper analysis of the occupancy schedule should be performed to analyze the IAQ with adapted occupancy, not standard values.

ICONE 5 values are considered very high confinement and show a lack of local air renewal. Our hypothesis is that the inhabitant is sleeping with closed doors and windows, meaning the bedroom airflow is extremely low at night. Night is considered in the non-occupied hours in the standard.

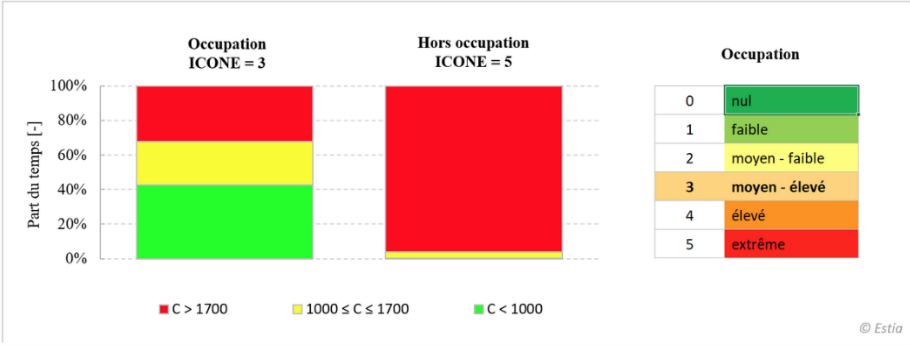


Figure 38: B1.4: Extreme ICONE result of a monitored apartment (last floor)

This individual result underlines the necessity of a new ventilation system that would guarantee a good IAQ and limit heat losses through exhaust air. A similar system as for B1.3 is foreseen, but we will wait for the refurbishment to take place.

5 Modelling

5.1 Models' development

The models for the dynamic building energy simulations were developed using the DesignBuilder software. This software facilitates the creation of the model's geometry and permits exporting the model in IDF format for inputting into EnergyPlus, the software utilized in the PREDYCE tool.

For all models, the HVAC systems were modelled using the simplified EnergyPlus ideal load system, which allows the definition of the thermostats' setpoints and gives the net-envelope energy demand for heating or cooling as output. Using these ideal energy demands for each building, a reasonable estimation of the final energy consumption can be obtained by adding the coefficient of performance of the building's HVAC system. The simplified modelling option was introduced to the outdoor air ventilation as the calculation would be highly time-consuming. In all models, the air exchanges were effectuated through three pathways: the infiltration from the envelope's cracks, the ventilation through the buildings' mechanical systems, and the ventilation through the window opening by the occupants.

All models were created using information from the inspection sheet. The first version of the model corresponded to the standard conditions of use, using the Swiss standard for dynamic simulations SIA 2024 [5]. In the following step, the models were adapted to the actual observed conditions of use, given that the standard conditions do not necessarily reflect the reality for each case. This procedure is crucial for the E-DYCE methodology and is described in deliverable D2.4. The modified parameters were mainly the outdoor air ventilation and infiltration rates, the solar shading, and the thermostat setpoint temperatures.

At this stage, the building models' zoning was detailed and done on the apartment level. So, each apartment constituted a separate zone in all four multifamily buildings. In addition, the staircases, basements, and other non-heated spaces formed distinct zones. This approach permitted a more detailed interpretation of the results, for example identifying the critical zones. Nevertheless, this zoning approach also led to highly time-consuming simulations. In a later stage, all models will be simplified in parallel with the T3.5 to identify better how the simplification of models can be done in real cases.

5.1.1 Building B1.1 - NZEB deep refurbishment

The model was created using information from the architectural plans and the inspection protocol available for this building.

The B1.1 is constituted of five floors, one attic and a ground floor. As each typical floor, including the attic, contained five apartments, the number of heated thermal zones of each floor was equally five. The ground floor contained two shops and several non-heated spaces which were zoned separately. The staircase was simulated separately as a non-heated zone. In total, the total number of zones was 35. The simulation time for this model was between 10 and 15 minutes, which may not be optimal for running multiple simulations and adapting the model. Thus, it is predicted to effectuate a simplification of the model to reduce the complexity and the simulation time.

Figure 39 presents the model's geometry, while Figure 40 presents the thermal zones of the typical floor.

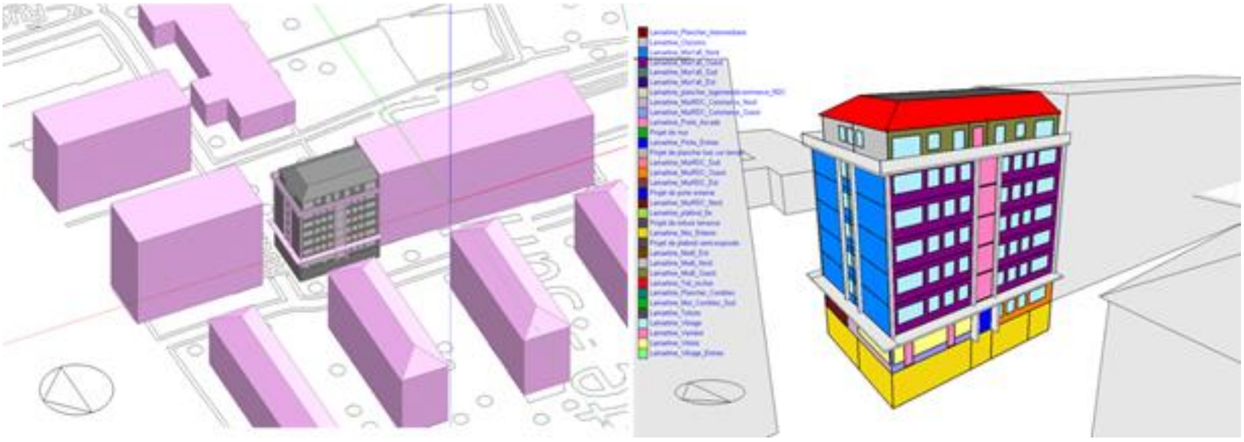


Figure 39: External views of the B1.1 presenting the external geometry of the investigated and neighbouring buildings.

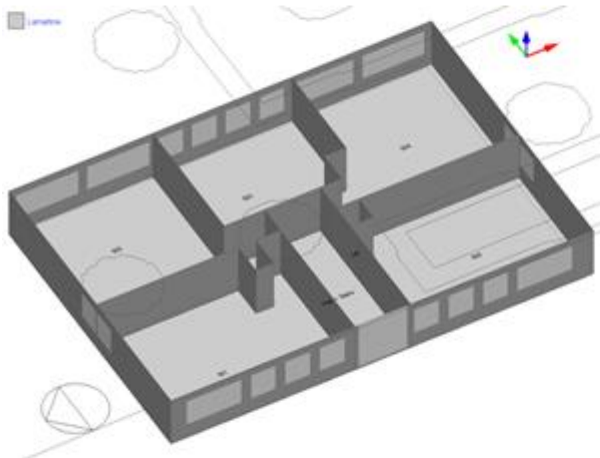


Figure 40: View of the model's thermal zones for a typical floor of B1.1.

Model adaptation

Initially, the model was built using the standard conditions of use, as demanded by the Swiss standard SIA 2024 [5]. However, as the standard values were different from the actual, the model was adapted accordingly. Initially, the heating thermostat temperature was increased from 21 °C (with a setback at 19 °C) to 22.2 (with a setback at 21.5 °C). This decision was taken as the monitored temperatures were higher than the ones indicated in the standard. In addition, the standard ventilation rates were also modified to better approach the observed values. More specifically, the continuous mechanical ventilation was adjusted from 0.4 ACH to 0.3 ACH, and a window opening logic was added to simulate the window opening for summer comfort. In this, the windows were considered open when the indoor temperature was overpassing 24 °C, the outdoor temperature was higher than 10 °C, and the outdoor temperature was lower than the indoor. In addition, it was simulated that the blinds for solar shading were closed during the day when the indoor temperature was above 24 °C. These actions were decided for the simulated indoor summer temperatures to be closer to the measured ones. Without these actions that try to imitate the occupant's behaviour, the simulated indoor temperatures were significantly higher than the actual.

5.1.2 Building B1.2 - New building NZEB

The model was created using information from the architectural plans only, as an inspection protocol available for this building was not available on time. It should be noted that due to the limited information regarding this building, the adaptation process at this point remained at a basic level.

The B1.2 is constituted of two twin buildings with six floors, each including the attic, where each typical floor has nine apartments except for the attic, where there are eight. Four staircases serve each building, from the basement to the attic and the ground floor is in contact with a non-heated basement. Following the zoning approach to the apartment level, gave 59 thermal zones for each building.

The simulation time for this model was between 20 and 25 minutes, which complicated the adaptation process. The model will be simplified to reduce the simulation time in the framework of T5.6.

Figure 41 presents the model's geometry, demonstrating the distinction between the twin buildings, while Figure 42 presents the thermal zones of a typical floor.

Figure 41: External views of the B1.2 presenting the external geometry of the investigated and neighbouring buildings.

