Prescient building Operation utilizing Real Time data for Energy Dynamic Optimization

WP7 – Demonstrations in operational environment

D7.6 – Demo site report #6 N. Denmark

Version 1.0

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PRELUDE CONSORTIUM PARTNERS

	Participant organisation name	Country
1	AALBORG UNIVERSITET	DK
2	TAMPEREEN KORKEAKOULUSAATIO SR	FI
3	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	ES
4	POLITECNICO DI TORINO	IT
5	FORSCHUNG BURGENLAND GMBH	AT
6	UNISMART - FONDAZIONE UNIVERSITÀ DEGLI STUDI DI PADOVA	IT
7	BRUNEL UNIVERSITY LONDON	UK
8	EMTECH DIASTIMIKI MONOPROSOPI IDIOTIKI ETAIREIA	EL
9	CORE INNOVATION AND TECHNOLOGY OE	EL
10	ESTIA SA	CH
11	EUROCORE CONSULTING	BE
12	IREN SMART SOLUTIONS SPA	IT
13	LIBRA AI TECHNOLOGIES PRIVATE IDIOTIKI KEFALAIOUCHIKI ETAIREIA	EL
14	STAM SRL	IT
15	LA SIA SRL	IT
16	TREE TECHNOLOGY SA	ES
17	1A INGENIEROS S.L.P	ES
18	DIMOS ATHINAION EPICHEIRISI MICHANOGRAFISIS	EL
19	BLOK ARCHITEKCI SPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	PL
20	CAISSE DE PREVOYANCE DE L'ETAT DE GENEVE	CH
21	INNOVACION Y CONSULTING TECNOLOGICOSL	ES
22	CORE INNOVATION CENTER NPO	GR

EXECUTIVE SUMMARY

Deliverable 7.6 (Demo site report #6 N. Denmark) is part of WP7 (Demonstration in operational environment). The report is public. The aim of T7.6 is to support the integration of the two NZEB residential single-family buildings into the PRELUDE platform and to integrate into these buildings, under real operation, the identified PRELUDE technologies. Data from the Danish demonstrations was also used for the development/validation of the PRELUDE technologies whenever possible. This reportsummarizes also the requirements and expectations of the Danish NZEB buildings for bothenergy use and IEQ. These are considered common for both buildings.

The report summarizes and elaborates on the motivation to use the selected demonstration cases for the enablers developed by PRELUDE and defines the intervention plans and the rationale for implementing or not the individual solutions developed by PRELUDE .

The task was to document the state of the buildings, their systems and the modifications that were carried out from the beginning of the project until M30. This process is carried out for each building and is documented in this report separately for each building case. The descriptions of buildings, systems, and modifications are documented in a detailed manner to provide a rich documentation of the technology enablers produced by PRELUDE. This includes securing the extensive monitoring of both buildings and the connection of the monitoring infrastructure to the PRELUDE platform (FusiX middleware) together with the identification of available data points in the middleware. Moreover, the first analysis of the data (energy and IEQ) was carried out to better identify the potential of the implementation of technology . Finally, the outcome of bilateral discussions and planning for each demo building and the PRELUDE technologies is summarized. Each technology that was identified as a potential for implementation and / or identified as being of value to the buildings or valuable for the technology to be tested in the operational environment is described.

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ABBREVIATIONS

ABM	Agent Based Model
AHU	Air Handling Unit
AL	Anomaly Level
API	Application Programming Interface
AWS	Amazon Web Service
CAV	Constant Air Volume
COP	Coefficient of Performance
CPU	Central Processing Unit
CV-RMSE	Coefficient of Variation of Root Mean Square Error
DCW	Domestic Cold Water
DH	District Heating
DHW	Domestic Hot Water
DMI	Danish Meteorological Institute
DPC	Data-driven Predictive Control
DSS	Decision Support System
DW	Dishwasher
ECM	Energy Conservation Measure
EPIQR	Energy Performance Indoor Environment Quality Retrofit
EPS	Extruded Polystyrene
EUDP	Energiteknologiske Udviklings- og Demonstrationsprogram
FPR	False Positive Rate
FTP	File Transfer Protocol
GUI	Graphical User Interface
HP	Heat Pump
HVAC	Heating Ventilation Air Conditioning
IE	Indoor Environment
IEQ	Indoor Environmental Quality
IHC	Intelligent House Control
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
IRR	Internal Rate of Return
KPI	Key Performance Indicator
LCOE	Levelized Cost of Electricity

LLE	Living Lab Energetikum
LSTM	Long Short-Term Memory
NMBE	Normalized Mean Bias Error
NZEB	Nearly Zero Energy Building
MAE	Mean Absolute Error
MAAPE	Mean Arc-tangent Absolute Percentage Error
MILP	Mixed Integer Linear Programming
ML	Machine Learning
HMM	Hidden Markov Model
KS	Kitchen Sink
NDA	Non-Disclosure Agreement
NHC	Niko Home Control
NPV	Net Present Value
PI	Piping and Instrumentation
PLC	Programmable Logic Controller
PM	Predictive Maintenance
PV	Photovoltaic
RES	Renewable Energy Source
REST	Representational State Transfer
RH	Relative Humidity
ROC	Receiver Operating Characteristic
ROI	Return of Investment
SFTP	Secure File Transfer Protocol
SH	Space Heating
SOC	State of Charge
TPR	True Positive Rate
UFH	Underfloor Heating
VOC	Volatile Organic Compounds
WB	Washbasin

1. INTRODUCTION

This report summarizes the work done to prepare Danish demonstration case buildings for the enhanced integration of PRELUDE technologies. The objective was to obtain building owners' acceptance and align project objectives with identified demo needs. It should be highlighted that the owners/tenants of the two Danish demonstration buildings provided access to their buildings and consent to the project on a fully voluntary basis, and were not stakeholders in the project consortium. This report refers to two newly built Danish single-family buildings named "Ry" and "Egernsund". The introduction part is common for the two buildings, while the rest of the report elaborates on each building separately.

In general, the common PRELUDE baseline methodology was followed but differentiated according to the individual needs of each use case. The overall methodology bridged PRELUDE technologies to the buildings by utilizing the common middleware, FusiX, which supports data flow from buildings to models and from models to buildings. PRELUDE allows for both automated communication if it was present and accessible in the building or through human interface, both experts and tenants in the building. Therefore, PRELUDE approach is flexible to the building's technology advancement readiness. The overall PRELUDE goals and motivations can be aligned for both Danish demo sites, and these are:

• To generate energy and financial savings

• To improve the quality of life and well-being of the tenants (improved indoor climate)

• To assess the potential of installing renewable energy sources, energy storage, and electric vehicle charging stations and quantify the investment

• To assess the comfort levels currently attained in their property by analysis of available but untapped monitored data

• To assess potential additional investments on a cost-efficiency basis

• To reduce maintenance costs through the implementation of predictive maintenance

Furthermore, the initial motivation and goals for the Danish demonstration cases were to detect the magnitude and reasons for the performance gap, which is the difference between the actual and the theoretically anticipated energy use in newly built NZEB houses. If possible, the objective was to remedy the energy operation of the building by adjusting the comfort conditions and monitor user acceptance.

The following chapter 1.1 provides an overall but thorough elaboration on the Danish demonstration case motivation and preparation. Detailed information about the building and its systems descriptions is provided in chapter 2 and 5 respectiveley for Ry and Egernsund. Interventions, monitoring and connection to PRELUDE middleware, FusiX, are further provided in the chapters 3 and 6 on "Preparation of demonstration case". In those chapters, each building is also evaluated based on an exploratory data analysis approach to better understand the good and bad buildings' operation and potential for improvement and alignment for PRELUDE technology implementation.

In the final part of the report, chapter 4 and 7 "Planning and implementation of project solutions," individual PRELUDE technologies that have the potential for demonstration in the Danish pilots or that utilize data from Danish pilots for their development are described including plan of their implementation plan and expected outcomes. The conclusion and elaboration on the possible impact is given in the chapter 8 "Expected impact". Report finishes with conclusions in chapter 9. The appendixes include an exhaustive lists of data points included in FusiX.

1.1 Objectives and motivation

The two selected demonstration buildings, "Ry" and "Egernsund", represent the new generation of NZEB buildings. Both are single-family houses, with Ry located in the Central Jylland region and Egernsund in the Southern Denmark region. These buildings are officially labelled as highly energy-efficient and fall into the most ambitious energy class for residential buildings in Denmark, making them representative of newly constructed single-family buildings. Detailed presentations of Ry and Egernsund can be found in chapter 2 and chapter 5 of this report, respectively.

A common observation for NZEB buildings involved in demonstration cases is that they consume significantly more energy in real operation than predicted through compliance energy calculations [1-2].

From the energy labels and measured energy of a large sample of new Danish buildings, it is observed that the houses that obtain the highest energy label (mostly new buildings like the two Danish demonstration cases) also reflect the highest energy performance gap. While their actual energy performance often exceeds the compliance performance by 100% or more, detailed reasons for the performance gap are still understudied. This observation is alarming and indicates that NZEB buildings, despite being equipped with energy-efficient solutions, do not perform as intended. It also suggests that user decisions in these houses lead to underperforming NZEBs. A common argumentation is that the difference in energy use is due to different loads and that, for example, the number of people is different than in asset calculations. The very recent results by BUILD AAU, not yet published, indicate that this might not be a sufficient argument, especially for energy use. The initial results indicate that the user behavior in terms of, set points and venting is more dominant for energy use than the presence and loads. It can be concluded that NZEB buildings require remedy actions while in operation. These remedy actions might include facilitating operation and raising user awareness. A better understanding of these buildings, including the rebound effect, the development of optimization strategies for energy efficiency, smarter operation, and user awareness enhancement are required if plans to decrease emissions and energy use are to be fulfilled.

Under the current Danish Building Regulations [3], all new buildings must receive at least energy label class A2020 (<27 kWh/m2 year). However, for the investigated buildings in the project, the still-valid A2015 energy label (≈30 kWh/m2 year) was used during their construction. Thus, the focus on NZEB buildings with even stricter energy performance expectations is relevant for the present and the future. Moreover, the replication potential for these buildings is excellent, albeit for different reasons than other demo cases.

The original motivation for the Danish demonstration cases was to use PRELUDE's data-driven approach to better understand the relationship between indoor environment performance and energy use in NZEBs. The goal was to identify the key parameters and behaviors responsible for the performance gap in NZEBs. This study is presented in the exploratory data analysis carried out in this report to the extend collected data allow for it, see chapters 3.5 and 6.4. Furthermore, the results of this study will be used to implement data- driven corrective actions to remedy the performance gap. This motivation was further enriched by the possibility to implement and test PRELUDE proactive measures that address indoor thermal comfort and energy use, such as the PREDYCE tool and Comfort-Energy Efficiency optimizer for human interface and optimized heat pump operation, predictive maintenance module, and enhancement of renewable systems by RES selector. To quantify savings by the end of the project, an assessment is to be carried out using the Measurement and Verification methodology, to the extent the collected data allow for it.

1.1.1 Monitoring plan specification

Before the PRELUDE project began, both Danish demonstration buildings were approached to assess their suitability and willingness to serve as demonstration cases for the possible PRELUDE implementation. At that stage, it was concluded that both represented buildings with high-end technological solutions, namely: smart IoT, tight and high insulation envelopes, energy-efficient systems with high COP and heat recovery possibilities, as well as renewable energy production with storage possibilities (only Egernsund has a battery and thermal storage), and that they were fully operational. Therefore, it was expected that in PRELUDE, buildings would not be equipped with additional facilities as they already reflected a very advanced level of smartness and that the intervention level would be insignificant. Still, it was planned that they might be equipped with insignificant additional sensors where required, and that their operation settings would be modified.

This initial assumption materialized only to some extent, as after a thorough inspection of both houses, it was discovered that several facilities did not work as intended, control functionalities were not present, and monitoring infrastructure was either faulty, not present, or, if present, not logging, and required significant effort to be bridged to the PRELUDE middleware. Moreover, access to data required signing a nondisclosure agreement with a third-party provider, which significantly delayed access to data. All these insufficiencies required a significant effort to make the buildings more operational and enable them to connect to the PRELUDE middleware, FusiX, and, therefore, suitable for PRELUDE technology implementation. These interventions are further elaborated in detail for each building in chapters 3.1 (Ry) and 6.1 (Egernsund).

The data acquisition capacities of each demo case were refined and consolidated, also taking into account technology requirements from project technology partners. This process was also more challenging and time-consuming than initially assumed since technologies were continuously under development while the demonstration cases had to a high extent anticipated data requirements for these technologies, especially predictive ones that require a very long data history to train their model algorithms. Moreover, due to unexpected challenges in the buildings and long delivery times for some components due to COVID and post-COVID broken supply chains, logging and interventions were delayed, and, as a consequence, resulted in shorter data availability than initially anticipated. After substantial effort, significant data availability was secured for both buildings. The monitoring infrastructure is provided in detail in chapter 2.2.7 (for Ry) and 5.2.7 (for Egernsund), and data availability through the FusiX middleware is given in Appendix B (Ry) and C (Egernsund).

The unexpected challenges concerning the establishment of a monitoring system and access to data and missing data are anticipated to be common for other buildings falling into the same building typology. These challenges limit the scale-up potential of PRELUDE and similar solutions that highly depend on data availability, and, as the reader of this report can see, require significant effort. Further conclusions on that aspect are included in the closing chapter 9 of this report.

1.1.2 Intervention plan

The PRELUDE intervention began with an exploratory building inspection and an assessment of the building's general state, with a particular focus on facilities and available monitoring systems. These assessments led to several necessary interventions. The building presentations are provided in chapter 2.1 (for Ry) and 5.1 (for Egernsund). Since both buildings are newly built, the envelope elements were intact and were not inspected in any other way than through a review of technical materials and drawings, which provided the necessary information to develop the white and grey box models required by the PREDYCE module and the Comfort and Energy-Efficiency prediction module.

Several on-site inspections of the building and the collection and review of technical documentation were required for the mechanical facilities and monitoring systems for indoor comfort and energy. Since both buildings are newly built, the technical documentation was considered complete and provided significant useful information. It is often the case that, for older buildings, documentation is often fragmented or even fully missing, which was not the case in this instance.

In general, different certification schemes such as DGNB, BREEAM, and LEED, which require the collection of information about the building and its facilities, can be helpful in this regard. They are considered supportive of the PRELUDE concept and similar data-driven approaches. The Egernsund building was certified according to DGNB scheme and documentation collected in this precess could support PRELUDE analysis of the building.

The report highlights that understanding the control and operation of building facilities such as heating, ventilation, domestic water, renewable energy production, and monitoring systems for indoor comfort and energy monitoring was challenging. The Egernsund building was particularly challenging due to its complex system for heat production and storage, PV production with battery and electricity management system, and two ventilation systems, all suffering from unclear control strategies. The required interventions for Egernsund are detailed in chapter 6.1. In the Ry case, although the assessment was significantly easier due to a more standard solution being implemented, the initial control system of the heating system was unclear and had to be redone, and the ventilation system was unbalanced. Additionally, the house energy meter was recommended to be changed to account for PV production, and the logging infrastructure was re-established. The exploratory building inspection revealed a common observation that although facilities were present, they often did not work as intended and suffered from unclear control strategies. Systems were often not properly commissioned, leading to faulty or unintended operation, requiring time-consuming interventions to implement remedy actions and correct operations. These interventions were carried out continuously in the first 30 months of the project duration for the Danish demonstration buildings.

The second type of intervention was conducted concurrently with the exploratory building inspection and correction actions to building facilities. It involved the implementation of additional monitoring infrastructure and logging capabilities, as well as connectivity to the FusiX middleware. This intervention was necessary to collect data from buildings to support the implementation and development of PRELUDE technologies. Long historical data (often 1 year or longer) was required for several predictive technologies, including Predictive Maintenance, Comfort-Energy optimizer, Predictive Control module, Energy Balance forecast, and RES selector. The outcome of this intervention was the establishment of data logging architecture and different API connections to the FusiX middleware during the first 30 months of the project's operation. The summary of this work is presented in chapters 3.2 (for Ry) and 6.2 (for Egernsund).

The third type of intervention is focused on preparing for the demonstration of PRELUDE technology in the operational environment, which is scheduled to take place after month M30 and continue until the end of the project duration. Several PRELUDE technologies are expected to be hosted during this period.

For instance, it is planned to implement and test PREDYCE operation in the Ry demonstration in the operational environment in the summer of 2023. The required models have been developed and validated using existing operational data. The output has been confirmed, and the technologies to be optimized have been identified, namely shading and mechanical ventilation.

The Comfort and Energy-Efficiency optimizer, together with a customized GUI, will be implemented and tested in Ry and Egernsund, with a focus on load shifting of electrical appliances, energy demand response, and indoor comfort conditions. The specific implementation plan differs for Ry and Egernsund, and it is elaborated in the next chapter 1.1.3 and in more detail in chapter 4.4 (Ry) and 7.1 (Egernsund).

The RES selector requires long historical data, and thus the application of this module is expected to be completed towards the end of the project, by the end of 2024. Currently, the required data is being collected.

The Predictive Maintenance module is expected to be applied for data from Ry and Egernsund and will be used to study anomalies in the heat pump since data of sufficient quality is expected.

The fourth type of intervention involves providing required data and supporting the development of modules that serve other modules. For example, data for validation of predictive occupancy or higher values, such as aggregation and heating forecast models based on federated machine learning. These models do not contribute directly to demonstration buildings but provide additional value indirectly by creating more credible models or higher value in the ecosystem, such as information on aggregated prediction for the supplier or aggregator.

To better understand which PRELUDE technologies reflect the positive potential for implementation and possible reasons for performance gap detection, the following activities have been carried out: i) valid regional regulations for comfort and energy use were collected, considering the demonstration case typology, and used to indicate their as-is operation with regards to these, ii) exploratory data analysis was conducted to highlight areas for higher and lower potential of improvement, and iii) data collection was enriched, and support for connectivity to the FusiX middleware solution was provided to ensure availability of data for feeding into PRELUDE technologies, considering technology input requirements. The rationale for including or excluding a particular PRELUDE technology module is presented in the subsequent chapter 1.1.3. The detailed elaboration of module application analysis for the respective demo case is given in chapters 4 (for Ry) and 7 (for Egernsund).

1.1.3 Implementation of PRELUDE

The report describes activities carried out in the demonstration cases considering motivation and rationale to implement/not implement PRELUDE solutions. The PRELUDE solution is modular and therefore allows for application of only required and relevant technologies.

To better understand which PRELUDE technologies reflect the positive potential for implementation, the following activities have been carried out: i) valid regional regulations for comfort and energy use were collected considering demonstration case typology and use to indicate their as-is operation with regards to these, ii) exploratory data analysis was carried out to highlight areas for the higher and lower potential of improvement, iii) enrichment of data collection and support the connectivity to PRELUDE middleware solution for availability to fed PRELUDE technologies considering technology input requirements.

FusiX integration – Implemented. The connection to PRELUDE middleware is crucial because of the modular design of the project and the dependence of the modular PRELUDE technologies on data accessibility from the buildings through FusiX. Moreover, FusiX can act as common data middleware for explorative data analysis, as presented in this report, to identify actions to reduce the performance gap and identification for action for energy/comfort improvement. Significant effort has been invested in connecting both Danish buildings to FusiX. Details on data availability and FusiX integration progress can be found in chapters 3.2 (Ry) and 6.2 (Egernsund), as well as in Appendix B and C.

Dynamic Free Running 24h forecast – Implemented. The Ry demonstration case provides a more compelling application scenario for testing and demonstrating the PREDYCE 24-hour indoor comfort optimization capability, as the building is equipped with two technologies that the module can optimize: ventilation rate and solar shading. The ventilation rate in the Ry building is controlled by a balanced mechanical ventilation system, and shading is provided on the south-oriented façade windows. The 24-hour predictive control of the ventilation rate is planned through an API based on the signal from FusiX and PREDYCE simulation outcome. Similar control is expected for the shading system, although this has not yet been confirmed with the shading control solution provider. The planning and implementation of PREDYCE in Ry are described in more detail in chapter 4.6.

Indoor-outdoor correlation module – Not implemented. The indoor-outdoor correlation module is specifically designed for naturally ventilated buildings and is therefore less suitable for the Danish case buildings, which are equipped with balanced mechanical ventilation with heat recovery, filtering, and, if required, the possibility for mechanical heating and cooling activation (only Ry building). Therefore, a demonstration of the indoor-outdoor correlation module is not scheduled in the Danish demonstration buildings.

Weather and insolation prediction model- Implemented This module and data can serve other models. The model rely on weather databases and do not require interaction with buildings itself.

Occupancy model – Implemented. The occupancy model was first developed and validated using data from an office building, but it is expected to be used for residential buildings as well. Therefore, additional effort has been made to validate this model using data specially collected from the Ry demonstration case. The work on validating the model using Ry data is described in more detail in chapter 4.2.

District heating integration module – Not implemented. This technology was developed and described in Task 5.3 and Report 5.3. The work is based on a dataset from Aalborg district heating and is considered a case study. The nature of the district and its data is significantly different from the work presented in this report, which focuses on specific single-family buildings. The selected results of the application of the district heating integration tool for the district heating data will be presented in Deliverable 7.7.

VRE community – Not implemented. The Danish single-family buildings were identified as less relevant for the study of the electricity community and studies carried out by TAU partner.

Renovation roadmap and EPIQR analysis – Not implemented. As mentioned earlier in the report, both Danish demonstration cases are newly built and therefore renovations are not expected in the near future.

Dynamic energy forecasting – Implemented. Short-term energy use forecasting for total electricity use was possible for the Egernsund building, which had a sufficiently long historical dataset. The real-time prediction outcomes are integrated with the PRELUDE ecosystem via the FusiX middleware. To monitor, validate, and visualize the results, a dashboard interface was also developed using the open-source Grafana application. More detailed information on this work is available in Deliverable Report 4.2.

Comfort and Energy Efficiency optimizer and customized GUI (STAM) – Implemented. The 7-day prediction model for load shifting and scheduled control is considered a valuable asset for both Danish demonstration cases as it promotes user empowerment by providing them with the right information and suggestions regarding energy consumption efficiency, employing a user-friendly GUI. This activity is also in line with the objective of decreasing the performance gap and increasing user awareness. The prerequisite to be able to test the module in operational conditions is that the identified subsystems can be fed with compulsory input data and that there is sufficient historical data available (minimum 3 months). The more detailed plan for customized technology implementation in the Danish demonstrations is elaborated in chapters 4.4 (Ry) and 7.1 (Egernsund).

Data Predictive Control (FB/STAM) - Implemented. It was identified that demonstration of this specific application of forecast-based control scheme for the heat pump operation to demonstrate demand side flexibility by a power-to-heat application in the residential sector is more applicable to Egernsund demonstration case in which heating system is supplied from the heat pump with a buffer tank while the building is equipped with PV installation and battery. Still, there are system-inherent inefficiencies and additional monitoring data-points, e.g., electricity to heat pump that need to be implemented. Detailes are provided in chapter 7.2.

Predictive maintenance – Implemented. The module's simple approach and limited requirements make it advantageous for testing telemetry on anomalies for power and energy for HVAC systems in both Danish demonstration buildings, specifically for heat pump operation. The required input data for conducting predictive maintenance analysis are expected to be available within the project's duration. However, the question remains about the added value of the obtained outcome, which only provides information on if, when, and the severity of the anomaly. Due to the type of applied algorithm, the method does not provide information about the nature of the fault/anomaly and a more precise location of the problem. Nonetheless, it is always better than not receiving any alert at all. Details are provided in chapter 4.3 (Ry) and 7.3 (Egernsund).

Measurement and Verification (M&V) – Implemented. The M&V process focuses on the operating performance after commissioning and optimization, compared to the performance of standard operation before interventions and optimization measures were implemented. For Ry building, the required input data points and baseline period before the energy conservation measure (implementation of Comfort and Energy Efficiency optimizer by STAM) were identified, as described in Deliverable 4.3. The KPIs of special interest are the energy consumption reduced while staying within the comfort level, with an objective of 30% energy use decrease. During the M&V evaluation of Egernsund, the data points were not yet available in FusiX, and therefore, no baseline condition was established. However, this may need to be revised as data updates on FusiX are expected to provide historical data information for heating season 2022/2023 that could serve as baseline for season 2023/2024. Details are provided in chapter 4.7 (Ry) and 7.5 (Egernsund).

Aggregation model (TREE) – Implemented. The model utilizes historical data on district heating (DH) energy consumption from the Ry building to train its algorithm using a deep learning model (LSTM) within a federated learning architecture. The output is a decision support system for the supplier/aggregator, and no optimization is done for the Ry building itself. A more detailed description of the work is presented in chapter 4.1.

1.2 Overview of local regulations and standards – comfort and energy

For the demo houses in Denmark, the local regulations include the Danish Building Regulation. The building regulation contains many clauses to follow, and in some instances refers to different Standards that should be followed to fulfill the building regulation. This chapter contains an overview and summary of the selected clauses relevant for the specific Danish demo houses Ry and Egernsund, with special regard to energy use and indoor environmental quality. The presented overview also provides the minimum requirements that are expected from this type of building considering the regulation that were valid during the construction of the buildings. To carry out an evaluation of the building's performance and its assessment it is necessary to first understand the expectations from the building. This chapter serves this purpose.

The Danish Building Regulation

This chapter focuses on the clauses from the building regulation, that should be fulfilled, and is partitioned into the different relevant chapters of the Danish Building Regulation.

<u>Chapter 11 – Energy use and climate impact</u>

§ 259 – Energy frames for residential building, dormitories, hotels and similar

"For residential units, halls of residence, hotels, etc. the total energy supply demand of the building for heating, ventilation, cooling and domestic hot water per square meter heated floor area may not exceed 30.0 kWh/sq. meter per year plus 1,000 kWh per year divided by the heated floor area."

The mentioned energy frame is a Danish energy compliance, which determines the energy use for operation of the building. It includes energy used for heating, cooling, installations, and domestic hot water. This energy uses primary energy factors to consider how 'clean' the used energy is. The primary energy factor for electricity is 1.9, district heating is 0.85 and 1.0 for remaining sources of heat, where the respective efficiency is used.

The compliance calculation is performed in the program Be18, which takes information about the building, such as metadata from the building, information about the building envelope, ventilation, internal heat sources, domestic hot water and other installations. The result of the calculation is the energy frame of the building, expressed in an annual energy consumption per unit heated square meter.

The energy frame calculations represent the asset rating of the buildings and are carried out for the synthetic and standard load conditions. Still, these calculations are often used as benchmark to assess building's energy performance.

Chapter 19 – Thermal indoor environment and installation for heating and cooling systems

§ 385 – The thermal indoor climate of building must be sufficiently healthy and comfortable in consideration of their use.

According to § 385, the indoor climate of the building has to be analyzed according to the use. The demo house is a residential building. The indoor climate will be analyzed and assessed using DS/EN 16798-1.

§ 386 – In rooms where people stay for longer periods of time, it must be ensured that a satisfactory thermal indoor climate in terms of health and comfort can be maintained during the intended use and activities of the room.

Clause § 386 should normally be investigated before constructing the building using a simulation tool, however, it will be analyzed using a data-driven approach instead in this case.

Chapter 22 – Ventilation

§ 420 – Buildings must be ventilated to provide a satisfactory air quality and moisture with consideration of the use.

Based on clause § 420, enough ventilation should be provided to ensure a satisfactory air quality. This will be determined using DS 447, which refers to DS 16798-1 for the requirements of the indoor environmental quality.

§ 443 – In residential rooms as well as throughout the residential unit, supply of outdoor air must be present at any time at minimum 0.30 l/s per square meter heated floor area. This provision also applies to demand-controlled ventilation.

DS 439 – Code of Practice for domestic water supply systems

This standard describes the legislation valid for domestic water supply systems, which should be followed in Denmark. Among other things, it describes the minimum temperature that should be ensured in a domestic hot water system.

"*Due to risk of bacterial growth, it shall be possible to heat the water in water heaters to a temperature of at least 60 °C. Furthermore, the system should be designed so that the temperature of the water feed in all parts of the system does not drop below 50 °C under normal use and 45 °C at peak load."*

DS/EN 16798-1 – Energy performance of buildings – Ventilation for buildings – Part 1

Based on the Danish Building Regulations [3], some clauses regarding the indoor climate have been established. To evaluate the indoor climate, the building regulation refers to different standards to assess it quantitively, one of which is DS/EN 16798-1. Based on this standard, the temperature range, relative humidity range and maximum allowed CO_2 concentration are determined.

For the range, it is based on what building category the building should fulfill, the clothing level and the activity level. The building category refers to how strict the requirements for the indoor climate are, the clothing level refers to the amount of cloth a person is wearing, and the activity level refers to the metabolic rate of the people in the building.

For normal residential buildings, a building category II is chosen. The temperature in different seasons can vary significantly for each country. Therefore, the two seasons are defined in Table 1 and the corresponding temperature ranges for different building categories are defined in Table 2.

Table 1: Definition of different periods in the Danish weather.

Season	Months
Heating season	November-March
Cooling season	May-September

Table 2: Temperature ranges for different building categories, in both the heating and cooling season. This assumes a clothing level of 1 clo in the heating season, and 0.5 clo in the cooling season.

Category	Heating season	Cooling season
I	21.0 – 25.0 °C	23.5 – 25.5 °C
II	20.0 – 25.0 °C	23.0 – 26.0 °C
III	18.0 – 25.0 °C	22.0 – 27.0 °C
IV	17.0 – 25.0 °C	21.0 – 28.0 °C

It should be highlighted that energy frame calculations assume a heating set point at 20 °C that does not fully align with comfort expectation ranges that define temperatures between 20 – 25 °C. The upper comfort level for cooling season at 26 °C aligns with the energy frame maximum temperatures above which punishment is added to the energy performance of the building for unwanted use of cooling system.

The standard recommends a relative humidity between 25 – 60 %, which does not vary for different building categories. Therefore, this range is chosen as the range for further analysis, where the data is evaluated based on if it is within the range, or out of the range.

Finally, the CO_2-concencentration in the different rooms in the building is based on the building category. The requirement stated as an acceptable CO_2-concentration above the outdoor measured CO_2-concentration, which is assumed to be 400 ppm in Denmark, see Table 3.

Table 3: Default design CO2-concentrations above outdoor concentration assuming a standard CO2-emission of 20 l/h per person.

Category	CO_2 level above outdoors [ppm]
I	550
II	800
III	1350
IV	1350

Based on the requirements from the Danish Building Regulations, requirements regarding the energy use of the building and the indoor climate have been established. From DS/EN 16798-1, requirements for the indoor climate have been quantitively expressed. The building should fulfill at least that of a category II building.

2 RY DEMONSTRATION

This chapter presents the demo case in Ry. To start with, the building is described with focus on layout, the constructions, the compliance calculated energy demand, and occupancy. Next, the technical control and monitoring systems is detailed, and last, the user motivation and engagement in the PRELUDE project is described.

2.1 Building description

The demo case is located in Ry, Denmark, and was constructed in 2017. The exterior of the building is shown in Figure 1, and the interior in Figure 2. The single-family house was built in the framework of an EUDP project, named: "Dwelling2020 with good indoor environment and high user comfort". The EUDP project's objective was to develop and demonstrate a second-generation low-energy dwelling of the Danish building class 2020. The house has had one change of ownership and is currently owned by a young couple with a toddler. The tenants moved into the house in December 2021.

The building is a high-tech building with underfloor heating (UFH), a mechanical ventilation system with heat recovery and an in-built heat pump in the AHU, photovoltaics (PV) system, indoor environment (IE) sensors in all rooms, automatic controlled solar shadings, and skylights. A smart home solution, Intelligent House Control (IHC), monitors the IE and controls the solar shadings, skylights, heating, and mechanical ventilation system to secure a high-quality indoor environment.

Figure 1: The façades of the demo case. Left picture: west and south façade. Right picture: north façade.

Figure 2: Left picture: living room. Right picture: dining area and corridor.

In the following, general information for the demo case is presented: a description of the plan drawings and measures of the building, envelope constructions, calculated energy demand, occupancy, and weather data.

Plan drawings and measure

The single-floor building has a gross area of 160.2 m^2 and an internal area of 132.3 m^2. There are 11 rooms with different room heights to follow the inclining terrain. The rooms' internal area, height, and volume are listed in Table 4. The plan drawing with external measures is shown in Figure 3.

Table 4: Internal area, room height, and volume of the rooms.

Room	Internal area [m^2]	Room height [m]	Volume [m^3]
Room 1	8.5	2.6	22.1
Room 2	12.4	2.6	32.2
Room 3	11.8	2.6	30.7
Bedroom	8.9	3.1	27.6
Walk-in	5.8	2.6	18.0
Corridor	11.3	2.6	29.4
Living room	24.4	3.1	75.6
Kitchen-dining area	30.9	2.6	80.3
Bathroom 1	6.0	2.6	15.6
Bathroom 2	4.7	2.6	12.2
Utility room	7.6	2.6	19.8
Total	132.3		364.0

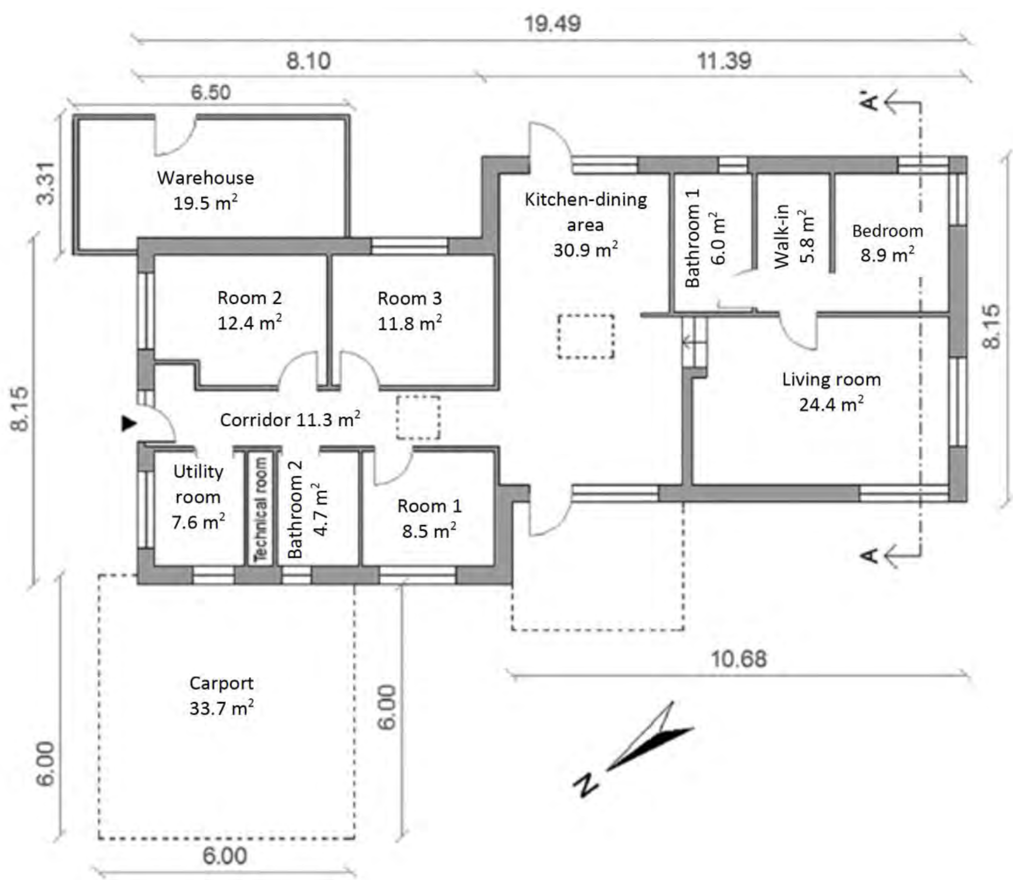


Figure 3: Plan drawing with external measures, measures given in [m].

Envelope constructions

The energy specifications and material layers of the envelope constructions are shown in Table 5 for the opaque constructions and Table 6 for the transparent constructions. An air tightness test was performed for the building and resulted in a leakage rate of 0.52 l/s per m^2 with a 50 Pa pressure difference.

Table 5: Opaque envelope construction specifications.

Construction	Thickness [m]	U-value [W/m² K]	Material layers
Ground deck	0.44	0.08	Wooden floor/tile, concrete, EPS
Roof/ceiling	0.54	0.09	Plastic board, granulate mineral wool, wood board, roofing cardboard
External wall	0.42	0.15	Aerated concrete, mineral wool, brick
Internal wall	0.11	-	Aerated concrete

Table 6: Transparent envelope construction specifications.

Construction	Type	Window U-value [W/m² K]	Glass g-value [-]	Glass share [-]	Light transmittance [-]

Windows	3-layer energy glass	0.83-1.01	0.49	0.71-0.85	0.67-0.70
Doors	3-layer energy glass	0.81-1.22	0.49	0.65-0.84	0.67-0.71
Skylight	2-layer energy + 1-layer hardened glass	1.44	0.53	0.7	0.72

Calculated energy demands

The building is a low-energy class after the Danish building regulation, just reaching the energy use limit of 27.0 kWh/m^2 per year for the low-energy class. The calculated energy use is shown in Table 7. The energy calculation is performed with the Danish compliance calculation software, Be18 [4]. The building was energy certified in 2017, where the former version of the compliance calculation tool was used, Be15. One big difference in the Be-versions is the primary energy factor. To compare the building performance in Denmark, primary energy factors for heating and electricity are used. In 2017 when the building was designed and the energy calculation performed, the energy factor for electricity was 2.5 and district heating 0.8. This gave an energy use of 24.6 kWh/m^2 per year.

To understand the calculated energy uses, it is important to note that not all electricity demands are accounted for in the "Total secondary energy". The electricity to the total secondary energy is only energy for the building operation. Furthermore, the Danish building regulation limits the amount of electrical energy produced by renewable energy sources to 25.0 kWh/m^2/a.

Table 7: The calculated energy demand for the Ry demo site. The Danish energy calculation software Be18 is used.

Energy [kWh/m^2/a]	**Calculated**
Heating total	34.5
- Space heating	24.1
- DHW heating	10.4
Electricity	34.0
Electricity from PV	4.5
Total secondary energy, electricity, Be18	-1.2
Total secondary energy, electricity, Be18	34.5
Total primary energy, Be18	27.0

Occupancy

A couple with a toddler occupies the house. They moved into the house in December 2021, and before them, a couple lived there from 2018 to December 2021. Table 8 shows the occupancy schedule for a normal week that was provided by the family that lives in the building.

Table 8: Occupancy schedule. X = all are home, / = one is home, and + = no one is home.

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
00:00 - 05:00	X	X	X	X	X	X	X
05:00 - 07:00	X	/	X	X	X	X	X

07:00 - 08:00	X	/	/	/	/	X	X
08:00 - 13:00	X	/	+	+	+	X	X
13:00 - 15:00	/	/	+	+	+	X	X
16:00 - 16:00	/	X	+	+	+	X	X
15:00 - 16:00	/	/	/	/	+	X	X
16:00 - 19:00	/	X	/	/	/	X	X
19:00 - 22:00	/	X	X	X	X	X	X
22:00 - 24:00	X	X	X	X	X	X	X

Weather data

The weather in Denmark is, according to the Köppen climate classification, an oceanic climate (cfb) with mild summer and winter, often cloudy, and wet winter. Table 9 shows the average monthly and yearly weather parameters for 2020 in Skanderborg (12.5 km from Ry).

Table 9: Average weather for Skanderborg in Denmark (12.5 km from Ry). Data is from Denmark Meteorological Institute (DMI).

Parameter	Max averaged (month)	Min averaged (month)	Average (year)
Temperature (°C)	17.6 (August)	4.1 (December)	9.5
Precipitation, total (mm)	165.3 (February)	23.9 (September)	776.7
Hours of Daylight	258.9 (May)	13.7 (December)	1728.6
Humidity (%)	93.7 (December)	69.3 (April)	82.4
Wind (m/s)	5.2 (February)	2.4 (August)	3.6

2.2 System description

The specifications of the monitoring and control systems in the building are described in this chapter. The concerned systems are:

- Indoor environment monitoring system
- Mechanical ventilation system
- Heating system
- Domestic water system
- Photovoltaic system
- Solar shading and skylight
- Control and monitoring system

2.2.1 Indoor environment monitoring system

The demo case is equipped with two IE sensors, GMW95R from Vaisala and Moisture- and temperature sensor LK Fuga (LK Fuga sensor) from LK IHC Control. The LK Fuga sensor, measuring temperature and relative humidity (RH), was installed in all rooms. However, due to a need for CO_2 concentration measurements the GMW95R was installed in all living spaces right next to the LK Fuga sensor. The sensors are placed 1.5 m above the floor and next to a door to a neighboring room. The sensors are shown in Figure 4, their specifications in Table 10, and their locations in Figure 5. All the measured IE parameters are monitored with the Schneider PLC, described in chapter 2.2.7, and available in FusiX. An overview of the parameters measured is given in Table 50 in Appendix B.

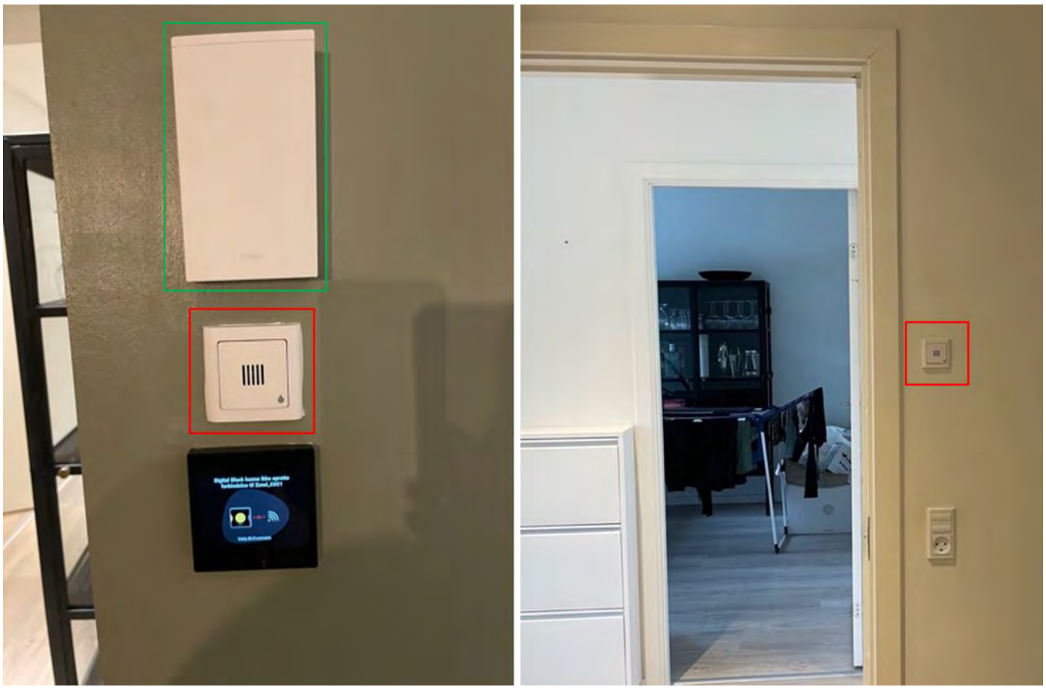


Figure 4: Left picture: GMW95R (green) in the kitchen-dining area next to the LK Fuga sensor (red). Right picture: LK Fuga sensor in Bathroom 1.

Table 10: Specifications of the IE sensors from Vaisala and LK IHC Control.

Model	Brand	Measure	Unit	Ranges	Accuracy
GMW95R (datasheet) **Temp:** Digital temperature sensor **RH:** Humidcap 180R **CO2:** Carbocap GM10	Vaisala	Temperature	°C	-5 to + 55 °C	-5 to +10 °C = ± 0.8 °C, +10 to +20 °C = ± 0.6 °C, +20 to +30 °C = ± 0.5 °C
		Relative humidity	%	0 – 95 %	-5 to +10 °C ± 3.5 % (0-60% RH), ± 4.0 % (60-80% RH), ± 5.0 % (80-95% RH) +10 to +40 °C ± 2.5 % (0-60% RH),

					± 3.0 % (60-80% RH), ± 4.0 % (80-95% RH)
		CO_2	ppm	0 – 5000 ppm	-5 to +10 °C = ± 45 ppm + 3.8 % of reading, +10 to +20 °C = ± 35 ppm + 2.7 % of reading, +20 to +30 °C = ± 30 ppm + 2 % of reading,
Moisture- and temperature sensor LK Fuga (datasheet)	LK IHC Control	Temperature	°C	-5 to + 35 °C	± 1.5 °C
		Relative humidity	%	5 to 98 %	± 5 %

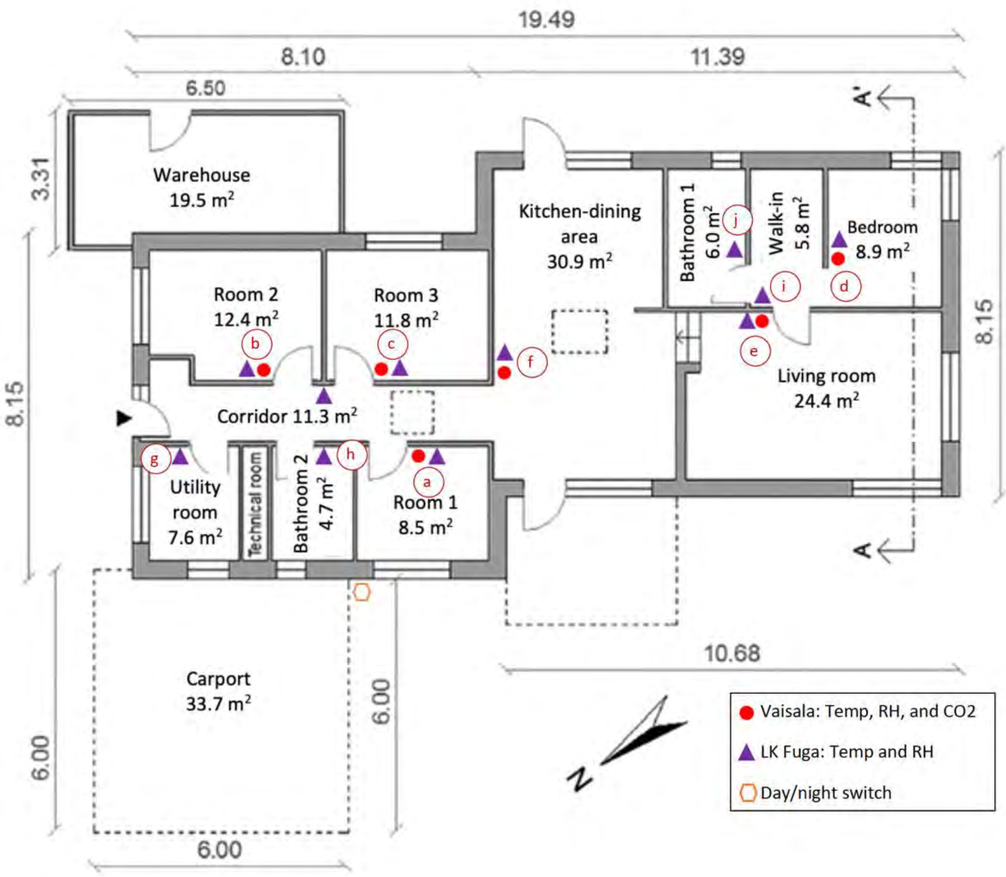


Figure 5: Location of the Vaisala and LK Fuga IE sensors. The letters in the circles are for data location in Appendix B. Name for data location: IEQ.

2.2.2 Mechanical ventilation system

In the demo case, a mechanical ventilation system is installed. The ventilation system is constant air volume flow (CAV) controlled. The air handling unit (AHU) is a Nilan Compact P with counterflow heat recovery and in-built heat pump, Figure 8. The AHU is placed in the technical room, and its specifications are listed in Table 11. The supply and extract diffusers, Figure 8, are with manually adjustable openings. Figure 6 shows the location of the AHU and the diffusers. The intake and exhaust air diffusers are placed on the roof.

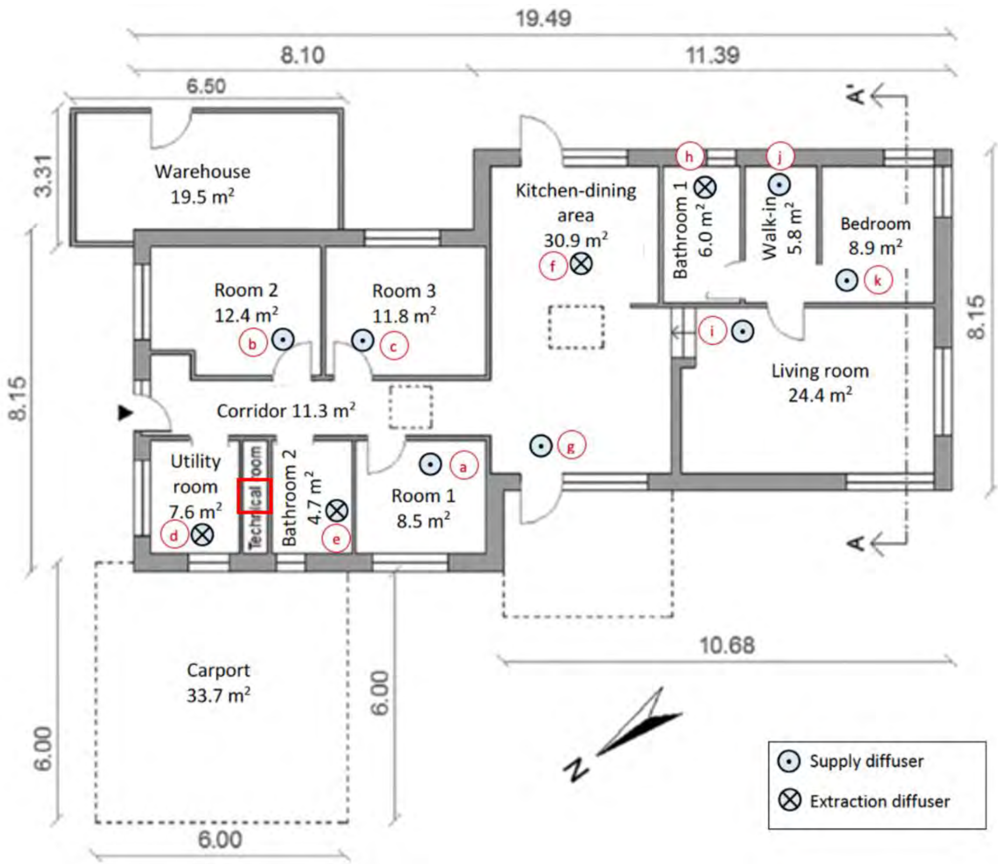


Figure 6: The location of the AHU and diffusers for the ventilation system. The AHU is marked with a red square. The letters in the circles are for data location in Appendix B. Name for data location: Vent.

Table 11: Specifications of the Nilan Compact P AHU.