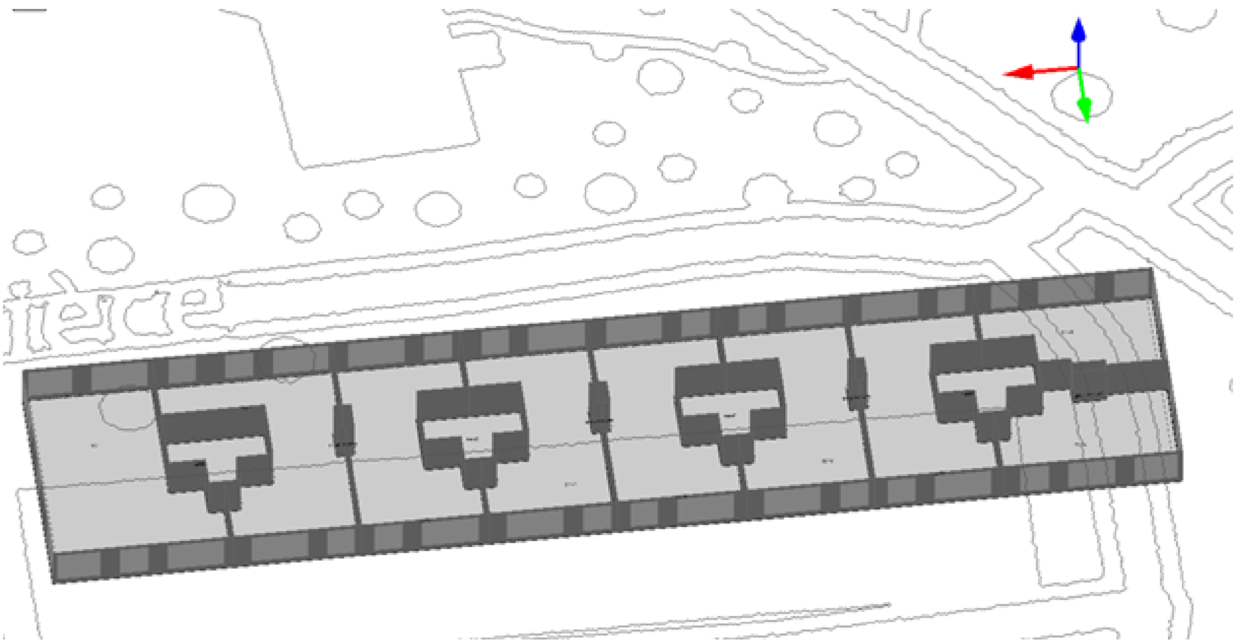


Figure 42: View of the model's thermal zones for a typical floor of B1.2.

Model adaptation

Initially, the model was built using the standard conditions of use, as demanded by the Swiss standard SIA 2024 [5]. However, as the standard values were different from the actual, the model was adapted accordingly. Initially, the heating thermostat temperature was increased from 21 °C (with a setback at 19 °C) to 22 (with a setback at 21.5 °C) as the monitored temperatures were higher than the ones indicated in the standard. In addition, a window opening logic was added to simulate the window opening for summer comfort. In this, the windows were considered open when the indoor temperature was overpassing 24.5 °C, the outdoor temperature was higher than 10 °C, and the outdoor temperature was lower than the indoor. In addition, it was simulated that the blinds for solar shading were closed during the day when the indoor temperature was above 24.5 °C. These actions were decided in order for the simulated indoor summer temperatures to be closer to the measured ones. Without these actions that imitate the occupant's behaviour, the simulated indoor temperatures were significantly higher than the actual. Further adaptation of the model will follow to match the simulated condition of use with the actual one.

5.1.3 Building B 1.3 - Low energy class building

The simulation model of B1.3 was created using information from the architectural plans and the inspection protocol. It should be noted that since the monitoring of the building started in November 2021, the information regarding this building was limited, and the adaptation process at this point remained at a basic level.

The B1.3 is an extensive complex of six buildings with six floors or seven floors each. A typical floor had three apartments, except for the attics, where there were two. Each building had a staircase at its core, while the first floor was in contact with outdoor air, as the building was built on pilotis. Following the zoning approach to the apartment level, each building's model had 18 to 21 thermal zones (according to the floors of the building). At the building level, the simulation time was 10-15 minutes, which was multiplied by six when the results were generated for the whole complex. Thus, simplification is anticipated to run the simulations of the entire complex in an acceptable time. This simplification will take place in the framework of T5.6.

Figure 43 presents the model's geometry, including the neighbouring buildings, while Figure 44 presents the thermal zones of a typical floor.

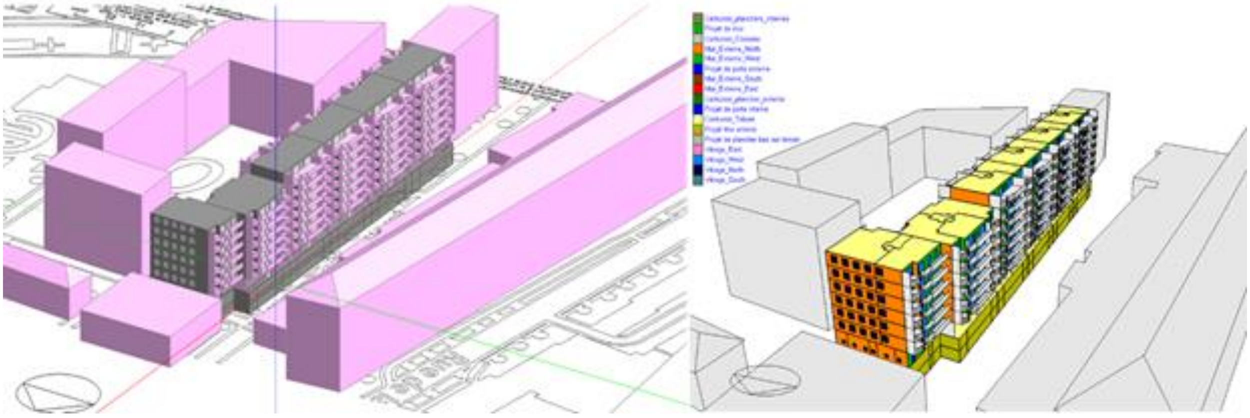


Figure 43: External views of the B1.3 presenting the external geometry of the investigated and neighbouring buildings.

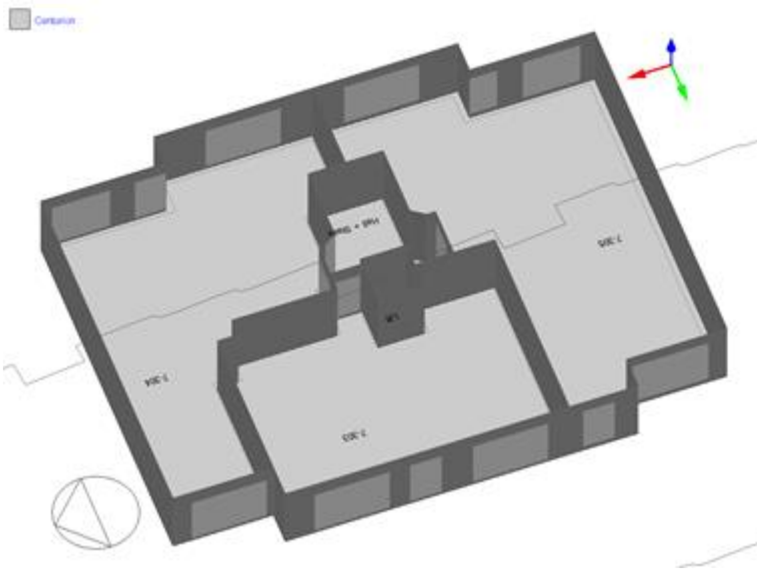


Figure 44: View of the model's thermal zones for a typical floor of B1.3.

Model adaptation

To adapt the simulation conditions to the actual, the heating thermostat temperature was increased from 21 °C (with a setback at 19 °C) to 21.5 (with a setback at 20 °C) according to the short-term monitoring effectuated between January and March 2022. Moreover, the ventilation rates due to the mechanical infiltration were modified from 0.4 ACH to 0.3 ACH. No data existed for the summer indoor temperatures, so no window opening strategy was simulated in this phase. Further adaptation of the model will follow to better match the simulated condition of use with the actual one.

5.1.4 Building B1.4 – Old and not renovated building

The simulation model of B1.4 was created using information from the architectural plans and the inspection protocol.

The B1.4 is a long three-floor building served by four staircases. Each typical floor has eight apartments, where each of the four staircases is situated at the core. Following the zoning approach to the apartment level, the model had 25 thermal zones. The simulation time at the building level was 10-15 minutes, which is a little long but acceptable. Further simplification is anticipated in the framework of T5.6.

Figure 45 presents the model's geometry, including the neighbouring buildings, while Figure 46 presents the thermal zones of a typical floor.

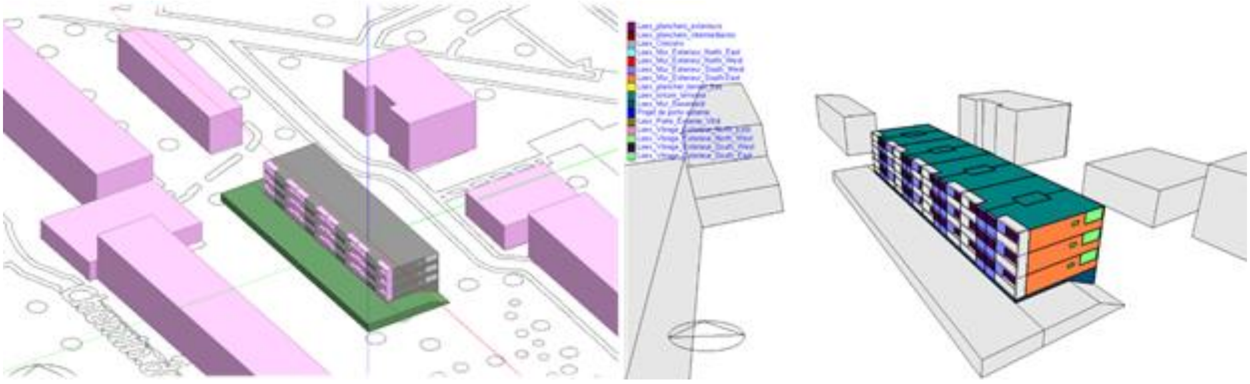


Figure 45: External views of the B1.4 presenting the external geometry of the investigated and neighbouring buildings.

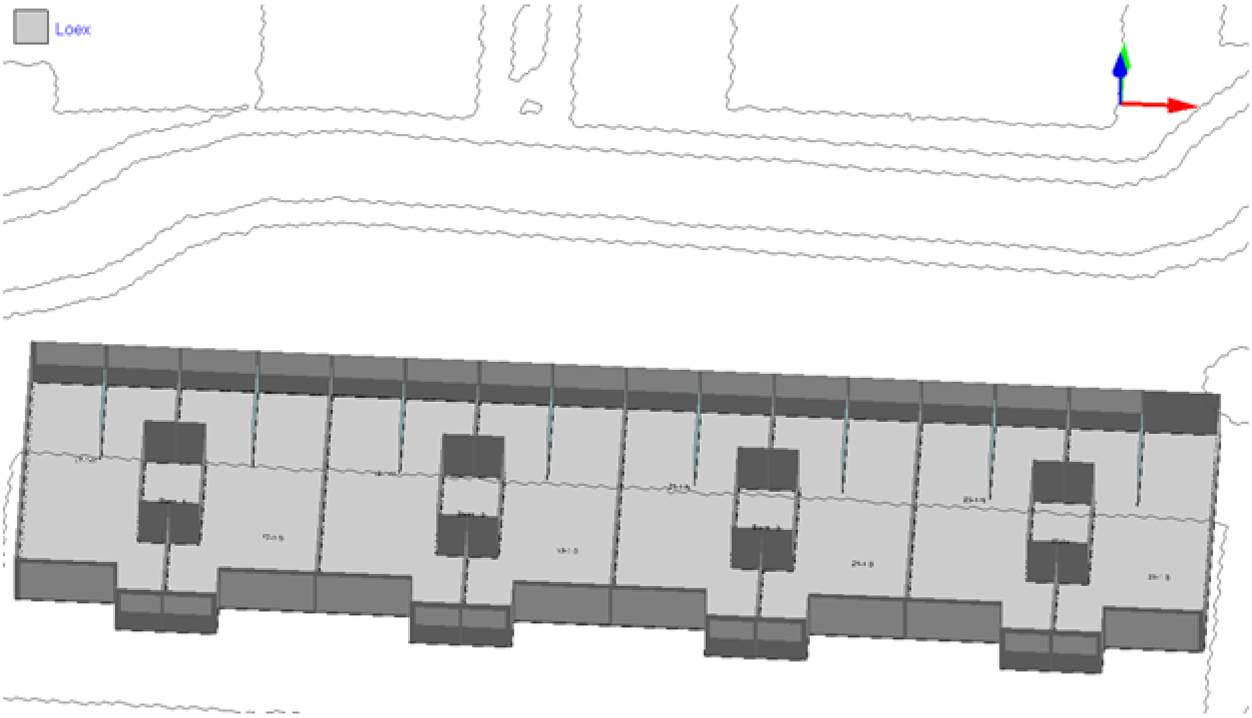


Figure 46: View of the model's thermal zones for a typical floor of B1.4.

Model adaptation

The simulation conditions were modified in order to better adapt to the actual ones. Firstly, according to the monitored values, the heating thermostat temperature was increased from 21 ^{o}C (with a setback at 19 ^{o}C) to 22.2 ^{o}C (with a setback at 21 ^{o}C). Moreover, the ventilation rates due to the mechanical infiltration were modified from 0.4 ACH to 0.3 ACH. Additionally, a window opening heuristic was added to simulate the window opening for summer comfort. In this, the windows were considered open when the indoor temperature was overpassing 26.5 ^{o}C, the outdoor temperature was higher than 10 ^{o}C, and the outdoor temperature was lower than the indoor. In addition, it was simulated that the blinds for solar shading were closed during the day when the indoor temperature was above 26.5 ^{o}C. These actions were decided in order for the simulated indoor summer temperatures to be closer to the measured ones. Without these actions that imitate the occupant's behaviour, the simulated indoor temperatures were significantly higher than the actual. Further adaptation of the model will follow to match the simulated condition of use with the actual one.

5.2 PREDYCE connection and transfer to FUSIX

All models were developed in EnergyPlus V8.9 to be compatible with the PREDYCE tool and eventually connect to FUSIX. This will be effectuated in a later stage, as the automatic connection via API of the monitored data with FUSIX was not totally available until this moment due to various issues related to the suppliers of the sensing material.

6 Comparison of the static and dynamic EPC

This chapter attempted to compare the preliminary results from the different EPC evaluation schemes to identify the added value of the E-DYCE methodology. In the four following sub-chapters are presentedthe energy signatures obtained from the four different EPC (EPC static, DEPC-AS, DEPC-AA, DEPC-O), as the energy signature is an efficient representation method that can aid in the interpretation of the results. It should be noted that, at his point, the interpretation of the results is limited as there is still some information missing from the case studies, or the simulation models are not 100% adapted to the actual conditions of use. Thus, the results presented are still in a preliminary phase, and the final conclusions may differ.

6.1 Building B1.1- NZEB deep refurbishment

Figure 47 shows that the different EPC schemes present different fitting lines for the energy signature. The energy signature of the static EPC (presented in red) underestimates the real energy consumption of the B1.1, as the fitting line of the energy signature of DEPC-O (measured consumption – presented in light blue) is higher. So, this building has a performance gap compared to the standard, static EPC. The energy signatures generated from the dynamic simulations, DEPC-AS (standard - presented in grey) and DEPC-AA (adapted – presented in yellow), seem to approach better the actual energy demand when the outdoor temperatures are between 8 °C and 15 °C. For lower temperatures, they derive more than the actual measurements. The slope of the dynamic energy signatures is closer to the actual measurements, which indicates that the dynamic models can better predict the dynamic behaviour of the building. The difference between the fitting lines of the DEPC-AS, DEPC-AA, and DEPC-O could probably be explained by the false hypotheses that were assumed for the efficiency of the heating system and the calorific power of the building's fuel. In fact, as the simulations in EnergyPlus only calculated the heating demand with the ideal HVAC, the coefficient of performance was assumed at 90% for the heating system. In reality, this could be even lower, which could bring the fitting lines of DEPC-AS and DEPC-AA closer to DEPC-O and better predict the behaviour of the buildings. In addition, the heating oil consumed for heating in this building does not have a standardized calorific power. So the assumption for the calorific power could also explain the difference between the fitting lines of DEPC-AS, DEPC-AA, and DEPC-O. Furthermore, a solar-thermal collector contributes to the DHW production in this building. This contribution is not known as the data from this heat meter are missing. This could also shift the DEPC-O line. Overall, there is an indication that the DEPC-AS and DEPC-AA can predict better the actual behaviour of the buildings, which is also dynamic. However, further investigation is necessary to adapt the simulation models and to explain the difference in the energy signatures.