Brand	Model	Max airflow	Heat recovery	Filter supply/extract
Nilan	Compact P, CTS700 control (datasheet for CTS602)	275 m³/h	95 %	G4/G4

The fans of the AHU can operate in four steps with different total supply and extract air volume flow rates. The current control of the AHU's operation step is based on thresholds for the measured CO_2 concentrations and RH levels, listed in Table 12. Step 1 is the starting step. If three rooms exceed the threshold for CO_2 or RH, the operation step will go from step 1 to step 2. If five rooms exceed a threshold, the operation change to step 3 and step 4 if 7 or more rooms exceed a threshold. In step 1, the AHU provides a total air volume flow rate that is half the minimum air volume flow rate demand prescribed by the Danish Building Regulation (BR18) [3]. The BR18 allows for half of the minimum air volume flow rate if the dwelling is not occupied. Occupation can be identified by CO_2 measurement. A cooker hood is in the kitchen above the stove, Figure 9. It has its own exhaust.

Table 12: IE thresholds for the ventilation control.

Parameter	Open damper	Close damper
CO_2	> 700 ppm	< 500 ppm
RH occupied spaces	> 70 %	< 55 %
RH non-occupied spaces	> 60 %	< 40 %

With the in-built heat pump, the AHU has five operating modes: i) Passive heat recovery, which uses the counterflow heat recovery module, ii) Active and passive heat recovery, the heat pump uses the remaining energy in the exhaust air after the heat recovery to heat up the supply air if the temperature is too low after the heat recovery, iii) Domestic hot water, the heat pump uses the remaining energy from the exhaust air to heat up the water in the domestic hot water tank, iv) Bypass function, in cooling periods, when outdoor air is colder than room temperature the bypass damper will open, and the intake air will bypass the heat recovery, v) Active cooling, the heat pump is reversible and if the cooling of the supply air with bypass function is insufficient the function can further cool down the supply air and allocate the energy to the DHW tank. The active cooling function can be deactivated, as it requires increased electrical energy. In Figure 7 are shown the conceptual drawings for active and passive heat recovery, Domestic hot water, and Bypass function.

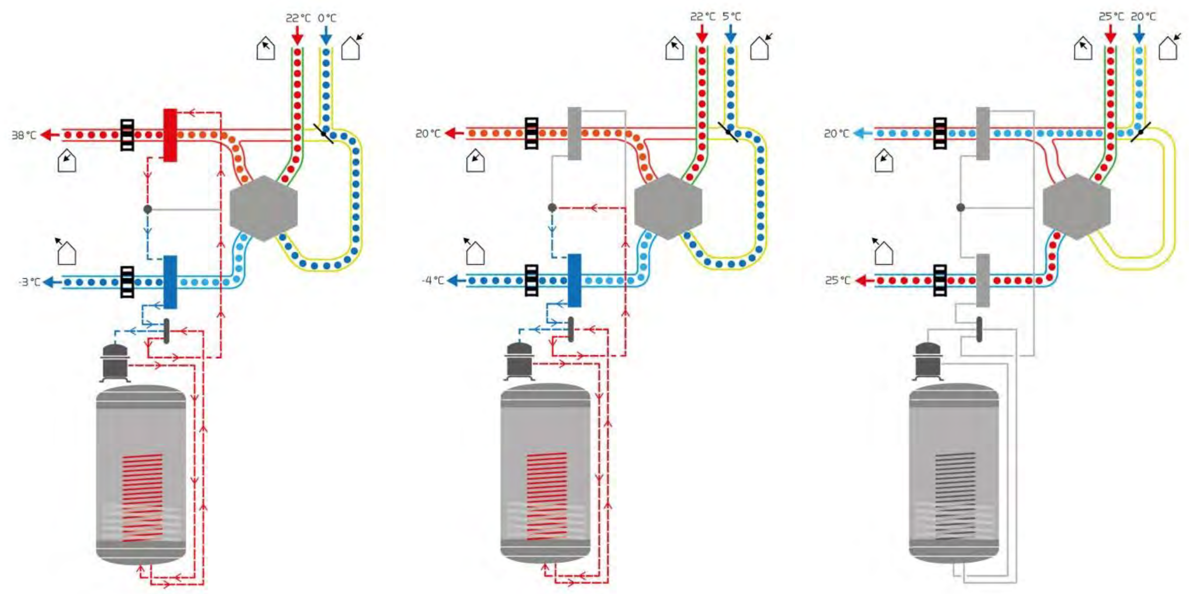


Figure 7: Conceptual drawings of the Nilan Compact P operation modes. From left to right: Active and passive heat recovery, DHW, and Bypass function.

With Modbus communication to the Schneider PLC, the AHU can be monitored and controlled according to the indoor environment. Furthermore, the PLC monitors two air flow sensors, Lindab UltraLink FTMU, that measure the total air flow rate and temperature. See the UltraLink FTMU in Figure 8 and Figure 9. The specification of the measured parameters from the UltraLink FTMU and the AHU are listed in Table 13. In the EUDP project, dampers with controllable openings were installed before each diffuser. The PLC could change between opening positions according to the IE thresholds, Table 12. In June 2020, the end of the EUDP project, the dampers were removed. However, the signal to the diffusers from the PLC is still being logged and can indicate rooms exceeding the IE thresholds. All mentioned measured parameters are available in FusiX, and listed in Table 50 in Appendix B.

Table 13: Specifications of the airflow sensor Lindab UltraLink FTMU and the AHU Nilan Compact P.

Brand	Model	Measures	Unit	Ranges	Accuracy
Lindab	Ultralink FTMU Ø160, Bluetooth (datasheet)	Air flow rate	m^3/h	0 to 1448 m^3/h	Biggest: ± 5 % or ± 1.6 l/s
		Temperature	°C	0 to +30 °C	± 1 °C
Nilan	Compact P CTS700 control (datasheet for CTS602)	Temperature: outdoor, indoor, supply air, and DHW	°C	- 30 to + 80 °C	No info. Typical accuracy for NTC: ± 0.05 to 1.5 °C
	Temp: NTC probe	Relative humidity	%	25 to 95 %	± 3.5 %
		Fan speed	%	0-100 %	No info

Figure 8: Left picture: The AHU Nilan Compact P with two Lindab UltraLink FTMUs placed on the supply and exhaust main ducts. Right picture: Supply diffuser in the ceiling in the living room.

Figure 9: Left picture: Cooker hood in the kitchen. Right picture: Air flow sensor Lindab UltraLink FTMU.

2.2.3 Heating system

The building is supplied by district heating (DH), and the heat distribution system is underfloor heating (UFH). The DH is weather compensated with a Danfoss ECL Comfort 110 (datasheet) that controls the mixing shunt for the UFH system by regulating the supply temperature and controlling the Grundfos Alpha 2 25-60 circulation pump (datasheet). The UFH system is heavy/slow UFH in concrete and is divided into 11 zones, as shown in Figure 11. The manifold with Wavin 24 V actuators (datasheet) is placed in the technical room. The IHC controls the actuators' on/off signals according to the measured room temperature and the rooms' individual set points. In the bathrooms, a scheduled control is used to heighten thermal comfort with warm floors. Each 3rd hour the floor heating is activated in the bathrooms for 10 minutes.

The heating energy for the UFH is measured with three Kamstrup Multical 603 energy meters and logged by the PLC. An energy meter measures the total DH energy, a second measures the energy to the UFH, and a third measures the DH energy to the DHW tank (this connection is closed). Specifications of the energy meter are listed in Table 14, and the logged parameters are listed in Table 50. In Figure 12, the piping and instrumentation diagram (PI diagram) shows the heating system and the location of the energy meters.

Figure 10 shows pictures from the technical room with the DH distribution system, manifold with actuators, and IHC modules for actuator control. In the picture of the technical room, two DH pipes to the DHW tank are located. The DH is not used to heat up the DHW, as the heat pump in the AHU carries out this function. The pipes are closed by a shut off valve.

Figure 10: The heating system, from left to right: Technical room with heating installation, the DH enters in the lower right corner, the ECL Comfort 110 and pump in the middle, and the UFH manifold in the bottom. Manifold with Wavin actuators. IHC modules to control actuators.

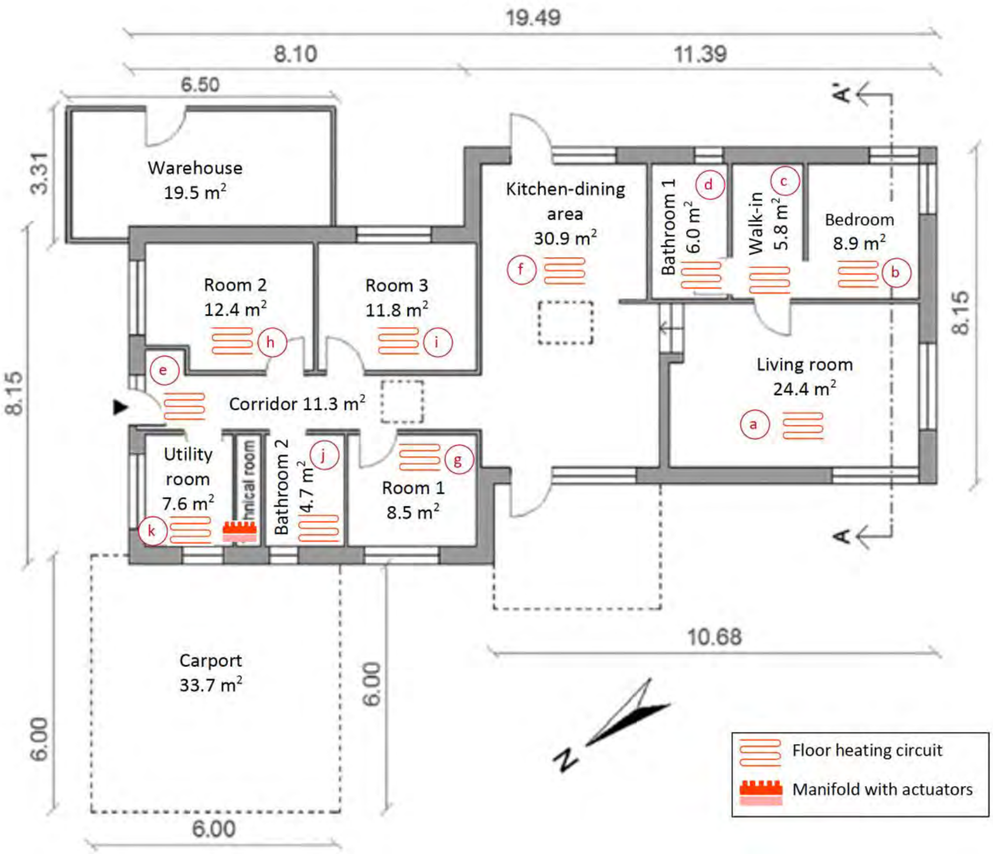


Figure 11: The 11 UFH zones and location of the manifold. The letters in the circles are for data location in Appendix B. Name for data location: UFH.

Table 14: Specifications of the heat energy meter Kamstrup Multical 603.

Brand	Model	Measures	Unit	Ranges	Accuracy

Kamstrup	Multical 603 q_p = 1.5 m^3/h (datasheet)	Water flow rate	l/h	0.6 – 1000 m^3/h	± (1 + 0.01 q_p/q) %
		Volume	m^3	Cumulative	No accuracy – depend on flow
		Temperature - Supply - Return	°C	2 to 130 °C	± (0.4 + 4/ΔΘ) % ΔΘ is temperature difference between supply and return
		Energy	MWh	Cumulative	± (0.15 + 2/ΔΘ) % ΔΘ is temperature difference between supply and return

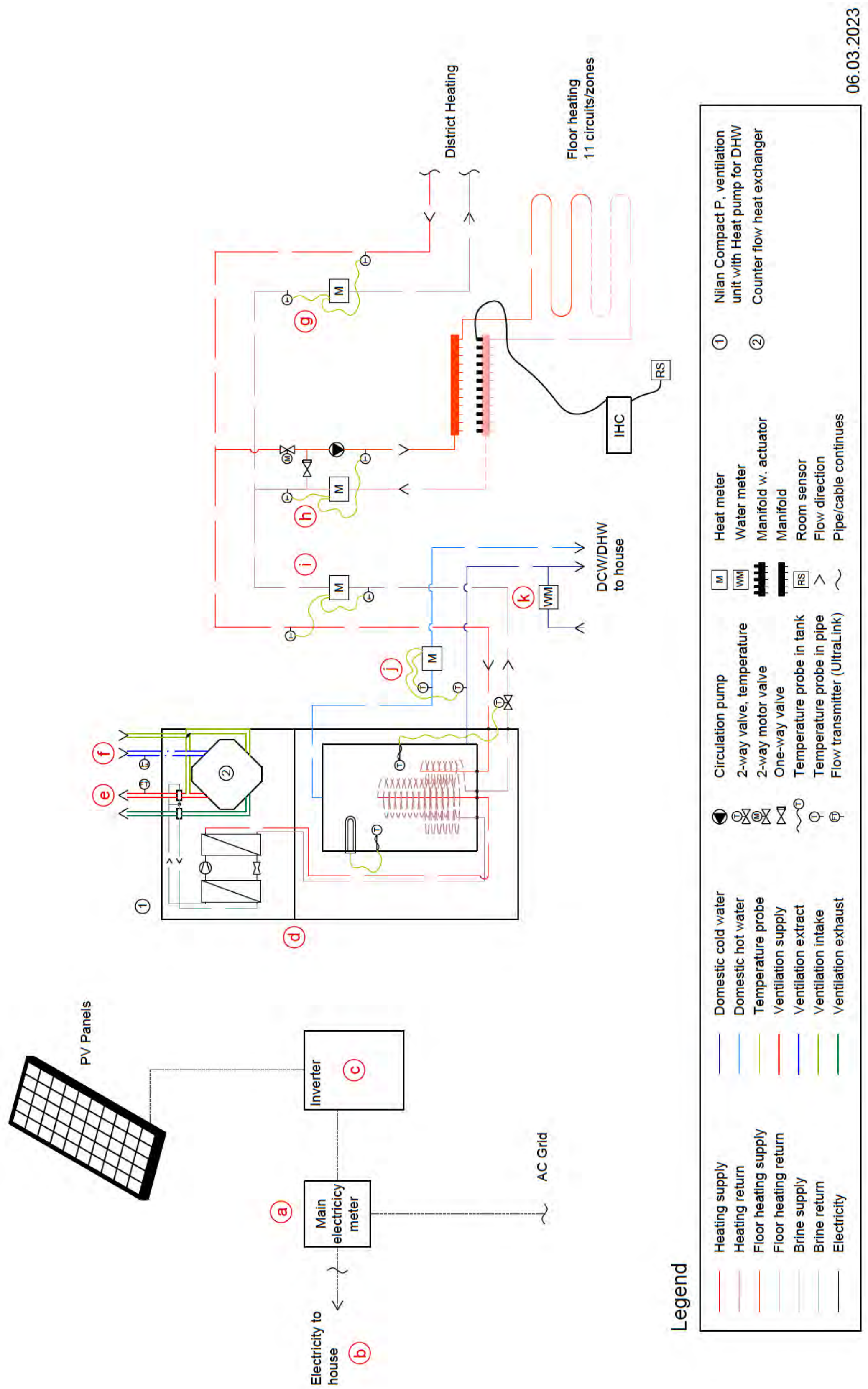


Figure 12: PI diagram for the heating system (DH, UFH, and DHW), ventilation system with heat pump, PV system (PV panels, inverter, and grid). The letters in the circles are for data location in Appendix B. Name for data location: PID.

2.2.4 Domestic water system

The supply of domestic cold water (DCW) is entering the building in the technical room. The domestic hot water (DHW) is stored in a 180 L DHW tank and heated by the heat pump in the AHU. There are ten tapping points in the building, as follows: two washbasins, two showers, two toilets, one kitchen sink, one utility sink, one dishwasher, and one washing machine. Besides this, a water boiler from Quooker, is installed under the kitchen sink.

The total DCW use is measured by a water meter, Kamstrup Multical 62, and the total DHW use and energy are measured with a heat energy meter, Kamstrup Multical 603. Specifications of the water meter are listed in Table 15, and the energy meter in Table 14. The PLC logs the measured parameters with Modbus communication. The measured parameters are available in FusiX and listed in Table 50 in Appendix B. The location of the water and energy meter in the domestic water installation can be seen in the PI diagram in Figure 12.

Table 15: Specifications of the water meter Kamstrup Multical 62.

Brand	**Model**	**Measures**	**Unit**	**Ranges**	**Accuracy**
Kamstrup	Multical 62 q_p = 1.6 m^3/h (datasheet)	Water flow rate	l/h	16 to 1600 l/h	+ 0.1 to + 30 °C: ± 5 % (16 l/h ≤ Q < Q2) ± 2 % (Q2 ≤ Q < 2000 l/h), use this! *Q2 is defined in datasheet*
		Volume	m^3	Cumulative	No accuracy – depend on flow

2.2.5 Photovoltaic system

The building has a small PV system with nine PV panels (13 m^2) and a 1.5 kW SMA inverter. It could have been more beneficial to install a larger PV system. However, the size of the PV system was chosen in the building's design phase to achieve the low-energy class energy criteria and not from an optimal operation perspective. The specifications for the inverter are listed in Table 16. The PV panels are an unknown brand and model. A smart meter, SMA Sunny Home Manager 2.0 (datasheet), is installed after the main electricity meter to measure the energy to/from the grid. With the SMA inverter and smart meter connected to the internet, the monitoring solution, SMA Sunny Portal, can monitor and visualize the energy balance for the electrical system. It is important to note that the total electrical consumption can be monitored with SMA Sunny Portal. The main electrical meter only measures the electricity from the grid for billing purposes. The data can be downloaded directly from Sunny Portal and accessed with the SMA API. In Figure 13, the energy balance is visualized. In Table 51 in Appendix B, the monitored values are listed.

Table 16: Specifications of the SMA inverter.

Brand	**Model**	**PV input**	**Nominal output**	**Max efficiency**
SMA	Sunny Boy 1.5 (datasheet)	3.0 kW 10 A	1.5 kW 6.5 A	PV-grid: 97.2 %

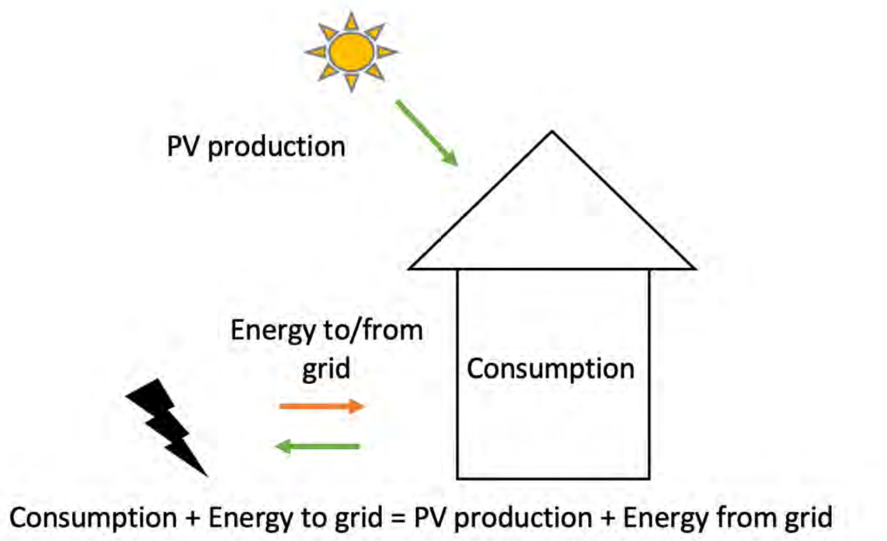


Figure 13: Energy balance with the measured parameters in the PV system.

2.2.6 Solar shading and skylight

To prevent overheating in the building, two strategies were initiated during the design of the building: solar shading and natural ventilation. The solar shading devices are external shutters with fixed horizontal lamellas that can roll for/from the windows, as seen in Figure 14. The shutters have only two positions: on and off. The natural ventilation was implemented by five façade openable windows and two Velux skylights. The opening status of the façade windows and the skylights were operating together to increase the natural ventilation flow rate. The facade windows were automatically controlled, but due to noise from the window opening devices, the owners of the house decided to dismount the automatic control. This automatic control of the façade windows is mentioned because the automation of the façade windows in the IHC still has a function to control the skylights. A façade window and a skylight are shown in Figure 14, and the locations are shown in Figure 15. The IHC control strategy and monitoring parameters for the solar shading and skylights are in the following described. All monitored parameters are logged with the PLC and available in FusiX, see Table 50 in Appendix B.

Figure 14: Left picture: Solar shading shutters in front of the bedroom and living room. Right picture: Skylight above the corridor.

Solar shading

Two shutters are located at the two windows in the living room. The south-oriented window has two shutters, functioning as one, and the west-oriented window has one shutter. The south and west-oriented shutters in the living room are automatically controlled together but can manually be controlled individually. In the bedroom, there is an east-oriented and a south-oriented shutter. The shutters in the bedroom are automatic and manually controlled together. The shutters follow an automated control. However, the user can oversteer the automatic control by manually activating or deactivating the shutter by pushing a switch. When the user oversteers the automatic control, it is valid for 6 hours before the automatic control is re-established. The automatic control for the shutters in the two rooms follows:

- The temperature in the living room activates the shutters if it exceeds the set point for the room.
- The temperature in the bedroom activates the shutters if it exceeds the set point for the room.
- Clock control activates all shutters in the time 21:00 to 09:00.

The Schneider PLC monitors the activation of the four shutters and when the user manually controls the shutters. There are two monitored parameters for each shutter. Take the south-oriented shutter as an example. The parameter "SH Living South (I/O)" is the physical activation of the shutter: 1 = roll for, and 0 = roll from. The parameter "SH Living South Man (I/O)" is when the user manually pushes the switch, this can be either activating or deactivating the shutter: 1 = pushing the switch and oversteering, and 0 = no oversteering and automatic control.

Skylight

One skylight is located in the kitchen, and one is in the corridor. The skylight control strategy is constructed nearly like the solar shading control. There is an automated control, and the user can manually oversteer. The oversteering is valid for 2 hours, and there is no clock control. The automated control of the skylight uses the opening status of the façade windows (which are not there anymore) that are controlled by the measured room temperature and the individually set points. The automatic control for the skylights is as follows:

- The temperature in room 1 and room 3 activates the skylight in the corridor if it exceeds the set point for one of the rooms.
- The temperature in the living room and bedroom activates the skylight in the kitchen if it exceeds the set point for one of the rooms.
- To deactivate the skylight, both temperature set points for the mentioned rooms should be met.

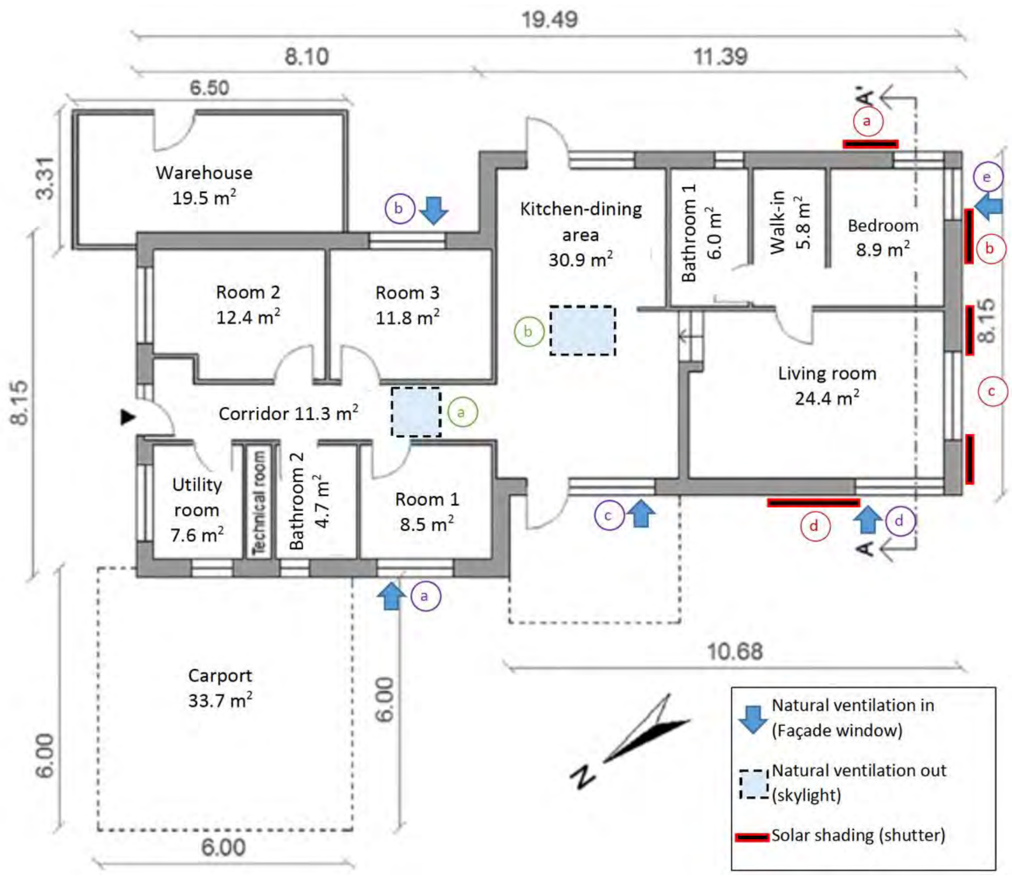


Figure 15: Location of solar shading shutters, skylights, and the previously controlled facade windows. The letters in the circles are for data location in Appendix B. Color and name for data location: Red = SH, Green = SK, and Purple = WO.

2.2.7 Control and monitoring system

There are two control systems in the building, and one is also a monitoring/logging system. The building is equipped with the smart home control, Intelligent Home Control (IHC) from Schneider, that only can control. The second control system is an industrial Programmable Logic Controller (PLC), Modicon M241 (datasheet), from Schneider, that also can monitor/log.

The IHC system consists of a controller with several input and output modules. In the IHC software, the coupling between the input and output can be set up as a simple system and a complex system with boundary conditions. The simple system can be lighting, where the input is the user pushing the switch, and the output is activating the light. The more complex system is when the IHC system gets input from the IE sensor, LK Fuga, and controls the following output according to the input signals and set point values: i) UFH actuators, ii) solar shading shutters, iii) skylights. With Modbus communication, the PLC can monitor the IHC parameters. The IHC has a user interface as a mobile app for the tenants, making it possible to change set points and take control over technical devices (open/close skylight, etc.). The IHC modules in the switchboard are shown in Figure 16.

The PLC system consists of a PLC with Modbus communication modules. It is placed in a box below the switchboard, as shown in Figure 16. The PLC collects data via Modbus from the following devices: electrical energy meters, AHU, UltraLink air flow sensors, Vaisala IE sensors, water meter, and heat energy meters. The electrical energy to appliances is divided with the electrical energy meters into ten groups: Cooking plate and ovens, Fridge and cooker hood, Control system, Pump UFH, Nilan AHU, Washing machine, Dryer, Dishwasher, Quooker, and Other usage (lighting and plug loads). The electrical energy meters are Schneider iEM3155 (datasheet) for 3-phases and Schneider iEM2010 (datasheet) for 1-phases. The only device the PLC controls is the AHU, where the PLC regulates the fans' operation step, further described in chapter 2.2.2.

Data transfer from the PLC to the PRELUDE middleware is established using a Synology NAS server, see Figure 16. Hourly, the PLC transfers a log file to the NAS server with FTP. FusiX connects to the NAS server with an SFTP connection to export the log file to the FusiX platform. To prevent lost data by disconnected internet, the PLC has an internal memory of one year of data, and the NAS server stores all the data collected. All the monitored parameters logged with the PLC are available in FusiX and are listed in Table 50 in Appendix B.

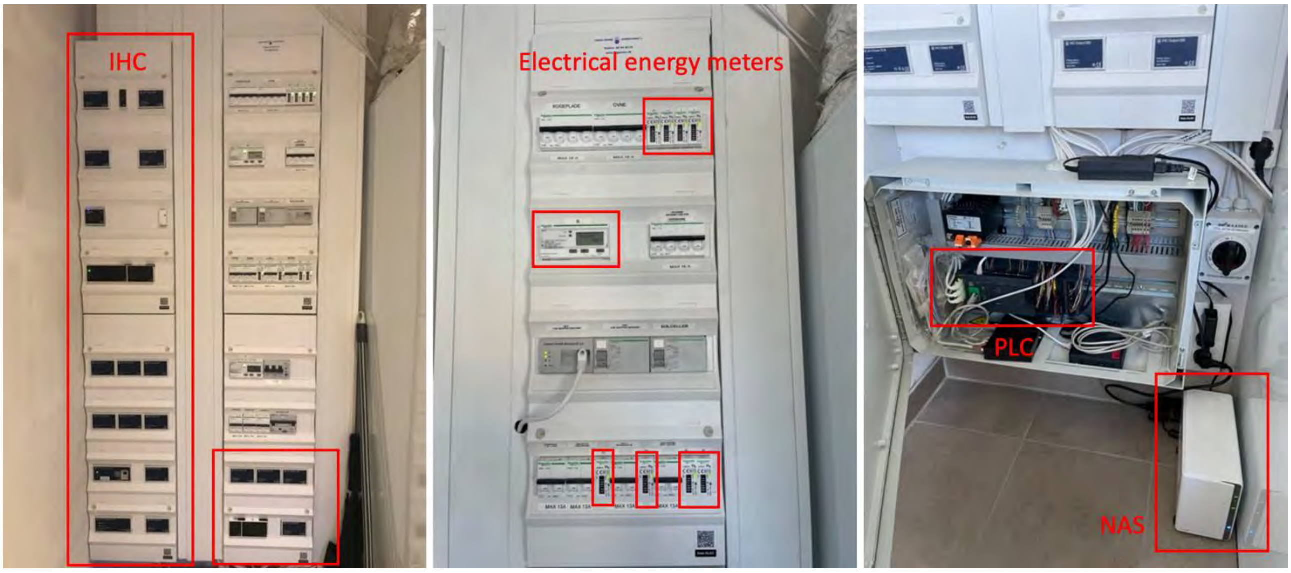


Figure 16: The control and monitoring systems, from left to right: The building's switchboard with IHC modules to the left and electrical energy meters. The electrical energy meters in the switchboard. The PLC and NAS server.

2.3 Motivation and user engagement to participate in the project

The single-family house in Ry has been a part of AAU research for five years, starting from the former EUDP project, as mentioned before in this report. Prior to the start of the PRELUDE project, the former owners were contacted about whether they would be interested in participating in the PRELUDE project. Around the time the PRELUDE project started, the owners informed AAU that they were about to sell the house but would inform the new owners about the project. Fortunately for the PRELUDE project, the new owners were interested in hosting the PRELUDE demonstration. The owners have been very supportive throughout the project during visits to the demo case. They have been very helpful with taking pictures, switching on/off devices, and performing tests to validate the log files, which are highly appreciated considering the distance from Aalborg to Ry. Furthermore, they have fulfilled three schedules, one for the occupancy in a normal week, one week noting their occupancy behavior with a 15-minute resolution for validation of the Occupancy module by FB, and one week noting the use of the dishwasher. When technical experts were needed to make changes in the house's technical installations, the tenants arranged appointments themselves.

The tenants are highly motivated by the outcome of the PRELUDE project and showed interest in understanding the systems in the house. They want to know how to decrease the energy use in the building and are willing to change user behavior if it has a significant impact and they don't need to make large compromises. Furthermore, they wanted more knowledge about the PV system and their electrical use, which from their perspective is high. They got access to SMA Energy App, which gave them knowledge about the PV system and their own electrical usage.

The owners have agreed to be part of the Free Running Module test by POLITO in July 2023 and test with EE-Comfort Module by STAM.

3 PREPARATION OF DEMONSTRATION CASE

To implement the PRELUDE technologies in the demo case and secure sufficient data, the building has been prepared. This chapter describes the modifications carried out in the building, the implementation of data transfer to FusiX, and preliminary data analysis with a focus on detecting sensor outliers, exploratory data analysis**,** and identification of building operation. Last in the chapter is an overview of the ongoing preparation.

3.1 Modifications carried out in the building

The modifications carried out in the Ry building can be divided into two groups. The first group is the installation and integration of sensors and monitoring systems, so the PRELUDE middleware and technologies can get the necessary data and communicate back to the systems with control inputs. The second group is the testing, balancing, and repairs to secure the function of the building's installation.

3.1.1 Installation and integration of sensors and monitoring systems

The following modifications to get the necessary data and control of the monitoring system have been carried out in the PRELUDE project for the technical systems presented in chapter 2.2.

From Niko to IHC: A small installation of Niko Home Control was installed in the house after the EUDP project (June 2020) to replace the IHC for UFH, solar shading, and skylight. This replacement should make user control for the tenants easier. However, after the change in building ownership, the new tenants did not have access to the Niko home control app and no control of the room temperature setpoint and activation of the solar shading and skylight. Furthermore, the actuation of the systems was not monitored in the PLC. In mid-June 2022, the Niko Home Control was replaced with IHC modules for better implementation of the PRELUDE solution. The tenants got access to control the temperature setpoint and activation of the solar shading and skylight through the IHC app. More important, was the former IHC version implemented again, with the heating schedule for the bathrooms, and the actuation of the systems was logged in the PLC from June 2022.

Logging interval changes: In the PRELUDE project, a high resolution of data has been wanted from the technology partners. Together with a Schneider technician, the highest resolution was found to be two minutes in the PLC without interrupting the monitoring. In June 2022, the logging interval was changed from 5 minutes to two minutes.

Water flow rate and DHW temperature in average value: In June 2022, the logged value of the water flow rate for the heat energy meters was changed from instantaneous to an average of 2 minutes. The same was applied to the DHW temperature. This change was made to enhance the precision of the energy flow profiles and capture tapping of DHW with a shorter duration than 2 minutes.

Installation of the NAS server: In June 2022, the NAS server was installed, and a connection between the PLC and NAS server was established. In late August, a connection between the NAS server and FusiX was established.

Remote control: A computer is installed in the building to have the IHC and PLC software installed. A remote control is established on the computer, which is beneficial with the long distance to Ry from AAU.

Data from the inverter and electrical smart meter: In June 2022, an SMA Sunny Portal account was established to monitor PV electrical production. The internet connection to the SMA inverter was established, and the PV system was created. The tenants got secondary access to the monitoring of the PV system in the

SMA Energy App. In late August 2022, the SMA smart meter was connected to the internet and created in the SMA Sunny Portal. This gave full monitoring of the electrical energy to/from the grid and the consumption in the building. The tenants could also benefit from this since they could see a visualization of their electrical use.

Preparation for Free Running Module test: The Free Running Module from POLITO is planned to be carried out in July 2023. To test this PRELUDE solution, the operation step of the fans in AHU and the solar shading shutters should be controlled by a 24-hour schedule for the next day. To implement this, configurations in the PLC are being implemented. The ongoing work is further described in chapter 3.6. Furthermore, the AHU's bypass should be activated and the skylight opening deactivated. This was found to be possible in the AHU control settings and IHC software, respectively.

3.1.2 Testing and calibration systems, regulation, balancing, repairs

The mechanical ventilation system is the only technical system in Ry that has needed modifications to function properly. The following describes those interventions.

Lost connection to AHU: The connection between the PLC and AHU has been lost since June 2020. In June 2022, the connection was re-established by connecting an ethernet cable to the AHU. Without connection, the AHU has run on fixed fan speed. When connected, the automatic control from the PLC was established again. The PLC control of the AHU's fan speed is critical and will be used in the Free Running Module by POLITO.

Active cooling: From June 2022 to the end of August 2022, the function "Active cooling" in the AHU was activated. Active cooling makes a reverse action of the heat pump in the AHU, cools down the supply air, and raises the water temperature in the DHW tank. This function has significantly increased the temperature in the DHW tank and the electrical energy to the AHU. Further, the air supply temperature has been down to 4 °C. AAU agreed with the tenants to deactivate the Active cooling function to test the impact on the indoor temperature in the summer of 2023.

AHU supply fan replaced: From the end of August 2022 to the start of September 2022, the supply fan has not been rotating. The supply fan was defective and replaced.

Balancing: The system was balanced at the end of August 2022. Before that, there was a high imbalance in the ventilation system. The balancing of the ventilation is done in two steps. First, the diffuser openings are adjusted to the necessary air volume flow rate, fulfilling the BR18 demand for supply and extract air volume flow rate. Second, the AHU's supply and extract fan speeds are balanced for the AHU's operation steps. Only steps 1, 2, and 3 out of 4. Step 4 is not balanced due to step 3 being close to the maximum speed of the extract fan, and step 4 is considered unlikely to be used. The four operation steps are defined below:

- Step 1: 0.15 l/s per m^2 = 50 % of the BR18 air supply demand for dwellings
- Step 2: 0.30 l/s per m^2 = BR18 air supply demand for dwellings
- Step 3: 0.38 l/s = Air extraction demands from BR18
    - Kitchen = 20 l/s, Bathroom with shower = 15 l/s, and Utility room = 10 l/s
- Step 4: 100 % fan speed

The balancing results can be seen in Table 17, where the supply and extract air volume flow rate for each room is listed for the three balanced operation steps of the AHU. In Denmark, there should be up to a 5 % difference between the total supply and extract air volume flow rate, with a higher extract to ensure a small negative pressure to prevent indoor moisture from being forced into the constructions.

Table 17: Distribution of the supply and extract air volume flow rate for the three operation steps of the AHU.

	Step 1		Step 2		Step 3	
Room	**Supply [m³/h]**	**Extract [m³/h]**	**Supply [m³/h]**	**Extract [m³/h]**	**Supply [m³/h]**	**Extract [m³/h]**
Room 1	8.0		18.0		19.5	
Room 2	9.5		17.0		25.0	
Room 3	9.0		17.0		23.5	
Bedroom	10.5		18.0		24.5	
Walk-in	4.5		8.0		10.5	
Living room	22.0		36.5		47.0	
Kitchen-dining area	25.5	35.5	42.0	66.0	54.5	80.0
Bathroom 1		21.0		36.5		48.0
Bathroom 2		23.0		42.0		53.0
Utility room		10.5		19.0		25.0
Total [m³/h]	89.0	90.0	156.5	163.5	204.5	206.0
ΔSupply-Extract ≤ - 5%	-1.1 %		-4.5 %		-0.7 %	

Wrong total return air flow measurement: At the time of the balancing of the ventilation system, a big difference in air flow rate, 55-70 %, between the two Lindab UltraLink, was observed. The measured total extract air flow rate did not match the summed air flow rate from the extract diffusers. Such a big difference between extract and supply air flow rates would be observed by slamming doors in the building. This was not the case. The possible reason is that the UltraLink is affected by turbulence from a flex duct right before the sensor.

3.2 Implementation in FusiX

This chapter will describe the FusiX platform and how different APIs, relays, and Modbus data have been integrated to the PRELUDE platform for Ry demonstration. The overall goal of the FusiX platform, is to have accessible data in a standardized platform, allowing for data to be extracted for different demo cases, even though there might be a variety of different communication protocols that collect data for each building. The common platform FusiX remedies this issue, as the data is retrieved in a standardized manner, and can be retrieved using the Javascript Object Notation, which is a standard file format, that uses human readable text stored in a 'tree-structure'.

FusiX is a common platform that collects a variety of data for the partners in the PRELUDE project. This platform has data for a total of seven demo cases in different parts of Europe, and it has different amount of historical data for each of these buildings. For the demo case in Ry, the available data is from DCW meter, air flow sensors, floor heating actuators, solar shading devices, skylights, IEQ sensors, energy meters (heat and electricity), weather station and forecasted weather and PV panels, which is collected in the building using APIs from different vendors, File Transfer Protocol (FTP), and SFTP. FusiX is, therefore, an API that uses different communication protocols to retrieve and store data. An overview of the data communication to FusiX is shown in Figure 17, and a detailed description is given in Table 18.

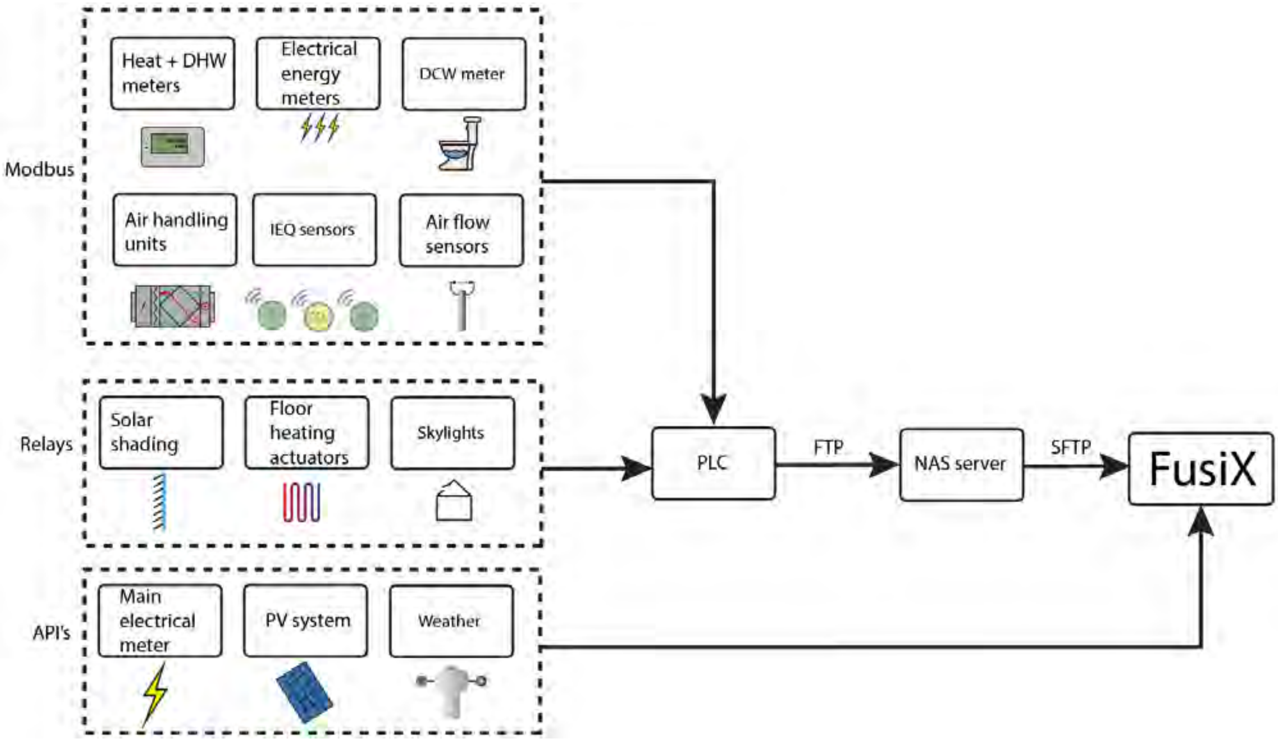
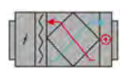
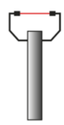


Figure 17: Overview of data communication to FusiX for the Ry demo case.

*Table 18: Overview of communication methods used to collect data to the common platform FusiX. * Not yet implemented in FusiX.*

Communication method	Description	Visual representation
API: Eloverblik	Main electrical meter data	
API: CORE	Weather data	
API: SMA*	Photovoltaic panels data	
Modbus: Heat + DHW meters	Smart heat meters	
Modbus: Air handling units	Air handling unit	
Modbus: Air flow meter	Air flow and velocity	
Modbus: Vaisala / LK Fuga	Indoor environmental quality sensors	

Modbus: DCW	Domestic cold water	
Modbus: Electric meters	Electricity for appliances	
Relay: Solar shading device	Solar shading devices	
Relay: Floor heating actuators	Floor heating actuators	
Relay: Skylights	Skylights	

For the Ry demo house, a total of 113 parameters are available as of May 2023. For each parameter, the name, unit, resolution and a brief description is given in Table 50 in Appendix B.

FusiX does not have a publicly available user interface to retrieve data, however, it can be accessed using a programming language with RESTful API capabilities, such as Python. Data from the Ry demo house can be retrieved and analyzed using Python and the 'requests' library. A showcase use of FusiX for exploratory analysis is shown below in the following 2 chapters.

3.3 Evaluation of sensor outliers

During the preliminary data analysis of the sensor data, a large number of outliers were found to occur, which is shown in the data in the form of single outliers deviating significantly from the remaining data. As the measured data is deemed unrealistic, these outliers are removed. The method of outlier removal is based on a simple algorithm, that determines a running mean of the data for each measured parameter. If a measurement exceeds the running mean with an arbitrarily determined amount, the data point is removed and not considered in the running mean.

As some data is missing, a data imputation method is utilized, with the chosen method being the method of Spline Interpolation, with 'natural' boundary conditions.

Based on the outlier detection and imputation method, the data shows more realistic trends. An example of the data before and after the outlier detection and data imputation is shown in Figure 18 and Figure 19, respectively.

Figure 18: Data for temperatures in Ry demo case before outlier detection and data imputation.

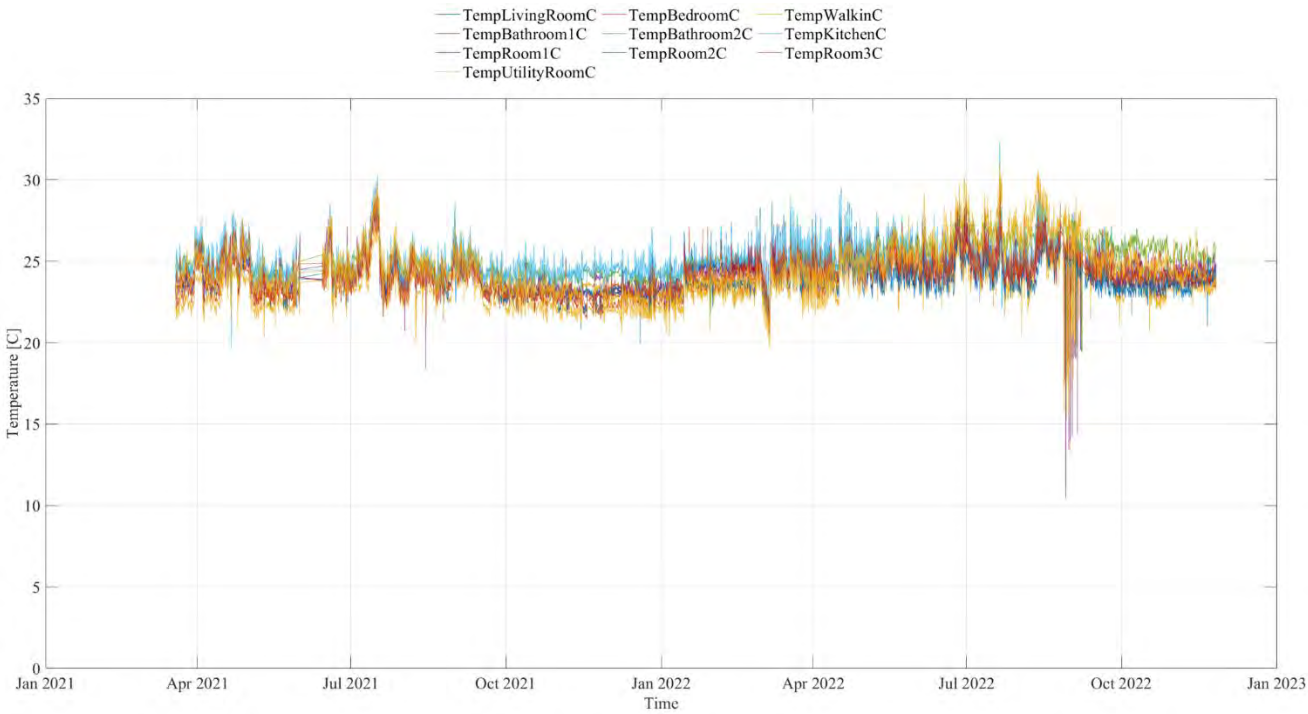


Figure 19: Data for temperatures in Ry demo case after outlier detection and data imputation.

As shown on the two figures, the data shows more realistic trends after removal of the data and the data imputation. The imputed data follow the previous trends, so they yield realistic data.

It can also be seen that most of the outliers occur after June 2022, where the logging interval in the PLC was changed from 5 to 2 minutes, as described in chapter 3.1.1. The outliers occur for the LK Fuga sensors, and the problem was solved in Maj 2023. It should also be noted that the method could not fully remove the outliers in data for September 2022 due to the sheer number of outliers, making trends difficult to follow for the Spline imputation method.

Finally, it should be noted that the temperature sensors were the only sensors experiencing this issue, with the relative humidity and CO_2 sensors not experiencing the same issues. Authors of this report would like to highlight that the accuracy of the sensors that are used is not the only parameter that secures the reliability of the measurements and data treatment should be always an obligatory step in the data analysis.

3.4 Simple exploratory data analysis for demo house

This chapter showcases the use of FusiX for exploratory analysis of the building. It includes code to obtain data from the FusiX platform using Python and the 'requests' Python library, along with code to visualize data, that can afterwards be used for exploratory analysis.