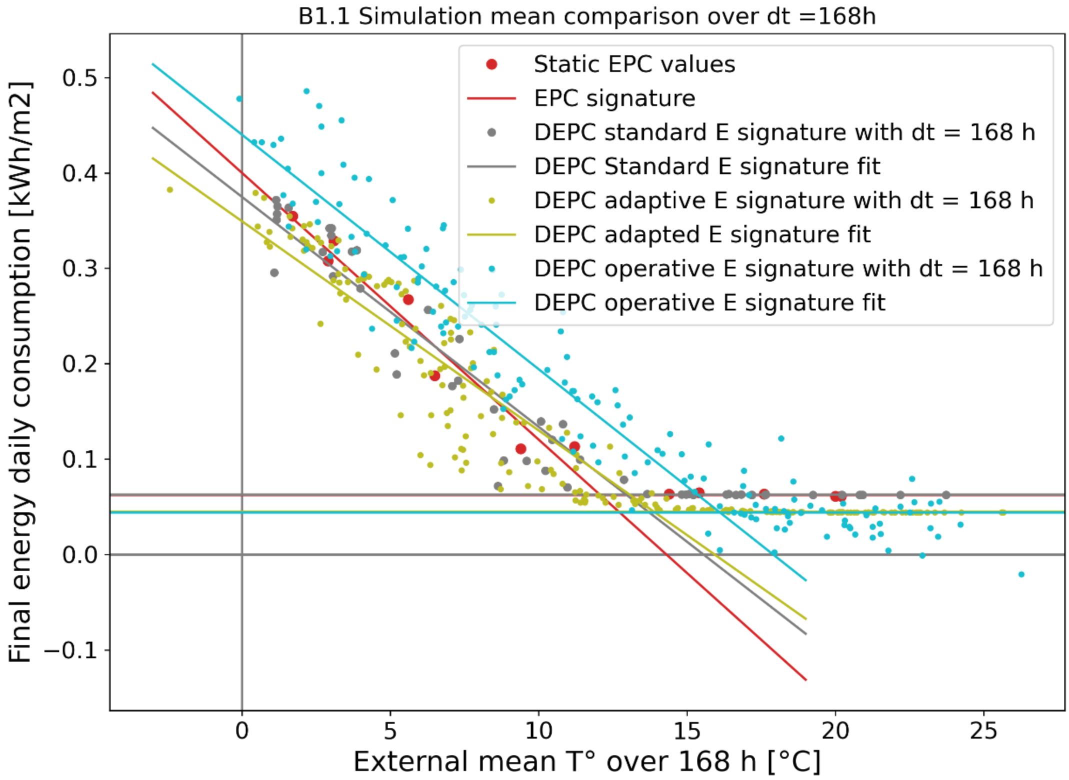


Figure 47: **Energy signature as a result of the tested EPC schemes for the B1.1.**

6.2 Building B1.2 - New building NZEP

Figure 48 shows the energy signatures produced by the EPC, DEPC-AS, DEPC-AA, and DEPC-O for the B1.2. The energy signature of the static EPC (presented in red) slightly underestimates the real energy consumption of the B1.2 indicating a performance gap. The energy signatures generated from the dynamic simulations, DEPC-AS (standard - presented in grey), is very close to the fitting line of the static EPC, even though their slopes differ. The slope of the DEPC-AA (adapted – presented in yellow) approach better the slope of the actual energy demand (DEPC-O). Nevertheless, as the dynamic models for this building were based on limited data, their predictions may not be that accurate. Furthermore, as in this building, a solar-thermal collector contributes to the DHW production without being known its exact contribution, the DEPC-O line cannot be considered 100% accurate. Overall, this case study indicated that if the dynamic models are based on limited information, they cannot be characterized as more accurate. Further investigation of the real consumption and adaptation of the dynamic models is necessary to explain the difference in the energy signatures.

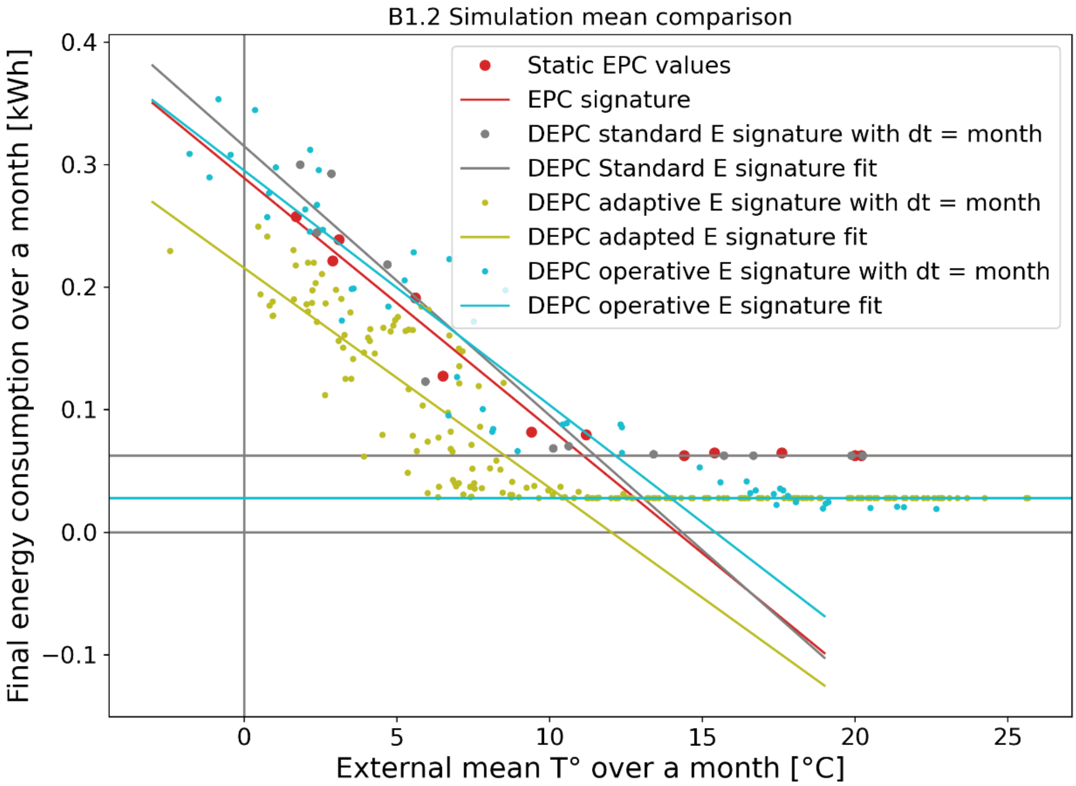


Figure 48: Energy signature as a result of the tested EPC schemes for the B1.2.

6.3 Building B 1.3 - Low energy class building

The energy signatures of EPC, DEPC-AS, DEPC-AA, and DEPC-O for the B1.3 are presented in Figure 49. The energy signature of the static EPC (presented in red) underestimates the real energy consumption of the B1.3, indicating a significant performance gap. The energy signatures generated from the dynamic simulations, DEPC-AS (standard - presented in grey) and DEPC-AA (adapted – presented in yellow), are close to the fitting line of the actual energy demand (DEPC-O), even though their slopes are different. This indicates that the assumptions for the coefficient of performance of the HVAC were realistic. In addition, the slope of DEPC-AA is closer to the DEPC-O, which indicates that the assumptions taken to adapt the model were in the right direction. Overall, this case study indicated that the dynamic models could be more accurate than the static EPC for the performance gap prediction. Further adaptation of the dynamic models could better predict the actual behaviour of the building.

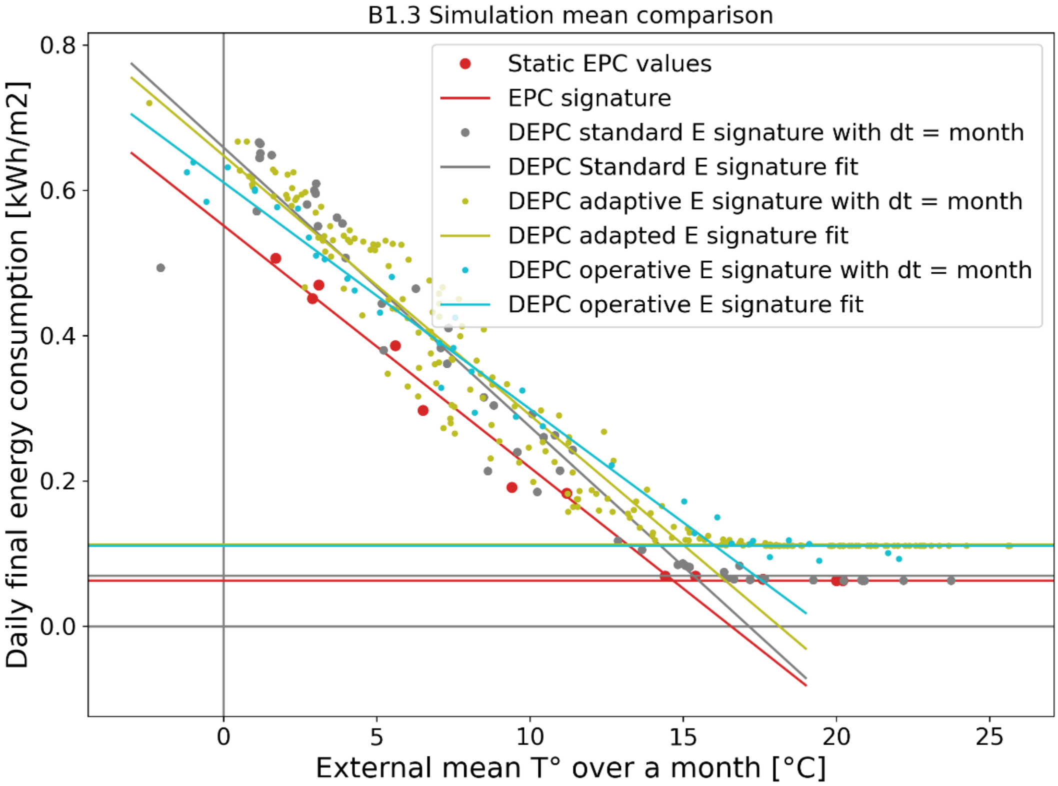


Figure 49: Energy signature as a result of the tested EPC schemes for the B1.3.

6.4 Building B 1.4 - Old and not renovated building

Figure 50 presents compiled the energy signatures of EPC, DEPC-AS, DEPC-AA, and DEPC-O for the B1.4. The energy signature of the static EPC (presented in red) overestimates the real energy consumption of the B1.4, indicating a significant negative performance gap, which is usual for old, not renovated buildings. The energy signatures generated from the dynamic simulations, DEPC-AS (standard - presented in grey) and DEPC-AA (adapted – presented in yellow), are close to the fitting line of the actual energy demand (DEPC-O). This indicates that the assumptions for the coefficient of performance of the HVAC were realistic. In addition, the slope of DEPC-AS is closer to the DEPC-O than the DEPC-AA, which indicates that the assumptions taken to adapt the model were not in the right direction. Overall, this case study indicated that the dynamic models could be more accurate than the static EPC for the performance gap prediction. Further adaptation of the dynamic models could better predict the actual behaviour of the building.

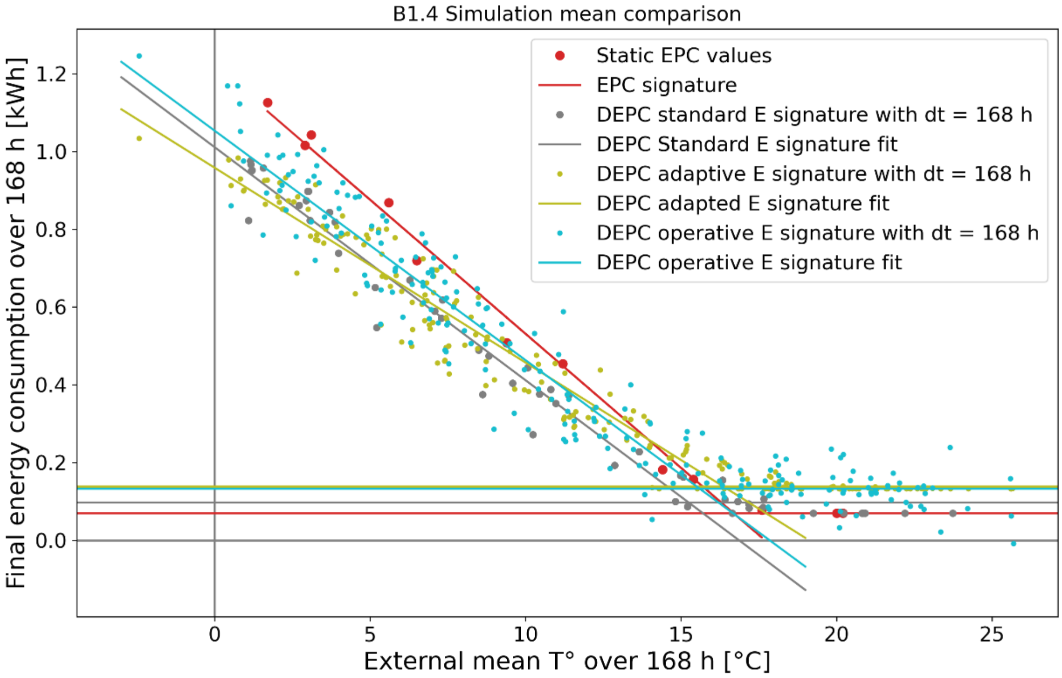


Figure 50: Energy signature as a result of the tested EPC schemes for the B1.4.

7 Demonstration case 5 – Geneva district

7.1 Methodology

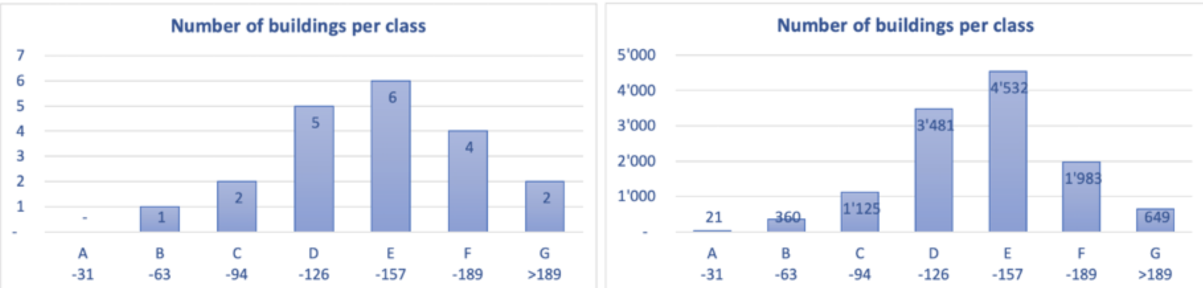
The methodology for the assessment of a sample of 20 buildings is straightforward and follows the steps listed here:

- Visit of the buildings by an independent EPC expert and fill up the E-DYCE inspection protocol.
- Realize an official EPC according to current business-as-usual practice by the expert.
- Re-visit the buildings by E-DYCE experts (ESTIA and OCEN) for quality control of the input data.
- Compare and analyze the gap between real (E_{HW}) and theoretical (EPC) heat consumption
- Use methodologies developed in E-DYCE to improve public policy monitoring.

7.2 Statistical representability of the upscaling sample.

7.2.1 Description of the sample

The E-DYCE statistical sample consists of 20 different entrances of multifamily residential buildings of 30,596 m^2 surface area owned by the same company (CPEG). The company owns 575 entrances covering 1,060,000 m^2, representing 5% of the Geneva Canton database. The building stock of CPEG was following the Geneva Canton energy consumption profile until 2017. Still, with a voluntary energy saving policy after 2017, there is an increasing gap between CPEG and Canton building stock. The total Canton multifamily residential building stock consists of 12,151 entrances of a total surface area of 19,339,073 m^2 in 2019.



Year	2019
Number of buildings	20
m² Heat Reference Area	30'596
Total heat consumption (GWh)	4.0
Mean E_{HW} (MJ/m²)	466
Mean E_{HW} (kWh/m²)	130
Tones of CO2 emissions	950
Greenhouse effect emissions kgCO2/r	31.1

Year	2019
Number of buildings	12'151
m² Heat Reference Area	19'339'073
Total heat consumption (GWh)	2'497.9
Mean E_{HW} (MJ/m²)	465
Mean E_{HW} (kWh/m²)	129
Tones of CO2 emissions	581312
Greenhouse effect emissions kgCO2/r	30.1

Figure 51: Energy profile of the E-DYCE sample (left) and the whole Canton building stock (right).

The energy database of Canton collects data from specially authorized energy experts that translate information on the bills (kWh, m^3 of gas, l of oil, tones of wood) of final energy for heating and hot water

(E_{HW}). The same experts should also declare that heated surface area is measured according to the norm with a precision of ±5%.

The heat consumption data do not correspond to the total energy consumption of the EPC, which includes as well electricity for ventilation, cooling, lighting, and general use. The same EPC methodology is used to determine a partial energy class, including only heat for heating and domestic hot water. The energy classes are presented in Table 13.

Table 13: Scale for E_{HW} class ranges

Lower limit	Energy Class	Upper limit
	A	≤ 0,50 EPgl' (31 kWh/m^{2}y)
0,50 EPgl' <	B	≤ 1,00 EPgl' (63 kWh/m^{2}y)
1,00 EPgl' <	C	≤ 1,50 EPgl' (94 kWh/m^{2}y)
1,50 EPgl' <	D	≤ 2,00 EPgl' (126 kWh/m^{2}y)
2,00 EPgl' <	E	≤ 2,50 EPgl' (157 kWh/m^{2}y)
2,50 EPgl' <	F	≤ 3,00 EPgl' (189 kWh/m^{2}y)
> 3,00 EPgl'	G	>3,00 EPgl' (189 kWh/m^{2}y)

7.2.2 1.3.2 Energy consumption and CO2 emissions of the E-DYCE sample

The E-DYCE sample of 20 buildings was selected to match well the energy consumption compared to the entire Canton database profile. After 2010 the sample building stock follows the entire building stock energy consumption profile (Figure 52) tightly. In 2019 E-DYCE sample at 466 MJ/m^{2}y was almost the same as the whole building stock (465 MJ/m^{2}y). Regarding GHE emissions, the E-DYCE sample was at 31.1 kgCO2, while the whole building stock was at 30.1 kgCO2.