The code is not supposed to show the full picture of using every parameter, but only a showcase of how the FusiX platform can be used to quickly retrieve and show data using Python. This simple exploratory analysis will therefore only show code for a single IEQ-sensor located in the living room in building Ry which has ID 6 and extraction of data for one week period from 01.05.2023 to 08.05.2023. Finally, data are plotted in a x-y (time – temperature) plot.

```python
from datetime import datetime, timedelta, timezone
from dateutil.parser import parse
from pprint import pprint
import requests
import matplotlib.pyplot as plt
import matplotlib.dates as mdates

AUTH = ("USER dummy", 'PASSWORD dummy')

URL = 'https: API URL '


# USER DEFINED PARAMETERS
###############################################
endpoint = '/get_building'
dt_to = datetime.utcnow()  # Required argument
dt_from = '2023-05-01 00:00:00'
dt_to = '2023-05-08 00:00:00'
building_id = 6  # Required argument
d_categories = "IAQ"
d_ids = "1111"
###############################################
payload = {
    "dt_from": dt_from,
    "dt_to": dt_to,
    "id": building_id,
    "d_ids": d_ids
}
# Preperation of request's payload
resp = requests.get(URL + endpoint, params=payload, auth=AUTH)
data = resp.json()['apartments']['21']['rooms'][0]['devices'][0]['Readings']
pprint(resp.json())
temperature = []
time = []
```

```
for reading in range(len(data)):
    temperature.append(data[reading]['Value'])
    time.append(data[reading]['Timestamp'])

fig = plt.figure()
ax = fig.add_subplot(1,1,1)

time_new = []

for time_str in range(len(time)):
    time_new.append(parse(time[time_str]))

ax.plot(time_new, temperature)
ax.xaxis.set_major_locator(mdates.DayLocator(interval=1))
ax.xaxis.set_major_formatter(mdates.DateFormatter('%Y-%m-%d'))
ax.set_ylabel('Temperature [C]',fontsize=20)
ax.tick_params(axis='y', which='major', labelsize=16)
ax.tick_params(axis='x', which='major', labelsize=16, rotation=45)
ax.grid()
plt.show()
```

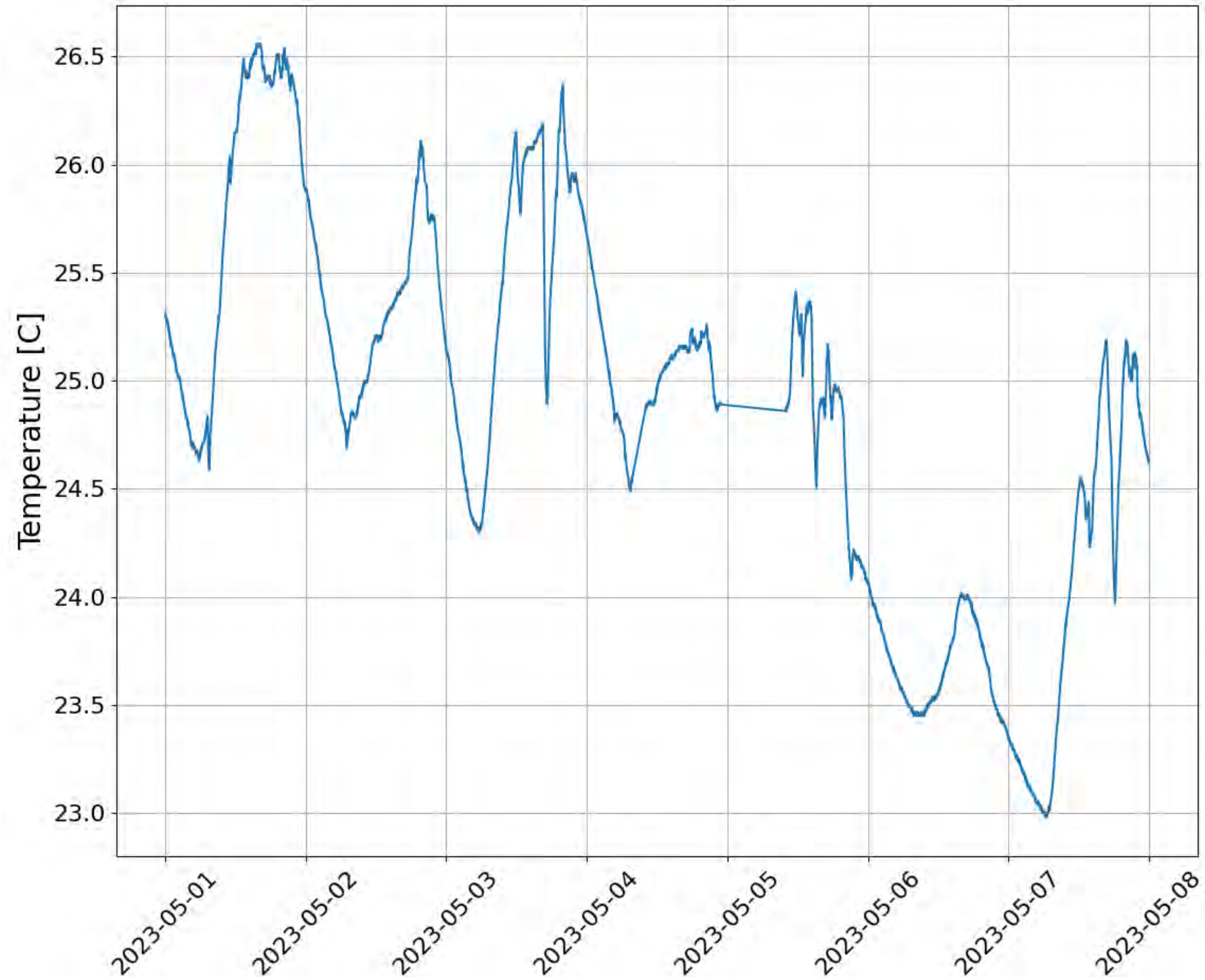


Figure 20: One week of data, between the 1st of May to the 8th of May, 2023, for a single temperature sensor in the Ry demo case.

3.5 Evaluation of building – identification of problems and good operation

This chapter describes the evaluation of the demo case in Ry. The focus will be on the indoor environmental quality in different rooms and electricity use. The indoor environmental quality of the building will investigate a total of 10 rooms. For each analysis performed, long-term measurement for an extended period will be shown, along with a shorter and representative period, to visualize tendencies more clearly. The indoor environmental quality is measured using two different sensors with different resolutions and measurement capabilities, see Appendix B.

Indoor environmental quality – Temperature

The temperature measurement performed in the period of March 2021, to February 2023 is showed on Figure 21.

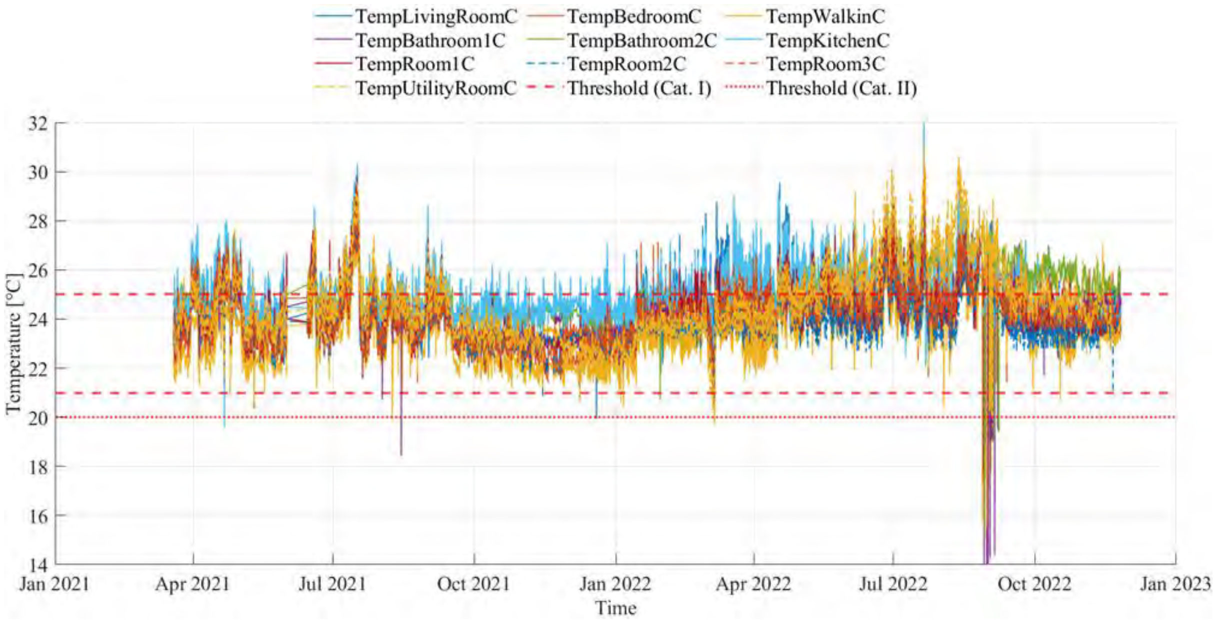


Figure 21: Time series data for entire measurement period of temperature for demo case in Ry.

From Figure 21, it is evident that the house has issues with overheating. The temperatures frequently reach above 25 °C and 26 °C, which are the thresholds for the temperature ranges described in DS/EN 16798-1 for the heating and cooling season. The temperatures in the measurement period fluctuate a bit, with some fluctuations of up to nearly 2 °C within one day. The temperatures for a winter and summer period can be seen in Figure 22 and Figure 23, respectively.

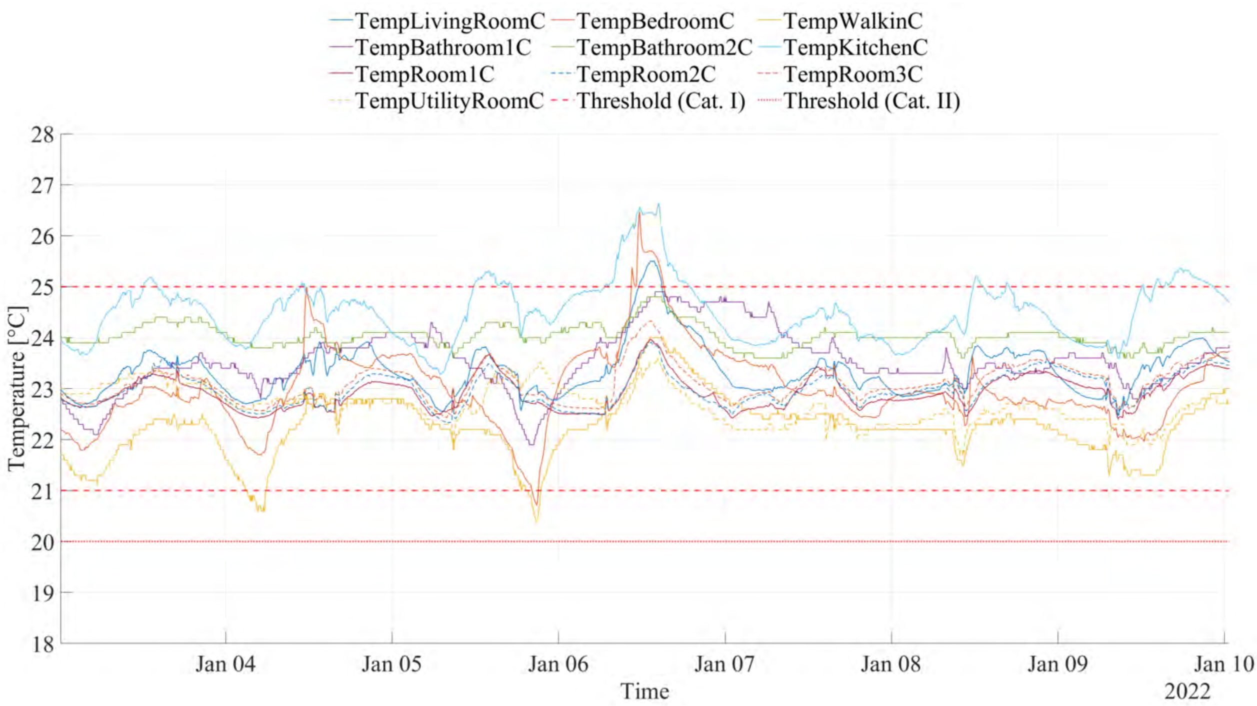


Figure 22: Time series data for one week of temperature for demo case in Ry, week 2.

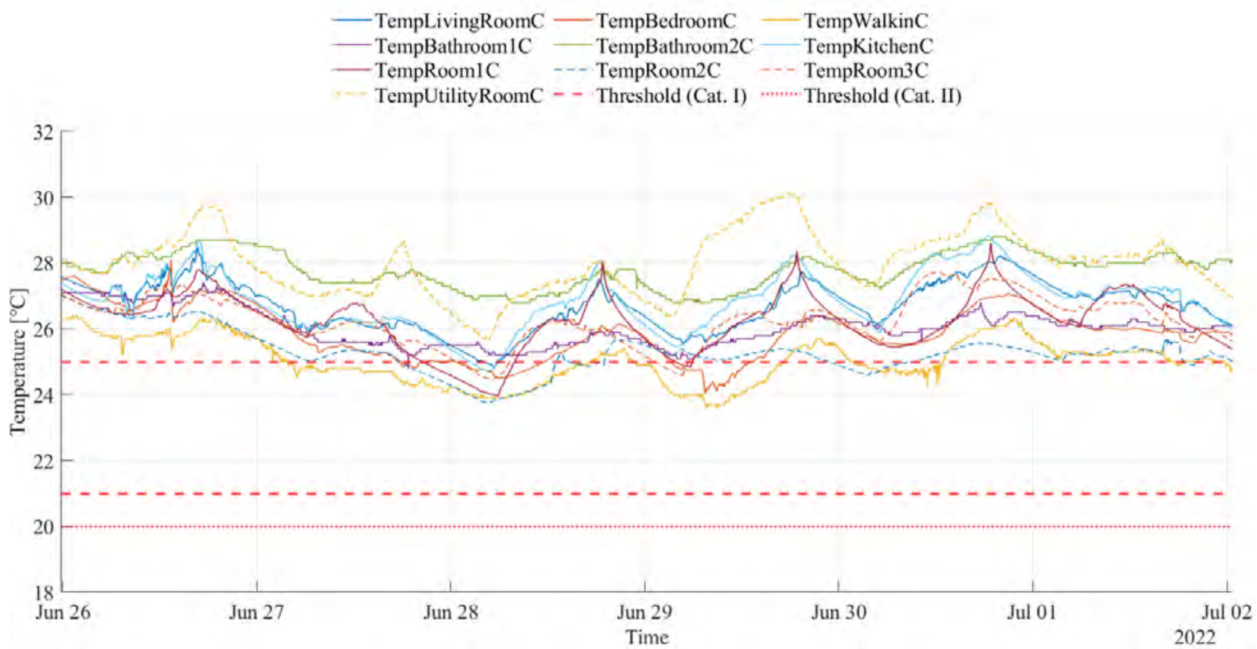


Figure 23: Time series data for one week of temperature measurements for demo case in Ry, Denmark, for week 26.

Based on these measurements, both the time series data for the entire measurement period along with a weekly sub-set of the data, it is evident that the house has issues with temperatures, however, the temperatures in the house are relatively stable. During the heating season, maintained temperatures are for the majority of time between 22-25 °C that is the upper range for comfort and that would result in high heating energy use. During the summer it can be observed that temperatures frequently exceed 26 °C. To more quantitively assess the temperatures in the house, the time distribution of the measured values in the different ranges, shown in Table 2, can be seen in Figure 24**.**

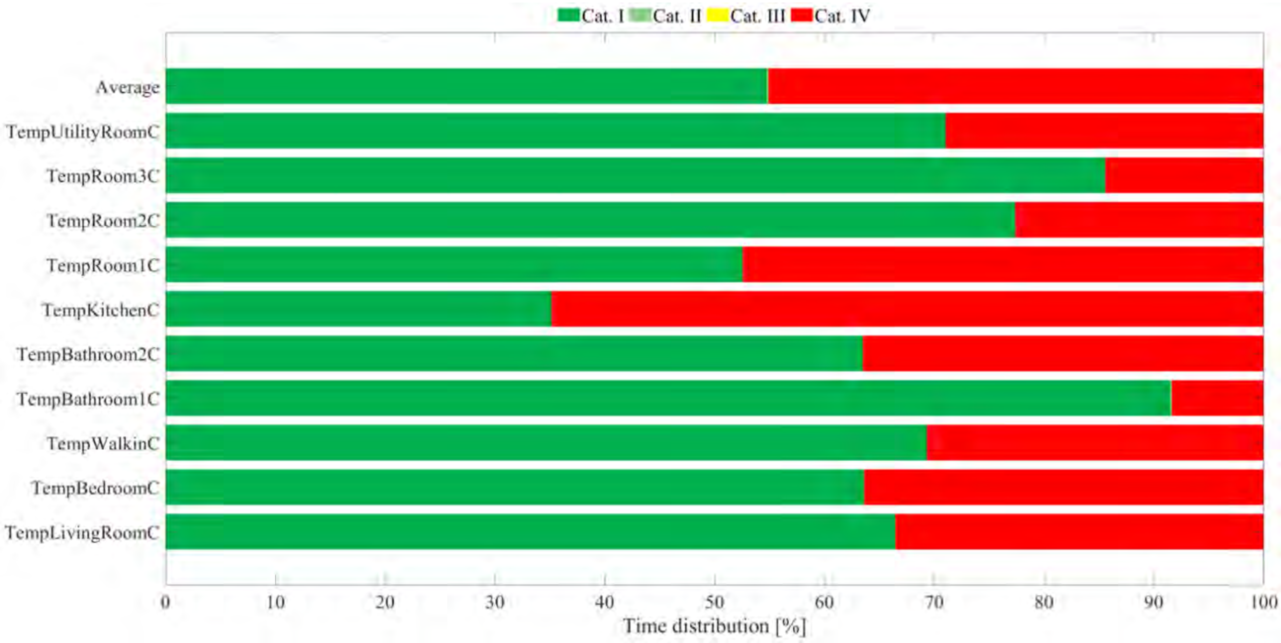


Figure 24: Time distribution of temperature for entire measurement period.

From Figure 24, it is shown that a large amount of time, the building is operating at a lower building category than acceptable, with regards to temperature. The building was expected to operate within the temperatures in category I or II, while it is operating for an unacceptable amount of time within category IV and for the reason of overheating problem.

Indoor environmental quality – Relative humidity

The relative humidity (RH) measurement performed in the period of October 26th 2022, to February 2023 is showed on Figure 25.

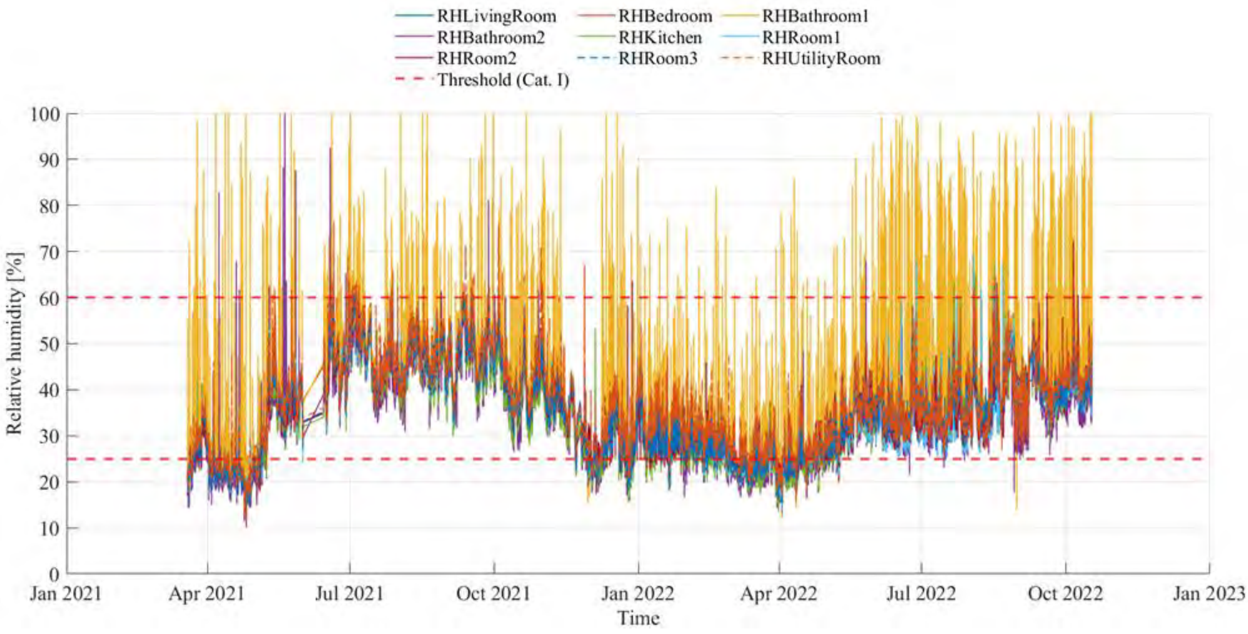


Figure 25: Time series data for entire measurement period of relative humidity for demo case in Ry.

The range for the relative humidity was determined to be between 25 – 60 %. The relative humidities measured in each room are well within this range and have a tendency to be in the lower end of the spectrum. This could also be due to the warmer temperatures in the house. The short peaks of high relative humidity can be seen in the bathroom and are most probably related to showering events. In Figure 26, the relative humidity can be seen from the first week of January 2022. As shown in the figure, the relative humidity are stable through the week and no significant daily fluctuations occurs.

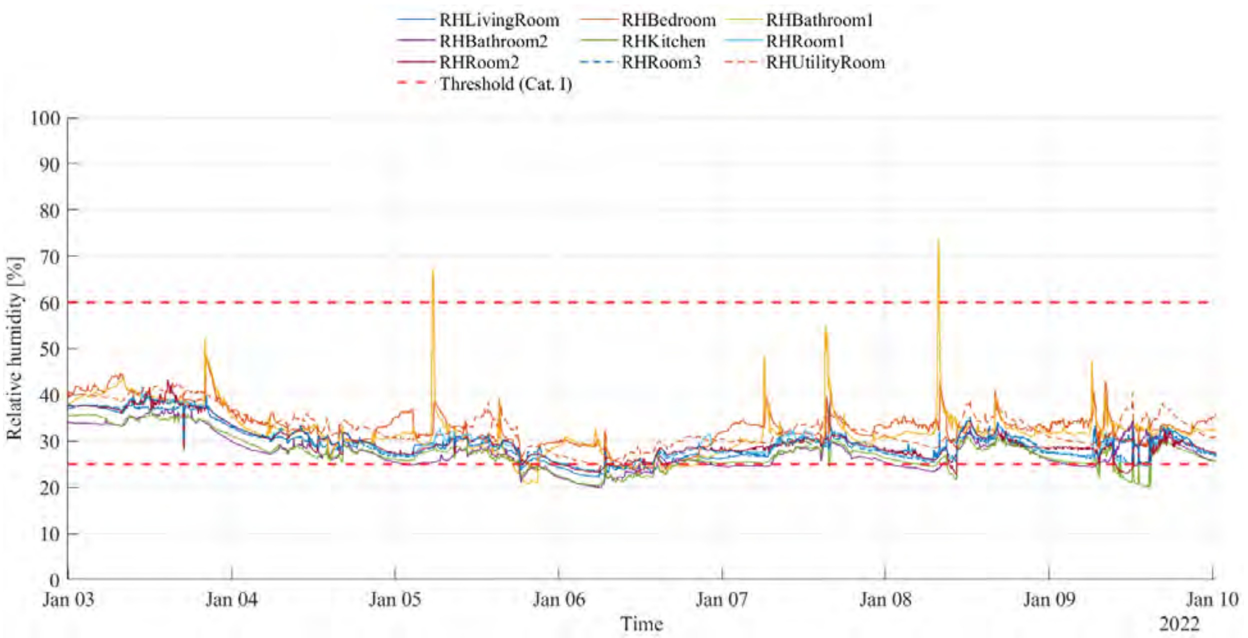


Figure 26: Time series data for one week of relative humidity for demo case in Ry.

The time distribution that the relative humidity is within or out of the specified range, as shown in Figure 27. The relative humidities from the different rooms in the building are a significant percentage of the time out of range, with an average of more than 10 % out of the range for the entire building.

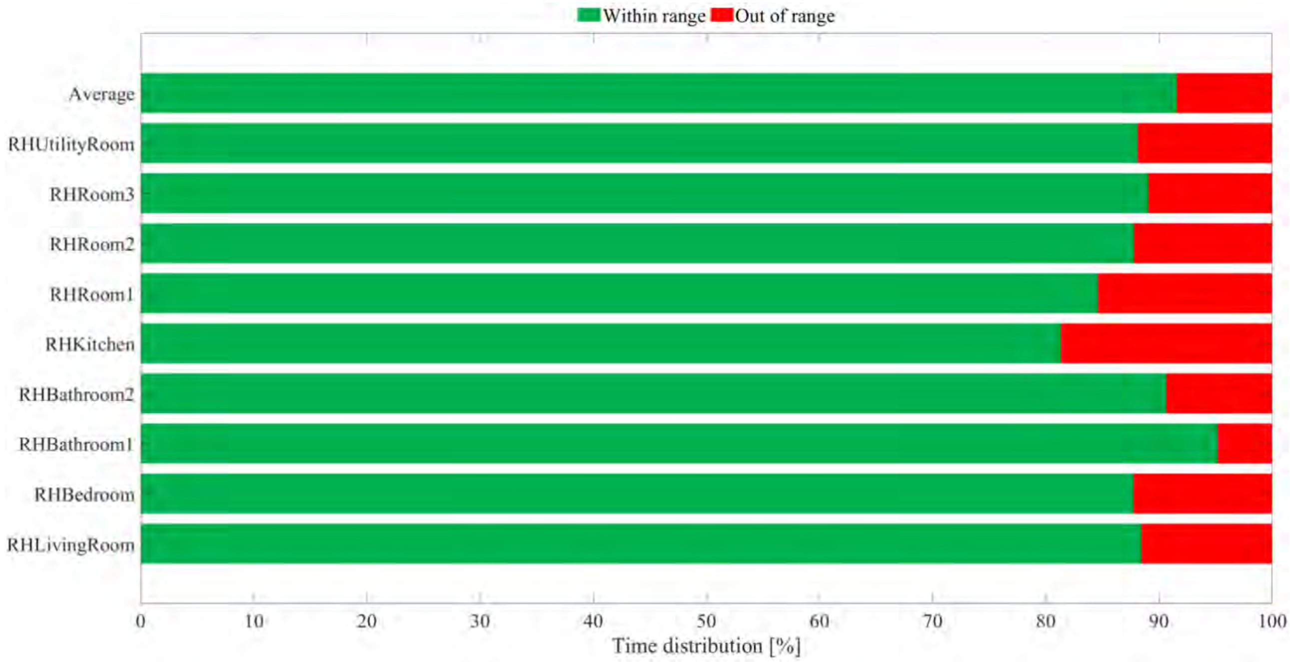


Figure 27: Time distribution of relative humidity for entire measurement period.

Indoor environmental quality – CO_2

The last IEQ parameter that was investigated is the CO_2-concentration in each room of the house. The CO_2-concentration measurements that were performed in the period of October 26th, 2022, to February 2023 are shown in Figure 28.

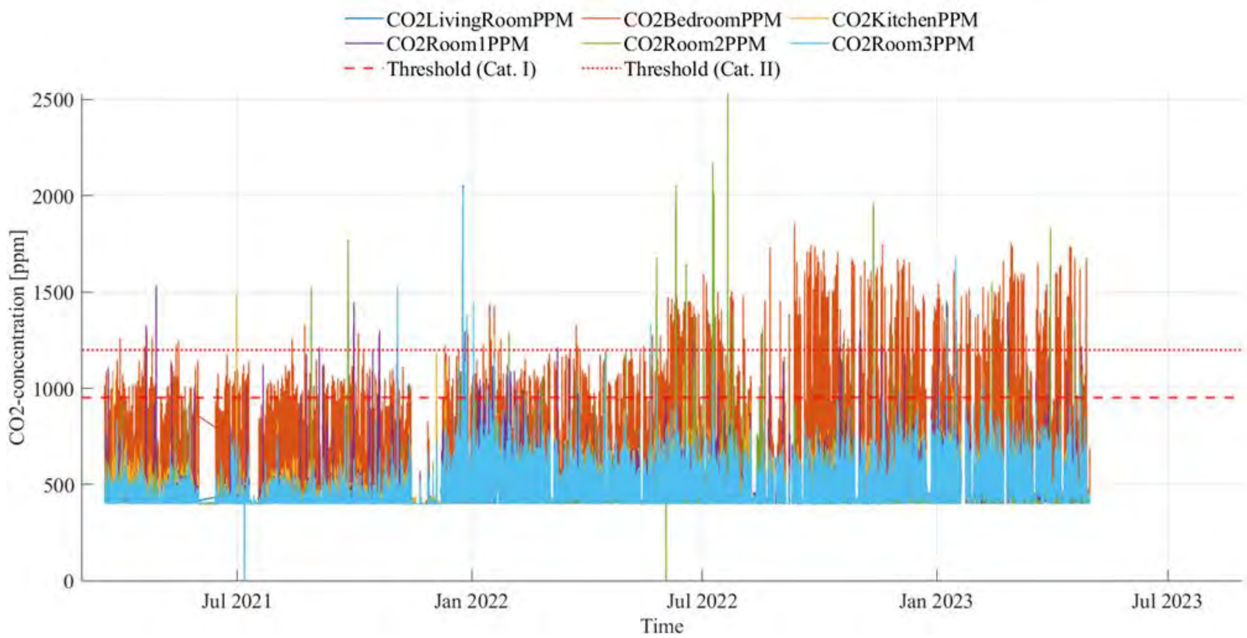


Figure 28: Time series data of CO_2-concentration for entire measurement period.

The CO_2-concentration measured in the period fluctuates a lot, with some periods where the upper thresholds are exceeded. To see the tendencies more clearly, Figure 29 shows the measurements for the first week of January, 2023.

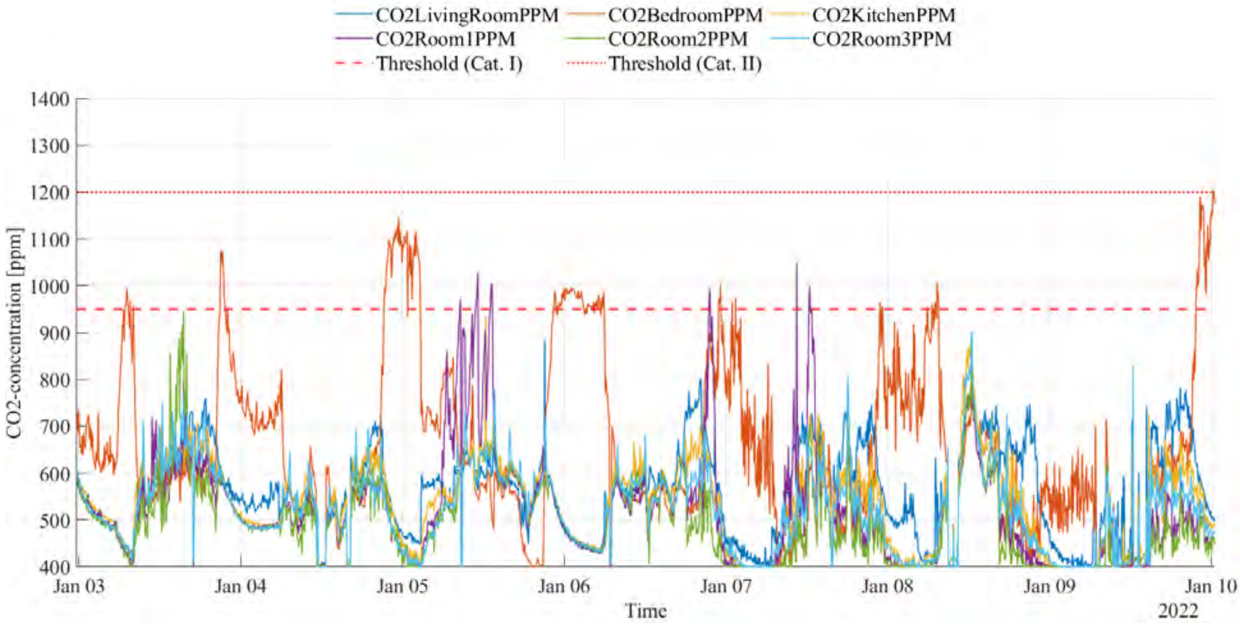


Figure 29: Time series data for one week of CO_2-concentration for one week.

From Figure 29, it is evident that the CO_2-concentration exceeds the threshold of category I multiple times but for short periods. The measured values are mostly below the threshold, with some exceptions, such as in the bedroom. This is to be expected, due to the proportionally higher time spent in the bedroom compared to the other rooms. To assess the CO_2-concentration for the entire measurement period, the time distribution has been shown for each room, see Figure 30.

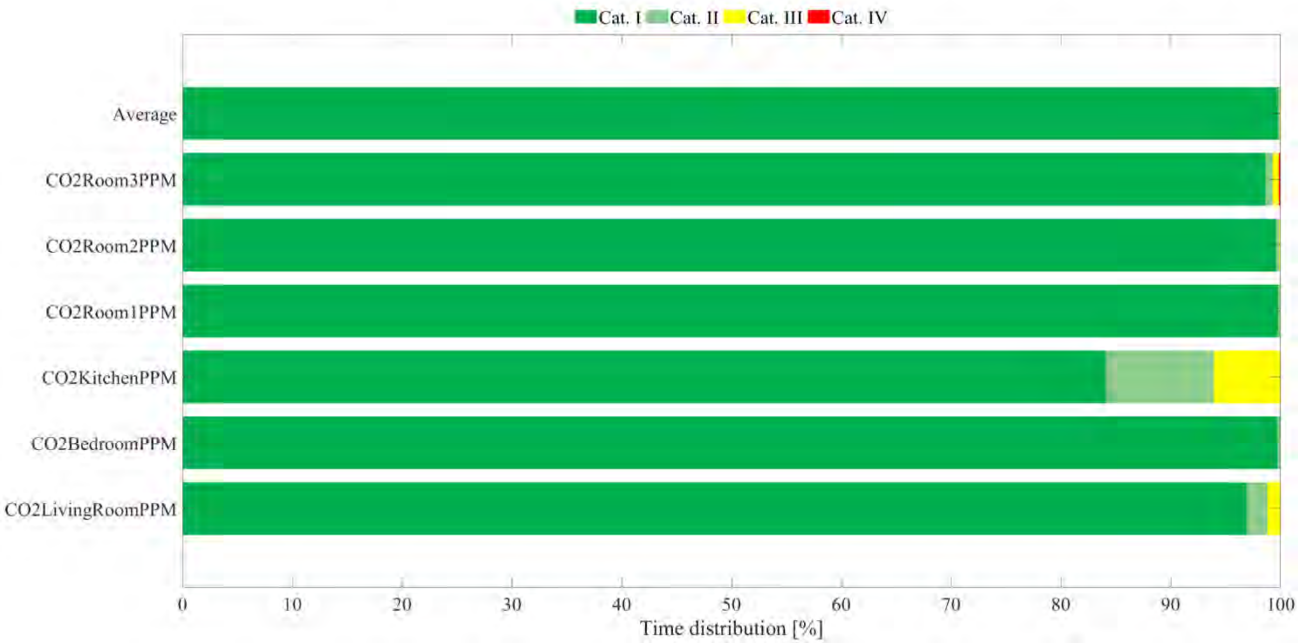


Figure 30: Time distribution of CO_2-concentration for entire measurement period.

As shown in Figure 30, most of the rooms are within category I or II, which is the acceptable range of the CO_2-concentration. Only the bedroom has some issues with the CO_2-concentration, with more than 10 % of the time operating within category III.

Electrical use of appliances

In the Ry demo case, a total of 10 electrical submeters are installed to measure the electrical usage of selected appliances. This consists of the following appliances:

- Cooking plate and ovens
- Fridge and cooker hood
- Control systems
- Pump for floor heating
- Air handling unit + heat pump
- Washing machine
- Dryer
- Dishwasher
- Quooker
- Other appliances (consists of plug loads and lighting)

Each of the different meters measures an accumulated electrical usage in the unit kWh, with a resolution of 0.01 kWh. The time resolution is 5 minutes before the 30th of June, 2022, and 2 minutes after the specified date.

To have a benchmark for comparison of the electricity usage, showing at what times of day the peak consumption occur, and therefore the peak electricity prices, a consumption profile based on a Danish study [5] is used to compare the profiles obtained in this study to the Ry demo case. Based on the study, electricity profiles has been constructed based on 10 different houses in Denmark, which have been averaged out for different seasons. The relative profiles are shown in Figure 31 and Figure 32, for weekdays and weekends, respectively.

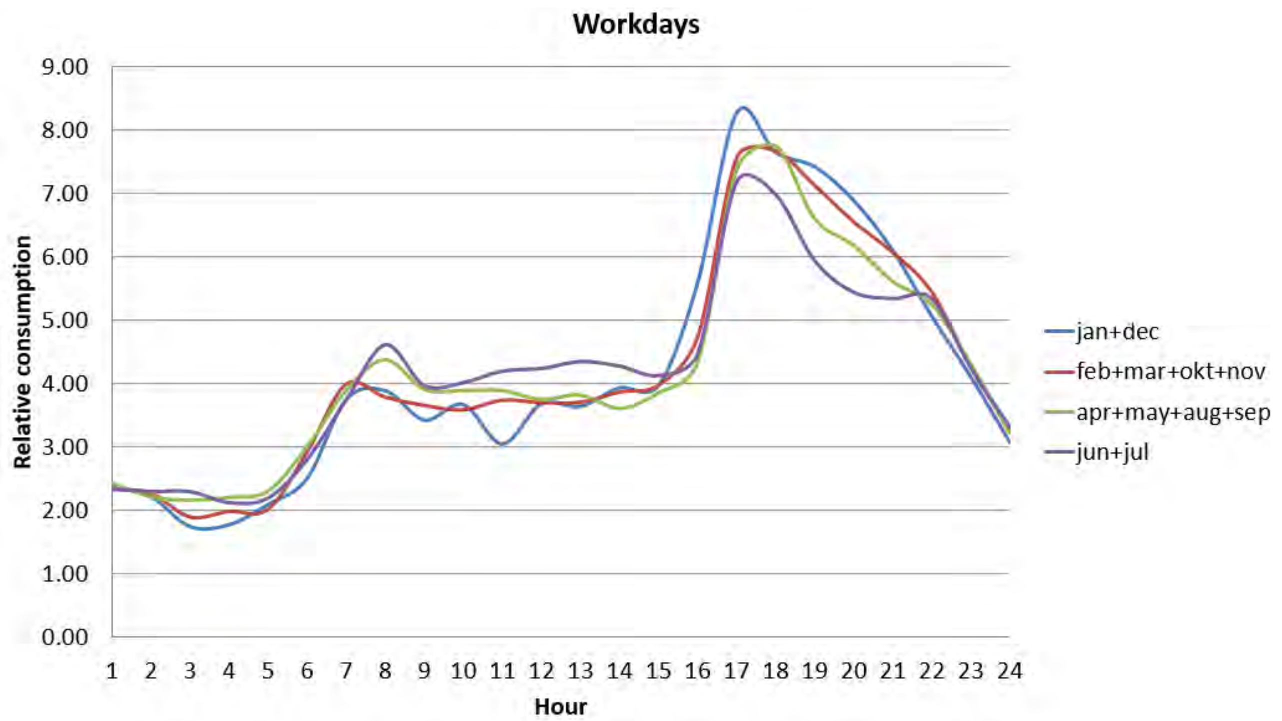


Figure 31: Relative electricity consumption profiles for weekdays in different seasons, based on a Danish study. [5]

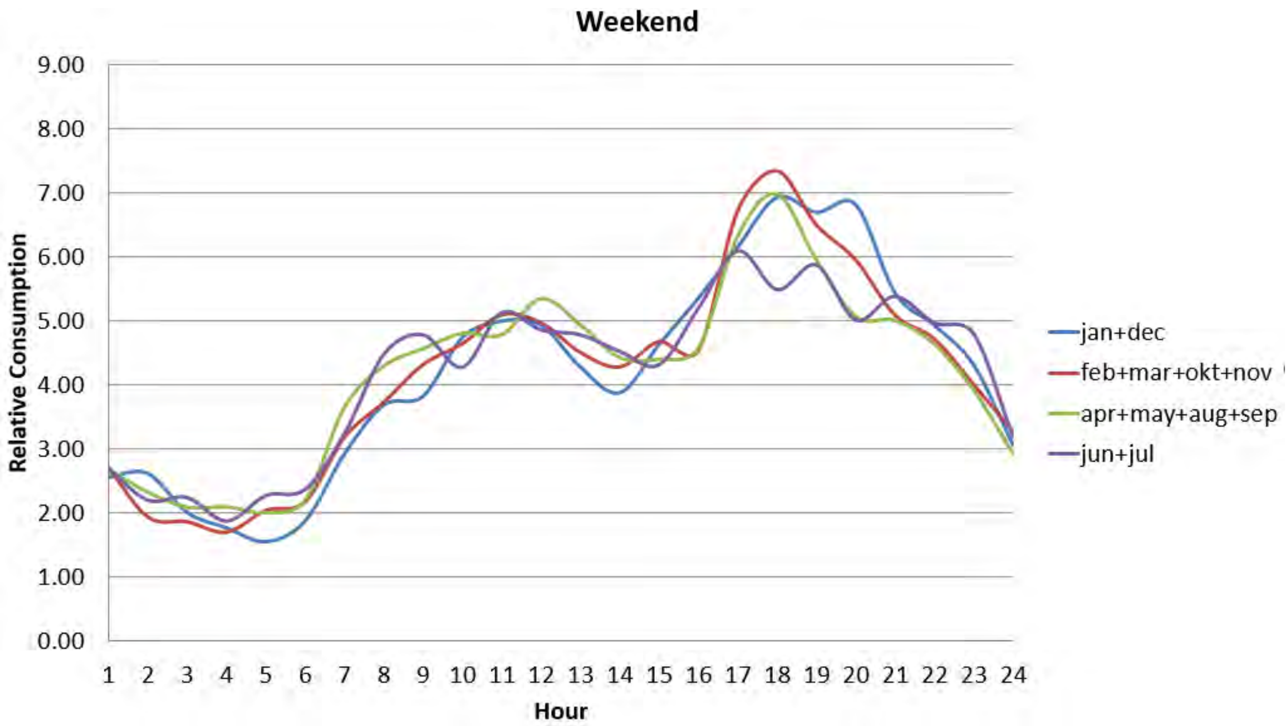


Figure 32: Relative electricity consumption profiles for weekends in different seasons, based on a Danish study. [5]

From Figure 31 and Figure 32, it can be concluded that the highest electricity consumption occurs in the time period 17 to 20, where the electricity will be at it's most expensive point as well, see analysis in Appendix D.

Each available meter in FusiX shows the accumulated electrical usage, and therefore, does not show the measured wattage at different timesteps. The raw data is shown in Figure 33, for 2022.

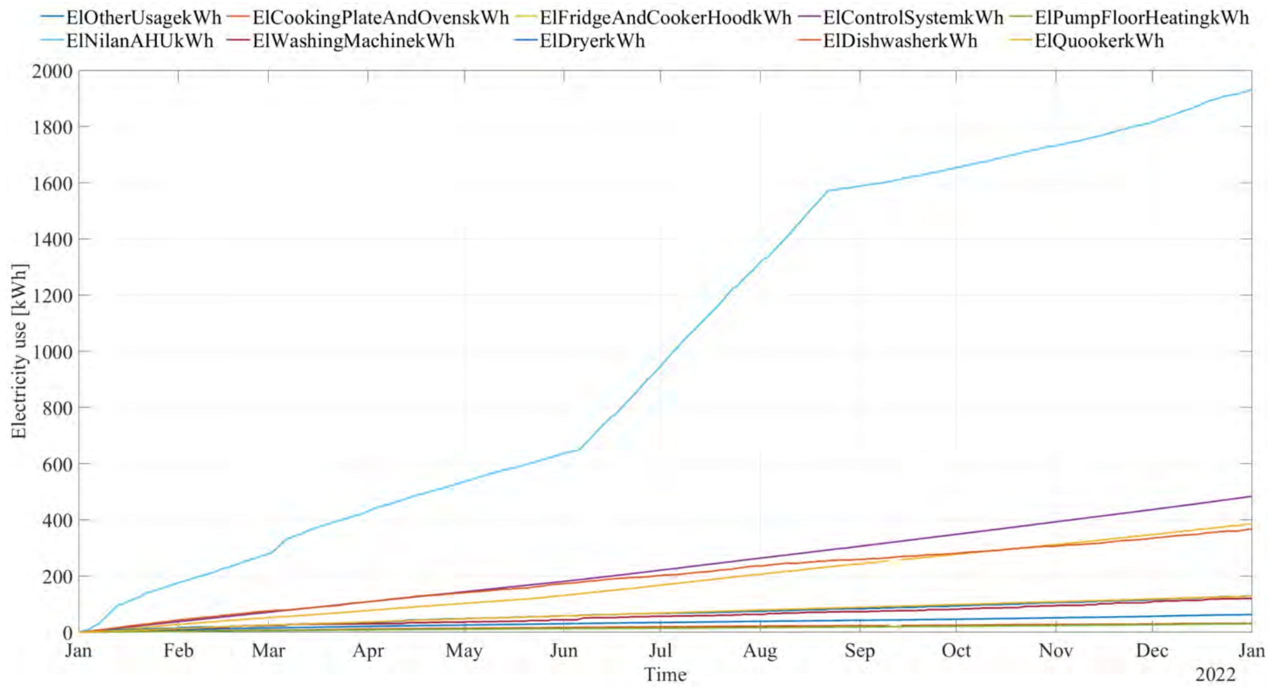


Figure 33: Accumulated energy usage for appliances in the Ry demo case for the year 2022.

From Figure 33, it can be observed that the majority of the electrical usage is due to the AHU and heat pump. The increase in slope for the AHU between June and August is due to the activation of the AHU's active cooling, mentioned in chapter 3.1.2. This feature has been turned off for the next cooling season in 2023.

A zoomed in view of the accumulated electrical usage in the winter period, the first week of January, is shown in Figure 34.

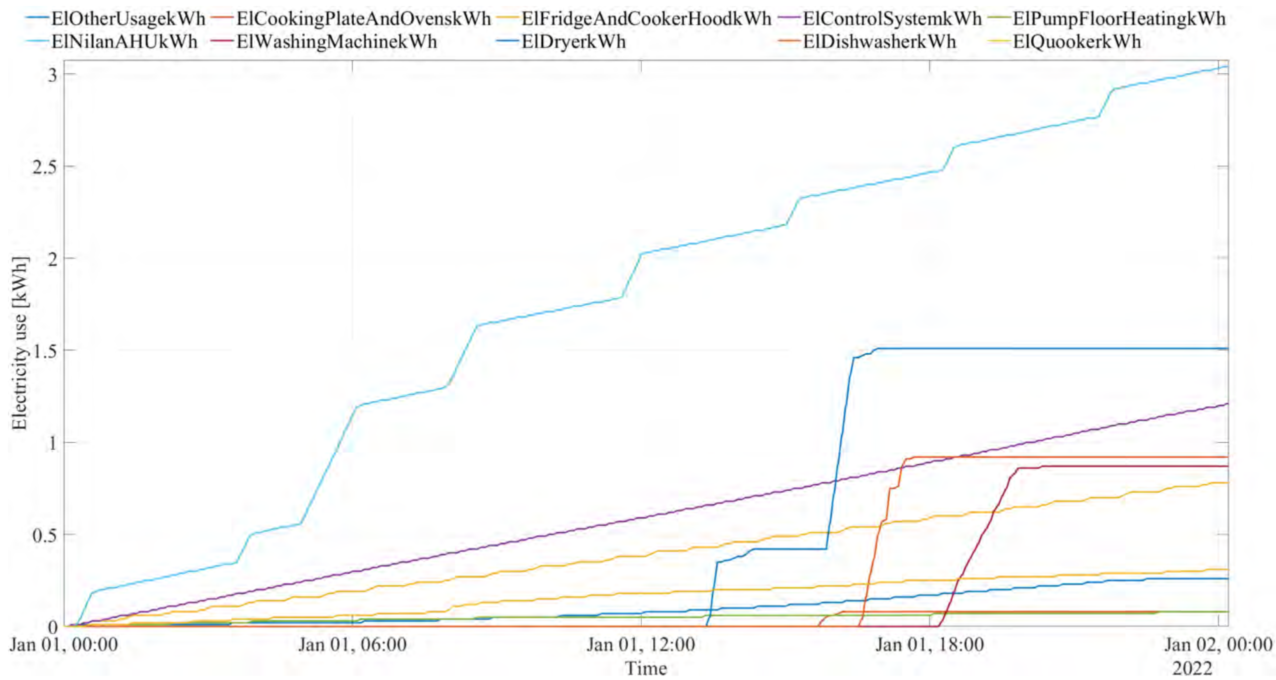


Figure 34: Accumulated energy usage for appliances in the Ry demo case for the year 2022.

From Figure 34, it can be observed that some appliances have a baseline usage, which can be observed by a positive slope, when looking at longer periods of time. This includes the AHU, the control system and the fridge and cooker hoods. Other appliances, such as the dishwasher, have a flat curve until usage, where it increases while it is turned on, after which the curve flattens again. Finally, from Figure 34, it can be observed when the heat pump is active. This can be derived from the meter with the air handling unit and heat pump, which has a positive slope along with sudden increases in electrical usage. The sudden increases is due to the heat pump activating.

To obtain a clearer picture of the daily profiles of the occupants, the time series data has been converted from accumulated values to difference values. From this, the difference between each time step of the accumulated electrical use is determined, which can be aggregated on an arbitrary time scale, e.g. difference between values for each time step. In the following analysis, a difference for values 10 minutes apart has been chosen. The difference in kWh for a 10-minute period is used to estimate the effect in watts for each appliance.

Based on this, the effect from the appliances has been estimated based on the difference in accumulated electrical use in the given time period, and over how long a period this difference is measured between. An example is given in Figure 35, where the effect from the dishwasher is estimated each day for a whole week, in a winter period. Based on these measurements, an average is calculated based on all values within that week, marked with a solid black bold line.

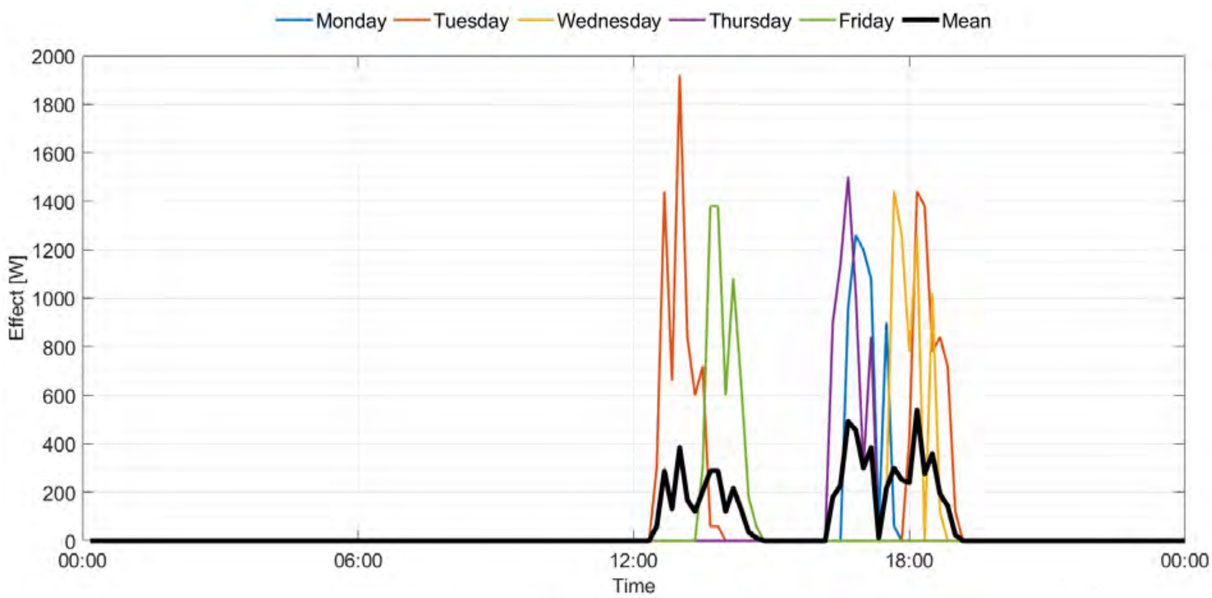


Figure 35: Electricity usage for dishwasher in Ry demo case, for weekdays in week 1 in 2022.

From Figure 35, it can be observed that the mean effect for the dishwasher is relatively low, because the dishwasher is used in irregular periods, and not at the same time each day. To obtain a more realistic day profile, where the dishwasher usage is allowed to deviate in some time span, the day profiles can be shifted so the average profile is calculated as the effect while the dishwasher is in effect, with the profile being shifted to the average start time of the dishwasher. This yields the day profile shown in Figure 36.