The sample and entire building stocks are also similar in terms of building size (1530 and 1590 m2 respectively), typology, age distribution, and use.

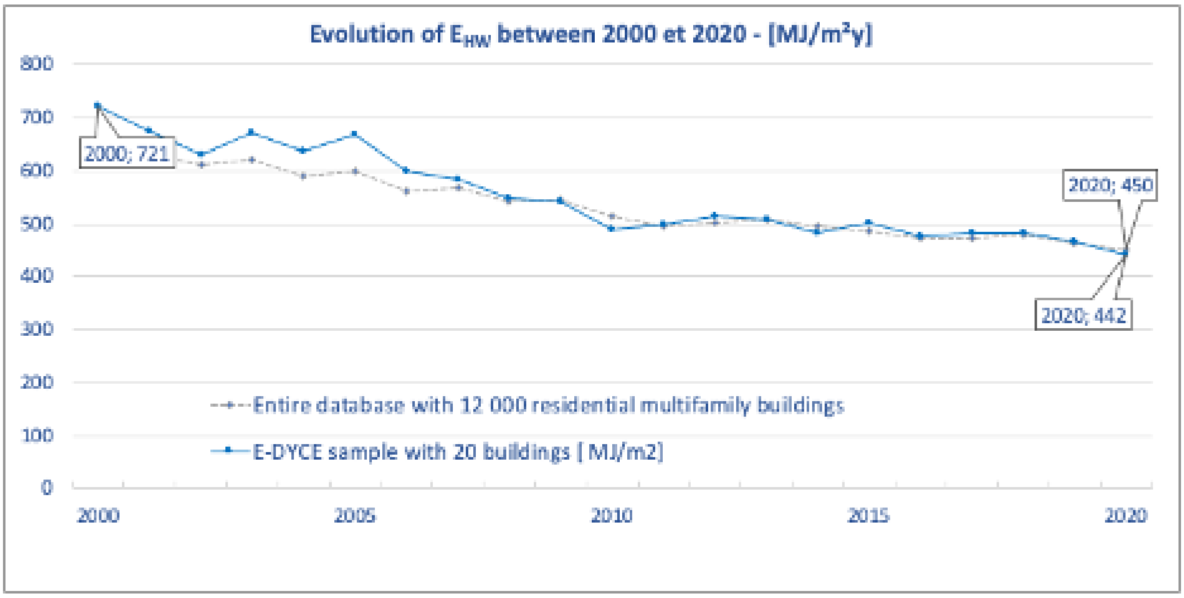


Figure 52: Evolution of the EHW of the E-DYCE sample and the entire Geneva building stock of residential buildings since 2000.

7.3 Comparison between measured and EPC expected energy consumption

7.3.1 1.4.1 E_DYCE sample envelope class and measured E_{HW} class

As presented in Figure 53 and Figure 54, the envelope energy performance according to the EPC is not correlated with the measured heat consumption for the E-DYCE sample of 20 buildings. Pessimistic EPC labelling could lead to false expectations for energy savings of class F and G buildings and consequently to wrong decisions.

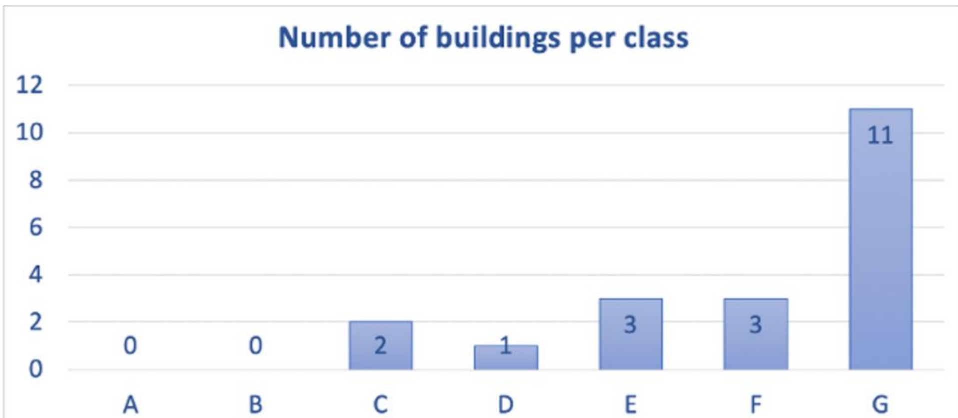


Figure 53: Envelope energy class according to Swiss EPC

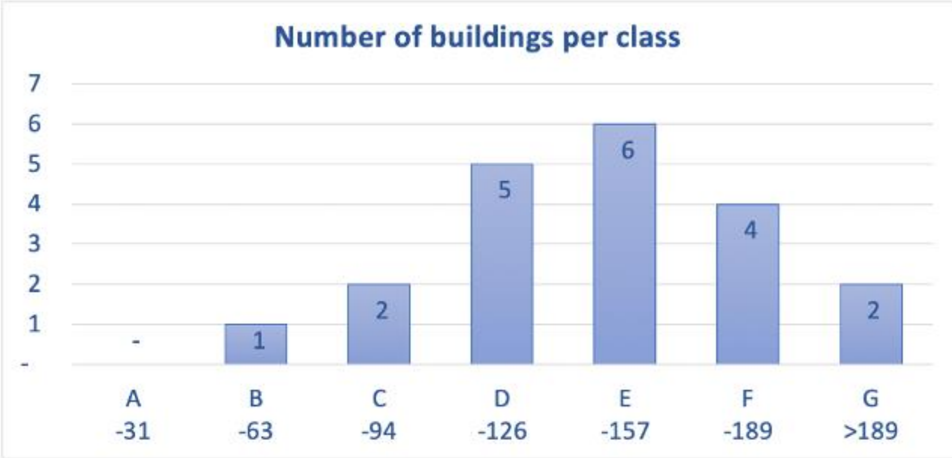


Figure 54: Envelope energy class according to measured heat consumption

Possible solutions to this problem could be:

- Use the measured E_{HW} of the last three years as a reference for energy savings instead of the envelope energy class according to the certificate.
- Use the certificate with standard conditions only to set requirements on the envelope but not to assess energy savings.
- Adapt the conditions of use as close as possible to reality, consolidating them by monitoring or collecting information during the on-site inspection to calculate the expected savings.
- To avoid making assumptions about the situation before the renovation, do not link the level of requirement to a relative saving (reduction of classes, percentage saving) but to a fixed objective according to the renovation context (e.g., 450 MJ/m^{2}a – 125 kWh/m^{2}y after optimization, 200 MJ/m^{2}y - 55 kWh/m^{2}y after global renovation, 110 MJ/m^{2}a – 30 kWh/m^{2}y for a very high energy standard renovation).

7.3.2 High energy performance renovated buildings label and measured class.

In this section are compared 85 buildings renovated with requirements E_{HWVC}<30 kWh/m^{2}y for eight buildings (<class A) and E_{HWVC} <55 or 60 kWh/m^{2}y for 77 buildings (<class B). The real energy performance of these labelled buildings is far (very far) from the label expectations, as presented in Figure 55 and Figure 56.

If the energy consumption after renovation is too optimistic according to labelling calculations, it could also create false expectations of savings and therefore generate frustrations of failure after renovation (performance gap). It is impressive to see the exact opposite phenomenon we see in existing old buildings. On paper, the building owner and the society who subsidized the renovations bought a promise for building A or B, and in the end, we have no class A building. We generally have 44 out of 85 classes for non-refurbished buildings, classes D, E, or even F.

A possible solution for this problem could be to use "realistic conditions of use" to assess post-retrofit expected energy consumption (indoor temperature, hot water requirements, window screening, ventilation rates, heating, and cooling outputs).