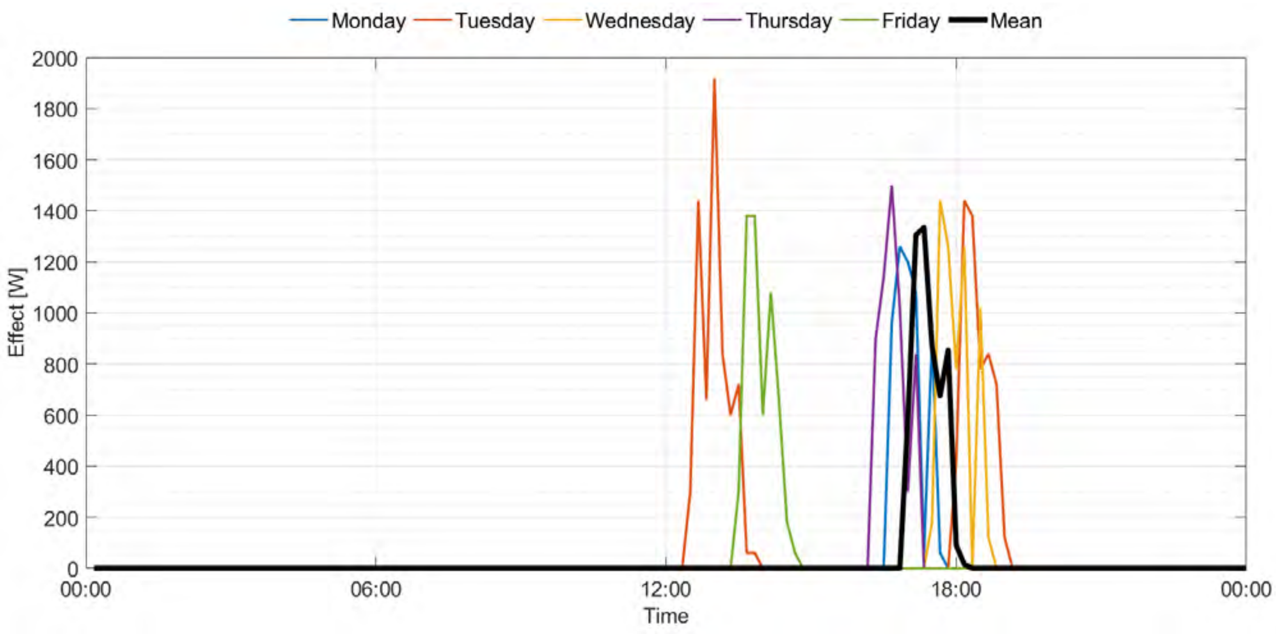


Figure 36: Electricity usage for dishwasher in Ry demo case, for weekdays in week 1 in 2022, with the average profile being based on shifted profiles.

The profile shown in Figure 36 is more realistic, when taking into account the shifting start time of the dishwasher throughout the week. From the figure, it can also be observed that the dishwasher is used in a peak hour, where the average person in Denmark also uses their appliances, which can be seen in Figure 31 and Figure 32. Since the dishwasher is used in the peak hour, it is, therefore, subject to significantly higher electricity prices, compared to if it was used outside the peak hour.

As the dishwasher is sometimes used multiple times a day, only consumption profiles from the afternoon is taken into consideration in the mean profile (marked with a bold black line). The electrical use from the dishwasher is shown in Figure 37-39. The figures are split into summer and winter periods, along with weekdays and weekends.

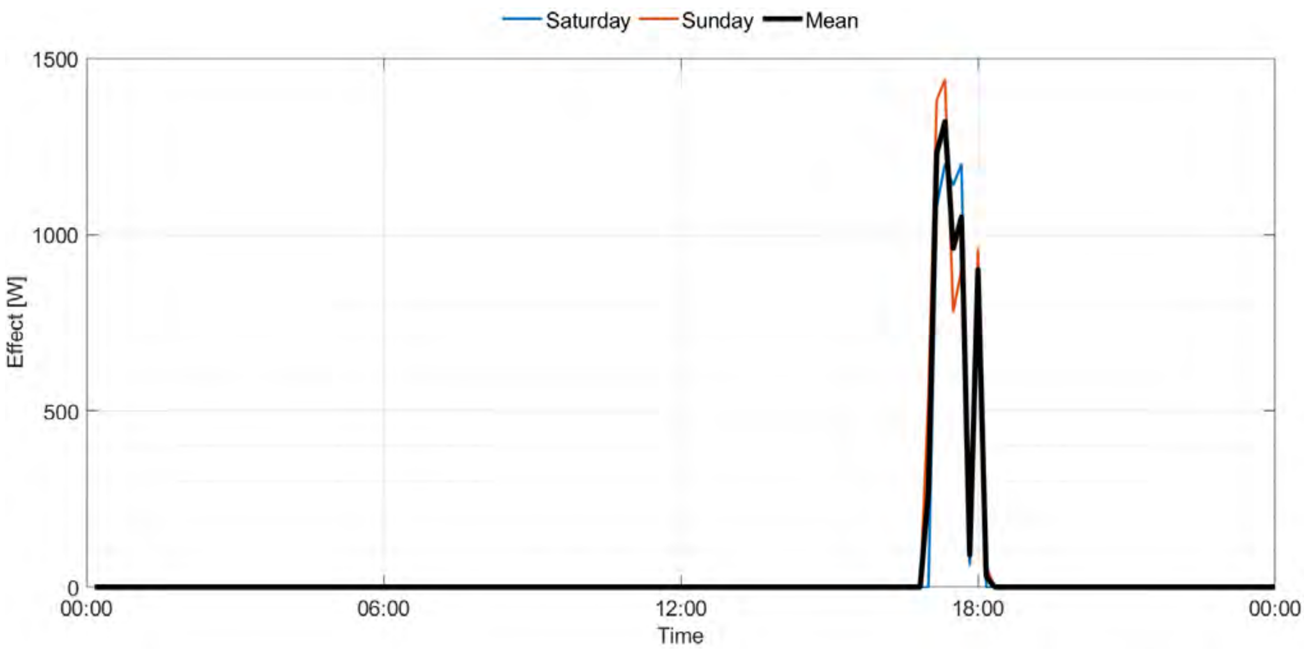


Figure 37: Electricity use for dishwasher in Ry demo case, for the weekend in week 1 in 2022.

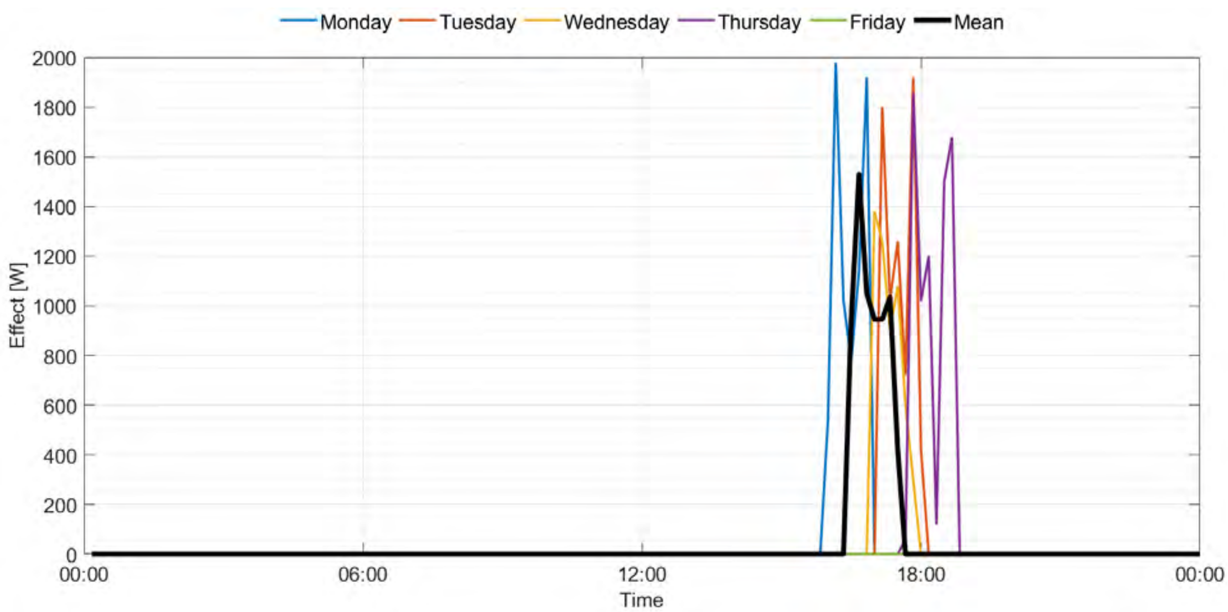


Figure 38: Electricity use for dishwasher in Ry demo case, for the weekdays in week 24, 2022.

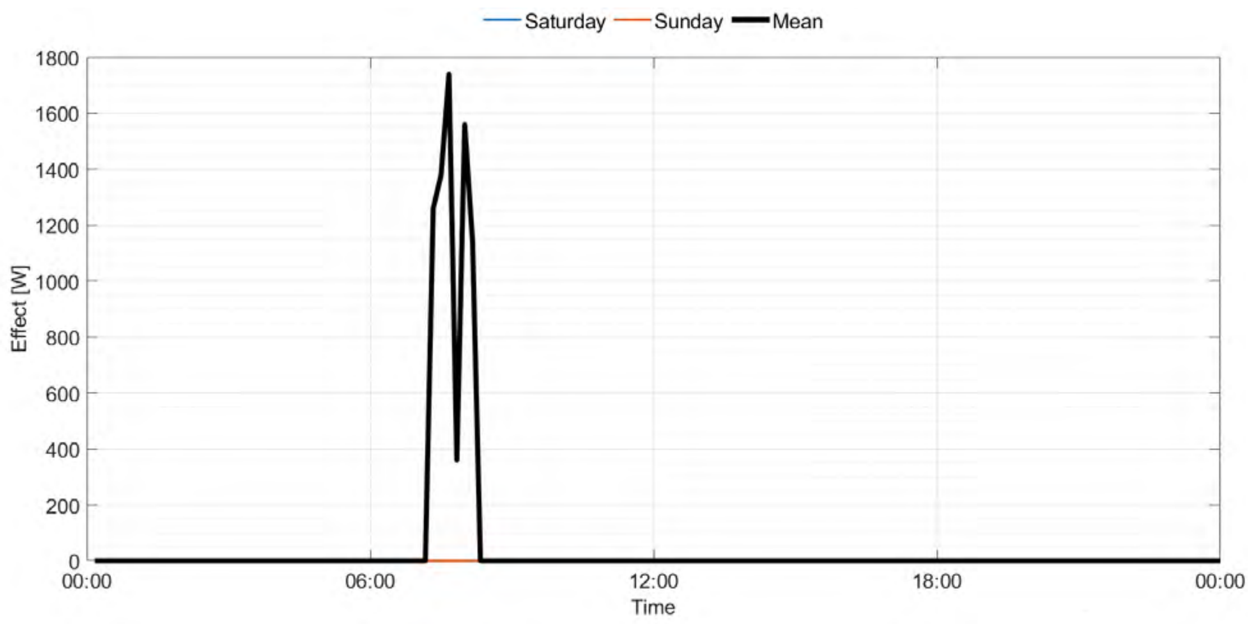


Figure 39: Electricity use for dishwasher in Ry demo case, for the weekend in week 24, 2022.

As shown in Figure 37-39, the daily usage for the dishwasher is mostly during peak hours. This is valid for weekdays and weekends, along with summer and winter periods. This is with the exception of the weekend in week 24, where the use is shifted to the morning.

As the dishwasher is able to delay its use, it is possible to shift the load from the peak hours to hours with less peak demand, which will lower the costs for the electricity used. This can be done for multiple appliances, such as the washing machine, dryer and heat pump.

A similar analysis can be performed for each of the other appliances, where an average profile can be determined for each appliance in a summer and winter period and split into weekdays and weekends. This will provide a better picture of the electrical consumption profiles of the different appliances, and help making recommendations to the tenants of the building for optimizing their energy usage, when considering the electricity prices,. Finally, the distribution of the electrical usage in the Ry demo case can be seen in Figure 40. This is the accumulated electrical usage for the year 2022, for each of the different appliances. The percentage share for each appliance of the total electrical use is shown in Figure 41.

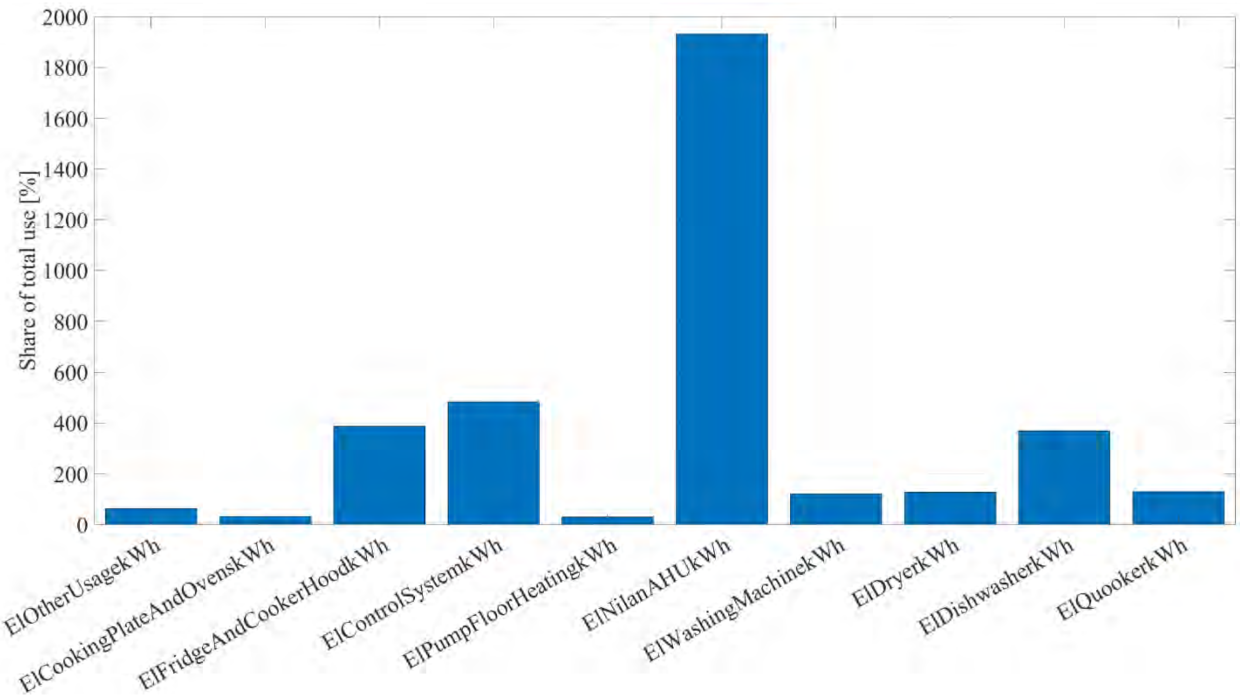


Figure 40: Distribution of the electricity use in Ry demo case, for the year 2022.

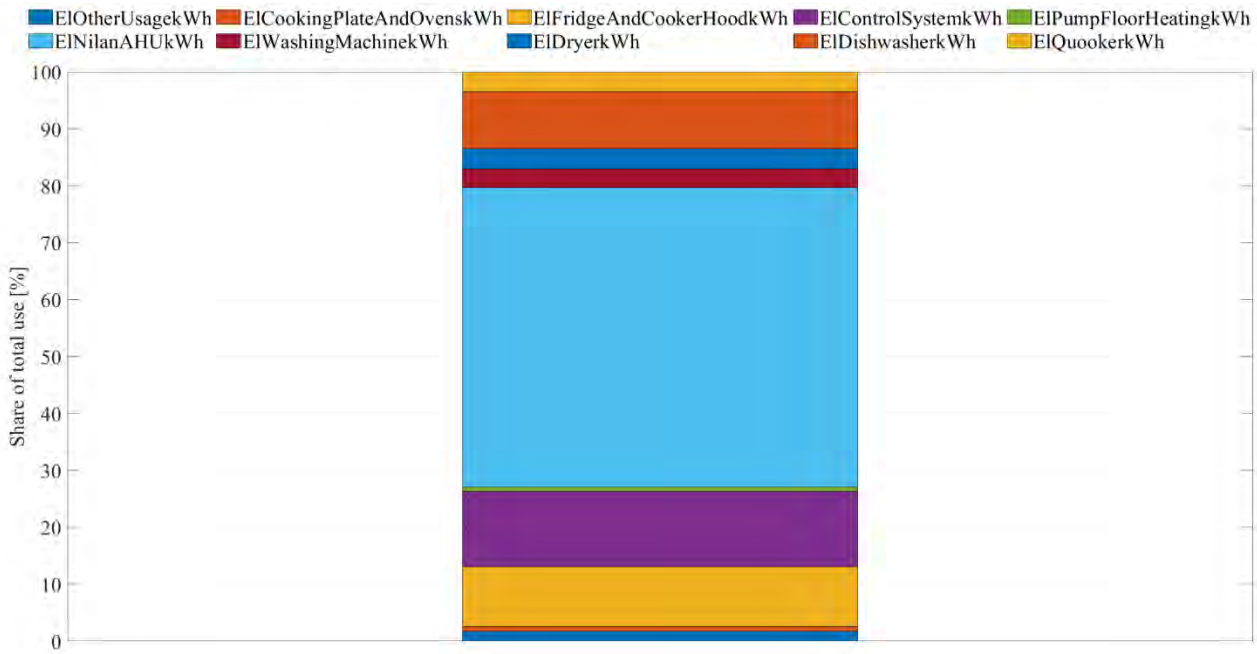


Figure 41: Percentage share of the electricity use in Ry demo case, for the year 2022.

From Figure 40 and Figure 41 it is evident, that the majority of the electrical use is from the AHU+HP, with a total percentage share of more than 50%. Other notable shares include the dishwasher, control systems and the fridge and cooker hood.

3.6 Ongoing preparations

As indicated in this chapter, a few ongoing preparations in the demo case must be finalized so the building is suitable for the planned implementation of PRELUDE technologies.

For the Free Running Module by POLITO, there is ongoing preparation to implement a scheduled 24-hour control of solar shadings and fan speed in the AHU. The preparations have two steps. Step one is to implement the file with the 24-hour values into the control system and design the control system to use this schedule for the devices. Step two is to automize the "way" from the PREDYCE tool to the control of the devices by using FusiX. The result of the PREDYCE tool is the 24-hour file that will either be calculated in FusiX or locally at POLITO and transferred to FusiX. From FusiX, the file should be transferred to the local computer or NAS server in the demo case and implemented in the control system by the PLC software. This preparation is planned to be finalized in June before the test of the Free Running Module in late July and the beginning of August.

The data communication from the demo case to FusiX is close to being complete. However, the data from the SMA PV system is missing in FusiX. There is ongoing work from AAU to be granted access to the SMA API. When access is granted, EMTECH can implement the API in FusiX, and data can be retrieved. In the meantime, data can be manually retrieved, and AAU has historical data from the PV system.

Regarding the data treatment of the Ry demo case, different user profiles can be constructed using the electrical use of the Ry demo case. In this report, the user profile of the dishwasher was investigated, where an average profile was constructed for a winter period, a summer period, for both weekdays and weekends. This can be done for more appliances, and in a longer period, to better understand when the tenants use the different appliances.

4 PLANING AND IMPLEMENTATION OF PRELUDE SOLUTIONS

In this chapter, detailed information for the implementation of all identified PRELUDE technologies relevant for the Ry demonstration are provided. The plans for implantation consider actions planned and already carried out.

4.1 Technology 1: Models' aggregation (TREE)

4.1.1 Overview of the proposed solution

In the context of T5.1, TREE team is working on innovative solutions to efficiently aggregate models in scenarios involving multiple buildings, such as neighbourhoods, districts, or even entire cities. The goal is to generate knowledge and intelligence at scale based on the aggregation of individual models, taking predictive models and optimization features to a larger scale.

To achieve this goal, we have developed a cloud-based data and model integration solution. It integrates and consolidates information from multiple buildings, including both static and dynamic, historical and real-time data, as well as models. Our approach to model integration is Federated learning [6-9], a machine learning technique that trains an algorithm across multiple decentralized nodes, such as edge devices or servers, that hold local data samples without exchanging them.

Compared to traditional centralized machine learning techniques where all data samples are uploaded to one server, our approach enables multiple actors to build a common, robust model without sharing data, addressing issues such as data privacy, security, access rights, and access to heterogeneous data while optimizing data transactions.

Our building-based models perform a 24-hour ahead forecast of energy consumption. While these nodes-models are trained separately, they are using collaborative intelligence from all active nodes. We use heating energy consumption data to train these models, and this big-data-technology implementation can be generalized to any other energy consumption type and scale, from individual apartments to entire buildings. This approach enables us to predict future energy consumption and perform the appropriate optimizations for energy gain. Furthermore, the deviation error of the federated forecasting architecture will be compared to the real energy consumption data in order to assess the efficiency of our method.

The data required to train/test aggregated forecast models is as follows:

- Building's characteristics: building type and size, and the total number of rooms.
- Heating system data: heating energy consumption, water flow, input/output water temperature. The time series has been resumed to have an hourly resolution.
- We also enrich this dataset with weather data (historical/forecast) of Ry city.

In the Ry case, we retrieve this data from FusiX API. Response to API calls to this Ry building's endpoint is as shown below:


```
{
  'type': 'sensor',
  'category': 'Consumption',
  'id': 1085,
  'sub_type': 'Thermal Energy Meter',
  'units': 'MWh',
  'name': 'DH - DHW (MWh)',
  'short_name': 'DH - DHW (MWh)',
  'Readings': [
    {
      'Value': 5.4,
      'Timestamp': '2023-05-09 12:26:45+00:00'
    },
    {
      'Value': 5.4,
      'Timestamp': '2023-05-09 12:28:45+00:00'
    },
    ...
  ]
}
```


Figure 42: FusiX API response for the thermal energy meter in Ry.

Our experiment involves two main types of models: nodes-models and central model.

The *nodes-models* refer to the local models in each building of our experimental setting (i.e., Ry building). Each building has its own associated model and is trained using historical data specific to that building. To ensure that the federated learning concept is centralized, we create separate processes/memory spaces to access building data and train the corresponding model. We use deep learning techniques to train the models. During training, the nodes' models only communicate vertically with the central node (as shown in Figure 43). After a predefined number of iterations, the central model receives and aggregates the node-model updates.

The central model has the same architecture as the nodes-models and uses deep learning techniques to aggregate all models' updates. The resulting aggregated model is then shared with all nodes, allowing collective knowledge to be propagated to all buildings. The models are designed to make a 24-hour ahead forecast of the district heating energy consumption.

It is important to note that the nodes-models are trained using only the data from their respective buildings. Data from other buildings is not accessible during this stage, ensuring data privacy and security.

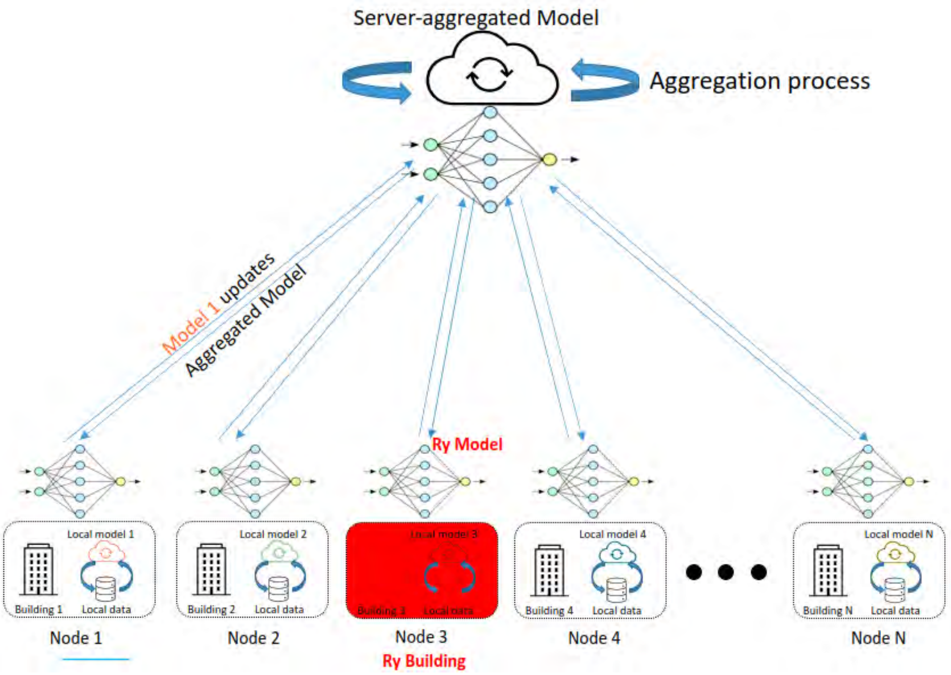


Figure 43: Federated learning architecture for the DH energy forecasting.

To implement our solution, we will be using AWS cloud services such as AWS EC2[1], ECR[2], S3[3], etc.

It is important to note that TREE is relying on AWS services which has all the relevant certifications for compliance with cloud related security standards, such as ISO/IEC 27001:2013, 27017:2015, 27018:2019, 27701:2019, 22301:2019, 9001:2015, and CSA STAR CCM v3.0.1 among others.

The selected zone code for our experiment is "*eu-central-1*". It means that all processing activities are performed on remote servers geographically located in Frankfurt, this is to comply with GDPR regulation.

The deep learning model (LSTM) has the following input/output parameters:

- **Input**: historic data about DH energy consumption (heating energy, water flow volume, inlet water temperature, outlet water temperature), historic weather data (temperature), weather forecast (for the predictions) and building's characteristics (number of rooms, total area, building type)
- **Output**: 24h-ahead forecast of the DH energy consumption

[1] https://aws.amazon.com/ec2/
[2] https://aws.amazon.com/ecr/
[3] https://aws.amazon.com/s3/

4.1.2 Implementation plan

The implementation plan is as follows:

1. Connect to the FusiX API and collect the DH energy consumption dataset:
    a. Identify the API endpoint for DH energy consumption data.
    b. Setup a connector to extract the data from the API. In the case of Ry, the dataset is from 2021-03-14 until 2023-03-22.
    c. Get the historic weather data for the city of Ry.
    d. Store the data in a cloud-based storage system.
2. Preprocess the dataset:
    a. Identify missing values and outliers.
    b. Clean the data by imputing missing values and removing outliers (use one hour resolution).
    c. Transform the data into a format suitable for training a deep learning model.
3. Develop a deep learning model for the time series forecast:
    a. Choose the appropriate deep learning algorithm (e.g., LSTM) for forecasting.
    b. Split the dataset into training and testing sets.
    c. Train the deep learning model on the training set.
    d. Evaluate the model's performance on the testing set.
4. Fine-tune the model using Bayesian optimization:
    a. Identify hyperparameters that affect the model's performance.
    b. Use Bayesian optimization to search for the optimal values of the hyperparameters.
    c. Fine-tune the model using the optimized hyperparameters.
5. Integrate the model in the Federated learning system:
    a. Configure the Federated learning system to work with the deep learning model.
    b. Set up a central server that aggregates the updates from the local models.
6. Train the model using the Federated learning approach Integrate the model in DH forecasting API:
    a. Develop an API that integrates the trained model.
    b. Setup the connector to the “predictions” endpoint of the FusiX API to get the weather forecast for the city of Ry. This information will be integrated as an input of the forecast model.
    c. Integrate a visualization dashboard to show the forecast result.
    d. Setup a cloud-based web server to host the API.
    e. Deploy the API on the web server Test the API's functionality and performance.

7. Deploy the solution:
    a. Deploy the entire solution on a cloud-based platform.
    b. Monitor the system for any issues or errors.
    c. Provide documentation and training materials for end-users.

This implementation plan is to ensure the successful deployment of a cloud-based IT solution that leverages artificial intelligence, deep learning, and federated learning to forecast DH energy consumption.

4.1.3 Performance assessment of the implemented solution

In the context of our FL-based solution, different performance aspects could be considered:

- **Accuracy**: This metric measures the accuracy of the predicted DH energy consumption values compared to the actual values. We are using different error metrics such as Mean Absolute Error (MAE), or Mean Arc-tangent Absolute Percentage Error (MAAPE) to calculate the accuracy of the model. We are also considering the comparison to a baseline (the LSTM model versus and XGboost one).
- **Scalability**: The solution should be scalable and able to handle large amounts of data.
- **Speed**: The solution should be able to process and generate predictions quickly.
- **Privacy and security**: we are considering the assessment of the security measures taken in the solution to prevent unauthorized access to the data and models. Authorization mechanism is set to grant access exclusively to authorized users.
- Integration: Evaluate how the model has been integrated into the DH forecasting API, ensuring that the model can provide accurate predictions in a production environment.
- During the implementation phase, these indicators are considered for the continuous improvement of the proposed solution. Energy saving and reduction of gas emission

4.1.4 Energy saving and reduction of gas emission

The DH forecasting solution predicts the next 24h energy forecast for each building (such as Ry building). To calculate the reduction of gas emissions, we need to know the carbon emissions associated with the energy consumption before and after performing an optimization process. This is by using the carbon emissions factor for the energy source used for DH energy production to calculate the emissions. The difference between the two emissions values will give us an estimate of the reduction in gas emissions.

In this context, the proposed solution consists in forecasting and does not perform a direct optimization of the energy use. The final consumer of our model is energy aggregator/supplier. It is a decision support system any optimization process is on end-user responsibilities. No automatic optimizers have been implemented.

4.2 Technology 2 – Occupancy module (FB)

4.2.1 Overview of the proposed solution

The occupancy module developed in Task 3.3 has been presented in Deliverable D3.3.

The occupancy module has been first tested in the Living Lab Energetikum (LLE), validating its application in an office building. To test and validate the module in a residential building, it is implemented in the single family house of Ry.

The occupancy module has been developed in MATLAB and translated in Python, for integration in the FusiX platform. Both versions have been adapted to Ry use case and tested.

This demonstration building has CO_2 measurements and a monitored mechanical ventilation, which enables the application of a similar approach to the one successfully applied in the LLE.

The CO_2 balance is calculated, with the CO_2 coming in and out of the room through the ventilation air flow. The difference provides an estimation of the CO_2 production rate in the building. If manual ventilation and CO_2 contributions from other living organisms are negligible, the CO_2 production rate corresponds to the occupants' metabolism.

4.2.2 Technical specification of the proposed solution and data collected

The monitoring data is available in FusiX. The code has been adapted to collect the relevant data for the occupancy module in weekly files. The data import procedure has been extended to test the module in MATLAB.

The weekly files tested in January revealed some data gaps, due to failure in the retrieval process. EMTECH has worked on the issue to improve the reliability of the data collection from the demonstration building.

For each zone (room) of the house, the parameters and the variables used in the occupancy module are summed up in Table 19, Table 20, and Table 21. The following variables are collected:

- Ventilation:
  - Air flow entering the house in m³/h: $AirFlowSupplym3h$
  - In each room, the supply air flowrate v_air_in is calculated based on the average share of air flow distributed to this room $fraction\_air\_flow\_supply\_average$ as :
  $$v\_air\_in = fraction\_air\_flow\_supply\_average\,.\,AirFlowSupplym3h$$
  - Air flow extracted from the house in m³/h: $AirFlowReturnm3h$
  - Similarly, in each room, the return air flowrate v_air_out is calculated based on the average share of air flow extracted from this room $fraction\_air\_flow\_extract\_average$ as :
  $$v\_air\_out = fraction\_air\_flow\_extract\_average\,.\,AirFlowReturnm3h$$
  - Infiltrations are considered to strictly balance the difference between supply and extracted airflow.
- Air properties:
  - Operative temperature
  - CO_2 concentration
  - Relative humidity
- Electricity: The power consumption is collected but has not been used yet:
  $$P\_el = [diff(building.tt.E\_el); 0] * 1000 * 3600/Delta\_t$$
  - Detailed electrical power consumption:
    - CookingPlateAndOvens,
    - FridgeAndCookerHood,
    - ControlSystem,
    - NilanAHU,
    - WashingMachine,
    - Dryer,
    - Dishwasher,
    - Quooker
  - Total power consumption: sum of the eight sub-meters
- Data from the windows are collected but have not been analysed/integrated in the model yet.

The CO_2 balance is calculated at zone level, considering that the air flowrate balance, between supply and extraction, is ensured by infiltrations. The missing air when supply is smaller than extraction, in rooms extracting air, is compensated with outside air, with the ambient CO_2 concentration. This is only the case in the kitchen/dining room. All other rooms equipped with a CO_2 sensor are supplying air only. In these cases, the extra air, where supply is stronger than extraction, is extracted with the CO_2 concentration measured in the room. The same assumption as in the office building is kept as first hypothesis, for the CO_2 production rate per person: 17 L/h/person, corresponding to light work. The resulting number of occupants is called *occupancy from CO_2*. Thresholds are defined based on data analysis to convert this *occupancy from CO_2* into an adjusted number of occupants. The thresholds are illustrated in Figure 44:

- over 0.4, the presence of at least one occupant is highly probable,
- over 1.2, the presence of 2 or more occupants is highly probable.

In cooperation with the tenants of the house, one week of detailed occupancy schedule has been recorded manually, with a 5 minutes time resolution. This is a great information for which we address our sincere recognition to the occupants of the house for their valuable contribution. Although this recording is one week long only, it is of high quality and can be used for training and for validation of the algorithms.

Table 19: Overview of variables from the house, used in the occupancy module: Ventilation air flowrates.

Zone name ↓ \ Variable description →	air flow entering the zone (supply	air flow extracted from the zone
Variable name →	v_air_in	v_air_out
Variable unit →	m^3/h	m^3/h
Building	AirFlowSupplym3h	AirFlowReturnm3h
All other rooms	*calculated*	*calculated*

Table 20: Overview of variables from the house, used in the occupancy module: CO_2 concentration, parameters of airflow distribution between the rooms, room volumes.

Zone number	Variable description → Zone name ↓	Operative temperature	Relative humidity	CO2 concentration	Average share of air flow distributed to the room	Average share of air flow extracted from the room	Volume
	Variable name →	T_op	RH	C_CO2	fraction_air_flow_supply_average	fraction_air_flow_extract_average	V
	Variable unit →	°C	-	ppm	-	-	m^3
	Building						
1	Living room	TempKitchenC	RHKitchen	CO2KitchenPPM	0.25	0	3.1*24.4
2	Bedroom	TempBedroomC	RHBedroom	CO2BedroomPPM	0.07	0	3.1*8.9
3	Kitchen, Dining room	TempKitchenC	RHKitchen	CO2KitchenPPM	0.20	0.06	2.6*30.9
4	Room 1	TempRoom1C	RHRoom1	CO2Room1PPM	0.13	0	2.6*8.5
5	Room 2	TempRoom2C	RHRoom2	CO2Room2PPM	0.14	0	2.6*12.4
6	Room 3	TempRoom3C	RHRoom3	CO2Room3PPM	0.15	0	2.6*11.8
7	Walk in	TempWalkinC			0.06	0	2.6*5.8
8	Bathroom 1	TempBathroom1C	RHBathroom1		0	0.36	2.6*6.0
9	Bathroom 2	TempBathroom2C	RHBathroom2		0	0.34	2.6*4.7
10	Utility room	TempUtilityRoomC	RHUtilityRoom		0	0.24	2.6*7.6
11	Corridor				0	0	2.6*11.3

Table 21: Overview of variables from the house, for possible extension of the occupancy module: windows and shading operation.

Zone number	Zone name	Windows automatic control	Windows manual operation	Shading manual operation
		Win_open	Win_open	Shad
1	Living room	WOLivingRoomIO	WOLivingRoomManIO	South: SHLivingSouthManIO
				West: SHLivingWestManIO
2	Bedroom	WOBedroomIO	WOBedroomManIO	East: SHBedEastManIO
				South: SHBedSouthManIO
3	Kitchen, Dining room	WOKitchenIO	WOKitchenManIO	
			SKKitchenIO	
4	Room 1	WORoom1IO	WORoom1ManIO	
5	Room 2			
6	Room 3	WORoom3IO	WORoom3ManIO	
11	Corridor	SKCorridorManIO		

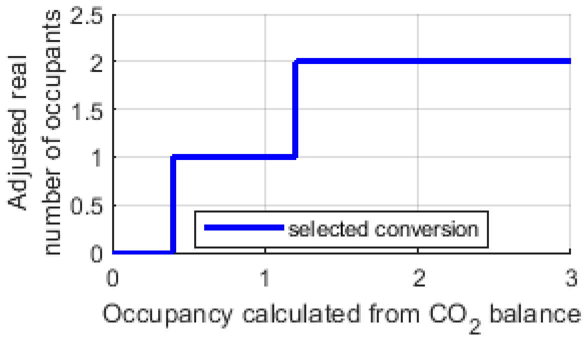


Figure 44: Threshold for the definition of presence and number of occupants, based on the calculated occupancy from the CO_2 balance.

In Figure 45, an overview of the measurement data is provided in several diagrams. The first diagram represents the total air flowrate supplied in the house (green line at the top) and the flowrate entering the house with consideration of infiltrations (black line on the top): the white surface between the green and black lines on the top represents the infiltrations. The total air flowrate extracted from the house is mirrored (light blue line at the bottom). The distribution of the airflow between the rooms can be appreciated by the different colours filling the surface below the top and bottom lines. The next diagrams in Figure 45 show for each monitored room, respectively the CO2 concentration, the relative humidity, the operative temperature and the calculated *occupancy from CO2,* derived from the CO2 balance. The last diagram shows the manually recorded occupancy, considered as ground truth.

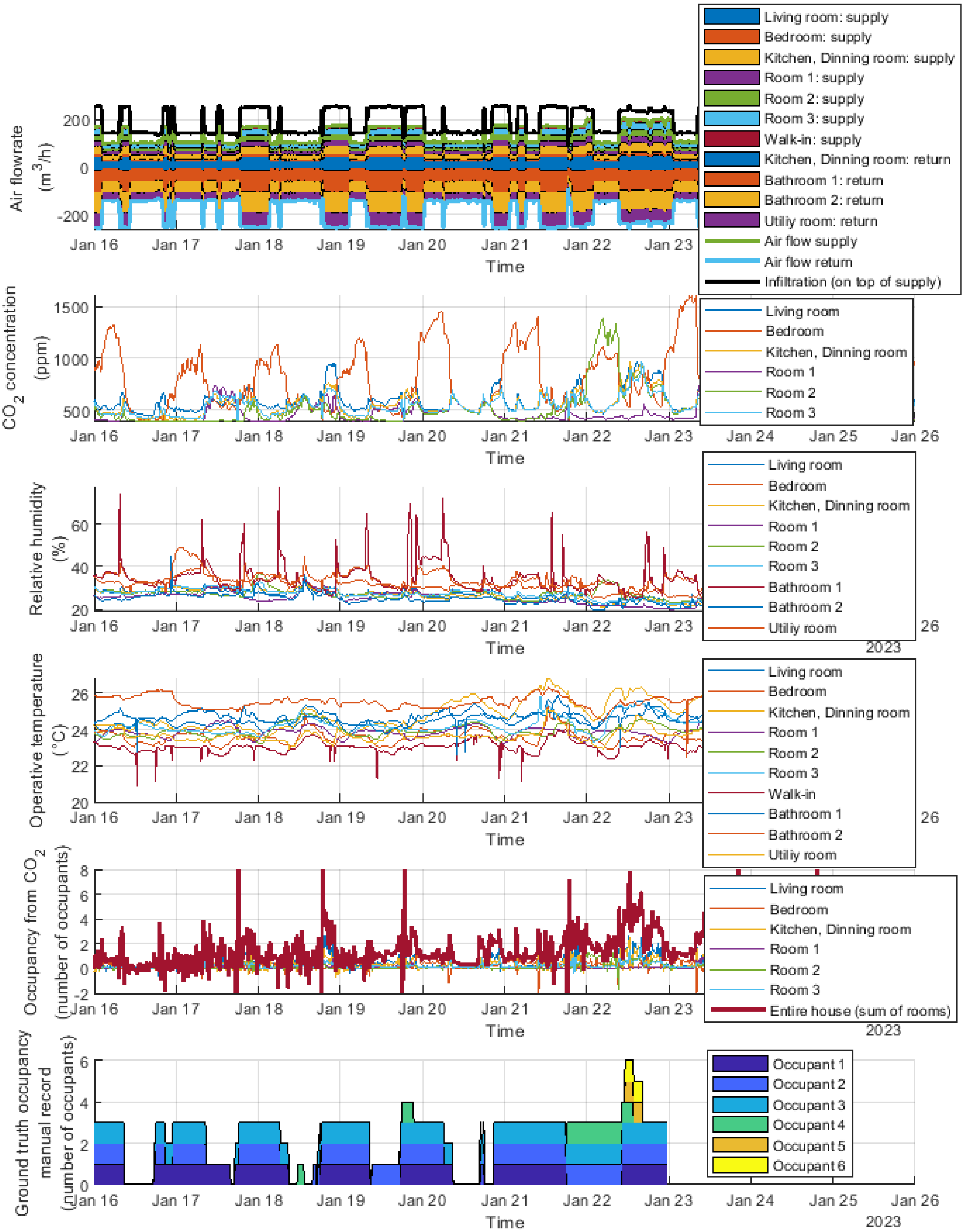


Figure 45: Overview of one week of selected variables from the single family house in Ry.

4.2.3 Implementation plan in FusiX

The occupancy module that is implemented with Python takes direct CO_2 measurements from the PRELUDE database as input to perform its calculations. The module can provide results at either an apartment or a room level, depending on the availability of CO_2 data and the structure of each demo site. It is designed to run once a week by retrieving 90-day CO_2 measurements and processing them to feed the Hidden Markov Model (HMM) in order to provide one week of occupancy forecast.

Beside the seven days of the week, national holidays of the corresponding country are considered as an eighth type of day. The time of dusk and dawn in the city where the building is located are also considered to provide more accurate forecast.

The first stage of the process is to determine the possible number of occupants by using the threshold defined previously. If the *occupancy from CO_2* is below the threshold value of 0.4, the number of occupants is set to 0. Between 0.4 and 1.2, one occupant is assumed. Over the threshold value of 1.2, two or more occupants are expected.

This procedure provides an estimate of the possible number of occupants with a 15-minute frequency within the past 90 days, preceeding the time it runs. The resulting occupancy estimates are then used as input for the HMM to be trained and provide forecasts.

The HMM is applied in two different ways to provide forecast results in terms of presence (0/1) or in terms of number of occupants. On the first variant, the HMM informs whether there is someone in a room or apartment: This can be used to determine the level of comfort that should be reached. In the second variant, it predicts the intensity of occupancy by estimating a number of occupants present. Figure 46 illustrates the flowchart of the Python implementation of the occupancy module in the family house in Ry.

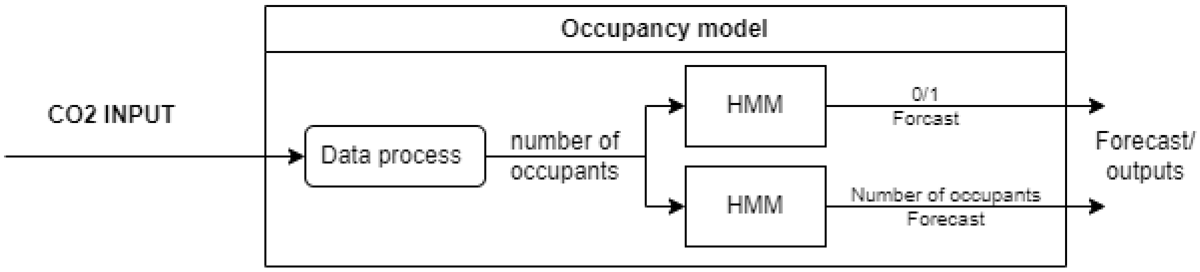


Figure 46: Python implementation flowchart

In MATLAB, further options have been tested as well. The 1st Order Markov Chain has been used to define probabilities of transition, between two-time steps, from one state to another. With this transition matrix as behaviour rules for the agents, a forecast is generated with the Agent-Based Model (ABM).

The feature-based machine learning approach has been tested at house level, to determine occupancy, using the ground truth information from the occupants' manual record. For this, the bagged tree machine learning method has been used, both in regression and classification modes. Five features have been selected and the analysis concentrated on the six rooms with CO_2 concentration measurement:

- The CO_2 concentration reduced by 400 ppm and summed over all six monitored rooms. In this way, the CO_2 concentration is close to zero when then concentration is close to the ambient values.
- The occupancy from CO_2 calculated from the CO_2 balance, summed over all six rooms.
- The sum of relative humidity over the same rooms,
- The sum of the air flowrate v_air_in, supplied to each room
- The sum of the air flowrate v_air_out, extracted from rooms (only from kitchen)

The model is trained with the manually recorded ground truth occupancy from the third week of January, from the 16th to the 22nd.

4.2.4 Performance assessment of the implemented solution – first results

The first test has been carried out over one week in January 2023, from Monday the 16th to Sunday the 22nd. This week is particularly interesting thanks to, as already mentioned, the manually recorded occupancy schedule. This represents a high-quality ground truth.

Figure 47 and Figure 48 present respectively the presence and the occupancy profiles, obtained with the HHM and the ABM algorithms. The seventh day, missing in the presented plot from the HHM, will be included in future forecasts. Both figures show for comparison the ground truth occupancy and the calculated presence or occupancy, respectively, derived from the CO_2 measurements. Some first trends can be noted. The HHM algorithm predicts with regularity occupancy in the bedroom and in room 1 in the evenings, as well as a stay in the kitchen/dining room, for diner. The presence and occupancy in the night is not well detected with this CO_2-based calculation. This is due to the reduced CO_2 production per person during sleep, while the conversion factor is kept constant (17 L/h/person) in the calculation. Although the current method does not reliably estimate all day long the number of persons present in the house, this approach will be more suitable for other applications. In particular, for the evaluation of the internal gains from the occupants, the thermal losses are more proportional to the CO_2 production, than to the number of persons.

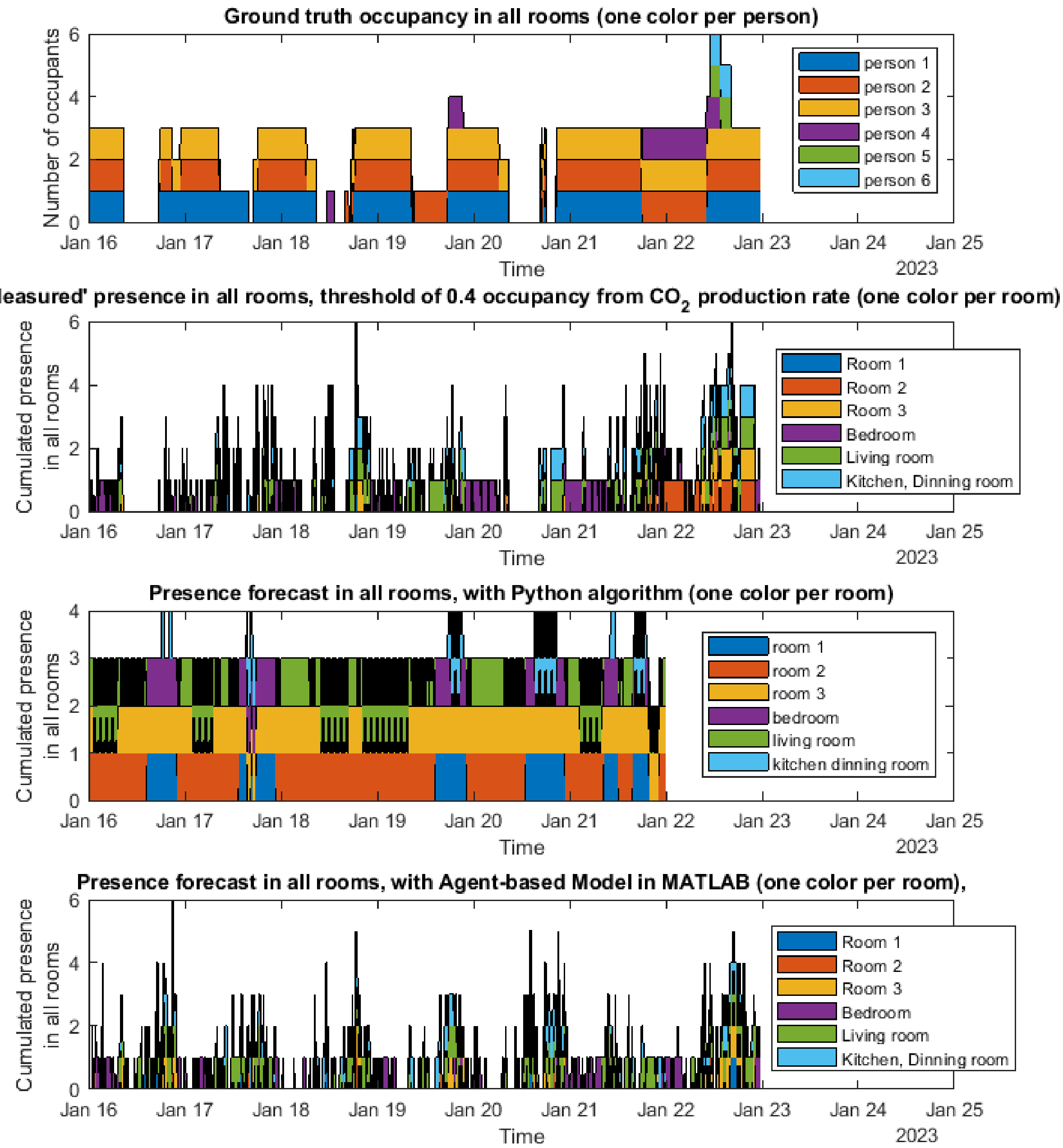


Figure 47: Presence forecast from the HHM (Python) and ABM (MATLAB) algorithms. Comparison with ground truth occupancy and processed monitoring data ("measured" presence).

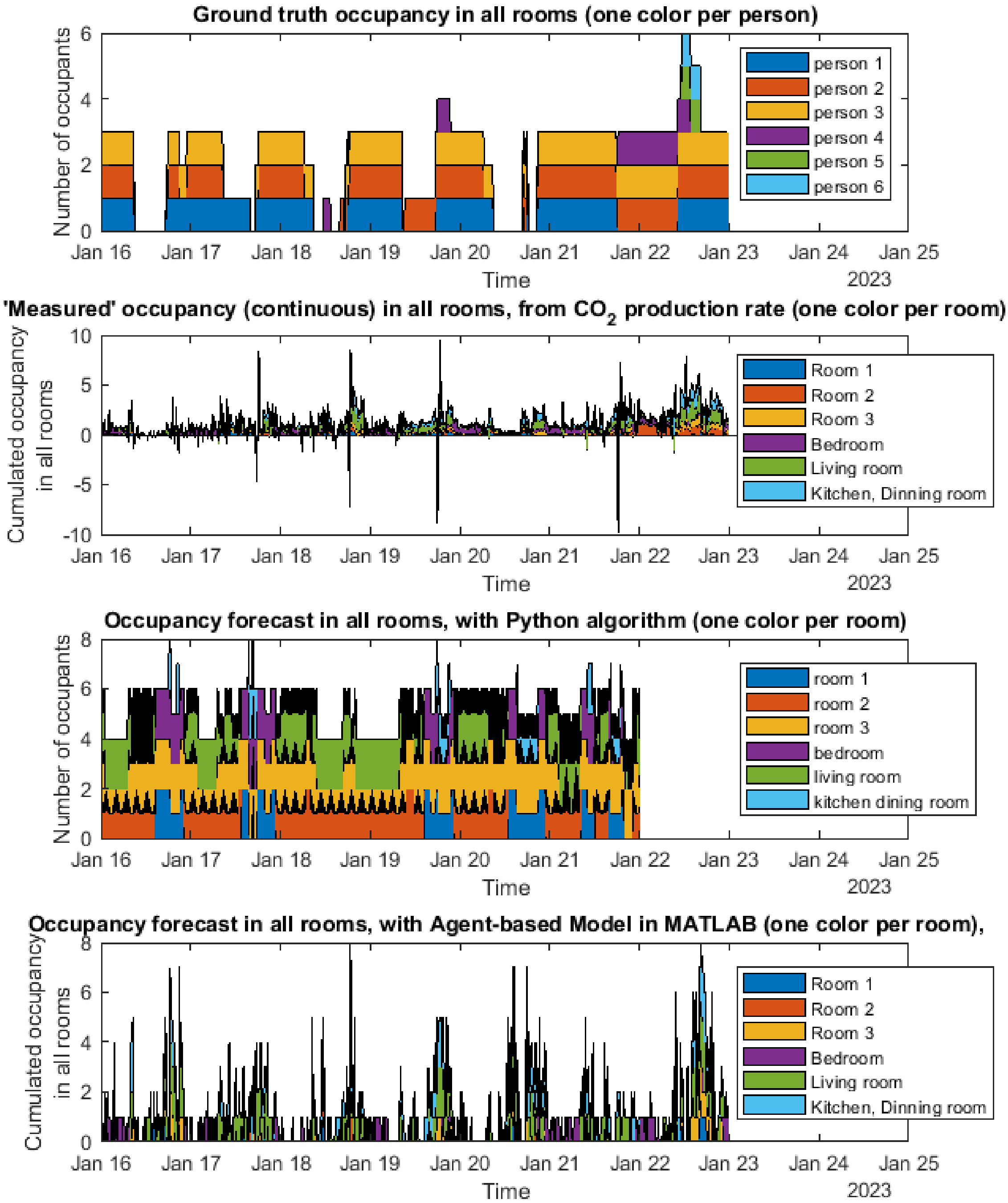


Figure 48: Occupancy forecast from the HHM (Python) and ABM (MATLAB) algorithms. Comparison with ground truth occupancy and processed monitoring data ("measured" occupancy).

To better evaluate the quality of the forecast, Figure 49 shows for each room, the comparison of the presence calculated from the measured CO_2 balance and the presence forecast from the ABM. The forecast seems plausible given the CO_2-based presence. Figure 50 shows the Receiver Operating Characteristic (ROC) of the ABM forecasts. It plots the ratio of True Positive Rate (TPR), against the False Positive Rate (FPR): share of time steps with actual presence, that are correctly predicted (TPR), compared to the share of time steps with actual absence, that are wrongly predicted as presence (FPR). The performance of the model is good when it is placed higher than the diagonal, ideal when it reaches the top left corner. In the present case, the model performs well, apart from the living room which gives similar results to a random guess. In all other rooms, the model detects correctly 40 to 55 % of the presence events, while only 10 to 25 % of the absence events are wrongly predicted with presence. Nevertheless, this performance is relative, when compared to the ground truth, because as already mentioned, the calculation of the CO_2 balance needs to be improved.

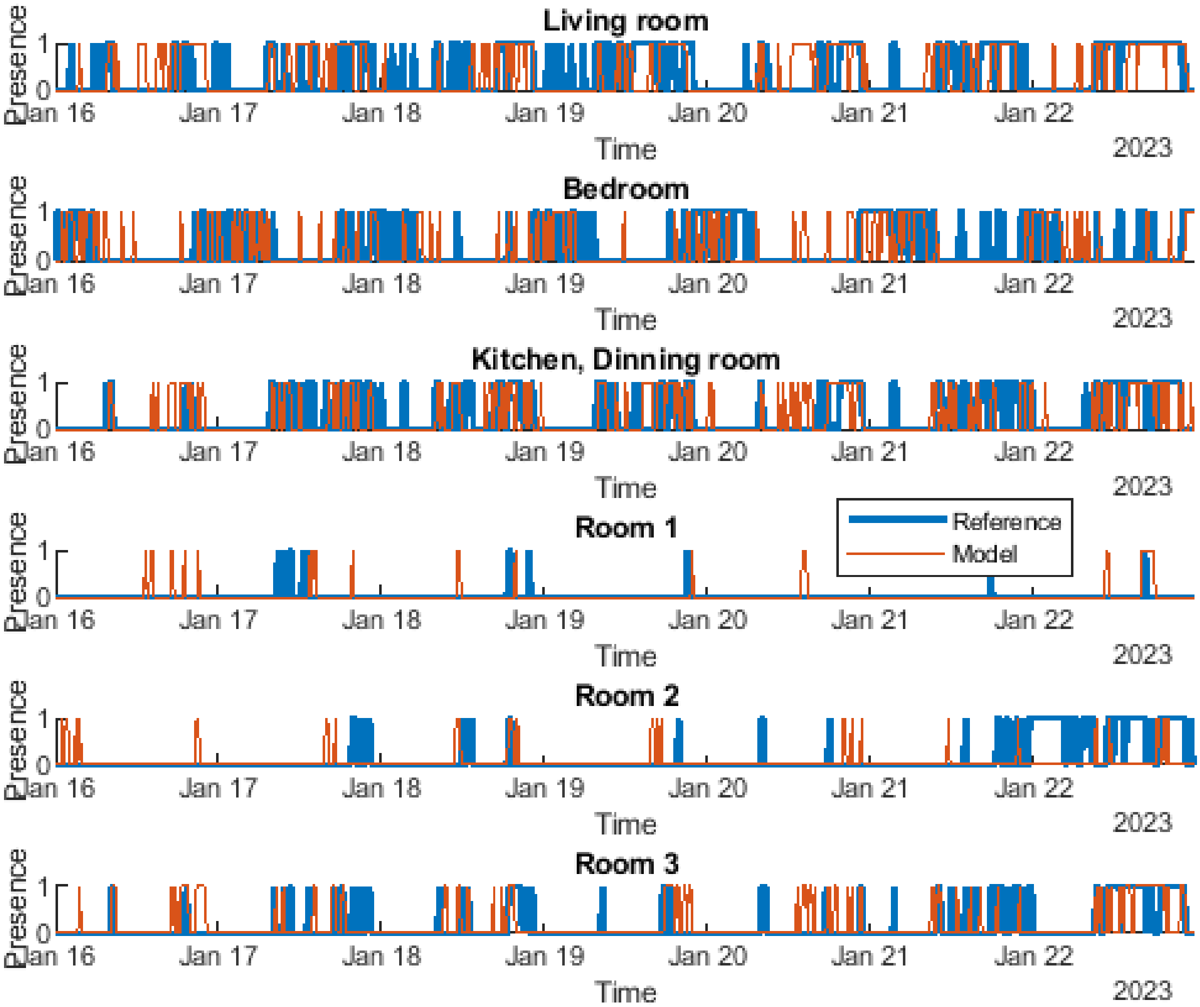


Figure 49: Presence profiles calculated from CO_2 measurements (Reference) and forecasted with the Agent-Based Model (Model).

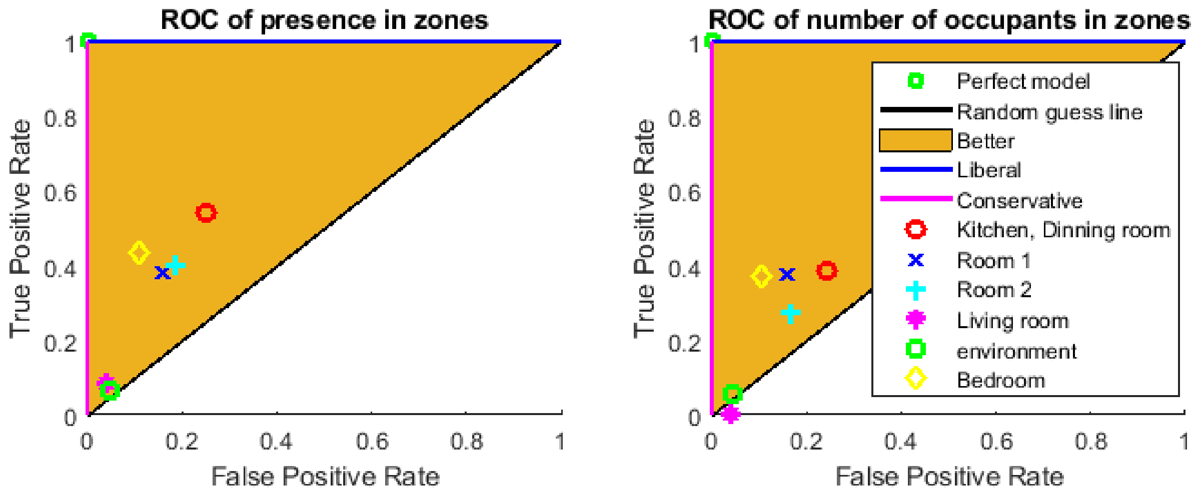


Figure 50: Receiver Operating Characteristic (ROC) from the Agent-Based Model forecast.

The machine learning algorithm is tested with one week training data. No proper validation can be obtained from another week with a similar ground truth recording, but the profile of occupancy can be visualised in the other weeks of January. Figure 51 presents the results of forecast over three weeks. So far, it is hard to estimate the quality of this approach. One way to test the interest of the method, would be to apply it to another module, for example the optimiser, and compare the performance of this other module with or without the occupancy module.

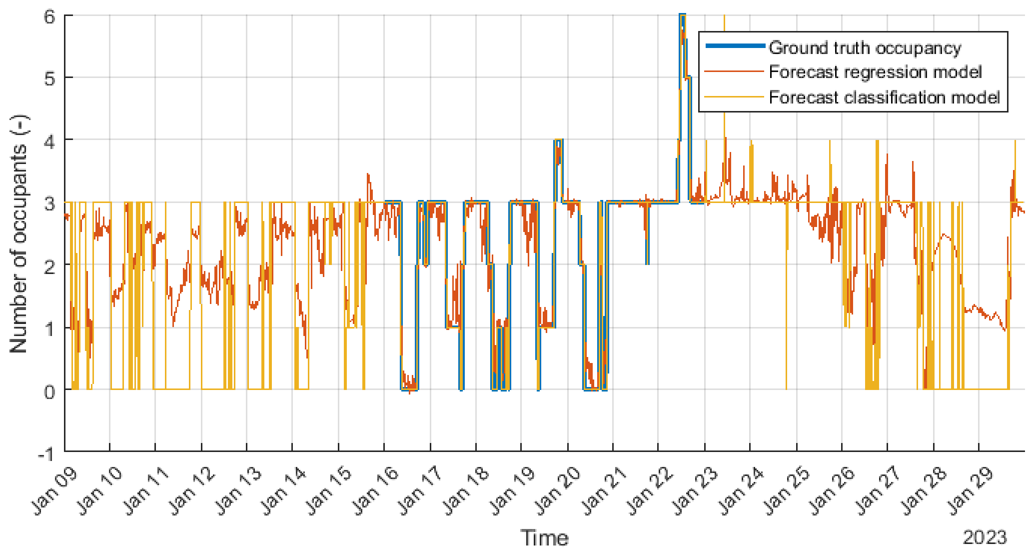


Figure 51: Machine learning (bagged tree) algorithm with regression and classification methods: forecast over three weeks, compared to ground truth occupancy used for training (middle week).

4.2.5 Next steps

As the first results reveal, the module needs further adaptation. The CO_2 balance in the rooms is not so robust, because of varying levels of occupants' activity in residential buildings. The air flows between the rooms might also need to be considered more closely. Establishing the analysis at the house level is an option that will be investigated. The use of additional variables like the power consumption or the temperature could also improve the feature-based machine learning algorithms. The windows measurements have not been exploited in the algorithm yet. This will be explored with partners to identify and test potential use cases.

The module will continue to be tested and validated in the single family house of Ry. It will then be implemented in Turin demonstration building. This will show the application of the module in a flat, with lower level of HVAC technical equipment. The occupancy module will operate in combination with the energy optimiser developed by STAM.

The module will therefore deliver the presence probability, based on a longer period of historical measurements: from 2 weeks test in MATLAB to at least 3 months, as used in Python. A weekly forecast will be delivered, considering that occupancy and behaviour patterns have a weekly regularity. For now, one average week pattern will be defined, typically based on three months past data. A further development could be to differentiate between varying week patterns, e.g., work or holidays week, cycle with morning/afternoon/night shifts. Beside the probability of presence for the following week, the module will provide an indirect information of occupancy, with the forecast of the internal gains from the occupants. These internal thermal gains will be estimated based on the CO_2 balance in the house and knowledge of the metabolism of human beings. This approach will be tested and validated with the available data from Ry and possibly in other demonstration buildings.

These applications in several demonstration buildings will demonstrate the applicability of the occupancy module in several contexts. When relevant, the occupancy module might be adapted in other demonstration buildings in agreement with the project partners.

4.3 Technology 3 – Predictive Maintenance (LASIA/STAM)

The plan for implementation is the same for Ry and Egernsund therefore the description is provided only for Ry. The only difference is in identified required input parameters from FusiX that are in Appendix B and C.

4.3.1 Overview of the proposed technology

This chapter describes the developed Predictive Maintenance (PM) module that enables smart maintenance systems based on data-driven and unsupervised approaches for active elements. In Deliverable 4.1, within Work Package 4 (Proactive optimization functions) which is part of the effort performed for Task 4.1 (Predictive maintenance) a detailed description of the methods and developments is discussed.

The work focussed on the development of a PM system based on IoT data acquisition to help users in the management of crucial building assets in the residential sector. The components taken into consideration by the algorithm are mainly related to the context of user energy consumption and production, i.e., HVAC system and PV systems in the group of electricity generation unit, due to their importance in the energy management operations of a typical house and for their economic significance.

The proposed PM methodology is based on an anomaly detection framework leveraging Machine Learning techniques which consume IoT data related to operations, e.g., power consumption/production. HDBSCAN is the underling unsupervised clustering algorithm, to detect the anomalous operations of the system. Added to the developed black-box model, a heuristic approach has been implemented, which allows the user to feedback the verified real status of the system after the anomalies have been detected. The integration of the two types of information is exploited to fine tune the prediction of the future behaviour of the component, by calculating a unique parameter called Anomaly Level (AL) the health status of the system.

The output of the module is presented in a user-friendly dashboard, which allows, at multiple level of technical expertise, a bilateral interaction between the user and the data-driven predictive maintenance model. The information presented in the UI can be exploited by different users to schedule and optimize maintenance, i.e., depending on the detected anomalies and the calculated AL.

4.3.2 Implementation plan

The plan for the technology implementation is based on the identification of the needed datapoints for the PM module deployment. For this matter, a data requirement table is constructed and shared among the interest partners (Table 22). The table is the result of a system modelling approach, which allows a generalization of all the PRELUDE use-cases from an energetic point of view. In Deliverable 5.4 "PRELUDE data driven control", a more extensive analysis of the identified systems and sub-system is discussed.

From the schematic representations shown in D5.4, it is possible to relate each system with the needed datapoints for each of the physical/technical quantity. In this context and in the table construction, two different types of data are considered: timeseries or single values. Moreover, a classification of the data is performed in the case the measure is needed for the modules deployment or it is optional for a more advanced version of the module. In the last column of Table 22, the related FusiX datapoints identifier is shown if available, else the direct static value or the status of the research performed by the pilot's owner for the specific datapoint.

Table 22: Datapoints summary for Predictive Maintenance module.

Data ID	Quantity	Is a time series?	Need	FusiX ID (if applicable) / Information
1	Weather data			
1.1	External temperature	time series	optional	Weather/Temperature in FusiX
1.2	Irradiance	time series	compulsory	Not available
2	Photovoltaics system			
2.1	Energy/power production	time series	compulsory	Not available yet in FusiX. Data available from June 2022
5	Heat pump system			
5.1	Energy measure	time series	compulsory	Should be posisble to estimate as a part of energy to AHU + HP: ID: 1094
5.3	Temperature Input	time series	compulsory	To be defined AAU/STAM
5.4	Temperature Output	time series	compulsory	To be defined AAU/STAM

For the Egernsund and Ry pilot the main technical units, for which the PM module can be implemented are the PV system and HP system. As shown in Table 22, the needed datapoints for these systems are listed. The respective datapoints are classified and the availability on FusiX or general information is depicted.

Due to the better data quality of the HP system, the PM module is focussed on the management of this type of installed unit, for both the pilots, keeping the implementation for the PV to a subsequent phase. It is important to state that, in the case of the Egernsund pilot, the above-mentioned HP system is modelled by simplifying the complex P&I diagram into a unique virtual HP machine. In this way, the electrical consumption

(Energy Measure) is the sum of the two electrical loads and the Temperature Input and Output are aggregated as average temperatures of the available measures.

This simplification is performed, for sake of simplicity, and to overcome a limitation in the data availability. As a matter of fact, the two HPs electrical consumptions are not measured, but estimated from the overall electrical energy of the household. This is done by disaggregating the total electrical measure into the HPs' one from the rest of loads' consumption, through an EDA process of the available data in FusiX.

4.3.3 Performance assessment of the implemented solution

This module offers a reliable and efficient solution for predicting maintenance needs, reducing maintenance costs, and improving the reliability of energy assets. The unsupervised approach employed by the module allows for the analysis of data without requiring prior knowledge of the system. This approach also enables the system to adapt and learn from new data as it becomes available, continuously improving its predictive capabilities.

The first step of the module implementation is tested and validated in terms of input data, that are retrieved from the FusiX common data platform. In this way it is possible to train the HDBSCAN model and test it on a near-real time application. The predictions are then manually analysed if there is any incoherency with the real measurements. The fine tuning of the model hyperparameters is performed in order to give more stable predictions to the user.

Once the model is trained, a test environment is developed with the connection of the graphical user interface in which the user-engagement is evaluated in terms of user feedbacks that are given to the module calculations. A limited time frame is organized for this purpose, such as one month, and then the user interface is deployed for the final operational phase.

4.4 Technology 4 – Comfort and Energy Efficiency module (STAM)

4.4.1 Overview of the proposed technology

In this chapter the Comfort - Energy Efficiency optimizer, developed by STAM in T4.4, is presented. The Deliverable 4.4, within Work Package 4 Proactive optimization function), offers a detailed description of the used methodology and developed tools. In this work a proactive optimization model of the customers' energy usage in the residential sector has been developed, by integrating and customizing STAMs' En-Power platform with a comfort module which considers electrical load shifting for energy demand response together with the indoor comfort conditions.

The algorithm relies on both an analysis of the appliances' flexibility of the household and on an empirical methodology for the thermal indoor comfort modelling. This information, together with an energy modelling approach of the building system, has been translated in mathematical terms to the Comfort-EE linear optimization model, in order to provide a seven-days ahead optimal scheduling for the energy loads.

Static information, such as building architecture, and dynamic measurements of the system status have been used to model the electrical/thermal systems. As possible to see in the following Table 23, part of the needed input data is retrieved thanks to the connection with the PRELUDE's dataspace FusiX.

The outputs of the work performed in Task 4.4. serves as input to the framework of Data Predictive Control and user interface (UI) development within Task 5.4. In this context a customized UI is developed to give the suggestion and recommendation on the optimal energy consumption scheduling and actuation in the next hour.

The user feedback is also taken into consideration by the optimization algorithm. Through the UI, the resident can tune the preferred degree of indoor comfort by looking at the trade-off between estimated indoor temperature in the next hours and energy/cost savings among the outputs of the optimization. The proposed approach is part of the low-tech solutions for the improvement of residential energy efficiency.

4.4.2 Implementation plan

As anticipated in the previous sub-chapter the focus of the proposed solution is the user's empowerment by exposing the right information and suggestions regarding his or her energy consumption efficiency. By means of a user-friendly UI.

The plan for the technology implementation is based on a two-steps process. First all the necessary datapoints are gathered in order to provide the input for the optimization. In this context data accessible from FusiX are analysed and the remaining static information, such as energy tariffs prices, nominal powers of installed units are given by the specific pilot owner.

The second step emphasises the UI deployment and the user acceptance. In this framework, the developed platform is tested on the specific use case. Because of the nature of the proposed low-tech solution, which relies on the citizen actions, the objective is to maximize the level of user-engagement in order to reach the most energy efficient possible building energy management.

As regards the first step, for each specific pilot implementation, a data requirement table is constructed and shared among the interested partners (Table 23). The table is the result of a system modelling approach, which allows a generalization of all the PRELUDE use-cases from an energetic point of view. In Deliverable D5.4 "PRELUDE data driven control", a more extensive analysis of the identified systems and sub-system is discussed.

From the schematic representations shown in D5.4, it is possible to relate each system with the needed datapoints for each of the physical/technical quantity. In this context and in the table construction, two different types of data are considered: timeseries or single values. Moreover, a classification of the data is performed in the case the measure is needed for the modules deployment or it is optional for a more advanced version of the module. In the last column of Table 23, the related FusiX datapoints identifier is shown if available, else the direct static value or the status of the research performed by the pilot's owner for the specific datapoint.

Table 23: Datapoints requirements for Comfort-EE module.

Data ID	Quantity	Is time series?	Need	FusiX ID (if applicable) / information
0.1	Measured energy/power	time series	compulsory	2383: Total 1089: Other usage 1090: Cooking plate and ovens 1091: Fridge and cooker hood 1092: Control system 1093: Pump floor heating 1094: Air handling unit and heat pump 1095: Washing machine 1096: Dryer 1097: Dishwasher

				1098: Quooker
0.1	Nominal power		optional	
0.1	Normal usage cycles		optional	
0.1	Dispatchable usage cycles		optional	
0.2	Internal temperature - real	time series	compulsory	1099: Room 1 1102: Room 2 1105: Room 3 1108: Bedroom 1111: Living room 1114: Kitchen 1117: Utility room 1119: Bathroom 2 1121: Walk-in 1122: Bathroom 1
0.3	DHW demand	time series	compulsory	1085: Energy (MWh) 1146: Volume (m^3) 1147: Flow (l/h) 1148: Temp warm (°C) 1149: Temp cold (°C)
0.4	Energy input for floor heating	time series	compulsory	1086: DH Energy (MWh) 1188: Volume (m^3) 1189: Flow (l/h) 1190: Supply temp (°C) 1191: Return temp (°C)
0.5	Skylights / shading system	time series	optional	<u>Skylights manual control:</u> 1177: Corridor 1178: Kitchen <u>Skylights automatic control:</u> 1139: Corridor 1140: Kitchen <u>Shading manual control:</u> 1173: Bedroom east 1174: Bedroom south 1175: Living room south 1176: Living room west <u>Shading automatic control:</u>

				1135: Bedroom east 1136: Bedroom south 1137: Living room south 1138: Living room west
1.1	External temperature	time series	compulsory	Weather/Temperature in FusiX
1.2	Irradiance	time series	optional	Not available
2.1	Energy/power production	time series	compulsory	Not yet implemented in FusiX. Available from June 2022
2.2	Peak power			1.55 kWp
4.1	Energy tariffs		compulsory	AAU provides to STAM information about fixed and variable tariffs in Denmark. AAU will provide average weekly price for summer and winter.
4.2	Maximum power retrievable from the grid		compulsory	11 kW
4.3	Offpeak power		optional	
5	**Heat Pump**			
5.1	Electrical consumption	time series	compulsory	Can be estimated. Part of energy to AHU.
5.2	Efficiency (-ies)		optional	
5	**District Heating**			
5.1	Energy measures	time series	optional	1088: Energy (MWh) 1184: Volume (m³) 1185: Flow (l/h) 1186: Supply temp (°C) 1187: Return temp (°C)
5.5	Energy cost		compulsory	AAU provides to STAM costs related to heat costs Euro/MWh for the average cost of MWh from heating season.
6.1	Internal Temperature	time series	compulsory	1154: DHW Tank temp (°C)
6.2	Volume		Compulsory	180 L
6.3	Maximum power exchanged		optional	

The construction of the thermal model of the building is configured considering the house as a unique thermal zone. Similarly, regarding the HP system, the modelling is performed by means of single-valued COPs that are able to give the transformation coefficient from electrical energy consumed by the unit and thermal energy produced for both heating and cooling. More clarifications on the system operations and a larger dataset of HP variables are needed to better characterize the HP functioning.

From an implementation point of view the focus of the Ry use-case is the low-tech framework. In this context, the user-engagement is maximized by means of the GUI in which the optimal scheduling of the energy consumption is displayed, and notifications are sent to the user.

4.4.3 Output

In the context of the Comfort-EE module integration process the models' output are described in this chapter.

For each hour of the 7 days ahead, the optimal values of the main decisional variables' quantity are given as outputs. This is done in order to provide the user with the suggestion of the optimal consumption and also for the possibility of modules integration within the PRELUDE project. Moreover, the Comfort-EE optimizer, can give, as outputs, the related weekly energy costs. This is done to provide the user with the final money savings which can be interesting, from a residential point of view, in order to tune the wanted indoor thermal comfort with the optimized energy costs.

From an electrical system perspective, the main output data, that can be considered by the optimizer as decisional variables are:

- Electrical appliances usage scheduling, in the form of information presented in the dashboard HMI, where the user can see, for each hour the week, the optimal appliance cycles. These data are based on the user engagement, thus his/her manual actuation;
- SOC of the battery, where present, which can be controlled if the electrical system permits it, otherwise it can be considered as an input parameter, by knowing which is the implemented control strategy;
- Power retrieved and injected from grid, which can be considered as secondary outputs, i.e., not controllable directly and useful for the calculation of the overall energy costs.

In terms of thermal energy control two different and important variables are considered among the optimizer output, which are:

- Thermal units (e.g., HP, AHU) usage scheduling, which consists of the optimal power outputs at each hour of the week that the thermal units or system must provide in order to maintain the desired indoor comfort. This output can be used to actuate directly the thermal units by regulating the power output, following the control strategy designed by the manufacturer;
- Indoor temperatures predictions, which represent the optimal values at each time step, constrained by the indoor comfort desired by the user. These values can be used as control set points when the thermal unit actuation is not feasible. In this way, either through direct actuation (high-tech) or manual user control (low-tech) the optimal trajectories are communicated to the building thermostats.

By showing and communicating with the user or the building energy management system these important and effective information, the Comfort-EE optimizer follows the aim of providing the important tools for the energy management of a general residential building considering the match between indoor comfort and energy or costs savings.

4.5 Technology 5 – RES selector (CORE)

The description of the RES selector application is the same for Ry and Egernsund and its implementation possibility depends on the same data inputs, which are electricity, heat use and weather data. Additionally, the type of RES technology to compose the solution can be differentiated for the two Danish case buildings.

4.5.1 Overview of the proposed solution

In the context of the PRELUDE project, and specifically in Work Package 4, a digital energy management tool was developed that suggests optimal RES investments in order to maximize electrical and thermal energy savings of a building, based on financial metrics, energy diagrams and diagrams related to RES devices. Specifically, the core function of the RES Selector tool is an optimization algorithm that receives as input historical data of electricity and heating demand of a building along with weather data and returns a set of optimized values related to the investment costs, sizing of RES devices, and energy metrics. The target of the optimization algorithm is to optimally cover the electricity and heating demand of a building with a combination of RES devices with respect to constraints of the energy system. Therefore, the tool gives advice to the user for potential investments on RES technologies to reduce energy costs and to propose a greener energy solution for a building. Also, the RES Selector tool gives the opportunity, to the user, to experiment with different test profiles based on the needs and select the best investment solution based on defined metrics that the tool provides.

4.5.2 Technical specification of the proposed solution

From a technical point of view, the RES tool solves an optimization problem which is in the form of Mixed Integer Linear Programming (MILP). In particular, the optimization algorithm tries to minimize an objective function which is the investment costs of a building's energy system. So, based on a predefined investment plan, meaning a set of available RES devices, the algorithm chooses the optimal combination of RES devices to be installed with respect to the financial and energy constraints of the system.

The first step of the pipeline is the required data. Since the algorithm tries to cover the energy demand of a building, electricity, and heating consumption profiles in the form of timeseries data are needed. Moreover, there are RES devices that depend on weather variables to produce energy (either electrical or thermal). Therefore, the tool needs the respective weather data to model the operating profiles of these RES devices. The operating profiles of RES devices are mathematically modeled according to physical laws that govern the operation of the devices. All mentioned input timeseries data should also meet some requirements. They should have an hourly sampling rate with a total length of 1 year because this is the minimum length to capture the seasonality consumption pattern of a building. Except for input timeseries, the RES Selector model also requires input constant parameters concerning the characteristics of RES devices. These parameters are mainly defined by users, and they are related to the technical characteristics of RES devices including capital costs, supply costs from the grid, and operational & maintenance costs (O&M).

4.5.3 Implementation plan

The implementation plan depends on the available data. As mentioned in the previous chapter the RES Selector tool needs at least one year of data with hourly resolution, meaning 8760 data points. So, regarding Ry and Egernsund demo site, the RES Selector will run properly when the minimum data requirements are met. Specifically, for the building located in Ry the data will be available in August 2023 and for Egernsund in November 2023 and then the RES Selector algorithm will produce the results.

4.5.4 Performance assessment of the implemented solution

Regarding the outputs of the RES Selector tool, the options can be many but limited to the objectives of Task 4.5. The first and main output is the optimal value of the total annualized costs of the proposed energy system. This value depicts the total costs of one year when running a simulation test profile. Energy diagrams concerning the operation and efficiency of RES technologies are also included. All these outputs are used to evaluate the optimal solution of the optimization problem with respect to a specific predefined design by the user. The set of outputs of RES Selector is divided into energy and financial metrics/KPIs. Specifically, Levelized

Cost of Electricity (LCOE [€/MWh]), Payback Period [years], Return of Investment (ROI [%]), Net Present Value (NPV [euros]), Internal Rate of Return (IRR [%]) constitute the financial metrics that the tool provides for a multifaceted assessment of investment plan. Energy diagrams such as boxplots and histograms of generated and consumed power of RES devices are included in the set of outputs to evaluate the optimal solution of the optimization problem from an energy perspective.

4.5.5 Energy saving and reduction of gas emission

As mentioned in the previous chapter, the outputs of RES Selector include only financial and energy metrics and diagrams. The optimal solution of RES Selector depends only on the available RES devices that could be installed on a building. The selection of available RES devices for installation is defined by the user and not by the tool. The only option for not selecting specific RES devices is to include in the optimization problem all available different types of RES devices on the market. RES Selector has a large pool of available RES devices, so usually the tool can cover even demanding cases such as large buildings that require many multiple energy sources.

4.5.6 Economic analysis and cost-effectiveness

For a specific investment plan which is primarily defined by a set of available RES devices for installation, the financial analysis is depicted from the technoeconomic indexes that the tool provides. Therefore, the user is able to evaluate and compare different test scenarios (investment plans) based on these indexes.

4.6 Technology 6 – Dynamic Free Running 24h forecast (POLITO)

The free running 24h forecast is a scenario of usage of the PREDYCE tool that aims to maximise thermal comfort in confined spaces by acting on control strategies of specific elements such as blind, ventilation and window opening. The scenario tries to optimise the schedule for these elements by performing several simulations of the building on forecasted weather data and get the combination of strategies that maximise the comfort for the entire day. The entire process is permitted by the PREDYCE Python library – see the PRELUDE Deliverable D3.2 – which allows to perform several parallel EnergyPlus simulations on the same machine, exploiting the different cores of the CPU. For good results, a calibrated model and accurate weather forecasts are required. Additionally, each application still requires an initial adaptation of the usage scenario to align it with the specific building configuration and controllable rules. The 24h forecasting scenario may provide results to be further used by end-users via GUIs or alerting services to support self-actuation, or to feed building management systems via specific middleware.

4.6.1 Procedure

The procedure for implementing the 24h forecasting scenario are described here below. At the start, the model goes through a preliminary setup where every actuator is associated to a schedule file which can be modified in order to change the behaviour of the system. Then, a set of building variations representing the combinations of parameters is created and dynamically simulated. For every simulated building, the adaptive comfort model based on standard EN 16798-1 is evaluated and a score is assigned, although Alternative target variables may be considered under request. For this purpose, the distance between the central line of the model is computed. The combinations of parameters which lead to a minimum distance from the line is evaluated with a higher score; given that, if more than one simulation falls under a certain category of comfort, other logics are followed in order to choose the best strategy: shading activation and ventilation flow are also minimised in order to exploit daylighting as much as possible and to reduce the noise of mechanical ventilation or unpleasant air flows of natural ventilation.

The schedules produced by the 24h forecasting script can be divided a priori according to specific blocks of hours, so that the hours belonging to the same blocks maintain the system status until next block is called, e.g., given the block [6, 7, 8, 9, 10], the status of blind and ventilation is optimised and remains the same from 6 am to 10 am. This approach is useful to support moments of the day when tenants are not able to modify the status of the system because they are away or sleeping. In case of automatic actuators which can follow a given schedule, the optimisation can be done hourly.

4.6.2 Ry demo case implementation

In Ry demo case, two different elements are optimised: blind activation and mechanical ventilation flow. Blinds are present on three different rooms, and are optimised independently on each window, in order to produce schedules that are compatible with the position of the sun. Mechanical ventilation is centrally managed and every room has its own coefficient in order to adapt the inlet/outlet air; for this system, only the central flow value is optimised in order to scale it automatically to the entire building. Both blind and mechanical ventilation are controlled by an automatic actuator which can follow a given schedule, so the optimisation is done hour-by-hour. The calibrated model of the building is provided by AAU; such model is then re-adapted by Polito in order to reassign blind and ventilation schedules and make them support the 24h forecasting application. Operative indoor variables such as air temperature and relative humidity are provided by AAU and retrieved by Polito through FusiX platform via a REST API. Environmental variables are instead taken from a weather station nearby Ry and made available on FusiX platform as well. The indoor variables are then embedded into the model via CSV schedule files in order to force the simulation to follow real historical data before starting the 24h forecasting script. Outdoor variables are merged with weather forecast retrieved by meteoblue service into a hybrid EPW file that contains both historical and forecast weather data. Every day, new weather and indoor data are downloaded from FusiX to update schedule files and EPW file; this permits to produce daily 24hf outputs based on real conditions.

4.6.3 Output

The main output of the 24h forecasting script in Ry consists in four schedules, three for shading activation and one for mechanical ventilation flow; such schedules are initially available in CSV format but they are then converted to a JSON file which is sent to FusiX platform via REST API and retrieved by AAU in order to be fed to automatic actuators.

4.7 Technology 7 – Measurement and Verification Framework (LIBRA)

4.7.1 Overview of the proposed solution

The M&V framework developed within the PRELUDE project encompasses the M&V methodology and the definition and implementation of the module, all of which are detailed in Deliverable 4.3. The primary focus of the M&V methodology is to evaluate the Data-driven Predictive Control (DPC) by STAM. In order to assess the energy savings resulting from the implementation of the intervention, the M&V 1.0 and M&V 2.0 approaches are utilized. Also, a module is designed and seamlessly integrated with FusiX to store and validate the information, enabling the quantification and monitoring of achieved savings. The core objective of the M&V module is to develop an adjusted baseline model for Ry, which will predict the energy consumption and track the energy savings accomplished by the PRELUDE solution monthly under normal operating conditions during the post-intervention period.

4.7.2 Technical specification of the proposed solution

The M&V methodology involves collecting data on the building's characteristics, non-routine events that have affected the energy consumption, and identifying data points for calculating heating and cooling energy consumption. Based on the available data sources, interactive tree maps have been analysed and mapped for each room and the central building (Figure 52 and Figure 53, respectively). This has enabled the identification of the necessary datapoints for computing the thermal energy consumption. Moreover, the necessary weather data, specifically outdoor air temperature, which is crucial for developing the baseline, is obtained from the Meteostat Python library [10].

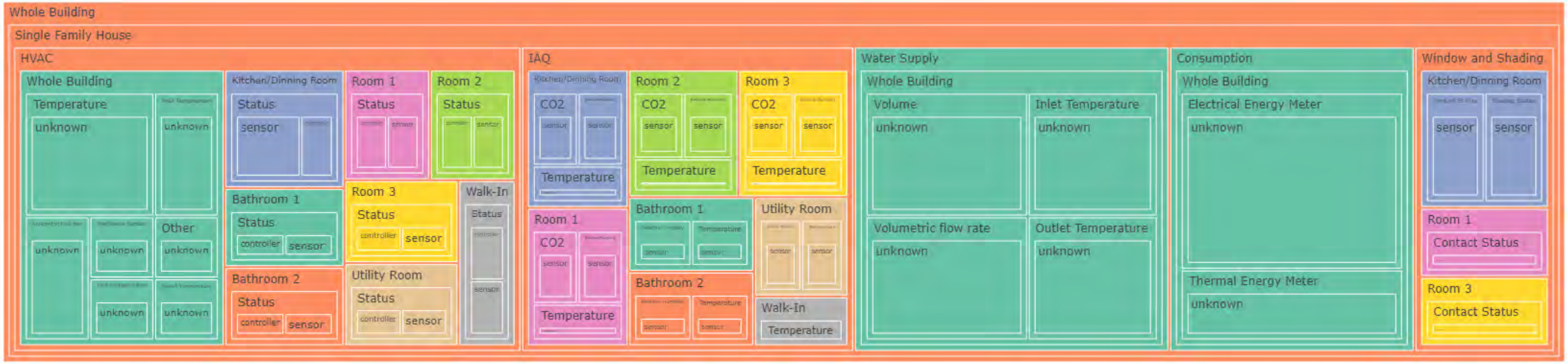


Figure 52: Mapping of the distribution of the devices per room in Ry.

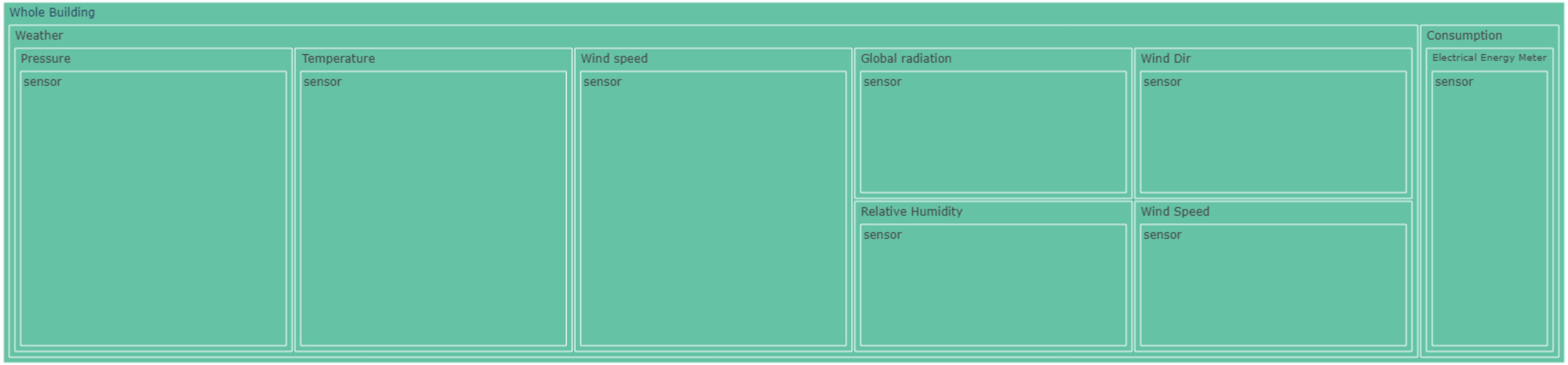


Figure 53: Mapping of the distribution of the facility's central devices in Ry.

4.7.3 Implementation plan

To assess the energy savings achieved by the DPC, the M&V 1.0 and M&V 2.0 proposed by LIBRA are applied. Based on the current status of Ry, the measurement boundary will be whole single-family building, the preferred option of the International Performance Measurement and Verification Protocol (IPMVP) methodology is option C (whole facility) with a focus on energy consumption measured using the thermal heating and electricity meters. Additionally, there are available data in FusiX referring from 2020 till today, allowing for the development of the adjusted baseline model. Once the ECMs are integrated, the reporting period will begin, and the monitor will take place probably for one full operating cycle (selecting the latest 12 months), evaluating the savings effectiveness under normal operating conditions. Hence, the data source considered by the module is the "Consumption Thermal Energy Meter" and the corresponding datapoint is "DH - Floor Heating (MWh)". Figure 54 and Figure 55 show correlations between temperature and energy consumption datapoints on a monthly and daily basis, respectively.

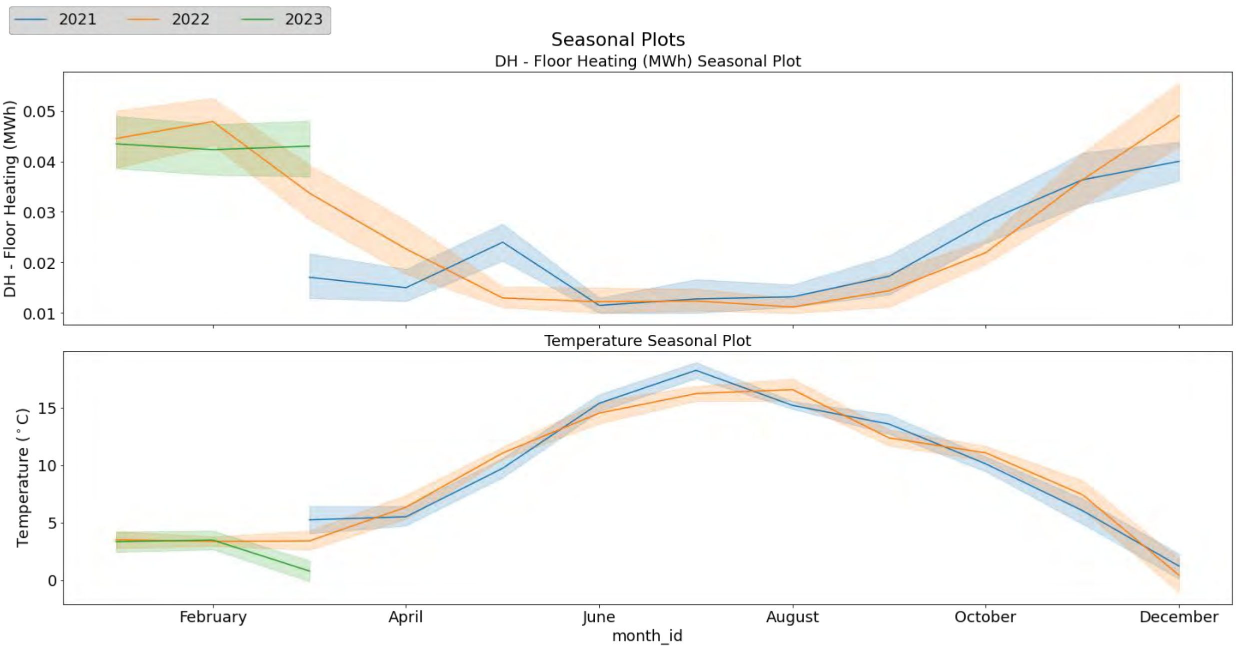


Figure 54: The correlation of the energy consumption datapoint "DH – Floor Heating" per year with the temperature (monthly resolution) [10].

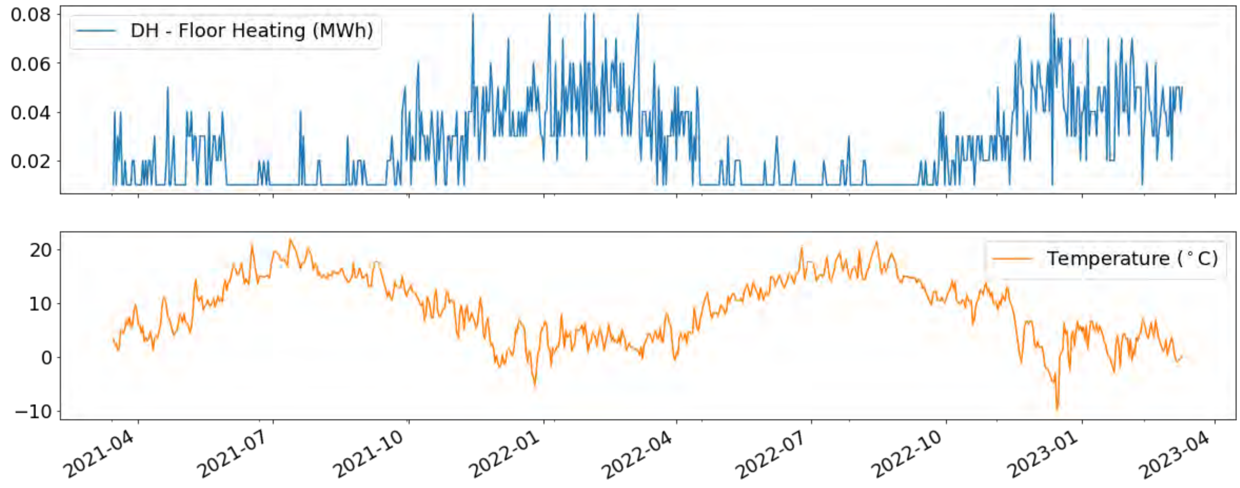


Figure 55: The correlation of the energy consumption datapoint "DH – Floor Heating" with the temperature (daily resolution).

[1] The data is presented from January to December per year. For this reason, there is a gap in the graph for the year 2023 and 2021. The start date of the data being collected from FusiX is March of 2021 till today.

4.7.4 Performance assessment of the implemented solution

To ensure accuracy in the model and the results of the methodology, the M&V framework proposed in D4.3 is adapted to Ry's characteristics and statistical and Machine Learning (ML) models are applied to develop the appropriate adjusted baseline model. To determine the most accurate reference model for Ry, two metrics were chosen: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalized Mean Bias Error (NMBE). The CV-RMSE value is used to calculate the uncertainty introduced, and the model performs better when this value is lower. The NMBE is an ancillary metric used to support model evaluation, but it is not used for model selection since positive bias can counteract negative bias, and the main goal is to minimize uncertainty in the modelling process.

4.7.5 Energy saving and reduction of gas emission

The advanced M&V module will generate two main outputs for Ry: (i) monthly time series data of estimated energy consumption and (ii) monthly time series data of energy savings. The energy savings data will be presented in both absolute (kWh) and relative percentage values, and the module will also include information on the uncertainty of the estimations, such as errors and confidence levels. The M&V module will be scheduled to request necessary input data from FusiX on a monthly basis. Accordingly, the output will be a time series of estimated energy consumption and energy savings for Ry, and the output of the adjusted baseline models will be directly available to Ry upon request via the Graphic User Interface (GUI) environment of the PRELUDE Decision Support System (DSS). It is important to note that the module's output is monthly and pertains to the period up to the previous month. Therefore, it will not provide a prediction for energy consumption but a retrospective estimate to enable end-users to evaluate the intervention made.

4.7.6 Economic analysis and cost-effectiveness

The primary focus of the M&V process is to evaluate the energy savings resulting from the Energy Conservation Measures (ECMs), which can indirectly facilitate an economic analysis to determine the cost savings based on the energy saved.

5 EGERNSUND DEMONSTRATION

This chapter presents the demo case in Egernsund. To start with, the building is described with focus on layout, the constructions, the compliance calculated energy demand, and occupancy. Next, is the technical control and monitoring systems is detailed, and last, the user motivation and engagement in the PRELUDE project is described.

5.1 Building description

The demo case is located in Egernsund, Denmark, and was constructed in 2019-2021. The exterior of the demo case is shown in Figure 56, and the interior in Figure 57. The demo case is owned by the brickyard Matzen-Tegl and named “Matzen-Tegl Huset”. The demo case is a two-floor single-family house developed to be a showcase of the external building block “CleanTechBlock”. The CleanTechBlock consists of two layers of bricks with a layer of insulation in between. The insulation material is foamed recycled glass. Matzen-Tegl was well aware that people would not have the highest interest in visiting a showcase only to see bricks. Therefore, they built a high-tech building with a focus on energy efficiency and sustainable solutions. The building is the first DGNB Platin-certified single-family house in Denmark. The project leader behind the building is also a DGNB auditor and has been a part of the development of the Danish DGNB manual for single-family houses, considering the perspective of Matzen-Tegl Huset’s bricks and CleanTechBlock application.

The project leader behind the construction of the house and contact person (called in this report “contact person”) between the house and PRELUDE project wishes to know how we can store and move energy use in terms of electricity and heat to optimize and increase the self-consumption of PV production. He also looks forward to benefiting from forecast weather and price models in finding a well-balanced ratio between using and storing energy. The building is a part of ProjectZero in Sønderborg, where the goal is to reach CO_2 neutrality in 2029 for the whole Sønderborg municipality in which builing is located [11].

The HVAC, electrical, and energy installation in the building are high-tech solutions, where companies were invited to show their products. The energy installations in the building are two heat pumps (one air-to-water heat pump and one ground source heat pump), photovoltaic panels, an electrical battery, and heat storage. The HVAC installations are underfloor heating, a shower system with a recycling water system, heat recovery on wastewater, and a ventilation system with heat recovery. Smart home control is installed to control the electrical installation, consisting of indoor and outdoor lighting controlled by lux and motion detectors, electrical sockets, and alarms. Room thermostats in all rooms are connected to the smart home control to control the underfloor heating per zone.

In the following, general information for the demo case is presented: a description of the plan drawings and measures of the building, envelope constructions, calculated energy demand, occupancy, and weather data.


Figure 56: The façades of the demo case. Left picture: south and west façade. Right picture: north façade.


Figure 57: Left picture: dining area on the ground floor. Right picture: big and small living room on the 1st floor.

Plan drawings and measures

The building has a gross area of 179.0 m^2 and an internal area of 143.1 m^2. There are 14 rooms in total on the two floors. The internal area and volume of the rooms are listed in Table 24. The plan drawings with external measures are shown in Figure 58 for the ground floor and Figure 59 for the 1st floor.

Table 24: Internal area and volume of the rooms.