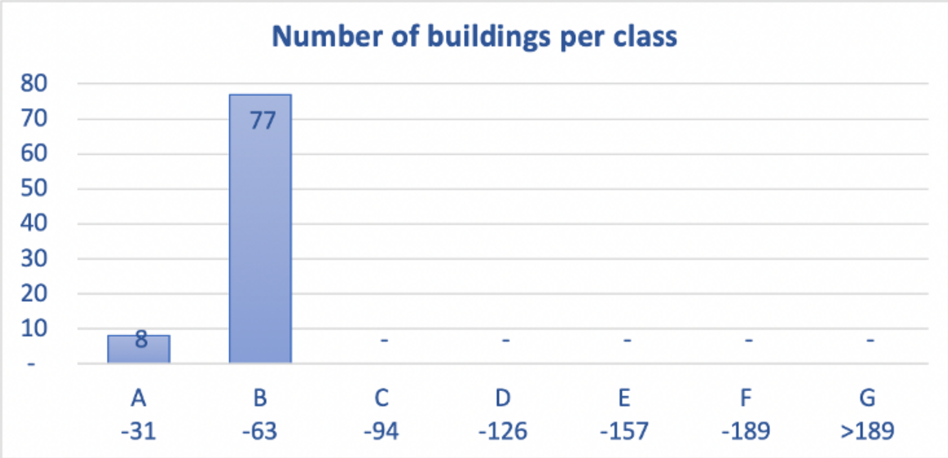


Figure 55: Expected E_{HW} of labelled high energy performance renovations

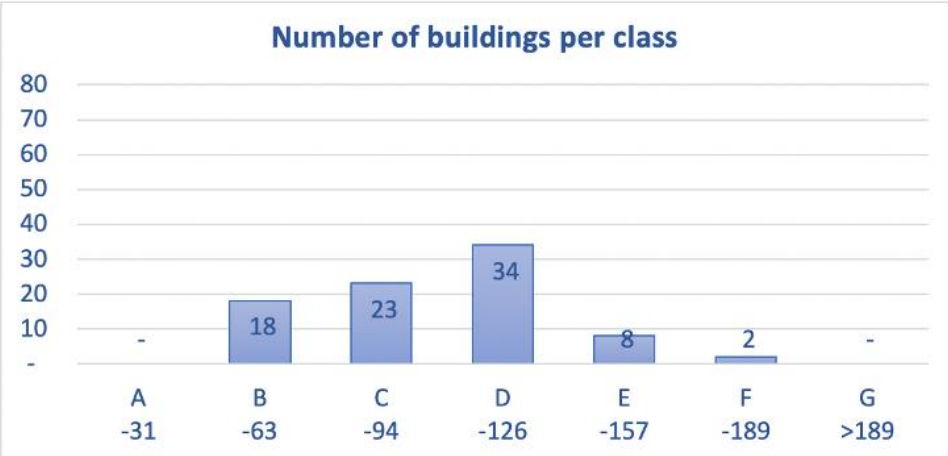


Figure 56: Measured E_{HW} in 2020

7.4 Use of measured historical energy consumption for policy implementation monitoring

This technique consists of comparing the evolution of real energy performance through the years and comparing a target sample with a reference sample, as shown in Figure 57 for CPEG building stock. The reference sample could be a sample of buildings that did not receive any renovation, but it could also be a large building stock like the entire Geneva Canton database. A real effect on the energy performance of the sample group of buildings can be read by a different slope in the evolution curve.

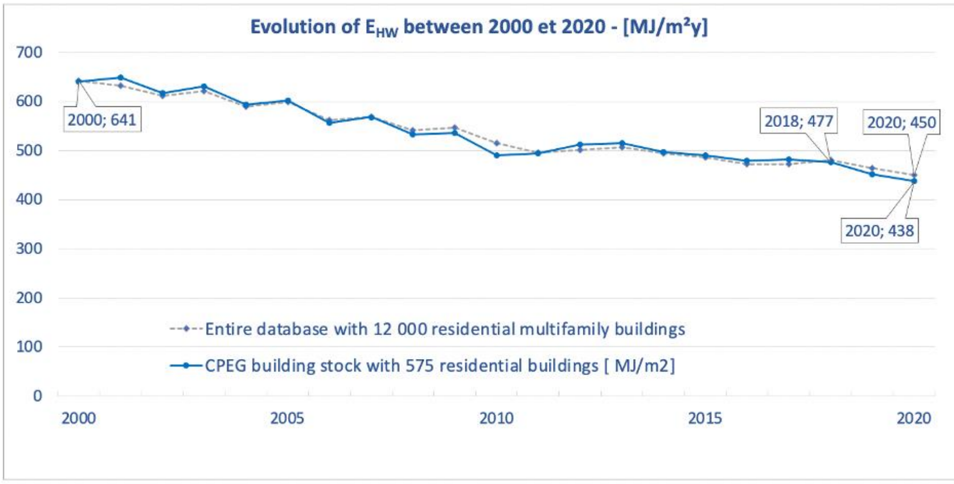


Figure 57: **Evolution of the E_{HW} of the entire CPEG building stock and entire Canton building stock of residential buildings since 2000.**

As can be read in Figure 57, the CPEG building stock (5% of the Canton database residential buildings) follows the general heat consumption. The same discrepancies before 2010 are due to different calculation methods translating l and m^3 of follicle fuels into MJ/m^2. We can see clearly on this graph that the CPEG building stock is reducing its heat consumption at a slightly higher rate than the entire canton building stock. In 2018 both sets of buildings were consuming 477 MJ/m^{2}y, and in 2020 the canton set consumed 450 MJ/m^{2}y while the CPEG 438 MJ/m^{2}y. This is 12 MJ/m^{2}y, 2.7% lower energy consumption in 2 years. In 2021 this tendency continued, but the result set for 2021 is not yet complete. Thus, the comparison stopped in 2020.

This technique is powerful if you have historical energy consumption data. The result is direct for single actions applied on a number of buildings, but somebody may apply more elaborated statistical analysis to disaggregate the individual impact of multiple actions. In this study, we only consider single actions [6]. In the following section, this technique is illustrated in some actions showing policy failure and others showing policy success.

7.4.1 From performance gap to policy implementation gap

As soon as an energy policy measure is pronounced and seeks to change an actor's behaviour, it must be translated into energy savings. Recent studies in the field of building energy have widely demonstrated and administered the existence of performance gaps in Switzerland [7]. When these performance gaps are identified because of decisions taken by the public authority, this results in a policy implementation gap or even a policy failure.

To give an example, let us take the well-documented case of a project seeking a very high energy performance that was the subject of a public subsidy and a tax exemption for a period of 20 years. This case does not achieve the promised performance, resulting in the non-achievement of the project's energy objectives, misallocating public money, and subtracting public money from the Geneva taxpayer. This shows that the performance gap analysis goes beyond the pure energy aspects.

There is a need to quantify the performance gap to qualify the extent of the problem and even to correct inefficient past policy measures and decisions. In this perspective, OCEN wishes to evaluate the current policy framework under elaboration.

7.4.2 Examples of policy success and policy failure

In the first example, Figure 58, one can see the comparison of E_{HW} of two building sets revealing policy failure. The subsidized, for several years, deep renovations targeting 200-210 MJ/m²y heat consumption do not meet the objectives. The group of 85 buildings renovated in the period 2005-2017 compared to the entire building stock should reduce its heat consumption to the target value. However, its mean real E_{HW} is still at 317 MJ/m²y, showing a performance gap of ~100 MJ/m²y, more than 150%.

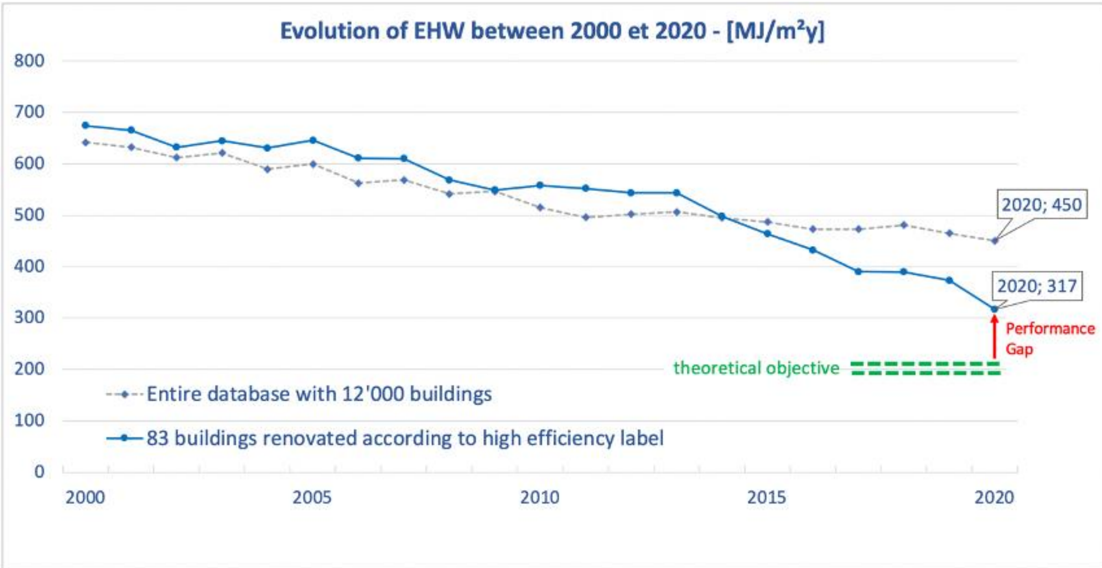


Figure 58: Example of policy failure reviled by historical real energy consumption analysis

In the following Figure 59, two graphs are presented. The left graph presents a set of 26 buildings with single glazing non-renovated windows, while the right graph presents a set of 37 buildings with single glazing renovated between 2010 and 2018, replaced with double or triple glazing windows. Comparing these two graphs, one can see a policy success of energy law in Geneva obliging building owners to change single glazing before 2019. On the left graph, buildings with single glazing consume more compared to the Canton average, and on the right graph, the effect of the law application brings the set of renovated buildings to the Canton average.

Figure 59: The left graph shows E_{HW} of a group of 26 buildings with non-renovated single glazing windows. The right graph shows E_{HW} of 37 buildings with renovated single glazing windows.

7.4.3 Limits of the yearly monitoring time step

The analysis of the annual heat consumption shows the clear benefits as outlined in the previous sections. However, the method has limitations. In the example presented in Figure 60, the public authority wishes to evaluate the effectiveness of a subsidy program for the renovation of ventilation systems with demand control ventilation and avoid dead band effects, which are suboptimal from the point of view of the public good. The fact is that it takes 2 to 3 years to get feedback based on annual consumption. This waiting time makes any corrective action difficult, if not impossible. Above all, this waiting time is even more problematic in a period of declared climate emergency and current energy shortage.

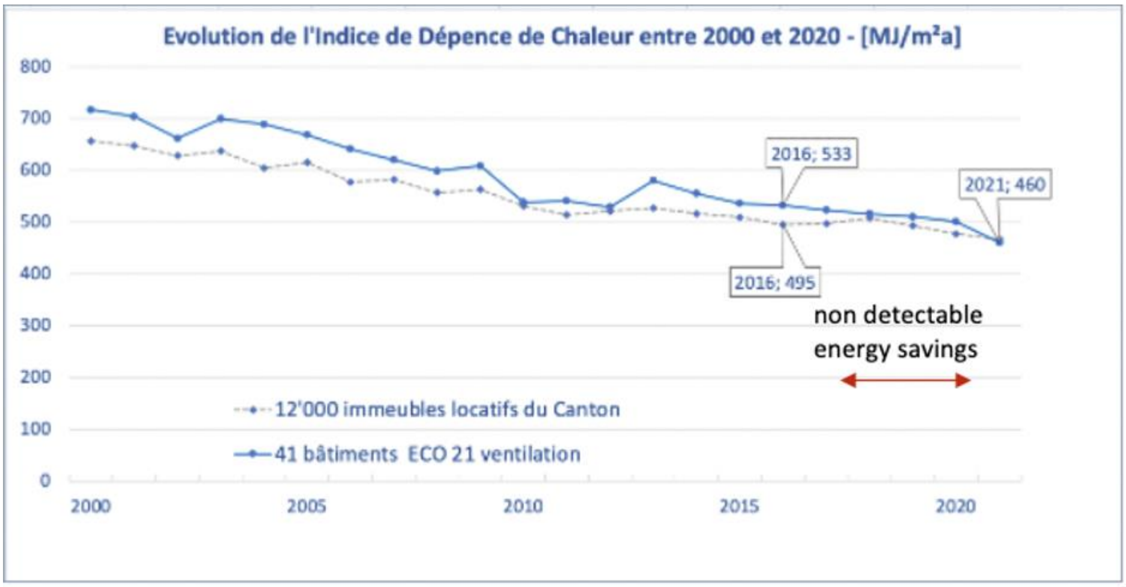


Figure 60: A set of 41 buildings with renovated ventilation systems between 2017 and 2019 show a real energy reduction in 2021, 3 years after the program monitoring.

7.5 Potential E-DYCE further contribution to the steering of public energy policies

E-DYCE proposes methods and tools in 3 dimensions: D-EPCs propose a simplified methodology to dynamically simulate the building energy performance and compare monitored and simulated results with shorter time steps. E-DYCE also proposes a middleware infrastructure putting together the simulation and monitoring approach.

7.5.1 Dynamic simulation according to D-EPC

Dynamic simulation, according to D-EPC, enables the public authorities to promote actions acting in the dynamic behaviour of the building. For example, demand control or ventilative cooling ventilation strategies cannot be simulated by current EPCs. The same happens with smart technologies optimizing the technical installation operation, such as predictive control of heating or hot water storage. We will try to test this type of energy policy measures potential through D-EPC simulations on the four Geneva case studies in the second part of the project, EDYCE D5.6. In other words, it enables the public authorities to produce ex-ante policy evaluations while designing new measures. Case study building B1.3 participated in the public subsidizing program and renovated its ventilation system to a demand control ventilation. Using the PRE-DYCE simulation framework, we would like to verify if the dynamic simulation predicts better energy savings and if ex-ante verification of the promoted measure could be reliable.

7.5.2 Monitoring with a shorter time step (monthly, weekly, hourly)

E-DYCE developed protocols for dynamic monitoring and interpretation of the results of a shorter time step. We will use these tools to test the E-DYCE case studies for faster feedback after implementing policy measures. In other words, it enables the public authorities to produce ex-post policy evaluations shortly after implementation and undertake corrective measures. In sensitive energy public subsidies, public authorities may, for example, require a declaration of monthly energy consumption immediately after commissioning to verify the effectiveness of the subsidized measure. In the project's second phase, this energy signature monitoring methodology will be evaluated in case study B1.3. OCEN is interested not only in the methodology reliability but also in monitoring technical feasibility and cost.

8 Conclusion and further steps

The integration of the E-DYCE protocol in the four individual case studies resulted in precious feedback for the project. Initially, it became clear that the monitoring solutions available in the market are costly and difficult to be installed. This could make monitoring more broadly accessible. In the case of the project, it was possible to use existing oil level sensors in the oil tanks installed for remote oil billing (B1.1, B1.4). Existing comfort sensors for heating control in three case study buildings provided a free solution for temperature and humidity measurements in the apartments. This could not be the case for the majority of European buildings. Thus, alternatives or reusable material for temporary wireless monitoring are recommended. This solution demonstrated in building B1.3 gives promising results.

Geneva Cantonal Energy Office has demonstrated the power of measured data in tailoring and monitoring public policies. The existing static EPC approach is a good tool to push for a high thermal quality envelope. However, performance gap studies showed that a high-quality envelope is insufficient for a high-energy performance building. E-DYCE analysis with measured data confirmed and quantified this phenomenon in refurbished residential buildings in Geneva. Energy performance is standing on two legs: a high-performance envelope and a high-performance operation, in addition to a fossil-free energy source. Yearly measured data analysis showed how energy authorities disposing of historic series may evaluate how successful or failing a measure promoted by public policies is. However, this method is possible 2-3 years after the measure implementation. Real energy consumption analysis on case studies B1.1-B1.4 has shown that the energy signature approach with a shorter time step may indicate the measure success with partial data of some months. Additionally, comparing the measured hourly, weekly or monthly data with the D-EPC energy signatures may give a much more precise insight into performance divergence. The more the D-EPC energy signature is adapted to the real conditions, the better the real performance evaluation.

In the project's second phase and having the monitoring setups running on the four Swiss case studies, we may go deeper to demonstrate concretely how someone may use the E-DYCE D-EPC to optimize building operation and reduce energy consumption.

With building B1.2, where we have a performance gap of a new high-performance labelled building, we also have a lack of comfort. In the past, there was a conflict between energy savings and comfort with occupant complaints. The company optimizing the building energy performance was obliged to make some trade-offs playing with the indoor temperature in order to find an acceptable compromise. With the D-EPC simulation framework, we may demonstrate how someone may use this tool to evaluate the energy cost of better indoor comfort conditions instead of trial and error. With the D-EPC approach, we may demonstrate how the process may be inversed. Instead of waiting to notice the error in the monitoring for correction, we calculate, find the correct temperature setting and use monitoring to verify the real result. This approach reduces the risks of occupant discomfort and annoyance and increases the confidence of the energy specialist who optimizes the systems.

With building B1.1 remaining small performance gap seems to come from poor boiler efficiency. A project for replacing the oil boiler with a heat pump is ongoing. Optimal dimensioning anticipating operation optimization knowing the dynamic profile through the D-EPC simulation framework and KPIs confirmed with dynamic energy consumption measurements is now possible to test using the first year monitoring results.

OCEN policy evaluation showed not only the power of yearly energy consumption monitoring and analysis but also its limits. Ventilation refurbishment and optimization with a better demand control system are supported by public subsidies. It needed three years to notice the first real results of the policy's success. Using case study B1.3 dynamic monitoring results, the interested public authority may reduce the time for ex-post public policy evaluation and using D-EPC framework ex-ante verification. Demand control ventilation gains are due to the dynamic nature of ventilation and can be simulated only with a dynamic simulation program. Next year dynamic monitoring will reveal the real validity of this theoretical hope. Validation and demonstration of rapid feedback of energy-saving actions are necessary for OCEN before integrating this kind of tool into public actions.

Building B1.4 renovation roadmap is under elaboration by a design team composed of architects, technical engineers, and building physicists. D-EPC simulations anticipated the real expected energy performance of the building with realistic conditions of use adapted to the observed ones. The design team and the owner signed a contract for a public subsidize according to the real measured performance of the building. D-EPC results are already communicated to the design team so that they anticipate and avoid the energy performance gap. Continuous monitoring according to the E-DYCE protocol will dynamically detect any drift from the expected D-EPC energy performance and help the technical team control the real energy performance giving a higher chance of the performance bonus. According to the final evaluation of this methodology, OCEN will include it in its toolbox to solve the energy performance gap. An existing performance gap (~160% average for deep high energy performance labelled renovations of a residential building) constituting a policy gap and unsolved will become a policy failure for the public authority.

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