Room	Internal area [m^2]	Volume [m^3]
Bedroom 1	9.1	21.8
Bedroom 2	9.1	21.8
Bathroom Gr.	6.1	14.6
Corridor Gr. + Staircase	10.5	25.2
Technical room Gr.	1.2	2.9
Kitchen	17.9	43.0
Dining area	17.5	42.0

Master bedroom	11.9	28.6
Walk-in	6.2	14.9
Bathroom 1st	8.8	21.1
Corridor 1st + Staircase	8.3	19.9
Small living room	9.5	22.8
Big living room	25.8	61.9
Technical room 1st	1.2	2.9
Total	143.1	343.3

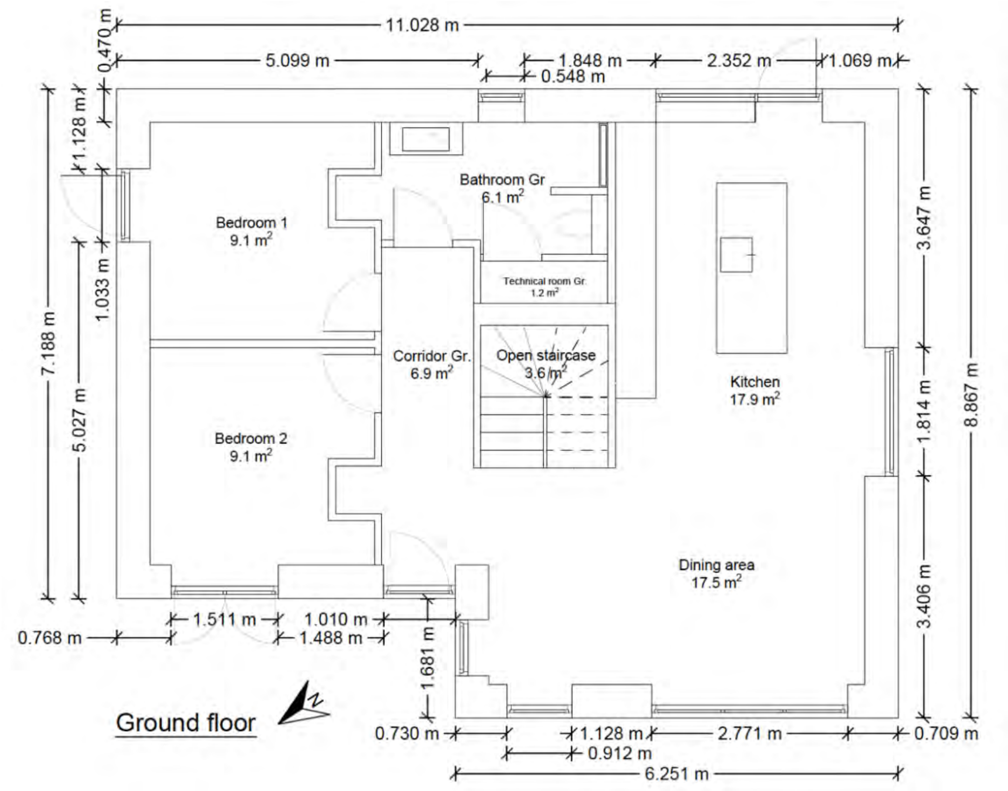


Figure 58: Plan drawing with external measures of the ground floor.

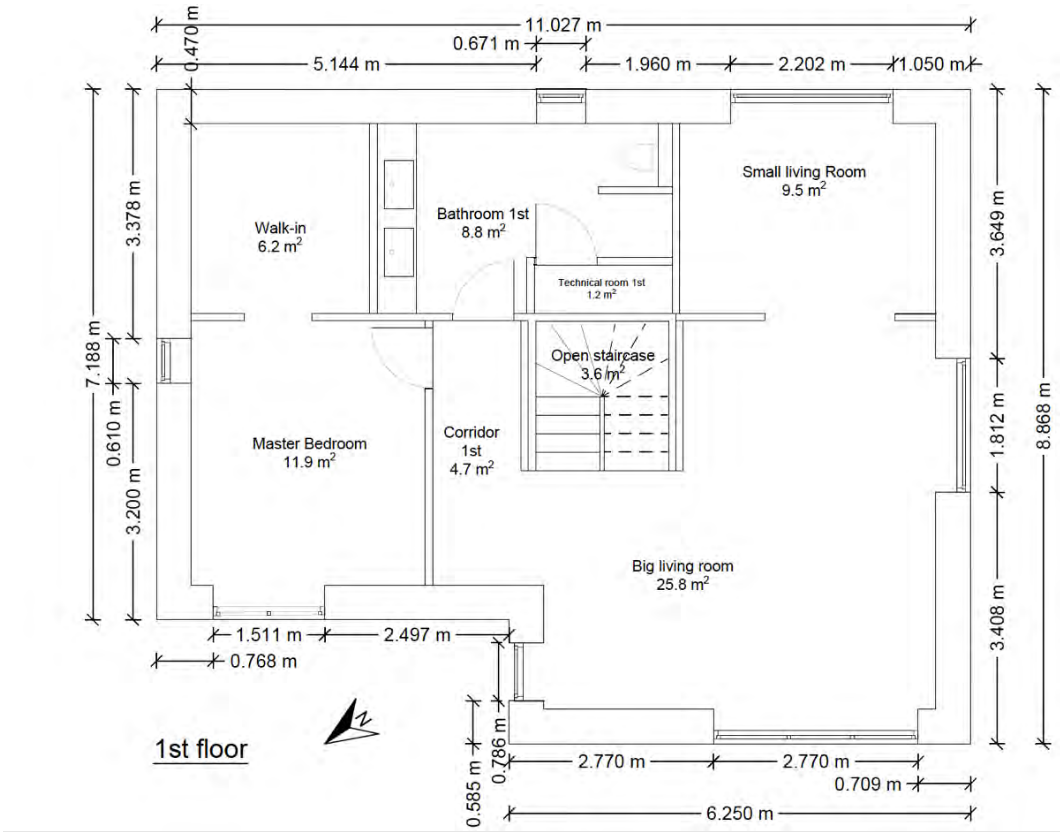


Figure 59: Plan drawing with external measures of the 1st floor.

Envelope constructions

The energy specifications and material layers of the envelope constructions are shown in Table 25 for the opaque constructions and Table 26 for the transparent constructions. An air tightness test was performed for the building and resulted in a leakage rate of 0.60 l/s per m^2 with a 50 Pa pressure difference.

Table 25: Opaque envelope construction specifications.

Construction	Thickness [m]	U-value [W/m^2 K]	Material layers
Ground deck	0.67	0.07	Wooden floor/brick, concrete, EPS
Roof/ceiling	0.54 (without suspended ceiling)	0.09	Lightweight concrete deck, glass wool insulation, suspended ceiling, wooden concrete
External wall	0.47	0.15	Brick, foamed recycled glass, brick
Internal wall	0.11	-	Brick
Floor separation	0.71	-	Wooden floor, Thermofloc cellulose insulation, concrete, suspended ceiling, wooden concrete

Table 26: Transparent envelope construction specifications.

Construction	Type	Window U-value [W/m² K]	Glass g-value [-]	Glass share [-]	Light transmittance [-]
Windows	3-layer energy glass	0.83-0.86	0.53	0.84-0.88	0.74
Doors	3-layer energy glass	0.73-0.88	0.53	0.60-0.68	0.74
Skylight	5-layer transparent acryl	0.93	0.47	-	0.58

Calculated energy demand

The building is a low-energy class building. The calculated energy use is shown in Table 27. The energy calculation is performed with the Danish compliance calculation software, Be18 [1 Aggerholm]. The heating is covered by a heat pump, which means that the heating energy is calculated as electrical energy and included in the energy "Electricity". To understand the calculated energy uses, it is important to note that not all electricity demands are accounted for in the "Total secondary energy". The electricity to the total secondary energy is only energy for the building operation. Furthermore, the Danish building regulation limits the amount of electrical energy produced by renewable energy sources to 25.0 kWh/m²/a.

To compare the building performance in Denmark, primary energy factors for heating and electricity are used. In 2018 when the building was designed and the energy calculation performed, the primary energy factor for electricity was 2.5.

Table 27: The calculated energy demand for the Egernsund demo site. The Danish compliance calculation software Be18 is used.

Energy [kWh/m²/a]	Calculated
Heating total	36.3
- Space heating	19.8
- DHW heating	16.5
Electricity	43.5
Electricity from PV	25.7
Total secondary energy, only electricity, Be18	2.8
Total primary energy, Be18	7.0

Occupancy

The building has been occupied by a couple with a child in the period December 2021 to May 2023. Further on, there are no fixed plans for occupancy of the house. Table 28 shows the occupancy schedule for a normal week for the family.

Table 28: Occupancy schedule. X = all are home, / = one is home, and + = no one is home.

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday

00:00 - 07:00	X	X	X	X	X	X	X
07:00 - 08:00	/	/	/	/	/	X	X
08:00 - 09:00	/	/	/	/	/	/	X
09:00 - 10:00	/	/	/	/	/	/	/
10:00 - 11:00	/	/	/	/	/	/	/
11:00 - 12:00	/	/	/	/	/	+	+
12:00 - 13:00	/	/	/	/	/	+	+
13:00 - 14:00	/	/	/	/	+	+	+
14:00 - 15:00	/	/	/	/	+	+	X
15:00 - 16:00	/	/	/	/	+	X	X
16:00 - 24:00	X	X	X	X	X	X	X

Weather data

The weather in Denmark is, according to the Köppen climate classification, an oceanic climate (cfb) with mild summer and winter, often cloudy, and wet winter. Table 29 shows the average monthly and yearly weather parameters for 2020 in Sønderborg (16 km from Egernsund).

Table 29: Average weather for Sønderborg in Denmark (16 km from Egernsund). Data is from Denmark meteorological institute (DMI).

Parameter	Max averaged (month)	Min averaged (month)	Average (year)
Temperature (°C)	19.3 (August)	4.8 (December)	10.6
Precipitation, total (mm)	150.6 (February)	14.6 (April)	720.6
Hours of Daylight	278.7 (June)	18.4 (December)	1898.5
Humidity (%)	90.2 (January)	69.9 (April)	80.5
Wind (m/s)	7.0 (February)	4.3 (May)	4.9

5.2 System description

The specifications of the monitoring and control systems in the building are described in this chapter. The concerned systems are:

- Indoor environment monitoring system
- Mechanical ventilation system
- Heating system
- Domestic water system
- Heat pumps and heat storage
- Photovoltaic system
- Control and monitoring system

5.2.1 Indoor environment monitoring system

The demo case was equipped with a development model of the Niko Multisensor, that is an indoor environment (IE) sensor. However, due to a development stop by Niko of this Multisensor, all sensors were replaced with temporary IE-sensors from IC-meter (mentioned as IC-meter). This chapter describes the IC-meter locations and monitored indoor environment parameters. The purpose and interventions with Niko Multisensor are described afterwards.

From 26.10.2022, the IC-meters are installed and placed close to the previous Niko Multisensor in 10 locations. In some rooms, the sensor is located differently to obtain a better quality of the measured IE parameters. For instance, the sensor location of the Niko Multisensor in Bedroom 1 was close to the internal door, where the sensor is affected by the condition in the corridor. The IC-meter in Bedroom 1 is located farther away from the internal door opening. This change of location is also done in Bedroom 2, Walk-in, Bathroom 1st floor, and Small living room. The locations of the IC-meters can be seen in Figure 61 for the ground floor and Figure 62 for the 1st floor. The sensors are placed 1.4 m above the floor and in places where they are not affected by direct solar radiation. In Figure 60, the location of two IC-meters can be seen.

The IC meter measures room temperature, relative humidity (RH), and CO_2 concentration. The specifications are listed in Table 30. All the measured parameters are available through IC-meters API and are implemented in Neogrids Preheat (described in chapter 5.2.7 and 6.1.1) and FusiX. An overview is given in Table 54.

Figure 60: Left picture: IC-meter in the kitchen next to Niko Multisensor. Right picture: IC-meter in Small living room.

Table 30: Specifications of the IC-meter.

Model	Measure	Unit	Ranges	Accuracy
Temp and RH: Sensirion SHT21 (datasheet) **CO2:** SenseAir S8 (datasheet)	Temperature	°C	-20 to 80 °C	± 0.3 °C
	Relative Humidity	%	0 to 95 %	± 2 %
	CO_2	ppm	380 to 10.000 ppm	± 30 ppm

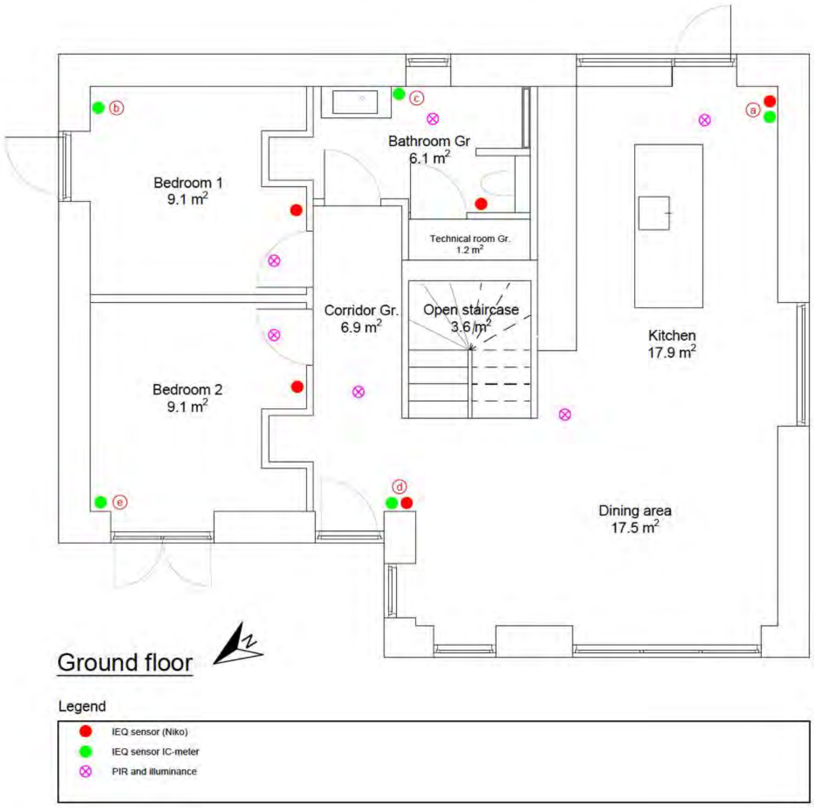


Figure 61: Location of the IC-meter IE sensors, the dismounted Niko Multisensors, and the Niko PIR sensors on the ground floor. The letters in the circles are for data location in Appendix C. Name for data location: Sensor_GR.

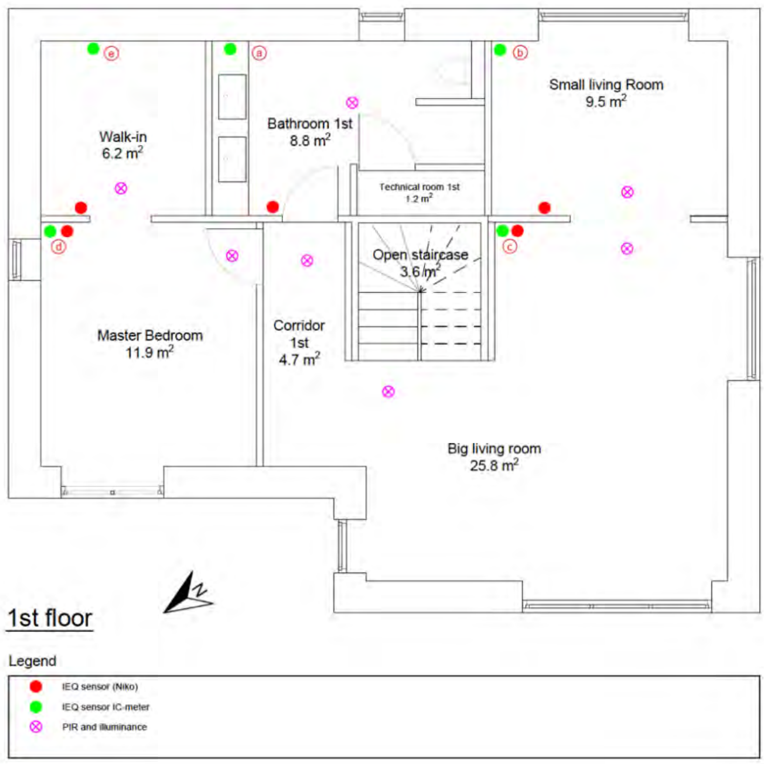


Figure 62: Location of the IC-meter IE sensors, the dismounted Niko Multisensors, and the Niko PIR sensors on the 1st floor. The letters in the circles are for data location Appendix C. Name for data location: Sensor_1st.

5.2.2 Mechanical ventilation system

The mechanical ventilation system in the building is divided into two systems on the ground and 1st floor. The ventilation systems after PRELUDE interventions are set to operate as constant air volume (CAV) system, meaning the opening position of the dampers is fixed, and the airflow distribution to the rooms is constant. Each ventilation system consists of an AHU, silencers, dampers, and diffusers. The ventilation system on the ground floor has two cooker hoods in the kitchen. The piping system and locations of AHU and dampers are shown in Figure 63 for the ground floor and Figure 64 for the 1st floor.

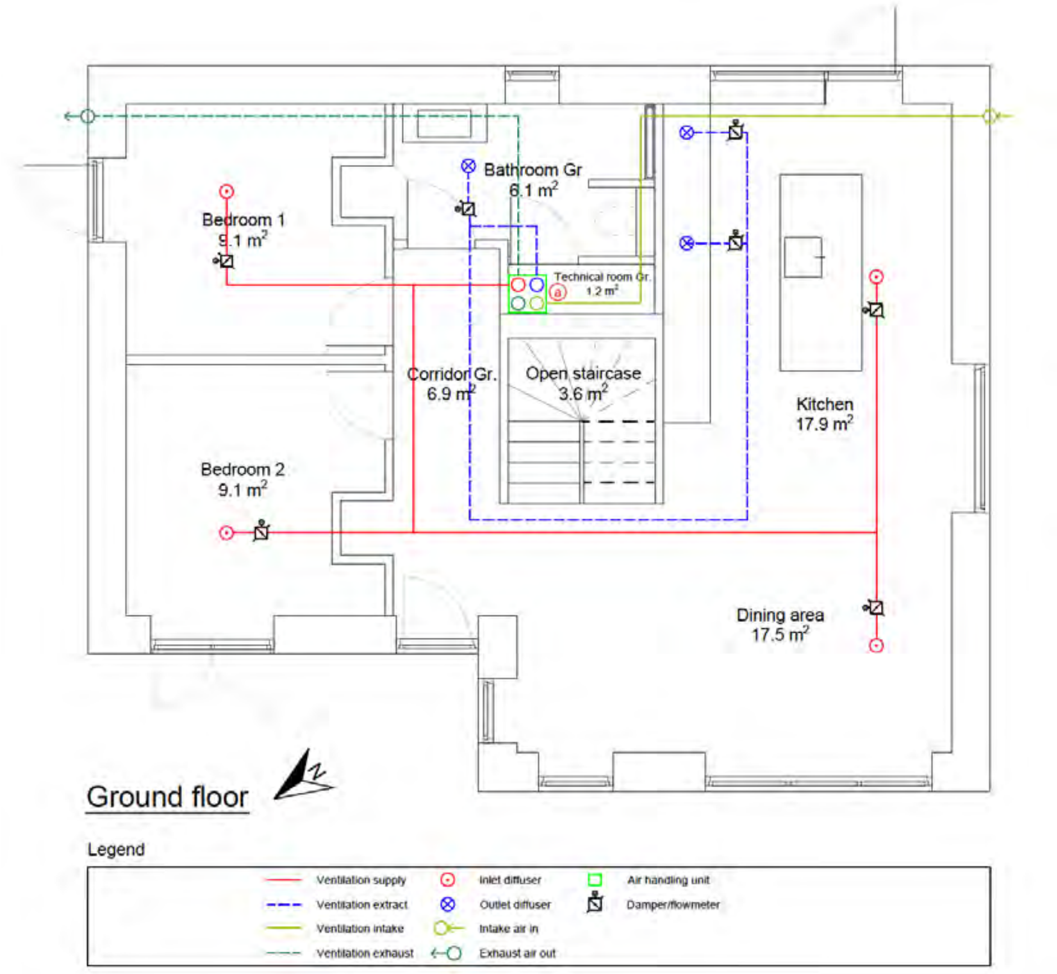


Figure 63: The duct system and the locations of AHU, dampers, and diffusers for the ventilation system on the ground floor. Name for data location: Vent_Gr.

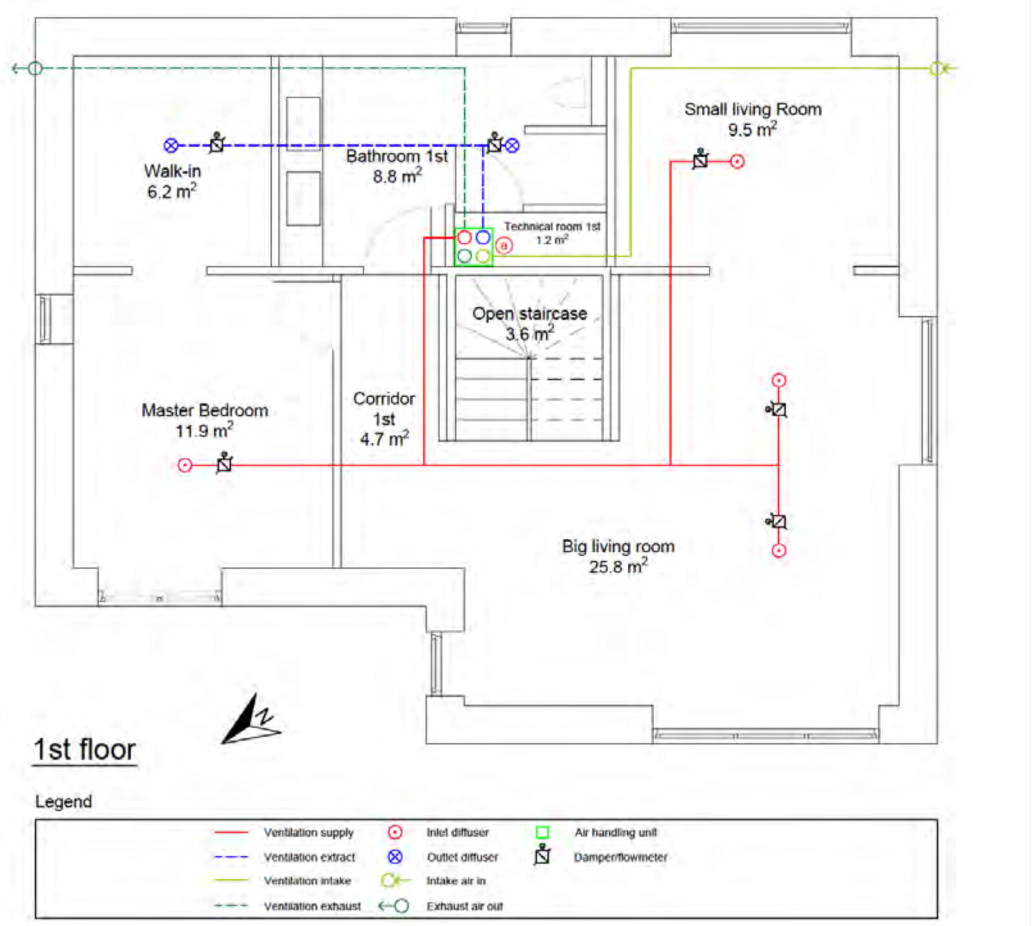


Figure 64: The duct system and the locations of AHU, dampers, and diffusers for the ventilation system on the 1st floor. Name for data location: Vent_1st.

Both systems have the same model of AHU, a Genvex ECO 375TS ALU with counterflow heat recovery, Figure 65. The specifications of AHUs are listed in Table 31. The AHUs are in each floor's technical room. The intake air diffusers are placed on the west façade, and the exhaust air diffusers are located on the east façade, Figure 67. The AHUs have Modbus communication to Neogrids Avenger box. This communication connection gives the possibility to read (log data) and write (control) parameters. The parameters that are logged are listed in Table 54 in Appendix C, and the parameters that can be controlled are listed in Table 32.

The settings for the operating step (steps 1-4) of the fan speed and the supply temperature setpoint can be adjusted by the user on a display for each ventilation system. In the Preheat platform and through the Preheat API (described in chapter 5.2.7 and 6.1.1), the same settings can be adjusted. The Preheat API and platform gives the control possibilities to the expert and is not meant for the tenants. It opens for the possibilities to control the fan speed and supply temperature according to indoor environment quantities (CO_2, temperature, relative humidity), weather forecast, and electrical price forecast.

Table 31: Specifications of the AHU. The building has two AHUs of the same model from Genvex.

Brand	**Model**	**Max airflow**	**Heat recovery**	**SEL/SPI**	**Filter supply/extract**
Genvex	ECO 375 TS ALU (datasheet)	470 m^3/h	82 %	792 W/m^3 (324 m^3/h)	F9/G4

Table 32: Control parameters of the AHU Genvex EC0 375TS ALU. It can be controlled through Neogrids Preheat.

Control parameter	Control interval	Control description
FanSpeed_display	0-4	Fan speed in the defined steps
Supply_level1	0-100 %	Supply fan speed of step 1
Supply_level2	0-100 %	Supply fan speed of step 2
Supply_level3	0-100 %	Supply fan speed of step 3
Extract_level1	0-100 %	Extract fan speed of step 1
Extract_level2	0-100 %	Extract fan speed of step 2
Extract_level3	0-100 %	Extract fan speed of step 3
Setpoint_Temp	10.1 – 30.0 °C	Setpoint of temperature
RegulationTemp	0-3	0 = Room temp, 1 = Supply temp, and 2 = Extract temp

A damper is installed before all supply and extract diffusers, Figure 66. The dampers are a Lindab UltraLink FTCU with Bluetooth. Two sizes are installed in the ventilation system: Ø125 and Ø160 mm. The FTCU have a controllable damper, an ultrasonic sensor measuring airflow, and a temperature sensor. See FTCUs specifications in Table 33.

Table 33: Specifications of the damper Lindab UltraLink FTCU.

Brand	Model	Measures	Unit	Ranges	Accuracy
Lindab	Ultralink FTCU Ø125/Ø160 Bluetooth (datasheet)	Airflow rate	m^3/h	Ø125 = 0 to 662 m^3/h Ø160 = 0 to 1087 m^3/h	Biggest: ± 5 % or ± 1.25 l/s Biggest: ± 5 % or ± 1.6 l/s
		Temperature	°C	-10 to +50 °C	± 1 °C
		Damper position	%	0 to 100 %	No information

The air is supplied to the room as diffuse ceiling ventilation. The supply air is blown into the space above the suspended ceiling, from where the air flows to the room through the ceiling panels, Figure 66. The pressure difference between the room and the space above the suspended ceiling causes the airflow. The outlet diffusers are placed in the ceiling panels (except in the walk-in, where the outlet is above the suspended ceiling), see Figure 67.

In the kitchen, two cooker hoods are installed, see Figure 68. One above the stove and one above the oven. The cooker hood above the stove is a rebuilt Exhausto ESL 125. The cooker hood is rebuilt with a standard exhaust part and a second exhaust part with a HEPA filter, see Figure 68. The exhaust part with the HEPA filter recirculates the extracted air to the space above the suspended ceiling. The cooker hood above the oven is a standard Exhausto ESL136SER. The two cooker hoods are mounted on the extract duct system of the ventilation system.

Figure 65: The AHU, Genvex ECO 375TS ALU, located in the technical room on the 1st floor.

Figure 66: Left picture: Ducts and dampers for supply and extract in the kitchen before the suspended ceiling is installed. Right picture: Duct above the suspended ceiling.

Figure 67: Left picture: Extract diffuser mounted in the ceiling panels in the bathroom on the 1st floor. Right picture: Exhaust diffusers on the east facade of the building.

Figure 68: Left picture: In the kitchen a cooker hood is placed above the stove and a cooker hood above the ovens. Right picture: The cooker hood above the stove is a rebuilt model. The standard exhaust part is to the left, and the extension part is the HEPA filter to the right. The extension part recirculates the air after the HEPA filter.

5.2.3 Heating system

The room heating distribution system in the building comprises of two underfloor heating (UFH) manifolds, one manifold per floor. Each UFH manifold supplies five zones, shown in Figure 70 for the ground floor and Figure 71 for the 1st floor. The UFH on the ground floor is heavy/slow UFH in concrete, and the UFH on the 1st floor is light/fast UFH in heat distribution panels just below the floor, Figure 69. The manifold and the actuators are placed in the technical rooms. The actuators are 24V (datasheet) on/off controlled by the NHC software, according to room temperature setpoints. The room temperature is measured by Niko HVAC Thermostat (datasheet).

The hydronic heating is supplied from the heat storage in the garage, placed approx. 8 m north of the building. The supply temperature is constant 35 °C, controlled by an ESBE VTA321 thermostatic mixing valve (datasheet) and circulated by a Grundfos Alpha 2 25-60 circulation pump (datasheet). The thermostatic valve and the circulation pump are placed in the garage with the heat storage. The PI diagram, Figure 76, shows the location of these components, which is further described in Chapther 5.2.5.

The heating energy for the underfloor heating is measured with two Kamstrup Multical 403 energy meters. One energy meter is in the garage, and the second is in the building in the technical room on the ground floor. With the locations of the two energy meters, the energy loss from the pipes in the ground from the garage to the building can be measured. Specifications of the energy meter are listed in Table 34, and the logged parameters are listed in Table 54 in Appendix C.

Besides the hydronic UFH in the bathroom on the 1st floor, electrical UFH is installed in the top layer of the floor. In the summer, when there is no need for room heating, the electrical UFH should keep the floor in the bathroom periodically warm to have better thermal comfort.

Figure 69: Left picture: Manifold and actuator to the UFH on the 1st floor. Right picture: The light UFH on the 1st floor.

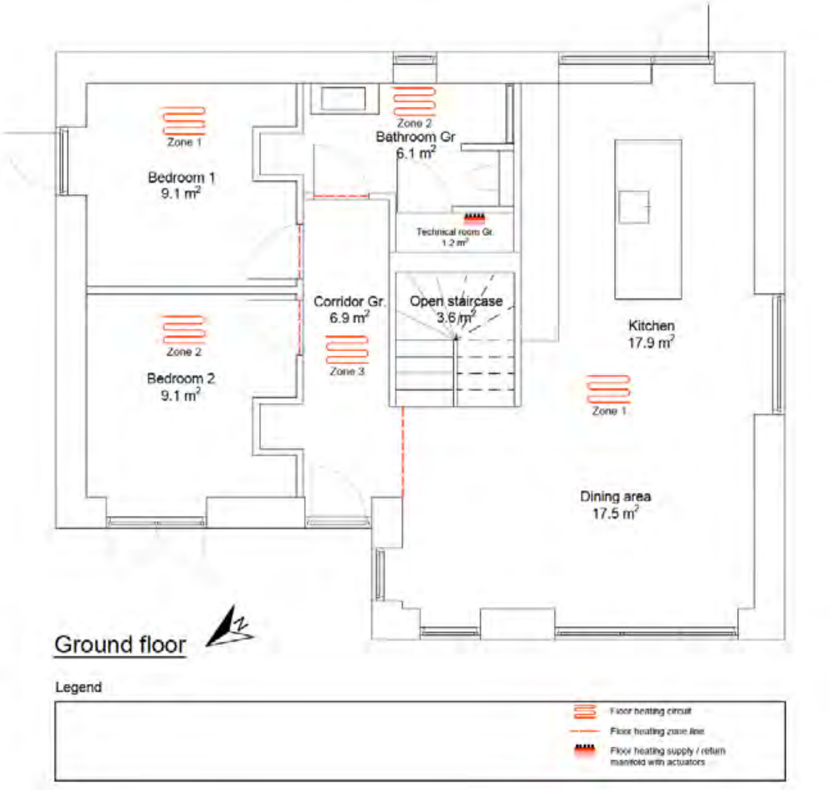


Figure 70: UFH zones on the ground floor and location of the manifold.

Figure 71: UFH zones on the 1st floor and location of the manifold.

Table 34: Specifications of the water flow energy meter, Multical 403 from Kamstrup.

Model	Measures	Unit	Ranges	Accuracy
Multical 403 q_p = 1.5 (Datasheet)	Water flow rate	l/h	15 l/h to 3 m^3/h	± (1 + 0.01 q_p/q) %
	Volume	m^3	Cumulative	No accuracy – depend on flow
	Temperature	°C	2 to 130 °C	± (0.4 + 4/ΔΘ) % ΔΘ temperature difference between supply and return
	Energy	MWh	Cumulative	± (0.15 + 2/ΔΘ) % ΔΘ temperature difference between supply and return

5.2.4 Domestic water system

The domestic cold water (DCW) supply is entering the building in the garage. The domestic hot water (DHW) is heated in a spiral in the heat pump tank, further described in chapter 5.2.5. From the garage, the DCW and DHW are distributed to the technical rooms in the building by two insualted pipes that are located in the ground. There are ten tapping points in the building, listed below:

- Ground floor: one washbasin (WB), one shower, one toilet, one kitchen sink (KS), one dishwasher (DW), and one washing machine.
- 1st floor: two WB, one shower, and one toilet.

The washbasins and kitchen sink have sensor fixtures installed to decrease water use. The shower on the ground floor is a standard shower system. The shower on the 1st floor is an Orbital shower system that recirculates the water and reuses the energy. The Orbital shower system can save up to 90 % of the water use and 80 % of the energy use. See Figure 72.

The total DHW use and energy use are measured by Kamstrup Multical 403 and logged by Neogrid Avenger box with Modbus communication. The energy meter is located in the garage and can be seen in the PI diagram in Figure 76. Specifications of the energy meter are listed in Table 34, and the parameters that are logged are listed in Table 54 in Appendix C. The separate heat meters for space heating and domestic hot water allow for monitoring of these two heat uses separately and not together as it is often done.

Six Huba flow sensor 236 are installed in the technical room on the ground floor to measure the water flow rate and temperature of the DCW and DHW tapping points. The specifications of the Huba flow sensor are listed in Table 35. The logging system for the Huba flow sensor is done with a Porcupine and developed by AAU and Seluxit. The setup can be seen in Figure 73. Table 36 shows which tapping points that are measured by the Huba flow sensors. Unfortunately, not all tapping points are covered, and as one can see, four of the Huba flow sensors cover more than one tapping point. However, the flow rate will distinguish the use of the different tapping points. "Huba 1" measure DCW to a washbasin and a toilet. The washbasin will have a fluctuating flow rate, whereas the toilet will have a stable flow rate when filling up the cistern after a flush.

The Huba flow sensor data is not implemented in FusiX, and the data is not analyzed at the moment of the deadline for the deliverable but can be used to understand the share of the energy use for DHW.

Table 35: Specifications of the Huba flow sensor 236.

Model	Measures	Unit	Ranges	Accuracy
Flow sensor 236 0-10 V model (Datasheet)	Water temperature	°C	-25 to +125 °C	± 0.5 ± 0.005 · ΔT
	Water flow rate	l/min	1.8 to 32 l/min	< 50 % fs = < 1 % fs > 50 % fs = < 2 % measuring value

Table 36: Overview of Huba flow sensor that measures the tapping points. WB = washbasin, KS = kitchen sink, DW = dishwasher.

	Huba 1	Huba 2	Huba 3	Huba 4	Huba 5	Huba 6
Cold or hot	Cold	Cold	Cold	Hot	Hot	Hot
Tapping point	WB, Gr. Toilet, Gr.	2 x WB, 1^{st} Toilet, 1^{st}	KS, Gr. DW	WB, Gr.	KS, Gr.	2 x WB, 1^{st} Shower 1^{st}

Figure 72: Left picture: Toilet and Orbital shower system on the 1^{st} floor. Right picture: two washbasins on the first floor.

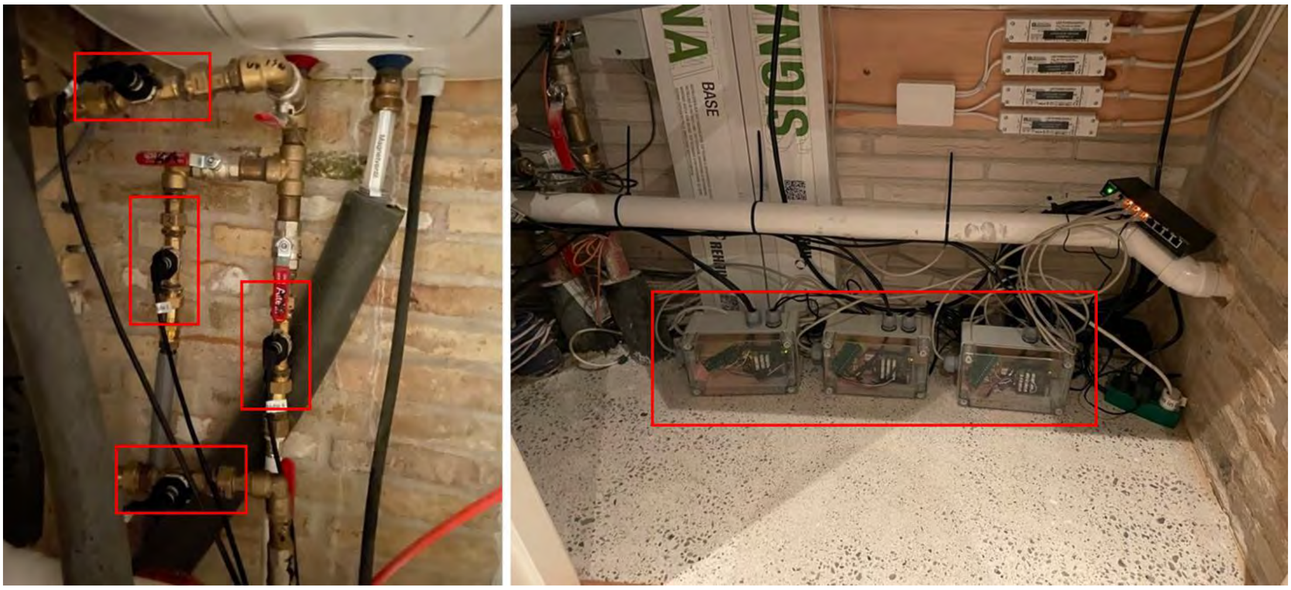


Figure 73: Left picture: Huba flow sensor. Right picture: Porcupine logging devices for Huba flow sensor.

5.2.5 Heat pumps and heat storage

In the garage, the complex system for producing space heating (SH) and DHW for the building is placed. It includes two heat pumps, heat storage, and utilization of surplus from PV production. The system is shown in Figure 74, and the piping and instrumentation diagram (PI diagram) in Figure 76. The surplus of the PV production is detailed described in chapter 5.2.6. The complex system is built in two steps in research collaborations with companies. Step 1 is the original design with two heat pumps. In a collaboration between the contact person of the building and a heat pump manufacturer (DVI), they wanted to test and compare an air-to-water heat pump with a horizontal ground source heat pump under real building operation and weather conditions. The second step was a collaboration with a PV system research company. They extended the original design with heat storage and utilization of the electrical surplus from the PV system. They wanted to test the heat pump smart readiness with a boost signal to increase the temperature in the heat storage when the operation was advantageous. Furthermore, if there was a surplus of electrical energy, it should be stored as heat energy by activating two electrical heating elements in the heat storage tank. This control of electrical surplus should be performed with an energy manager, Smartfox Pro Light, from Smartfox.

Figure 74: Technical installation in the garage. From left to right: PV battery, heat storage tank, cabinet with ground source heat pump and buffer tank, pipes to the building (DCW, DHW, UFH), pipes to the ground source brine, pipes to the air-to-water heat pump, PV inverter, and electrical board for the installations in the garage.

The current setup of the heat pumps is that they are series connected, with the ground source heat pump as master (main source) and air-to-water as slave (supplement). The setup can be changed between in total four setups by exchanging the master/slave role between the heat pumps and the use of a bypass: i) Only ground source – by activating the bypass and deactivating air-to-water, ii) Only air-to-water – master control is air-to-water and the ground source is deactivated, iii) Series connection with ground source as master and air-to-water as slave, iv) Series connection with air-to-water as master and ground source as slave. The warm circuit of the heat pumps creates the possibility for the series connection. The return water from either the DHW tank, SH tank, or heat storage is circulated through the heat exchanger of the air-to-water heat pump, then to the heat exchanger of the ground source heat pump and the supply back to the DHW tank or SH tank. By activating the bypass, the warm circuit only circulates to the ground source heat pump. The circuit can be seen in the PI diagram in Figure 76, and the specifications of the heat pumps can be found in Table 37.

Table 37: Specifications of the two DVI heat pumps.

Heat pump type	Model	Nominal effect	SCOP	Operation mode	Regulation mode
Ground source (datasheet)	VV5	5.66 kW (Floor heating)	5.04 (Floor heating)	On/Off	Heat curve
Air to water (datasheet)	LV7	4.08 kW (Floor heating)	3.92 (Floor heating)		

In the cabinet of the ground source heat pump (no. 1 in the PI diagram), there is a buffer tank with a capacity of 293 L water. The buffer tank is divided into two volumes by a metal plate. The top volume, 225 L, is for heating the DHW spiral, and the lower volume, 68 L, is for space heating. Below the buffer tank, a 3-way valve (no. 8 in the PI diagram) is controlling which of the buffer tank's two volumes should be circulated in the heat pump's warm circuit. DHW is prioritized above space heating. The volume for space heating is extended with a 500 L buffer tank for heat storage (heat storage tank, no. 4 in the PI diagram) next to the cabinet of the ground source heat pump. A pump is constantly circulating the water from the buffer tank and the heat storage tank. There are two return options from the heat storage tank (middle and bottom) that are controlled by an ESBE thermostatic 3-way valve. The temperature setting of the 3-way valve is 60 °C. If the temperature is below 60 °C, the return is from the middle of the tank, and if above 60 °C, the return is from the bottom. Installed in the heat storage tank are two 3 kW heating elements with modulating electrical effect. The function of the Smartfox Pro Light (no. 5 in the PI diagram) is controlling the two heating elements if there is a surplus of produced electricity. A water temperature of 80 °C is the limit for the water in the heat storage tank, and at that temperature, the heating elements will be disconnected. The space heating for the UFH is supplied from the heat storage tank. An ESBE 3-way thermostatic mixing valve mixes the return water with the supply water to keep a setpoint of 35 °C. After the 3-way valve for UFH, a Grundfos Alpha 2 pump constantly circulates the water with a constant pressure curve.

A control and monitoring system for the heat pump and heat storage system has been developed in the PRELUDE project, as it did not exist before besides the Smartfox Pro Light for the heating elements. The development of control and monitoring system can be divided into "heat pumps" and "outside heat pumps". For the heat pumps, access to the DVI API is established, where control parameters and setpoints can be found in Table 38, and measured parameters are listed in Table 55 in Appendix C. DVI also has a web interface, DVI Smartcontrol, shown in Figure 75, where live measured values are presented, and the user can change settings. The DVI heat pumps do not have a data logging system, which means a logging script in FusiX is established. The measured values are divided into four categories: i) "sensor" - all temperatures in the heat pump, locations are shown in Figure 75, ii) "relay" – all relays in the heat pump for pumps, compressor, mixing valves, etc., iii) "timer" – run time for compressor, DHW production and in-built heating element, iv) "setting" – the settings that can be controlled.

Table 38: Control parameters of the ground source heat pump. The same control parameters apply to the air-to-water heat pump. It can be controlled through DVI API.

Control parameter	Control interval	Set point	Control description
WW_SH_State	0-2	1	Status SH: 0 (off), 1 (on), 2 (external controlled)
WW_SH_Offset_HeatCurve_(C)	0-20	13	Offset heat curve: °C
WW_SH_SetPoint_Curve_(C)	-	Heat curve + offset (above)	Is calculated according to the outdoor temperature
WW_SH_SetPoint_Constant_(C)	20-48	25 (Not in use)	Setpoint thermostat temperature (constant): °C
WW_DHW_State	0-2	1	Status DHW: 0 (off), 1 (on), 2 (external controlled)
WW_DHW_SetPoint_(C)	5-65	51	Setpoint DHW temperature: °C
WW_DHW_ClockControl	0-2	1	DHW clock control: 0 (week plan), 1 (constant on), 2 (constant off)

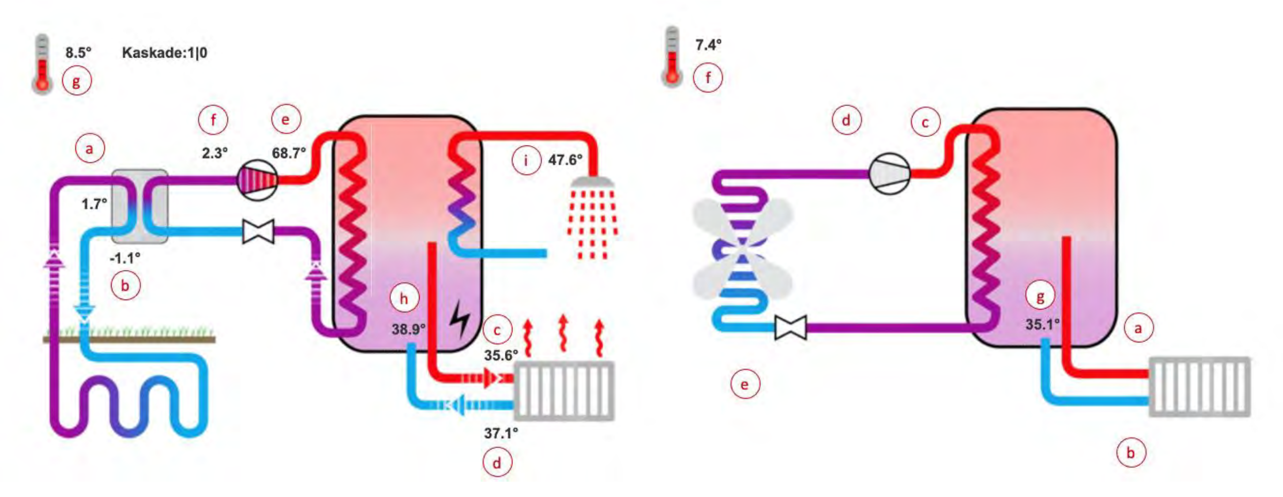


Figure 75: Graphical interface of the DVI heat pumps. Left picture: Ground source. Right picture: Air-to-water. The letters in the circles are for data location in Appendix C. Name for data location: Ground source: HP_WW and Air-to-water: HP_AW.

Outside the heat pumps, only a monitoring system is established. The monitoring system can be upgraded to a control system, which will be implemented later in the PRELUDE project. Together with a third-party provider, Neogrid A/S, a gateway (no. 6 in the PI diagram), is installed. A more detailed description and status of the Avenger box implementation is described in "Control system". In the heating system, the gateway collects measured data from four Kamstrup Multical 403 heat energy meters (specifications in Table 34) and three PT1000 temperature probes. The heat energy meters indicate the energy flows: i) the heat pump buffer tank to the heat storage tank, ii) the heat storage tank to the UFH, iii) the energy to DHW. The temperature probes measure the water temperature in the heat storage tank in three locations: top, middle, and bottom. The locations of these energy meters and temperature probes are shown in the PI diagram, Figure 76.

Electrical energy meters to measure the energy use by the heat pumps and the UFH circulation pump are planned to be installed. These energy meters will improve the analysis of the heating system. However, with long waiting time for delivery and an electrician to install the energy meters have delayed the installation. At the moment for the deliverable deadline, the energy meters are planned to be installed. The situation is further described in chapter 5.2.7 and 6.1.1.

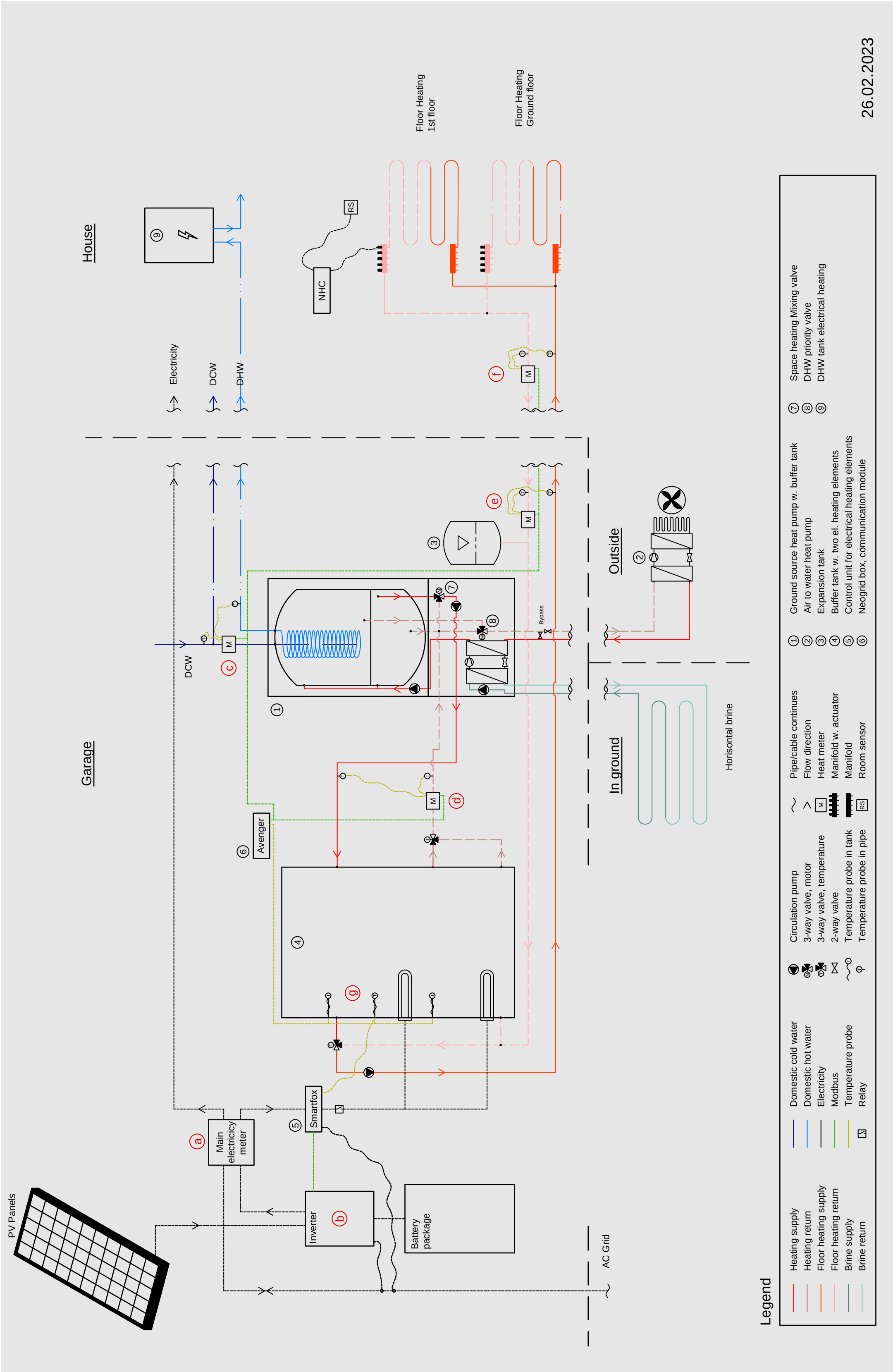


Figure 76: PI diagram for the heating system (heat pump, heat storage, UFH, and DHW), PV system (PV panels, inverter, battery, heating elements, and grid), and monitoring system. The letters in the circles are for data location in Appendix C. Name for data location: PID.

5.2.6 Photovoltaics system

The building is equipped with a PV system consisting of 24 Hyundai PV panels (39 m^2), a Fronius 5.0 kW inverter, and a Fronius 3.6 kWh battery. The specifications for the panels, inverter, and battery are listed in Table 39, Table 40, and Table 41, respectively. In the PI diagram, Figure 76, the location of the PV system is shown. The monitoring solution for the PV system is established with the Fronius Datamanager 2.0 (datasheet), implemented in the inverter, as the gateway between measuring devices and the Fronius data portal. The inverter measures the electrical energy production from the PV panels and energy output from the inverter. A data connection between the battery and inverter is done with a Wifi access point established by the inverter. Measures retrieved from the battery are: charging status, energy to the battery, and energy from the battery. With a Modbus connection between the Datamanager 2.0 and Fronius SmartMeter (datasheet), the total electricity use from/to the grid can be measured. The Datamanager 2.0 is connected to the ethernet and sends data to Fronius cloud service Fronius Solarweb, where the energy balance is visualized, and data can be exported. Data can also be exported with the Fronius API, and is almost been implemented in FusiX. In Figure 77, the energy balance is visualized. In Table 56 in the Appendix C the measured values are listed.

It is important to notice that the total electrical consumption can be achieved with Fronius Solarweb. The main electrical meter only measures the electricity from the grid for billing purposes.

Table 39: Specifications of the Hyundai PV panels.

	Brand	Model	Amount	Nominal output	Module efficiency
Panels (datasheet)	Hyundai	HiS-S290RG Mono-crystalline silicon	24 39 m^2	290 Wp Total 7.0 kWp	17.7 %

Table 40: Specifications of the Fronius inverter.

	Brand	Model	PV input	Nominal output	Max efficiency
Inverter (datasheet)	Fronius	Symo Hybrid 5.0-3-S	8.0 kW 16 A	5.0 kW 8.3 A	PV-grid: 97.6 % PV-battery-grid > 90 %

Table 41: Specifications of the Fronius battery.

	Brand	Model	Capacity	Nominal charge/discharge power
Battery (datasheet)	Fronius	Solar Battery 4.5	3.6 kWh	2.4 kW

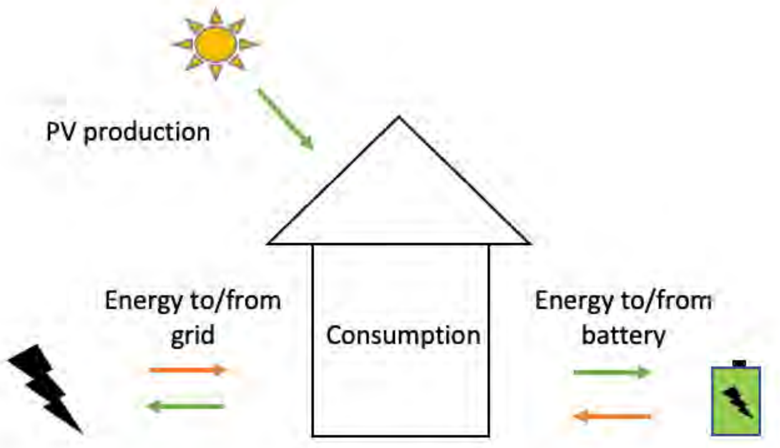


Figure 77: Energy balance with the measured parameters in the PV system.

As mentioned before in the description about heat storage, an energy manager, Smartfox Pro Light, is a part of the electrical installation. The function of the Smartfox Pro Light is to activate the heating elements in the heat storage tank if there is a surplus of electrical energy from the PV system. The Smartfox Pro Light is connected to the PV inverter with Modbus to measure the electrical energy production and with electrical clamps on the main electrical supply to measure the energy to and from the grid. If there is a surplus (energy to the grid), the Smartfox Pro Light will activate the heating elements to store the electrical energy as heating energy in the heat storage tank.

The complete overview of the electrical energy use in the building is at the deadline for the deliverable not achieved. This is due to the not installed electrical energy meters for the heat pumps, not collected electrical energy data from the house described in chapter 6.1.1, and the extensive work to understand and repair the PV system. In the following chapters, is described the work carried out to make the battery function and establish the connection to the inverter, smartmeter, and Smartfox Pro Light.

5.2.7 Control and monitoring system

The control system of the building has extensively been reorganized to fit the implementation of the PRELUDE technologies. A fully equipped Niko Home Control (NHC) solution was installed in the building as a showcase of Niko products and as a research setup with the Niko Multisensor. In the research setup, the NHC should facilitate the monitoring of the IE in all rooms. In relation to the IE measurement, NHC should control the heating system (actuator opening) and ventilation systems (damper opening and total air flow rate). As described in "Indoor environment sensor", the work with Multisensor has been troublesome. The sensor is exchanged with IC-meter and Niko HVAC Thermostat to measure IE quantities and control the heating system, respectively. Last, the ventilation system is changed to a CAV system. The modifications made are further described in chapter 6.1.2 and the following describes the current NHC control and what the implemented Avenger Box from Neogrid controls.

The NHC controls the indoor and outdoor lighting installation by motion detection and illuminance level with PIR detectors in all rooms and outside. Furthermore, the light in all rooms and outdoors can be turned on/off or dimmed by the Niko Home app installed on a tablet or a smartphone. The on/off control in the app also applies to the sockets in the house. In the switchboard, 12 electrical energy meters are installed to measure the house's electrical energy use (without the electrical appliances in the garage) and several appliances in the house. The house's main switchboard, shown in Figure 78, is quite extensive and is located on the ground floor under the stair at the backside of the technical room. In the NHC software, the control strategy and the setpoints for the devices can be changed.

The monitoring and control system for Niko will not be further described in this report, as final access and understanding of the API are not achieved. Our experience with the Niko company is that they can provide great possibilities to control electrical devices. However, monitoring solutions and control of HVAC systems are not their expertise. With the extensive setup in the house, the communication bus system has been and still is overloaded. The overloading does not affect the systems in the house, but data packages are lost. The historical data Niko has offered are insignificant, with a lot of missing data points.

Figure 78: The main switchboard in the house. The first row to the left is normal electrical safety devices. The rest is Niko Home Control.

Neogrid's Avenger box, Figure 79, was installed in the building as a consequence of the missing control possibilities in Niko, a need for a monitoring solution for the measuring devices with Modbus communication (AHUs and heat energy meters), and a wish from the contact person to have an optimized heat pump solution. The Avenger box's functionality is to be a gateway between Neogrid's web platform, Preheat, and the devices in the building. The Avenger box can control the devices by a wide range of communication protocols (Modbus, MBus, Lora, etc.) and relays. Further, the Avenger box can measure on NTC and PT probes. In Preheat, control settings can be made, and measurements can be visualized. With the Preheat API, data can be exported. Preheat API is implemented in FusiX, and the data available is listed in Table 54 in Appendix C. AAU aims to connect all HVAC systems to the Preheat and use it for the PRELUDE solutions to have one single control system to interact with. Implemented are IC-meter, AHUs, heat energy meters, and heat storage tank temperature. The ones missing are heat pumps, PV system, and UFH system. FusiX has an API connection to heat pumps and PV system. For now, Preheat serves as a monitoring solution. When control strategies and algorithms are implemented, the AHUs' parameters, in Table 32, are controllable through Preheat API.

Figure 79: Neogrid's Avenger box - a gateway between Preheat and devices in the building.

5.3 Motivation and user engagement to participate in project

The demo case in Egernsund is a single-family house built for research purposes. For companies to test and show their products and for research institutes to test technologies that can reduce energy use in buildings. Through the PRELUDE project, AAU has been very welcomed. Before the PRELUDE project, AAU has been a part of testing the external building block the house is built of and was also part of the research project testing the heat storage solution. The collaboration between AAU and the contact person behind the building has been positive even though the building was not operating well and previous research implementations were with mixed outcomes. In chapter 6, the modifications to the building installations made in the PRELUDE project are described. The chapter gives an overview of a wide range of problems that have been solved. The contact person's benefit from the proejct is that he can use AAU as the expert when this is needed for considering new technology implementation.

The contact person has been much helpful by providing all the needed information and documentation. In case of missing documentation, the contact person has established contact with the companies behind the construction of the building. Even though the contact person doesn't have the technical expertise, he has several times driven to the building to find information, take pictures, or switch a device on/off. The contact person does not prevent any of the PRELUDE work and facilitate when third-party providers are slow in delivering.

6 PREPARATION OF DEMONSTRATION CASE

To implement the PRELUDE technologies in the demo case and secure sufficient data, the building has been prepared. This chapter describes the modifications carried out in the building, the implementation of data transfer to FusiX, exploratory data analysis and an identification of building operation. Last, in the chapter is an overview of the ongoing preparation.

6.1 Modifications carried out in the building

The modifications carried out in the Egernsund building can be divided into two groups. The first group is the installation and integration of sensors and monitoring systems, so the PRELUDE middleware and technologies can get the necessary data and communicate back to the systems with control inputs. The second group is the testing, balancing, and repairs to secure the function of the building's installation.

6.1.1 Installation and integration of sensors and monitoring systems

The following modifications to get the necessary data and control of the monitoring system have been carried out in the PRELUDE project for the technical systems presented in chapter 5.

Niko Home Control: The modifications of the Niko Home Control system to controllable control systems with monitoring/logging solution for the PRELUDE technologies has been a big time-consuming task. The purpose was to build a building with a high sustainable class and high-tech technical installations. The high sustainable class was reached with platin in the DGNB certification. To reach this certification, it was necessary to measure several IE parameters, including temperature, RH, CO_2 concentration, and volatile organic compounds (VOC). To do so, the contact person of the building agreed with Niko to run a research setup with their demo product of an IE sensor, Multisensor. Furthermore, together with the installation of the Multisensor, it was envisioned to use the measured IE parameters to control the ventilation system and heating system. Unfortunately, the work with the Niko Multisensor has been troublesome and with long waiting times. The interventions are described chronologically in the bullet points bellow:

- **Data from Niko:** For the project to get data, Niko required a non-disclosure agreement (NDA) between Niko Servodan A/S, AAU, and the building owner. Through long waiting times from legal offices in Niko and AAU, the NDA was signed in April 2022 (approximately 1.5 years after the first contact). This waiting time has set back the work with the Niko Home Control system, analysis of data, and implementation of Niko into FusiX.
- **Not working sensors:** One Multisensor was found not working in the kitchen and replaced with the sensor from the Walk-in. Niko promised to mount a new Multisensor in the Walk-in, which never was done. Three Multisensors were found error-prone and showed unrealistic measurements as frozen values (the same values a whole day) and 0 in value. This was expected as malfunctioning Multisensors. However, the NHC application version to iOS had an error and showed wrong measurements from the Multisensor.
- **One API access:** Niko has only allowed one access to the NHC API. This access has been granted to EMTECH, to implement Niko into FusiX. With only one API access, it has required a lot of communication between AAU, EMTECH, and Niko to share information about the NHC system. AAU has contacted Niko to be granted a second API access. This has not been granted at the moment of this deliverable deadline.
- **No update of NHC software:** The Multisensor is a demo product, and in the NHC software, the use of the device was only implemented in a version last updated from May 2021. With an update to a newer software version, the functions with the Multisensor would be removed. This would influence the heating and ventilation control. As long as the Multisensor was a part of the NHC installation, the

NHC software was on a Niko service computer placed in the building. Remote control of this computer has been troublesome, and several times AAU has lost connection to the computer. Establishing the connection required visiting the building (~300 km from the AAU office).

- **Stop of development:** The 25.10.2022, Niko informed AAU that the development of the Multisensor is stopped, and the Multisensor would not be a device to include in the newer versions of NHC software. AAU agreed with Niko and the contact person of the Matzen-Tegl Huset to find other solutions that could perform IE measurements and interact with the heating and ventilation control systems.
- **Niko Multisensor replaced and update of NHC software:** After a long delivery time to get the replacement of the Multisensors, all Multisensors were dismounted mid-March 2023 and replaced with Niko thermostats. The thermostat devices were implemented in the NHC software, and the software was updated to the latest version and moved to an AAU computer.
- **New control of the heating system:** With the Multisensor, it was not possible for the user to change the setpoint. However, the user could, in the NHC app, activate/deactivate the heat (open/close the actuator) in each zone. When the user activated the heat, they oversteered the automatic control, which was not set back. The setback to automatic control should be done in the NHC software that experts should do. The manual user control resulted in high room temperatures. With the replacement to Niko HVAC Thermostats, the set point for each heating zone can be controlled by the user at the display of the thermostat.
- **New control of ventilation:** A replacement of the Multisensor, measuring CO_2, to control the ventilation system has not been installed, and the ventilation system is controlled with fixed damper opening positions. It is expected to remain as CAV for the rest of the duration of the PRELUDE project.
- **Niko electrical energy meters:** Much work have been allocated to get data from electrical energy meters to the appliances in the house but has not succeeded. In April 2022, the NDA with Niko to get access to data was signed. In May 2022, EMTECH and AAU got an introduction to the Niko API and were granted a single access. In June 2022, two extra energy meters were installed, and the total energy meters in the switchboard went to 12 devices. Nine energy meters were ordered in November 2022 but never installed because of waiting time from the electrician and critical information from Niko about an overload of the NHC bus system. In the parallel work to extract data from the Niko cloud, EMTECH experienced to get inconsistent data with critical missing data points. In March 2023, Niko informed us that the NHC bus was overloaded and the data points missing were lost. The work with reducing messages sent in the NHC bus is ongoing, and the aim is to get consistent data from the electrical energy meters.

Installation of Avenger box and data from technical systems: Neogrids Avenger box is not a standard solution. In collaboration with AAU, Neogrid develops the functions of the Avenger box and the Preheat to fit the demo case's technical systems. Especially the connection to Fronius API and DVI API is ongoing work to implement in Preheat. The implementation of the Avenger box in the demo case was started in late October 2022. The systems that have been implemented and monitored by the Preheat are the IC-meters, the AHU, and the heat energy meters.

The Avenger box is connected to the AHUs with Modbus. In the Preheat web interface, parameters to read or write are implemented. With the installation of the Avenger box, it is possible to control and check online the parameter of the AHUs. Together with the implementation of IC-meters in Preheat, it is also possible to regulate the AHUs' fan speed and measure the CO_2 concentration in each room. However, this functionality is currently not identified as a required PRELUDE intervention.

The building was equipped with two heat energy meters for the UFH. The energy meters were without communication modules, and no logging system was installed. Furthermore, there was a need for two heat energy meters to measure domestic hot water energy and the energy flow between the buffer tank and heat pump tank for space heating. The two energy meters and the Modbus communication modules were ordered in January 2022. Unfortunately, due to repercussions from the corona pandemic in China and the global lack of microchips, the modules arrived in late September. They were installed in the building by a plumber in late October 2022. Afterward, the communication with Neogrids' Avenger box was established, and the logging system was set up at the beginning of November 2022. The late integration of heat meters influenced the Measurements and Verification module described in D4.5, which could not access sufficient data to create reference conditions for the duration of its task. However, the data from the winter season 2022/2023 should be sufficient to produce benchmark conditions before planned DPC interventions scheduled for winter 2023/2024.

Logging system for Huba flow sensor: The Huba flow sensors were mounted in the domestic water installation before the PRELUDE project, but no logging system was implemented. Together with Seluxit, AAU has developed a logging system for measurements with the Huba flow sensor [12]. This logging setup is installed in the building, and data are available from January 2022.

Data from heat pumps with DVI API: To set up the data storing solution from the DVI heat pumps have been troublesome. In November 2021, AAU was informed by a DVI consultant that there was no data logging system for the DVI heat pump and that the heat pump only could be remotely controlled by using the web interface DVI Smartcontrol. In November 2022, by contact with the head of development in DVI, AAU was informed that API access was possible. However, there was no data logging system, only live operating values. In December 2022, API access was established, and EMTECH and AAU developed a data logging script.

Electrical energy for heat pumps: After extensive work to identify, understand, and repair errors in the heating system, it became clear in May 2022 that electrical energy meters for the heat pumps were not installed. In late October 2022, the installation of the electrical energy meters was agreed. In November 2022, the electrician got the last detail about the wanted devices from AAU, and installation was planned for December 2022. However, due to the busyness in the building sector, device delivery time, and communication problems with the electrician company, the installation of the energy meters have not been implemented. AAU was promised the installation in mid-May 2023.

Connection Fronius Datamanager and Smartfox Pro Light: After the inverter replacement in September 2021, described in chapter 6.1.2, the Smartfox Pro Light has not been connected to the Fronius Datamanager. Meaning the Smartfox Pro Light did not have access to PV production energy and charge of battery. The connection was established in late May 2022. In November 2022, this connection was lost again due to a disconnection of the inverter. However, this connection seems not to be relevant, as the Smartfox Pro Light only needs the energy to and from the grid to control the actuation of the heating elements.

Data connection to Fronius SmartMeter: A connection between the Fronius SmartMeter and Fronius Datamanager was not connected with Modbus. In late May 2022, this connection was established. As the SmartMeter is installed to measure the energy to and from the grid to have the correct calculated energy balance in Fronis SolarWeb, this was needed.

6.1.2 Testing and calibration systems, regulation, balancing, repairs

The mechanical ventilation system, heat pumps, and PV systems were the technical system in Egernsund that needed modifications to function properly. The following describes those interventions.

Balancing of the mechanical ventilation system: The NHC implemented in the house, described in chapter 6.1.1, was set up to control the damper opening in each room according to the CO_2 ndIR concentration measured by the Niko Multisensor. This control strategy was simple and functioned with two fixed damper openings positions:

- If "CO2_room > 500 ppm"
  - True "damper_opening_room = 60 %"

- False "damper_opening_room = 20 %"

However, this demand control did not take balancing into consideration. If one damper opening was changed, the remaining dampers' opening should be regulated too, to maintain balance in the ventilation system. Furthermore, the NHC had no control over the AHUs, meaning the NHC could not regulate the fan speed of the AHU according to a need for a higher or lower total air volume flow rate to the house. As mentioned in chapter 6.1.1, the Niko Multisensors were dismounted, and the ventilation system is CAV controlled with fixed damper openings. This control strategy is well-known to be used in dwellings. After this change of control strategy, the ventilation systems were balanced in mid-March 2023.

The balancing of the ventilation is done in two steps. First, the damper openings are adjusted to the necessary air volume flow, fulfilling the BR18 demands for supplied and extracted air volume flow. Second, the AHU's supply and extract fan speeds are balanced for the AHU's operation steps. Only steps 1, 2, and 3 out of 4 are balanced. The balancing of step 4 cannot be done since the settings are locked. The four steps are defined as follows:

- Step 1: 0.15 l/(s m^2) = 50 % of the BR18 air supply demand for dwellings (0.3 l/(s m^2)
- Step 2: 35 l/s = Air extraction demands from BR18
    - Kitchen = 20 l/s and Bathroom with shower = 15 l/s
- Step 3: 70 l/s = 2 times the air extraction demands from BR18
- Step 4: 100 % fan speed (locked by the manufacturer)

The balancing results can be seen in Table 42 for the ventilation system on the ground floor and Table 43 for the 1st floor. In Denmark, there should be up to a 5 % difference between the total supplied and extracted air volume flow, with a higher extracted air volume flow to ensure a small negative pressure to prevent indoor moisture from being forced into the constructions.

With two ventilation systems functioning independently, the balancing is performed for one ventilation system at a time, with the other ventilation system turned off. With both ventilation systems running, the balancing can be slightly different. The balancing is performed with the app for Lindab UltraLink to measure the air volume flow at the FTCU damper, the NHC app to adjust the damper opening, and the Preheat platform to change the ventilation fan speed setting for each of the three steps in the Genvex AHU.

Table 42: Balancing and airflow distribution of the ventilation system on the ground floor.

	Step 1		Step 2		Step 3	
Room	**Supply [m^3/h]**	**Extract [m^3/h]**	**Supply [m^3/h]**	**Extract [m^3/h]**	**Supply [m^3/h]**	**Extract [m^3/h]**
Bedroom 1	13.0		24.8		43.0	
Bedroom 2	11.2		27.5		46.3	
Kitchen	24.5	39.0	37.5	80.1	77.9	145.9
Dining area	15.7		37.0		74.1	
Bathroom Gr.		27.5		51.3		100.4
Total [m^3/h]	64.4	66.6	126.8	131.4	241.3	246.3
ΔSupply-Extract ≤ - 5%	-3.3 %		-3.5 %		-2.0 %	

Table 43: Balancing and airflow distribution of the ventilation system on the 1st floor.

	Step 1		Step 2		Step 3	
Room	**Supply [m³/h]**	**Extract [m³/h]**	**Supply [m³/h]**	**Extract [m³/h]**	**Supply [m³/h]**	**Extract [m³/h]**
Master bedroom	11.3		21.1		43.5	
Small living room	7.9		16.5		32.8	
Big living room	15.5		35.2		65.6	
Bathroom 1st		27.4		55.1		109.0
Walk-in		8.9		19.2		39.0
Total [m³/h]	34.7	36.3	72.8	74.2	141.8	148.0
ΔSupply-Extract ≤ - 5%	-4.4 %		-1.9 %		-4.2 %	

Cooker hood dampers adjusted: At the time of the balancing of the ventilation system, the opening of the two cooker hoods' built-in damper was checked. When the cooker hood is deactivated, the in-built damper should be open to work as an extract diffuser in the ventilation system. However, both cooker hoods' dampers were closed when the cooker hoods were deactivated. This has been adjusted, so the built-in damper in the cooker hoods is open, and the UltraLink FTCU dampers are controlling the air volume flow.

DVI Smartcontrol offline: From the start of the preparation of the demo case in Egernsund, there was no online access to the DVI heat pumps by DVI Smartcontrol (web solution). A Raspberry Pie was defective and replaced in April 2022.

Leakage of refrigerant: Again, from the start of the preparation of the demo case, the ground source heat pump had long run times and difficulties in reaching the temperature setpoint for space heating. The reason for this was a leakage of refrigerant in the heat pump; thus, no energy was extracted from the brine source. The refrigerant was filled on the heat pump in mid-December 2021, and no problems since.

Battery and inverter replacement: From the start of the installation of the PV system, an incorrect size (too small) of the inverter has been installed. Later, the battery was identified as critically discharged, and the inverter could not charge on this. In May 2021, the electrician was contacted for the first time to replace the inverter and repair the battery. In September 2021, the inverter was replaced to the correct size. In late January 2022, the battery package was replaced. However, no online connection to Fronius Solarweb and, therefore, no monitoring of the system. In late February 2022, the online connection was established.

Disconnected Fronius inverter and battery: In November 2022, the fuse for the PV system was switched off, and no energy was produced, or data was collected. In December 2022, this was observed, and the PV system switched on again.

6.2 Implementation in FusiX

The FusiX platform is previously described in chapter 3.2 for the Ry demo house.

For the demo house in Egernsund, Denmark, the available data consists of heat pump data, indoor environmental quality, energy use (heat and electricity), weather, heating system sensors and PV panels, which is collected in the house using different APIs from different vendors. FusiX is, therefore, an API that uses different API's or BUS connections to retrieve and store data. An overview of the different API's and what data is collected through these, is shown in Figure 80.

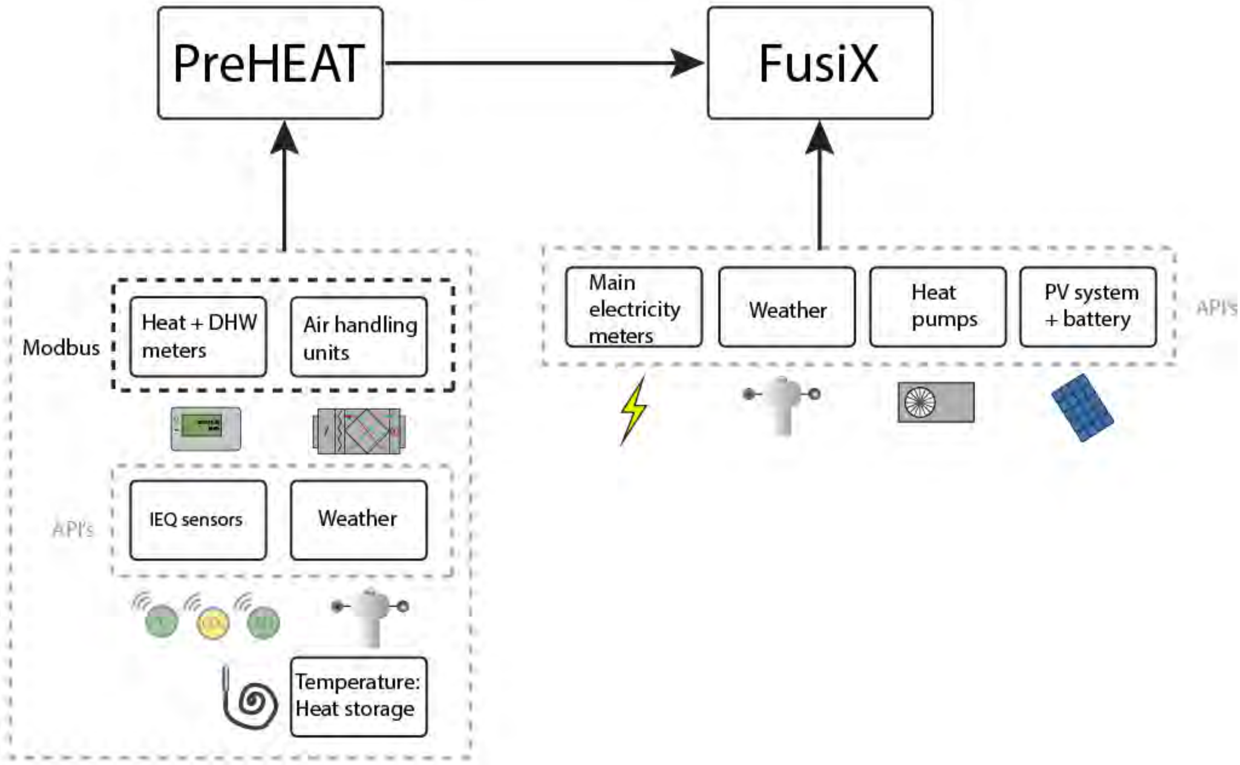
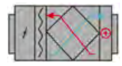


Figure 80: Overview of data integration to FusiX.

Therefore, a total of 5 API's are used, and the data is stored in the FusiX platform. The name of the different APIs is shown in Figure 80 along with a visual representation of what data is collected through each of the APIs. A more detailed overview is given in Table 44.

Table 44: Overview of API's used to collect data to the common platform FusiX.

Communication method	**Description**	**Visual representation**
API: Eloverblik	Main heat meter data	
API: IC-meter / Niko	Indoor environmental quality sensors	
API: YR.no / CORE	Weather data	
API: DVI	Heat pump data for two heat pumps (air-to-water and water-to-water)	
API: Solar.web	Photovoltaic panels data	

BUS: Heat meters	Smart heat meter	
BUS: Air handling units	Air handling unit	
Temperature: Heat storage	PT 1000	

For the Egernsund demo house, a total of 152 parameters is available as of the date of this report. For each parameter, the name, unit, resolution and a brief description is given in Appendix C.

The FusiX does not have a publicly available user interface to retrieve data, however, it can be accessed using a programming language with RESTful API capabilities, such as Python. Data from the Egernsund demo house can be retrieved and analyzed using Python and the 'requests' library. A showcase use of FusiX for exploratory analysis is shown below.

6.3 Simple exploratory data analysis for demo house

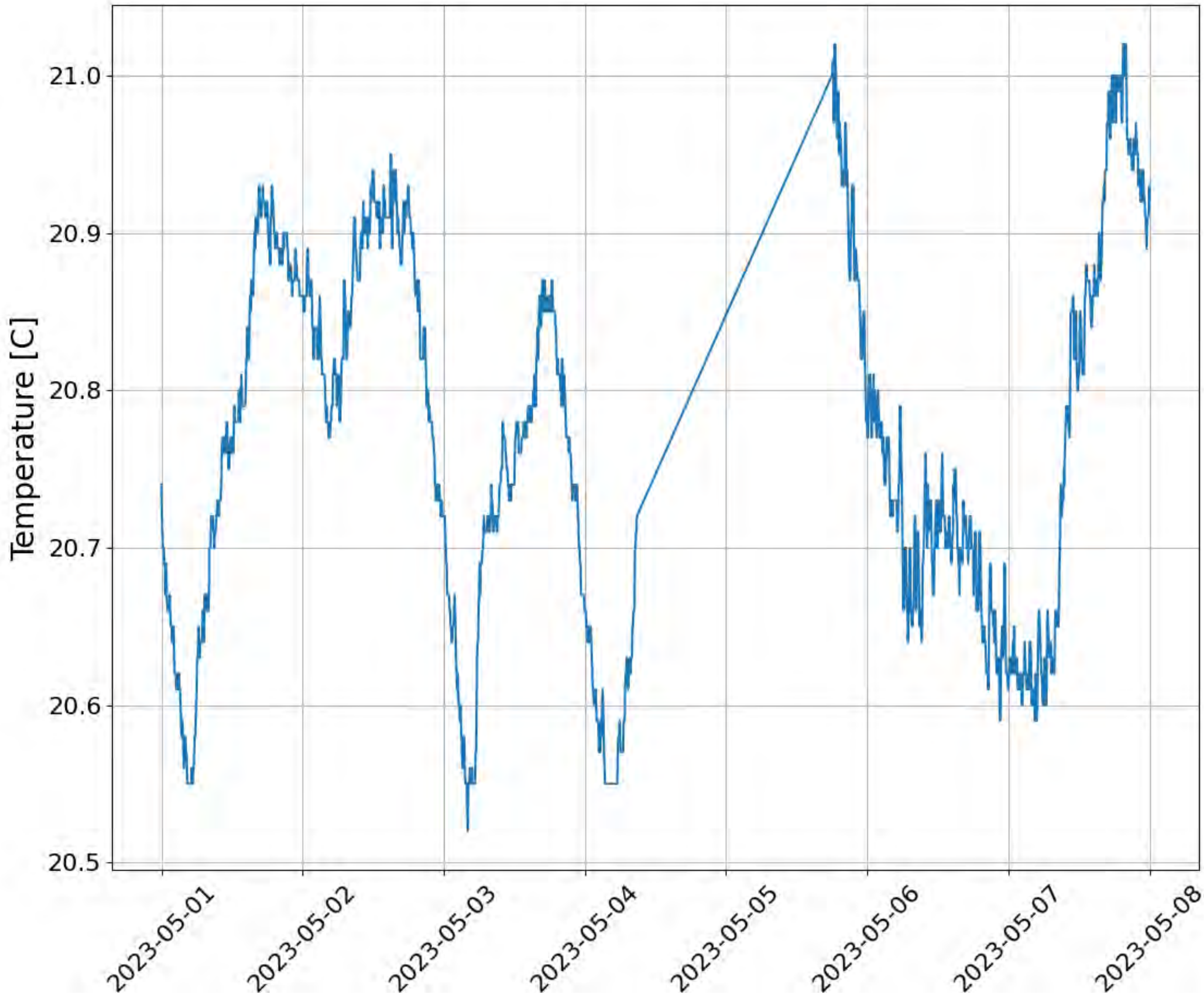
This chapter showcases the use of FusiX for exploratory analysis of the building. This constitutes code to obtain data from the FusiX platform using Python and the 'requests' Python library, along with code to visualize data, that can afterwards be used for exploratory analysis.

The code is not supposed to show the full picture of using every parameter, but only as a showcase of how the FusiX platform can be used to quickly retrieve and show data using Python. The procedure is the same as for Ry building and therefore with great upscaling potential once building is connected to FusiX. This simple exploratory analysis will therefore only show code for a single IC-meter located in bedroom 1 in building Egernsund which has ID 7 and extraction of data for one week period from 01.05.2023 to 08.05.2023. To save space generated plot is not shown as for Ry building.

```
from datetime import datetime, timedelta, timezone
from dateutil.parser import parse
import requests
import matplotlib.pyplot as plt
import matplotlib.dates as mdates

AUTH = ("USER dummy", 'PASSWORD dummy')
URL = 'https: API URL '

# USER DEFINED PARAMETERS
################################################
endpoint = '/get_building'
dt_to = datetime.utcnow()  # Required argument
```

```
dt_from = '2023-05-01 00:00:00'
dt_to = '2023-05-08 00:00:00'
building_id = 7  # Required argument
d_categories = "IAQ"
d_ids = "2939"
###############################################
payload = {
    "dt_from": dt_from,
    "dt_to": dt_to,
    "id": building_id,
    "d_ids": d_ids
}
# Preperation of request's payload
resp = requests.get(URL + endpoint, params=payload, auth=AUTH)
data = resp.json()['apartments']['33']['rooms'][0]['devices'][0]['Readings']

temperature = []
time = []

for reading in range(len(data)):
    temperature.append(data[reading]['Value'])
    time.append(data[reading]['Timestamp'])

fig = plt.figure()
ax = fig.add_subplot(1,1,1)

time_new = []

for time_str in range(len(time)):
    time_new.append(parse(time[time_str]))

ax.plot(time_new, temperature)
ax.xaxis.set_major_locator(mdates.DayLocator(interval=1))
ax.xaxis.set_major_formatter(mdates.DateFormatter('%Y-%m-%d'))
ax.set_ylabel('Temperature [C]',fontsize=20)
ax.tick_params(axis='y', which='major', labelsize=16)
ax.tick_params(axis='x', which='major', labelsize=16, rotation=45)
```

```
ax.grid()
plt.show()
```



6.4 Evaluation of building – identification of problems and good operation

This chapter describes the evaluation of the demo house in Egernsund, Denmark. The focus will be on the indoor environmental quality in different rooms. The indoor environmental quality of the building will investigate a total of 10 rooms.

For each analysis performed, long-term measurement for an extended period will be shown, along with a shorter and representative period, to visualize tendencies more clearly.

The indoor environmental quality is measured using the IC-meters in each room, as the Niko Multisensors proved to be unreliable for IEQ measurements. Measurements of the IEQ will, therefore, only date back to October 2022.

Indoor environmental quality – Temperature

The temperature measurement performed in the period of October 26th, 2022, to February 2023 is shown in Figure 81.

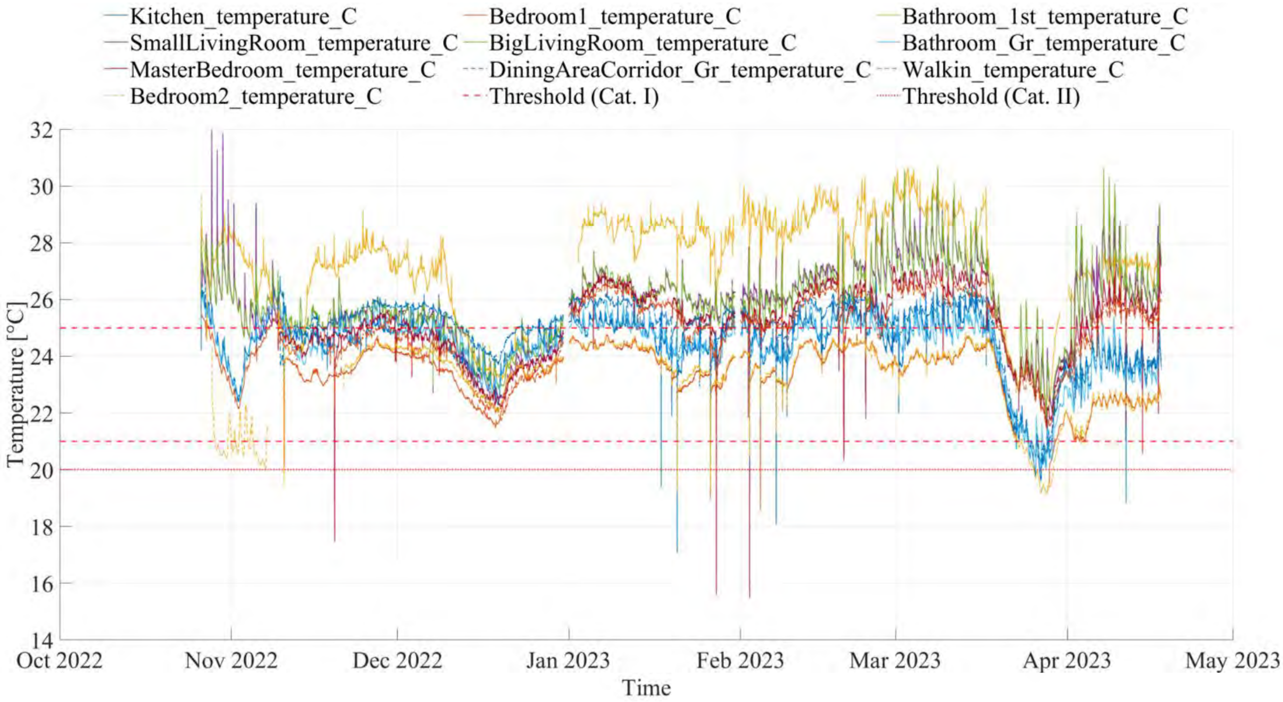


Figure 81: Time series data for entire measurement period of temperature for demo case in Egernsund.

From Figure 81 it is evident that the house has issues with overtemperatures. The temperatures frequently reaches above 25.5 °C, which is the threshold for the temperature ranges described in DS/EN 16798-1. This is especially true for the bathroom on the 1st floor, which often is above 27 °C. In general temperatures are maintained very high often exceeding 24 °C in the heating season what can cause high energy use. The temperatures in the measurement period are relatively stable, especially when looking at the data on a weekly basis. The temperatures are rarely fluctuating significantly, which can be seen in Figure 82.

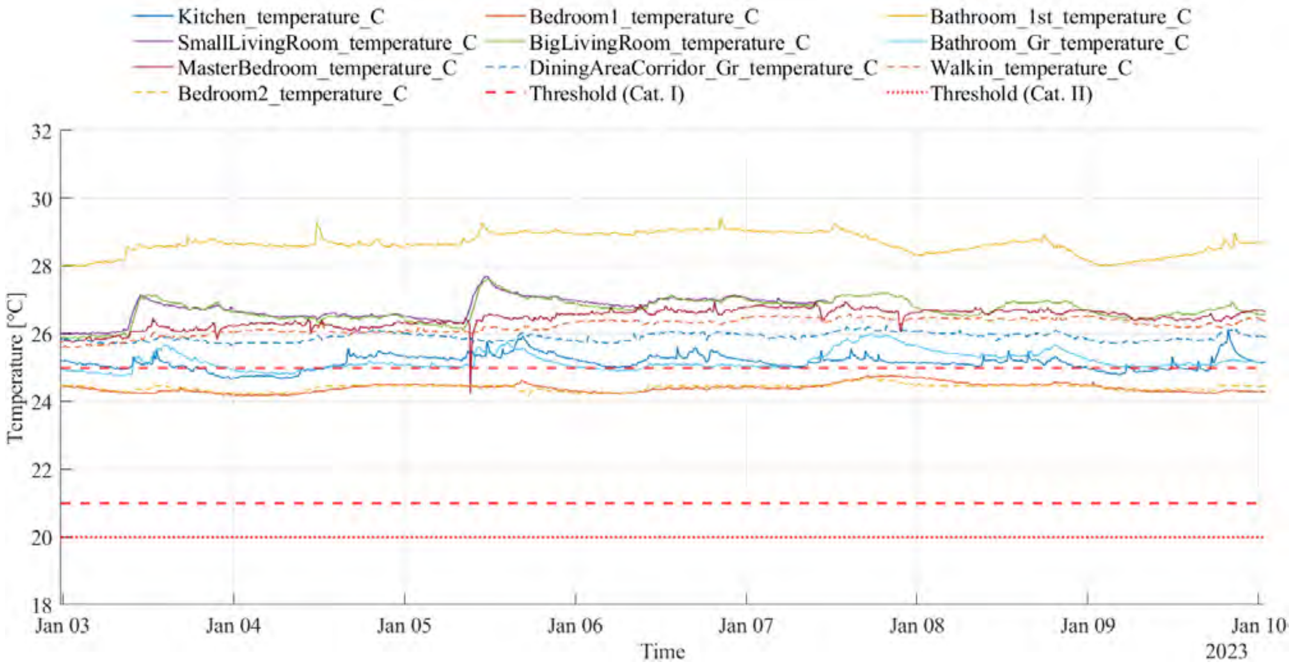


Figure 82: Time series data for one week of temperature for demo case in Egernsund.

Based on these measurements, both the time series data for the entire measurement period along with a weekly sub-set of the data, it is evident that the house has issues with temperatures, however, the temperatures in the house are relatively stable. To more quantitively assess the temperatures in the house, the time distribution of the measured values in the different ranges, shown in Table 2, can be seen in Figure 83.

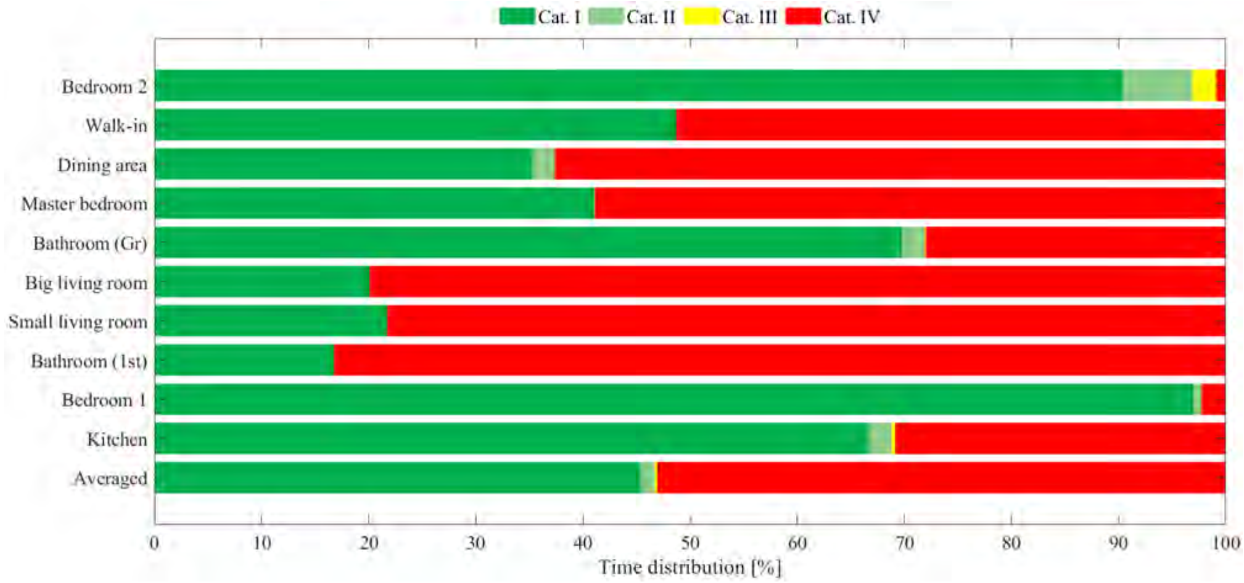


Figure 83: Time distribution of temperature for entire measurement period.

From Figure 83, it is showed that a large amount of the time, the building is operating at a lower building category, with regards to temperature, than acceptable. The building was expected to operate within the temperatures in category II, while it is operating an unacceptable amount of time within category IV. This is due to the tenants of the building, which prefer significantly warmer temperatures in the house.

Indoor environmental quality – Relative humidity

The relative measurement performed in the period of October 26th 2022, to February 2023 is showed in Figure 84.

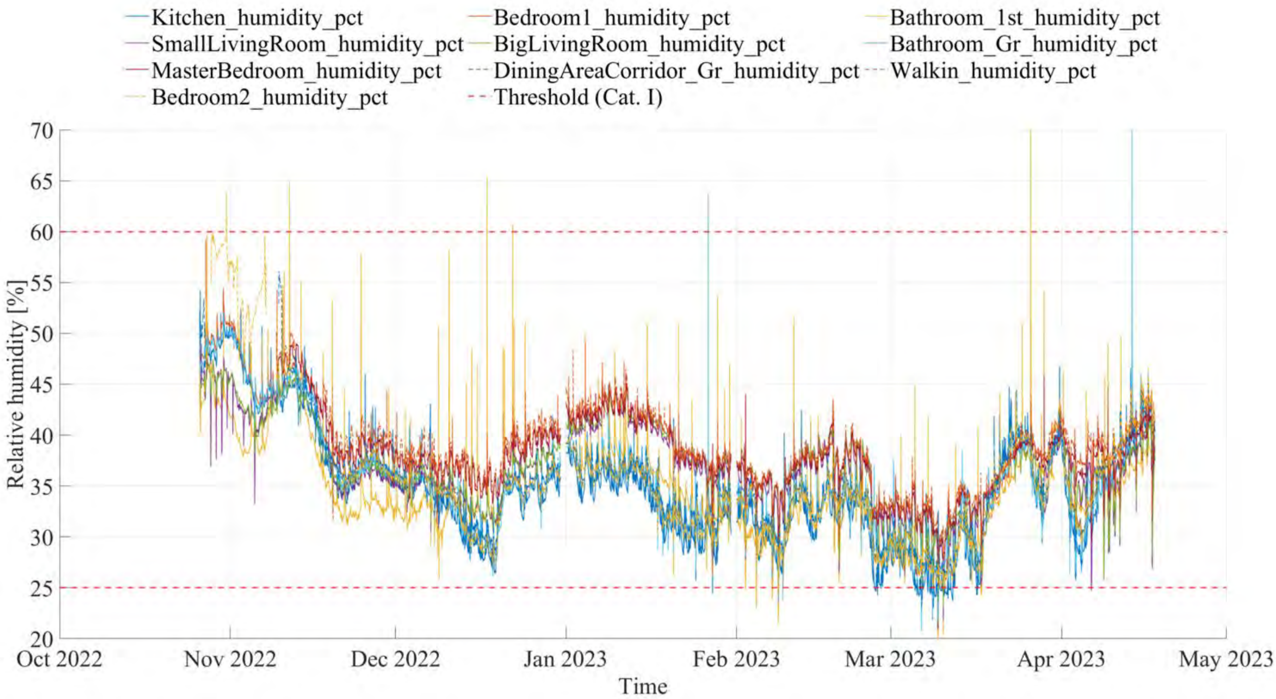


Figure 84: Time series data for entire measurement period of relative humidity for demo case in Egernsund.

The range for the relative humidity was determined to be between 25 – 60 %. The relative humidities measured in each room are well within this range and has a tendency to in the lower end of the spectrum. This could also be due to the warmer temperatures in the house and operation of mechanical ventilation.

In Figure 85, the relative humidity can be seen from the first week of December 2022. As shown in the figure, the relative humidity is stable through the week and no significant daily fluctuations occurs.

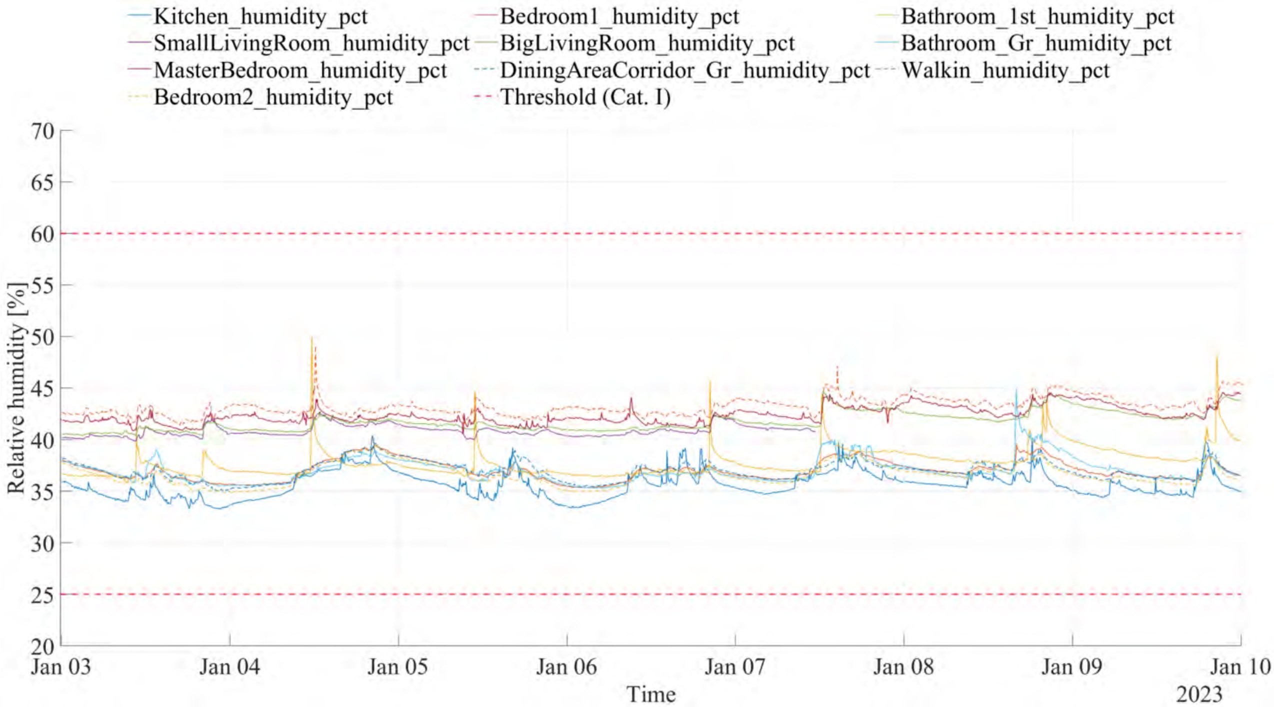


Figure 85: Time series data for one week of relative humidity for demo case in Egernsund.

The time distribution that the relative humidity are within or out of the specified range, as shown in Figure 86. The relative humidities from the different rooms in the building are almost within the range, with minor insignificant periods outside the range.

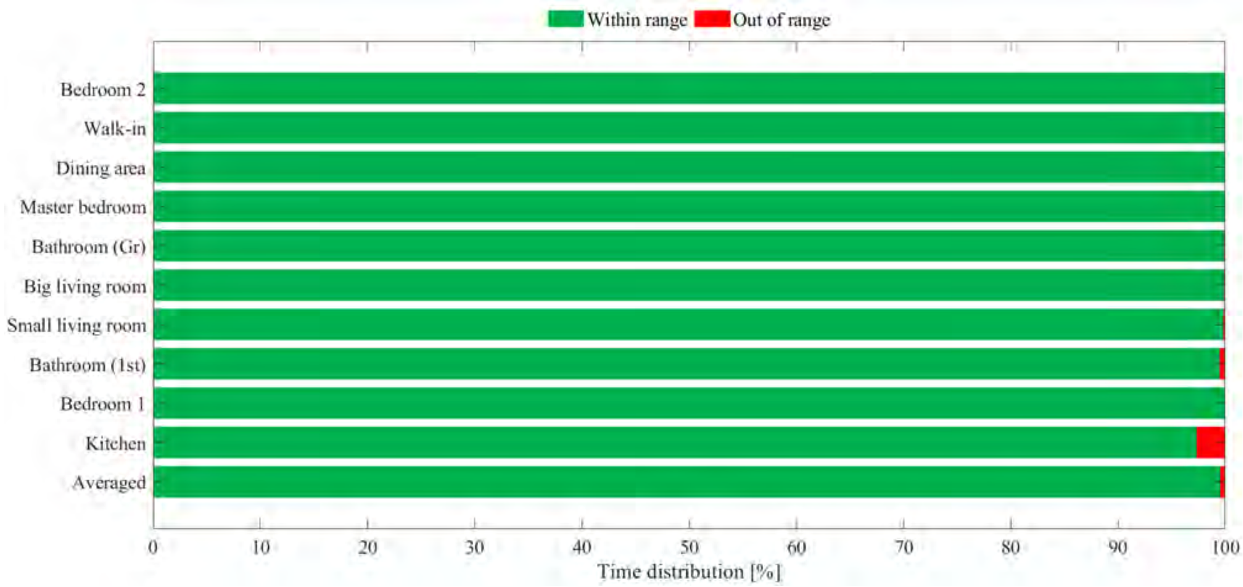


Figure 86: Time distribution of relative humidity for entire measurement period.

Indoor environmental quality – CO_2

The last IEQ parameter investigated, is the CO_2-concentration in each room of the house. The CO_2-concentration measurements performed in the period of October 26th, 2022, to February 2023 is shown in Figure 87.

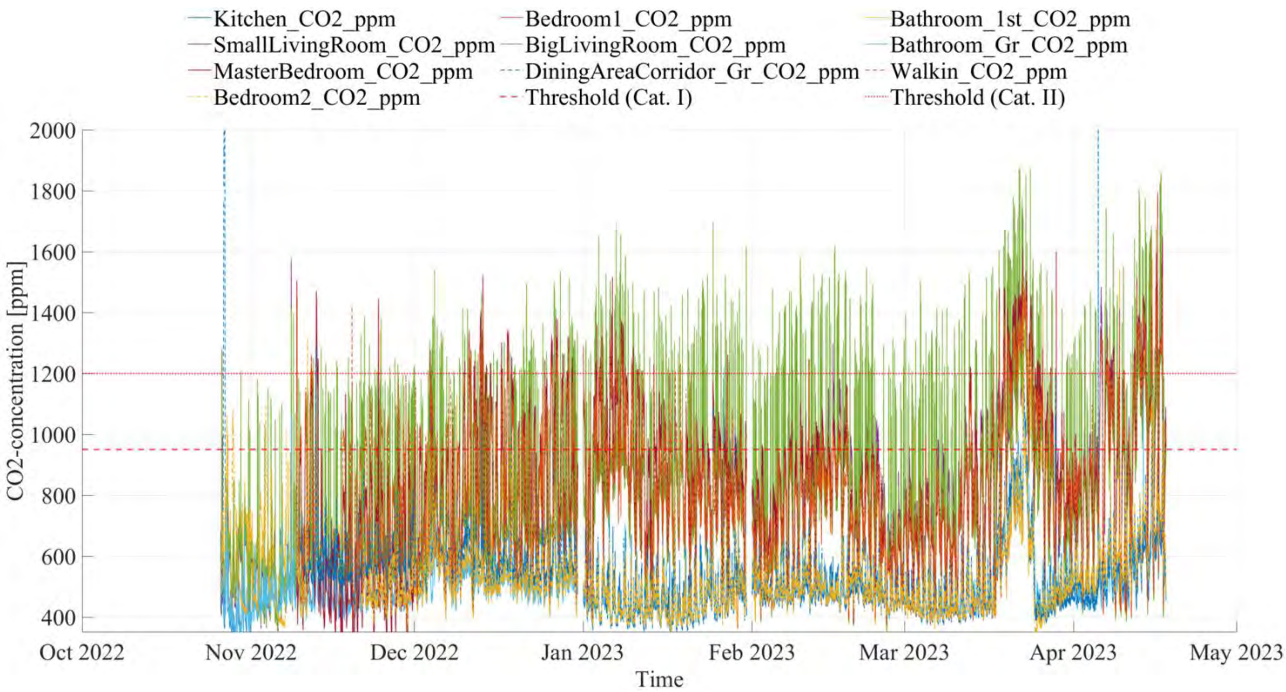


Figure 87: Time series data of CO_2-concentration for entire measurement period.

The CO_2-concentration measured in the period fluctuates a lot, with some periods where the threshold is exceeded. To see the tendencies more clearly, Figure 88 shows the measurements for the first week of December 2022.

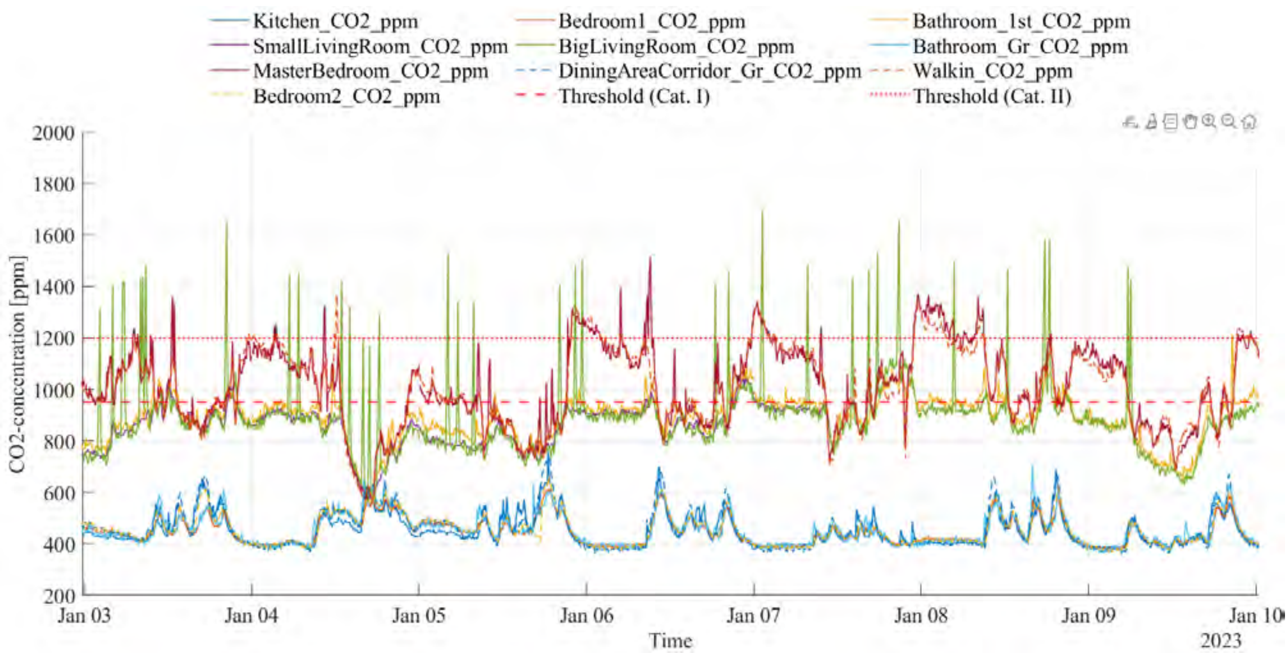


Figure 88: Time series data for one week of CO_2-concentration for one week.

From Figure 88, it is evident that the CO_2-concentration does not exceed the threshold for the most part. The measured values are mostly below the threshold, with some exceptions. To assess the CO_2-concentration for the entire measurement period, the time distribution has been shown for each room, see Figure 89.

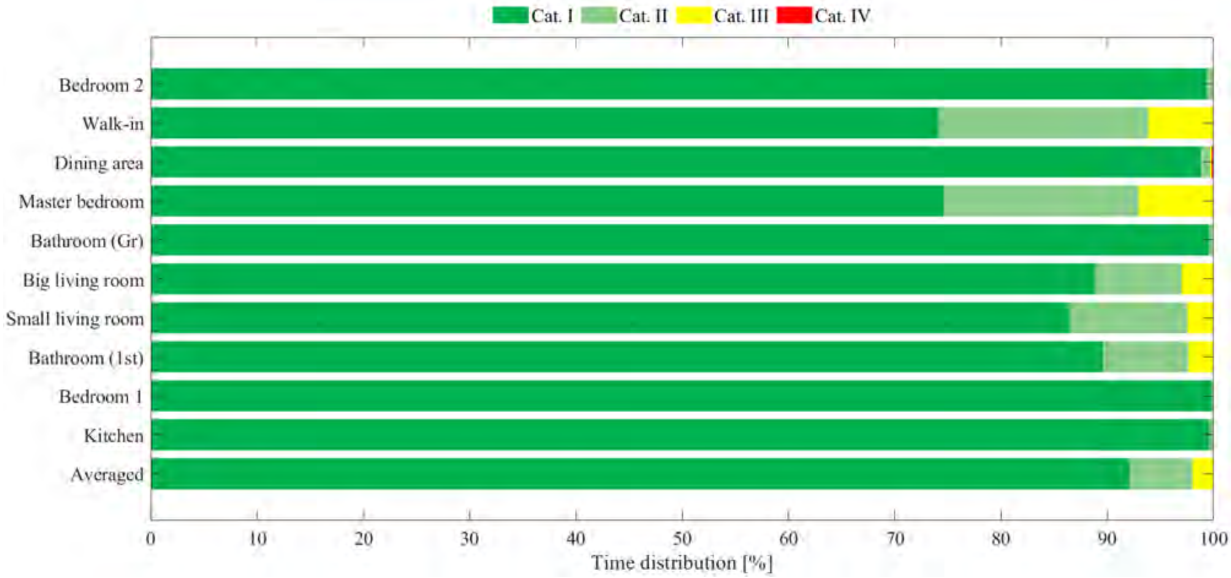


Figure 89: Time distribution of CO_2-concentration for entire measurement period.

As shown in Figure 89, most of the rooms are within category I or II, which is the acceptable range of the CO_2-concentration. Very few values exceed the ranges in these categories, meaning that no issues with the CO_2-concentration are found.

6.5 Ongoing preparations

As indicated in this chapter, there are still ongoing preparations in the demo case to finalize the building so it is suitable for the planned implementation of PRELUDE technologies. In the following, the ongoing work is described, and the status of preparations.

The data communication from the demo case to FusiX is close to being complete. However, the data from the Fronius PV system is missing in FusiX. EMTECH will, at the beginning of June 2023, implement the Fronius API in FusiX, and data can be retrieved. In the meantime, data can be manually retrieved, and AAU has historical data from the PV system, dated from the 15th of February, 2022.

The Fronius API and the DVI API, are also being implemented in Neogrid's platform Preheat. These implementations have two functions. The first is that FusiX will have only one building control and monitoring system to interact with, which will reduce the complexity of the code to implement in FusiX and the list of possible errors. The second is that the building will have a combined control and monitoring system for IE measurements, PV, ventilation, heating, and heat pump. This will again reduce the complexity for the expert to control the system and find errors. Furthermore, it will be easier to implement optimizing strategies for the technical systems. Neogrid is the head of this implementation, and unfortunately, no timeline has been provided to AAU. In the situation that Neogrid can't deliver the solutions in time for the PRELUDE technologies, a simple solution is to control the heat pump directly through the DVI API.

The Niko UFH control system needs to be replaced with another control system to be oversteered by PRELUDE technologies. Together with Neogrid, AAU will implement a UFH control system that Neogrid already has implemented in other buildings with success. The new control system will be mounted in the building and connected to Preheat in autumn 2023. This preparation is critical for the Data Predictive Control (DPC) for heat pump operation by FB, which is planned to be tested in winter 2023.

Another preparation for the test of the DPC by FB is the possibility of changing the control settings in the heat pump and the UFH system. This preparation can be divided into two steps. The first step is to test that the control settings can be controlled. For the heat pumps, the controllable settings are identified and can be done through DVI API. For the UFH system, the control system first needs to be implemented, as described above, and then it is possible to control through the Preheat API. The second step is to change the control settings via FusiX. FusiX should run the DPC algorithm and, with the results, change the control settings in the heating system accordingly.

The electricity use in the Egernsund demo case is, for now, only available in the total use and production of the PV system. Electrical energy meters for the appliances have been installed from Niko in the house, but until now, it has been troublesome to get the data from the API because of NHC bus is overloaded, as described in chapter 6.1.1. AAU is working on getting the electricity use for the appliances in the house, but due to the long list of issues with Niko, it is not of high priority. On the contrary, the electrical use of the heat pumps, total electrical use of the house (appliances, lighting, and plug loads), and electricity of the heating elements in the heat storage tank are a high priority. When this is installed, an analysis of the electrical usage can be performed, such as the heat pump activation during the day, to see if this can be shifted to periods outside the peak hours during the day to reduce costs. Especially the electricity to the heat pumps is necessary for the DPC module by FB and Comfort-EE module by STAM. The energy meters will be installed before June 2023.

Missing data points in the Preheat collected by the Avenger box were identified in January 2023. On average, 1 hour of missing data is lost each day. Neogrids is working on fixing this issue.

Finally, the access to Niko API has been approved, and AAU is waiting on getting the credentials to work further with this API.

Regarding the data analysis for Egernsund, some of the data is incomplete to the extent that it is hard to make an analysis, which include data from the air handling units and other data from the PreHEAT platform. The data availability for these units should be investigated, such that conclusions can be drawn from the data.

7 PLANNING AND IMPLEMENTATION OF PROJECT SOLUTIONS (contribution from technology providers)

This chapter provides detailed information for plan of implementation of all identified PRELUDE technologies relevant for Egernsund demonstration. The plans for implantation consider actions planned and actions already carried out.

7.1 Technology 1 - Comfort and Energy Efficiency module (STAM)

7.1.1 Overview of the proposed technology

In this chapter the Comfort - Energy Efficiency optimizer, developed by STAM in T4.4, is presented. The Deliverable 4.4, within Work Package 4 (Proactive optimization functions), offers a detailed description of the used methodology and developed tools. In this work a proactive optimization model of the customers' energy usage in the residential sector has been developed, by integrating and customizing STAMs' En-Power platform with a comfort module which considers electrical load shifting for energy demand response together with the indoor comfort conditions.

The algorithm relies on both an analysis of the appliances' flexibility of the household and on an empirical methodology for the thermal indoor comfort modelling. This information, together with an energy modelling approach of the building system, has been translated in mathematical terms to the Comfort-EE linear optimization model, in order to provide a seven-days ahead optimal scheduling for the energy loads.

Static information, such as building architecture, and dynamic measurements of the system status have been used to model the electrical/thermal systems. As possible to see in the following Table 45, part of the needed input data is retrieved thanks to the connection with the PRELUDE's dataspace FusiX.

The outputs of the work performed in Task 4.4. serves as input to the framework of Data Predictive Control and user interface (UI) development within Task 5.4. In this context a customized UI is developed to give the suggestion and recommendation on the optimal energy consumption scheduling and actuation in the next hour.

The user feedback is also taken into consideration by the optimization algorithm. Through the UI, the resident can tune the preferred degree of indoor comfort by looking at the trade-off between estimated indoor temperature in the next hours and energy/cost savings among the outputs of the optimization. The proposed approach is part of the low-tech solutions for the improvement of residential energy efficiency.

7.1.2 Implementation plan

As anticipated in the previous sub-chapter the focus of the proposed solution is the user's empowerment by exposing the right information and suggestions regarding his or her energy consumption efficiency. By means of a user-friendly UI.

The plan for the technology implementation is based on a two-steps process. First all the necessary datapoints are gathered in order to provide the input for the optimization. In this context data accessible from FusiX are analysed and the remaining static information, such as energy tariffs prices, nominal powers of installed units are given by the specific pilot owner.

The second step emphases the UI deployment and the user acceptance. In this framework, the developed platform is tested on the specific use case. Since the nature of the proposed low-tech solution, which relies on the citizen actions, the level of user-engagement is the objective to maximize in order to reach the most energy efficient possible building energy management.

As regards the first step, for each specific pilot implementation, a data requirement table is constructed and shared among the interest partners (Table 45). The table is the result of a system modelling approach, which allows a generalization of all the PRELUDE use-cases from an energetic point of view. In Deliverable D5.4 "PRELUDE data driven control", a more extensive analysis of the identified systems and sub-system is discussed.

From the schematic representations shown in D5.4, it is possible to relate each system with the needed datapoints for each of the physical/technical quantity. In this context and in the table construction, two different types of data are considered: timeseries or single values. Moreover, a classification of the data is performed in the case the measure is needed for the modules deployment or it is optional for a more advanced version of the module. In the last column of Table 45, the related FusiX datapoints identifier is shown if available, else the direct static value or the status of the research performed by the pilot's owner for the specific datapoint.

Table 45: Datapoints summary for Comfort-EE module.

Data ID	Quantity	Is time series?	Need	FusiX ID (if applicable) / Information
0.1	Measured energy/power	time series	optional	Not available

0.1	Nominal power		optional	
0.1	Normal usage cycles		optional	
0.1	Dispatchable usage cycles		optional	
0.2	Internal temperature - real	time series	compulsory	IC-meter: 2939: Bedroom 1 2936: Bedroom 2 2933: Bathroom Gr. 2942: Dining area 2945: Kitchen 2918: Bathroom 1st 2921: Walk-in 2927: Small living room 2930: Big living room 2924: Master bedroom
0.3	DHW demand	time series	compulsory	2821: Energy (kWh) 2822: Supply Temp (°C) 2823: Volume (m^3) 2824: Power (kW) 2825: Return Temp (°C)
0.4	Energy input for space heating	time series	compulsory	2852: Energy (kwh) 2853: Supply Temp (°C) 2854: Volume (m^3) 2855: Power (kW) 2856: Return Temp (°C)
1.1	External temperature	time series	compulsory	weather/Temperature in FusiX
1.2	Irradiance	time series	optional	Not available
2.2	Peak power		compulsory	6 kWp
3.1	Capacity		compulsory	3.5 kW (85% of max is available)
3.2	SOC	time series	compulsory	Available – under implementation in FusiX
3.3	Maximum power exchanged		optional	
3.4	Charge / discharge efficiency		optional	
4.1	Energy tariffs		compulsory	AAU provides to STAM information about fixed and variable tariffs in Denmark. AAU will provide average weekly price for summer and winter.

4.2	Maximum power retrievable from the grid		compulsory	17 kW
4.3	Offpeak power		optional	
5.1	Energy measures	time series	compulsory	Can be estimated. Part of energy to AHU.
5.2	Efficiency (-ies)		optional	SCOP Space heating: 5.04 SCOP DHW: 3.84
6.1	Internal Temperature	time series	compulsory	2844: Space heating mid of Buffer tank and in addition an ID will be available from DHW tank
6.2	Volume		compulsory	Space heating: 500 L (Buffer) + 68 L (Heat Pump) DHW tank: 225 L
6.3	Maximum power exchanged		optional	

As regards the construction of the thermal model of the building, it is configured, considering the house as a unique thermal zone.

Moreover, from the complex P&I diagram it is possible to see that two different thermal storages (buffer tanks) and two heat pumps are present. In order to simplify the technical layout, a unique model of one unit per each type of component is proposed, i.e., one thermal storage and one heat pump. This is done by aggregating the information of the two units such as the total volume of the buffer tanks and the total power consumed by the two heat pumps.

Regarding the battery storage system, the modelling is performed considering that the battery is able to exchange energy directly with the electrical grid. This model assumption must be verified with the real installation and its technical limits in order to understand if such direct connection is possible and/or technically feasible in the future.

From an implementation point of view the focus of the Egernsund use-case is the high-tech framework in which the technical asset actuations is performed by means of the FusiX middleware using the optimal scheduling of the set points for control of heating system in Egernsund building.

7.1.3 Performance assessment of the implemented solution

In order to evaluate the developed module in the considered use case, a multistep process is implmented. First the given data are analysed. This is performed by exploiting the PRELUDE common data platform FusiX. In this context the data are downloaded using FusiX APIs, pre-processed and finally stored for data visualization and analysis.

Once a reasonable amount of useful historical data is available, such as a minimum time frame of 3 months, the second step can be performed. In this phase, as described in D4.4, the datapoints of the thermal energy inputs of the building, such as energy consumption of HVAC system and direct global irradiation, and indoor and outdoor local temperature measurements are consumed. The training of the thermal model of the building is run using one of the three possible version, namely R, R-C, or the α-R-C model. Thus, the estimated parameters are used for the test and validation of the predicting performance of the model in terms of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE).

Having the built thermal model and the required data points, a test environment of the real application can be constructed. In this framework, during a fixed amount of time the overall architecture is operating, from back-end to front-end, testing and validating the overall data flows, from FusiX databases to the UI. The technical adjustments will be completed in this phase, in parallel with a first attempt in analysing the user acceptance of the proposed platform in terms of clarity of the information and finally the engagement of the residents.

After the implementation of the discussed technology the long-term test can take place. In this phase of the process the assessment of the intervention is carried out by the Measurement & Verification (M&V) module. The addressed methodology is described in D4.3 which concerns the cutting-edge methods for the calculation of different KPIs related to energy and cost savings, after a defined technological implementation takes place.

7.2 Technology 2 – Data Predictive Control for heat pump operation (FB/STAM)

7.2.1 Overview of the proposed technology

In the Egernsund test building, it is planned to implement a forecast-based control scheme for the heat pump operation to demonstrate demand side flexibility by a power-to-heat application in the residential sector. The intended solution addresses various load-shift scenarios with the highest priority being the increased use of local renewable energy provided by an existing residential photovoltaic system. Moreover, the procedure is prepared to realize an electricity gird friendly operation if incentives like time variant energy prices and/or capacity-based grid fees are offered or assumed at the grid connection point.

The design of the control scheme is based on the data-driven predictive control algorithm applied in the pre-demonstration building Energetikum in Austria. In its core, the procedure comprises the following developments including the mentioned key **technical specifications**:

1. <u>Forecasts of internal and external operational boundary conditions</u> like the outdoor temperature, the expected solar radiation, the availability of local renewable energy, the domestic electricity consumption and/or future energy costs. The extent of the forecasts (datapoints and prediction horizon) depends on the addressed scenario and are provided by PRELUDE project partners or proprietary predictive models within the control framework.
2. A <u>data-driven model</u> to reproduce the thermal behaviour of the building including the controlled heat pump and the hydraulics of the under-floor heating system. Compared to the template solution (office building Energetikum) the model structure is adapted to the requirements of a residential application, e.g. reduced influence of the solar radiation on the building dynamics due to the lack of large-scale glass facades. The general modelling approach by defining a grey-box model structure and estimating the model parameters from historic monitoring data is adopted.
3. A <u>recurrent optimization algorithm</u> to identify the optimal, future heat pump operation considering the respective objective function and the thermal constraints within the building. As long as a linear model structure can be derived in (II) "Mixed-Integer-Linear-Programming" has proven successful as shown in the pre-demonstration building Energetikum. The deployed optimization scheme will also depend on the local integration at the Egernsund test building and if the solution can be virtual operated in PERLUDE's FusiX dataspace or on a local edge device within the building automation network.

7.2.2 Implementation plan

The current **implementation** status is based on an extensive explorative analysis of historic operational data to gain insights of the hydraulic and electric energy flows and the available data-points to define a sufficient model structure. The analysis revealed an unexpected high residential electric energy consumption and indicated some possible sources for either inefficient operation or high demand. Although a central heat-pump operated hydraulic system is in place, additional decentralized components like an electric under-floor heating, an electric domestic hot-water heater and an electric photovoltaic-surplus heating device are active. The individual controls of the decentralised components might not be in line with an overall optimized central control strategy and may contribute to the high electric energy consumption. Furthermore, the analysis shows that some individual operational datapoints, which will be needed for the final performance assessment of the solution, like the electricity consumption of the heat-pump, are missing. At the moment, measures are taken to investigate and fix possible system-inherent inefficiencies and to retrofit additional monitoring data-points. The next steps will be the identification, definition and manual testing of available manipulatable inputs of the building to link the future optimization results with the local hardware setpoints of pumps, valves or the compressor of the heat-pump. If the controllability of the hardware is guaranteed, the detailed modelling and optimization procedure can be defined and the deployment of the solution can first be tested in a virtual environment and subsequently transformed and compiled to the final operational environment (e.g. FusiX). The first test operation is expected to start with the beginning of the upcoming heating season. To cover a reasonable long term evaluation period, the system should be fully implemented in late Autumn 2023.

7.2.3 Assessment plan

The **performance assessment** of the implemented solution will be based on a quantifiable evaluation of the estimated load-shift potential compared to the realized load-shift of the heat-pump operation. Supplementary, the operational performance can be compared with historic data of the uninfluenced operation if PRELUDE's "Baseline-Adjustment" module is applied to account for changing boundary conditions.

It is expected that the flexible heat-pump operation will (a) reduce electricity import from the grid (b) increases self-consumption of local renewable energy, (c) decreases consumption related greenhouse gas emissions, (d) reduces the operational costs depending on the relevant feed-in and purchase tariffs and (e) still maintains a defined minimal thermal comfort inside the building.

A final economic analysis can assess the cost-effectiveness of the implemented solution by opposing assumed operational costs to the achieved savings under different future market conditions.

7.3 Technology 3 - Predictive Maintenance (LASIA/STAM)

The plan for implementation is the same for Ry and Egernsund therefore the description is provided only for Ry in chapter 4.3. The only difference is in identified required input parameters from FusiX that are given in Appendix C.

7.4 Technology 4 - RES selector (CORE)

The description of the RES selector application is the same for Ry and Egernsund and its implementation possibility depends on the same data inputs, which are electricity, heat use and weather data. Additionally, the type of RES technology to compose the solution can be differentiated for the two Danish case buildings. The module description is provided only for Ry in chapter 4.5. The only difference is in identified required input parameters from FusiX that would have different IDs.

7.5 Technology 5 – Measurement and Verification Framework (LIBRA)

7.5.1 Overview of the proposed solution

As in Ry, the M&V framework is planned to be implemented in Egernsund. As presented in D4.3, the primarily focus will be on evaluating the suitability of the DPC by STAM, determining its effectiveness in achieving energy savings. Both the M&V 1.0 and M&V 2.0 approaches will be utilized, and the M&V module is planned to be applied and to create an adjusted baseline model for Egernsund.

7.5.2 Technical specification of the proposed solution

The M&V methodology involves collecting data on the building's characteristics, non-routine events that have affected the energy consumption, and identifying data points for calculating heating energy consumption. These aspects will be closely monitored and collected, when available via FusiX. Due to the state of the PRELUDE solutions and their implementation in the demo site, the final selection of the datapoints, the measurement boundary, and the baseline and reporting period is subject to change. Currently, no data is collected from FusiX regarding the demo site Egernsund. Therefore, LIBRA does not consider a potential baseline model for Egernsund, as there is no data available. Moreover, the necessary weather data, specifically outdoor air temperature, which is crucial for developing the baseline, will be obtained from the Meteostat Python library [10].

7.5.3 Implementation plan

Based on the current status of Egernsund, there are no historical data with the installation of all the sensors. The selection of data period before the DPC is applied, is crucial. As the measurement boundary is defined as the whole single-family building, thus, LIBRA is currently examining the potential M&V option C, (Whole Facility). Based on the current available information and the potential available data, the evaluation process will concentrate on the energy submeters that provide details about the thermal heating energy consumption. At present, no baseline or reporting period has been chosen as there is a lack of data from FusiX.

7.5.4 Performance assessment of the implemented solution

Based on the existing data and the M&V methodology outlined in D4.3, a combination of statistical and ML models will be employed to develop the adjusted baseline model for Egernsund. The aim is to ensure the accuracy of the model and the subsequent results. In order to determine the most precise reference model, two specific metrics have been selected: the Coefficient of Variation of Root Mean Square Error (CV-RMSE) and the Normalized Mean Bias Error (NMBE). The purpose of these two metrics is the same as explained in the case of Ry.

7.5.5 Energy saving and reduction of gas emission

If the appropriate prerequisites of the M&V methodology are met, the advanced M&V module will produce two outputs for Egernsund. Firstly, it will generate a monthly time series dataset of estimated energy consumption. Secondly, it will provide a corresponding monthly time series dataset of energy savings. The energy savings data will be presented in both absolute values (measured in kilowatt-hours, kWh) and relative percentage values. Additionally, the module will incorporate information regarding the uncertainty of the estimations, including errors and confidence levels. Hence, the output of the M&V module for Egernsund is similar to the case of Ry, as explained previously

7.5.6 Economic analysis and cost-effectiveness

The objective of the M&V process is to assess the achieved energy savings resulting from the Energy Conservation Measures (ECMs). This evaluation serves as a valuable tool for conducting an indirect economic analysis to quantify the corresponding cost savings derived from the reduced energy consumption.

8 EXPECTED IMPACT

The expected impact depends on the technologies that were identified as possible for integration. At the current stage of the project, technology providers did not provide explicit information on the savings and improvements as these depend on many factors. However, they provided information on the nature of the savings/improvements, for example, energy savings, comfort improvement, increase of renewables, and load shifting. Together with the information about energy tariffs and source emissions, these can be calculated also to cost saving and CO_2 reductions. The spectrum of technologies identified for Danish demos cover all improvement aspects, for example:

Energy saving – by Comfort – Energy Efficiency optimizer by STAM and DPC of heat pump by FB, quantification by Measurement and Verification framework by LIBRA.

Indoor comfort improvement – thermal comfort improvement by Free Running 24h forecast by POLITO and Comfort – Energy Efficiency optimizer by STAM.

Renewable energy increase – RES selector by CORE.

Awareness increase – Measurement and Verification framework by LIBRA.

Faults and maintenance reduction – Predictive Maintenance of heat pump by LASIA/STAM.

Load shifting (also monetary savings)– electricity use shifitng by Comfort – Energy Efficiency optimizer by STAM and DPC of heat pump by FB and also by expert exploratory data analysis from FusiX.

Decrease of the performance gap and heat savings– by changing set points for heating based on exploratory data analysis from FusiX (user acceptance has to be aligned).

The summary of the planned technologies implementation and the impact nature is presented in Table 46 and 47 for respectively Ry and Egernsund.

Table 46: Impact in Ry.

Nr.	PRELUDE technology	Provider	Expected impact-Ry: Energy saving	Indoor Comfort	Renewable energy increase	Faults and maintenance reduction	Load shifting	Awarness increase	Decrease of performance gap and load shifting
1	Models aggregation & prediction	TREE	yes		yes		yes		
2	Occupancy model	FB	yes	yes			yes		
3	Predictive Maintenance	LASIA/STAM				yes			
4	Comfort and Energy Efficiency Module	STAM	yes	yes	yes		yes	yes	yes
5	RES selector	CORE			yes				
6	Dynamic Free Running 24h forecasting	POLITO		yes					
7	Measurement and Verification	LIBRA	yes					yes	yes
8	FusiX-based expert data-driven control	EMTECH/AAU	yes	yes					yes

Legend:
yes probable

Table 47: Impact in Egernsund.

Nr.	PRELUDE technology	Provider	Expected impact-Egernsund: Energy saving	Indoor Comfort	Renewable energy increase	Faults and maintenance reduction	Load shifting	Awarness increase	Decrease of performance gap and load shifting
1	Models aggregation & prediction	TREE							
2	Occupancy model	FB	probable	probable			probable		
3	Predictive Maintenance	LASIA/STAM				yes			
4	Comfort and Energy Efficiency Module	STAM	yes	yes	yes		yes	yes	yes
5	RES selector	CORE			yes				
6	Dynamic Free Running 24h forecasting	POLITO							
7	Measurement and Verification	LIBRA	probable					probable	probable
8	FusiX-based expert data-driven control	EMTECH/AAU	yes	yes					yes

Legend:
yes probable

9 CONCLUSIONS

This report summarizes the work carried out in the two residential single-family Danish demonstration buildings called “Ry” and “Egernsund”. The motivation behind the selection of these buildings is that they are considered representative of the newly built single-family buildings that correspond to NZEB. In reality, these kind of buildings often suffer overtemperature problems, rebound effects and significantly higher real energy use than anticipated from the asset rating assessment. Moreover, these buildings are often equipped with some kind of on-site renewable technology, e.g., heat pump and/or PV installation and IoT solution for the control of the building’s operation that allows for scheduling set points. The common challenge in these buildings is that even though they oftenreflect advanced smartness levels, the systems are not properly commissioned, for example, hydraulic and airborne systems are not regulated, logging infrastructure is seldom present, control systems are closed to specific manufacturer settings and, systems miss common integration. Moreover, due to missing logging infrastructure the building energy, comfort performance, systems and components performance cannot be analyzed and therefore the performance levels of these are unknown. What is more, a lack of historical data hinders the implementation of data-driven technologies and predictive solutions. All these aspects have been experienced while working with the Ry and Egernsund demonstration buildings.

The works described in this report focus on three aspects:

- description of the buildings and their systems together with controls,
- preparation of demonstration buildings to integrate them in the PRELUDE solution,
- identification and planning of the implementation of PRELUDE technologies.

The key conclusions related to the works carried out for the three domains are summarized below.

First, extensive work has been done to collect information about the properties of the buildings, including all their mechanical systems and existing monitoring and control systems. This has been done by collecting technical documentation and several onsite inspections of both buildings. This information is considered valuable to define the baseline condition in the buildings and their systems. The collected information also provides input information to create the required (white and grey box) and identify possible interventions for the PRELUDE technologies.

Second, thorough work has been carried out in both demonstration buildings to implement the required modifications and corrective actions. It can be concluded that the effort spent in this phase was significantly higher than initially expected. The interventions were required first to secure the proper operation of the systems and monitoring and secondly to enable the logging of data and bridging the data to FusiX. For the first, it was experienced that several mechanical systems did not perform as intended. These required fixing fix of these is underlying activity before further improvements and optimization suggestions couldan be recommended. For the second, as one can read in the report, the data exported from the buildings to FusiX does not rely on one API or communication protocol but several. Moreover, it was detected that some of the existing monitoring systems had to be either replaced with new ones to provide more reliable data transfer or effort had to be spent to identify protocols to connect the data to FusiX. Finally, it was identified that to comply with some of the PRELUDE technology requirements, additional monitoring systems need to be purchased, installed and integrated. Here the progress of the works is observed to be highly dependent on third-party providers, both hardware availability and installations that require certified staff. Once the method to connect the technology to FusiX is identified and it is bridged to middleware it is expected that there is the potential to upscale. Still, the first connection reflects significant effort. Also in this activity, the first use of the FusiX platform for exploratory data analysis has been carried out. Namely, the data of the specific interest has been uploaded from FusiX and analyzed to better identify the application potential from PRELUDE technologies application potentials.

Third, many bilateral meetings and correspondence between AAU, who has overall responsibility for the Danish demonstration cases, and the PRELUDE technology providers together with the rich data availability secured in the process resulted in the identification of possible demonstrations of many PRELUDE developments. The interplay between demonstration cases and technologies is threefold. The first is when the technology utilizes data from the pilot building but does not directly influence the building itself. The example of this interplay is, for example, the validation of the occupancy prediction module by FB using the ground-through data and input data from Ry building which then serves the energy optimization module by STAM that is used in the demonstration case. Another example is the model aggregation by TREE. The proposed solution consists in forecasting and does not perform a direct optimization of the energy use. The final consumer of this model is the energy aggregator/supplier and not directly the household itself. The second interplay constitutes technologies whose objective is to provide optimization, either energy, comfort, or both. This technology's implantation requires intervention in the building. For example, free running 24h forecast by POLITO, requires not only input data from FusiX/buildings but also modification in the house controller to be able to write forecasted control settings in the ventilation AHU and solar shading system in Ry building. Another example of this kind is the comfort energy optimizer by STAM and FB which requires smaller interventions, in the case of Ry, in the form of the introduction of GUI to the house owners/tenants to influence their daily routines. In Egernsund, the planned intervention of data predictive control expects a higher intervention level in the specific system, such as the heat pump where edge device is required to write in control settings received from the optimization algorithm. The third interplay belongs to technologies that provide fault detection or recommendation to increase renewable energy production, respectively module by STAM/LASIA and CORE. These technologies rely on the availability of historical data from the buildings and can provide higher-value information to the owner-tenant but do not require further intervention to be implemented. The higher-value information can lead the owner of the building to either perform check/maintenance or to invest in renewable energy. These technologies also have Measurements&Verification protocols that support the quantification of energy savings before and after interventions are carried out and also considers boundary conditions. It is expected that the Measurement&Verification assessment is to be carried out for both Danish buildings and provide awareness for the owners.

Finally, some PRELUDE technologies were identified as being less appropriate forthe Danish demonstration cases. For example, the renovation roadmaps with EPIQR by ESTIA/CORE are not relevant since the Danish buildings are relatively new and do not expect to be renovated. Another example is the indoor-outdoor correlation model by BUL that is targeted to naturally ventilated buildings and both Danish demonstrations although have the possibility for natural ventilation are continuously operated with mechanical ventilation.

For the remainder of the project further analyses of the demonstration buildings is planned in order to provide countermeasures to decrease the performance gap, to implement the identified technologies and perform long and middle-long-term assessments of them in operation and to secure sufficient historical data for the technologies that utilize machine learning algorithms.

APPENDIX A: Bibliography

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APPENDIX B: Data and FusiX ID – Ry

In the tables below the Type is identified as: I = Instantaneous, C = Cumulative, and A = Average

Weather data

Table 48: Weather data in Ry from CORE in FusiX.

Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
Barometric pressure	I	Hourly	hPa	1 hPa	20.08.2022
Cloud coverage	I	Hourly	%	1 %	20.08.2022
Relative humidity	I	Hourly	%	1 %	20.08.2022
Temperature	I	Hourly	°C	0.01 °C	20.08.2022
Weather description	I	Hourly	-	-	20.08.2022
Wind direction	I	Hourly	deg	10 deg	20.08.2022
Wind speed	I	Hourly	m/s	0.01 m/s	20.08.2022

Eloverblik

Table 49: Main electricity energy data in Ry from the Danish data hub, Eloverblik, in FusiX.

Location	FusiX ID	Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
PID_a	2383	Main electrical energy	I	Hourly	kWh	0.001 kWh	01.02.2021

Schneider PLC

Time resolution 2 and 5 minutes

Table 50: Parameters logged by the Schneider PLC and stored on the NAS-server. The parameters are available in FusiX.

Indoor environment						
Location	FusiX ID	Parameter name	Type	Unit	Value Resolution	Start Period
IEQ_a	1099	Temp Room 1 (C)	I	°C	0.01 °C	15.03.2021
IEQ_a	1100	CO2 Room 1 (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_a	1101	RH Room 1 (%)	I	%	0.01 %	15.03.2021
IEQ_b	1102	Temp Room 2 (C)	I	°C	0.01 °C	15.03.2021
IEQ_b	1103	CO2 Room 2 (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_b	1104	RH Room 2 (%)	I	%	0.01 %	15.03.2021
IEQ_c	1105	Temp Room 3 (C)	I	°C	0.01 °C	15.03.2021
IEQ_c	1106	CO2 Room 3 (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_c	1107	RH Room 3 (%)	I	%	0.01 %	15.03.2021

IEQ_d	1108	Temp Bedroom (C)	I	°C	0.01 °C	15.03.2021
IEQ_d	1109	CO2 Bedroom (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_d	1110	RH Bedroom (%)	I	%	0.01 %	15.03.2021
IEQ_e	1111	Temp Living room (C)	I	°C	0.01 °C	15.03.2021
IEQ_e	1112	CO2 Living room (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_e	1113	RH Living room (%)	I	%	0.01 %	15.03.2021
IEQ_f	1114	Temp Kitchen (C)	I	°C	0.01 °C	15.03.2021
IEQ_f	1115	CO2 Kitchen (PPM)	I	ppm	1 ppm	15.03.2021
IEQ_f	1116	RH Kitchen (%)	I	%	0.01 %	15.03.2021
IEQ_g	1117	Temp Utility room (C)	I	°C	0.1 °C	15.03.2021
IEQ_g	1118	RH Utility room (%)	I	%	0.1 %	15.03.2021
IEQ_h	1119	Temp Bathroom 2 (C)	I	°C	0.1 °C	15.03.2021
IEQ_h	1120	RH Bathroom 2 (%)	I	%	0.1 %	15.03.2021
IEQ_i	1121	Temp Walk-in (C)	I	°C	0.1 °C	15.03.2021
IEQ_j	1122	Temp Bathroom 1 (C)	I	°C	0.1 °C	15.03.2021
IEQ_j	1123	RH Bathroom 1 (%)	I	%	0.1 %	15.03.2021
		Heating				
PID_h	1086	DH - Floor Heating (MWh)	C	MWh	0.001 MWh	15.03.2021
PID_i	1087	DH - DHW Tank (MWh)	C	MWh	0.001 MWh	15.03.2021
PID_g	1088	DH - Total (MWh)	C	MWh	0.001 MWh	15.03.2021
PID_g	1184	DH Total (m3)	C	m^3	0.01 m^3	15.03.2021
PID_g	1185	DH Total (l/h)	A	l/h	0.1 l/h	15.03.2021
PID_g	1186	DH Total Temp Supply (C)	A	°C	0.01 °C	15.03.2021
PID_g	1187	DH Total Temp Return (C)	A	°C	0.01 °C	15.03.2021
PID_h	1188	DH - Floor Heating (m3)	C	m^3	0.01 m^3	15.03.2021
PID_h	1189	DH - Floor Heating (l/h)	A	l/h	0.1 l/h	15.03.2021
PID_h	1190	DH - Floor Heating Supply (C)	A	°C	0.01 °C	15.03.2021
PID_h	1191	DH - Floor Heating Return (C)	A	°C	0.01 °C	15.03.2021
PID_i	1192	DH - DHW Tank (m3)	C	m^3	0.01 m^3	15.03.2021
PID_i	1193	DH - DHW Tank (l/h)	A	l/h	0.1 l/h	15.03.2021
PID_i	1194	DH - DHW Tank Supply (C)	A	°C	0.01 °C	15.03.2021
PID_i	1195	DH - DHW Tank Return (C)	A	°C	0.01 °C	15.03.2021
UFH_a	1158	Heating Living (I/O)	I	-	-	15.03.2021

UFH_b	1159	Heating Bedroom (I/O)	I	-	-	15.03.2021
UFH_c	1160	Heating Walk-in (I/O)	I	-	-	15.03.2021
UFH_d	1161	Heating Bath 1 (I/O)	I	-	-	15.03.2021
UFH_e	1163	Heating Corridor (I/O)	I	-	-	15.03.2021
UFH_f	1162	Heating Kitchen (I/O)	I	-	-	15.03.2021
UFH_g	1164	Heating Room 1 (I/O)	I	-	-	15.03.2021
UFH_h	1165	Heating Room 2 (I/O)	I	-	-	15.03.2021
UFH_i	1166	Heating Room 3 (I/O)	I	-	-	15.03.2021
UFH_j	1167	Heating Bath 2 (I/O)	I	-	-	15.03.2021
UFH_k	1168	Heating Utility (I/O)	I	-	-	15.03.2021
Ventilation						
PID_d	1150	AHU Temp Outdoor (C)	I	°C	1 °C	03.06.2022
PID_d	1151	AHU Temp Indoor (C)	I	°C	1 °C	03.06.2022
PID_d	1152	AHU RH (%)	I	%	1 %	03.06.2022
PID_d	1153	AHU Compressor (min)	C	min	1 min	03.06.2022
PID_d	1154	AHU DHW Tank Temp (C)	I	°C	1 °C	03.06.2022
PID_d	1155	AHU Air Supply Temp (C)	I	°C	1 °C	03.06.2022
PID_d	1156	AHU Heatpump Temp (C)	I	°C	1 °C	03.06.2022
PID_d	1157	AHU Fan speed (%)	I	%	1 %	03.06.2022
PID_e	1169	Air Flow Supply (m3/h)	I	m^3/h	0.001 m^3/h	15.03.2021
PID_e	1170	Air Temp Supply (C)	I	°C	0.1 °C	15.03.2021
PID_f	1171	Air Flow Return (m3/h)	I	m^3/h	0.001 m^3/h	15.03.2021
PID_f	1172	Air Temp Return (C)	I	°C	0.1 °C	15.03.2021
Vent_a	1124	Damper In Room 1 (I/O)	I	-	-	15.03.2021
Vent_b	1125	Damper In Room 2 (I/O)	I	-	-	15.03.2021
Vent_c	1126	Damper In Room 3 (I/O)	I	-	-	15.03.2021
Vent_d	1127	Damper Out Utility (I/O)	I	-	-	15.03.2021
Vent_e	1128	Damper Out Bath 2 (I/O)	I	-	-	15.03.2021
Vent_f	1129	Damper Out Kitchen (I/O)	I	-	-	15.03.2021
Vent_g	1130	Damper In Kitchen (I/O)	I	-	-	15.03.2021
Vent_h	1131	Damper Out Bath 1 (I/O)	I	-	-	15.03.2021
Vent_i	1132	Damper In Living (I/O)	I	-	-	15.03.2021
Vent_j	1133	Damper In Walk-in (I/O)	I	-	-	15.03.2021

Vent_k	1134	Damper In Bedroom (I/O)	I	-	-	15.03.2021
Solar shading						
SH_a	1135	SH Bedroom East (I/O)	I	-	-	16.06.2022
SH_b	1136	SH Bedroom South (I/O)	I	-	-	16.06.2022
SH_c	1137	SH Living South (I/O)	I	-	-	16.06.2022
SH_d	1138	SH Living West (I/O)	I	-	-	16.06.2022
SH_a	1173	SH Bed East Man (I/O)	I	-	-	16.06.2022
SH_b	1174	SH Bed South Man (I/O)	I	-	-	16.06.2022
SH_c	1175	SH Living South Man (I/O)	I	-	-	16.06.2022
SH_d	1176	SH Living West Man (I/O)	I	-	-	16.06.2022
Skylight and window opening						
SK_a	1139	Skylight Corridor (I/O)	I	-	-	16.06.2022
SK_b	1140	Skylight Kitchen (I/O)	I	-	-	16.06.2022
SK_a	1177	Skylight Corridor Manual (I/O)	I	-	-	16.06.2022
SK_b	1178	Skylight Kitchen Manual (I/O)	I	-	-	16.06.2022
WO_a	1141	Window Opening Room 1 (I/O)	I	-	-	
WO_b	1142	Window Opening Room 3 (I/O)	I	-	-	
WO_c	1143	Window Opening Kitchen (I/O)	I	-	-	
WO_d	1144	Window Opening Living room (I/O)	I	-	-	
WO_e	1145	Window Opening Bedroom (I/O)	I	-	-	
WO_a	1179	Window Opening Room 1 Manual (I/O)	I	-	-	
WO_b	1180	Window Opening Room 3 Manual (I/O)	I	-	-	
WO_c	1181	Window Opening Kitchen Manual (I/O)	I	-	-	
WO_d	1182	Window Opening Living room Manual (I/O)	I	-	-	
WO_e	1183	Window Opening Bedroom Manual (I/O)	I	-	-	
Domestic water						

PID_k	1084	DCW (m3)	C	m^3	0.01 m^3	15.03.2021
PID_j	1085	DHW (MWh)	C	MWh	0.001 MWh	15.03.2021
PID_j	1146	DHW (m3)	C	m^3	0.01 m^3	15.03.2021
PID_j	1147	DHW (l/h)	A	l/h	0.1 l/h	15.03.2021
PID_j	1148	DHW Temp Warm (C)	A	°C	0.01 °C	15.03.2021
PID_j	1149	DHW Temp Cold (C)	A	°C	0.01 °C	15.03.2021
PID_k	1196	DCW (l/h)	A	l/h	0.1 l/h	15.03.2021
Electrical use						
PID_b	1089	El - Other Usage (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1090	El - Cooking Plate and Ovens (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1091	El - Fridge and Cooker Hood (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1092	El - Control System (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1093	El - Pump Floor Heating (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1094	El - Nilan AHU (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1095	El - Washing machine (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1096	El - Dryer (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1097	El - Dishwasher (kWh)	C	kWh	0.01 kWh	15.03.2021
PID_b	1098	El - Quooker (kWh)	C	kWh	0.01 kWh	15.03.2021

Not in Fusix

SMA

Data export: Webpage, File type: .csv, Timestamp: UTC+1 and UTC+2, follows Danish summer and winter time.

Table 51: Parameters logged in SMA Sunny Portal. NOT implemented in Fusix yet.

Location	Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
	Direct consumption	A	15 minutes	W	1 W	26.08.2022
PID_c	Power from grid	A	15 minutes	W	1 W	26.08.2022
PID_c	Power to grid	A	15 minutes	W	1 W	26.08.2022
	Consumption	A	15 minutes	W	1 W	26.08.2022
PID_c	PV power production	A	15 minutes	W	1 W	03.06.2022

APPENDIX C: Data and FusiX ID - Egernsund

In the tables below the Type is identified as: I = Instantaneous and C = Cumulative.

Weather data

Table 52: Weather data in Egernsund from CORE in FusiX.

Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
Barometric pressure	I	Hourly	hPa	1 hPa	19.08.2022
Cloud coverage	I	Hourly	%	1 %	19.08.2022
Relative humidity	I	Hourly	%	1 %	19.08.2022
Temperature	I	Hourly	°C	0.01 °C	19.08.2022
Weather description	I	Hourly	-	-	19.08.2022
Wind direction	I	Hourly	deg	10 deg	19.08.2022
Wind speed	I	Hourly	m/s	0.01 m/s	19.08.2022

Eloverblik

Table 53: Main electricity energy data in Egernsund from the Danish data hub, Eloverblik, in FusiX.

Location	FusiX ID	Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
PID_a	2384	Main electrical energy	I	Hourly	kWh	0.001 kWh	01.01.2020

Neogrid Preheat

Table 54: Parameters logged by Neogrids Avenger box and available with API to Neogrids web interface "Preheat". The parameters are available in FusiX.

Location	FusiX ID	Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
	2797	Weather_Temperature_(C)	I	Hourly	°C	No info	02.11.2022
	2798	Weather_Humidity_(%)	I	Hourly	%	No info	02.11.2022
	2799	Weather_WindDirection_(deg)	I	Hourly	deg	No info	02.11.2022
	2800	Weather_WindSpeed_(m/s)	I	Hourly	m/s	No info	02.11.2022
	2801	Weather_Pressure_(hPa)	I	Hourly	hPa	No info	02.11.2022
	2802	Weather_LowClouds_(%)	I	Hourly	%	No info	02.11.2022

	2803	Weather_MediumClouds_(%)	I	Hourly	%	No info	02.11.2022
	2804	Weather_HighClouds_(%)	I	Hourly	%	No info	02.11.2022
	2805	Weather_Fog_(%)	I	Hourly	%	No info	02.11.2022
	2806	Weather_WindGust_(m/s)	I	Hourly	m/s	No info	02.11.2022
	2807	Weather_DewPointTemperature_(C)	I	Hourly	°C	No info	02.11.2022
	2808	Weather_Cloudiness_(%)	I	Hourly	%	No info	02.11.2022
	2809	Weather_Precipitation_(mm)	I	Hourly	mm	No info	02.11.2022
	2810	Weather_DirectSunPower_(kW/m2)	I	Hourly	kW/m^2	No info	02.11.2022
	2811	Weather_DiffuseSunPower_(kW/m2)	I	Hourly	kW/m^2	No info	02.11.2022
	2812	Weather_SunAltitude_(deg)	I	Hourly	deg	No info	02.11.2022
	2813	Weather_SunAzimuth_(deg)	I	Hourly	deg	No info	02.11.2022
	2814	Weather_DirectSunPowerVertical_(kW/m2)	I	Hourly	kW/m^2	No info	02.11.2022
Heat energy meters							
PID_c	2822	DHW_SupplyTemp_(C)	I	1 minute	°C	0.01 °C	02.11.2022
PID_c	2825	DHW_ReturnTemp_(C)	I	1 minute	°C	0.01 °C	02.11.2022
PID_c	2823	DHW_Volume_(m3)	C	1 minute	m^3	0.01 m^3	02.11.2022
PID_c	2826	DHW_Flow_(l/h)	I	1 minute	l/h	1 l/h	02.11.2022
PID_c	2821	DHW_HeatEnergy_(kWh)	C	1 minute	kWh	1 kWh	02.11.2022
PID_c	2824	DHW_Power_(kW)	I	1 minute	kW	0.01 kW	02.11.2022
PID_d	2815	HP_Buffer_SupplyTemp_(C)	I	1 minute	°C	0.01 °C	02.11.2022
PID_d	2816	HP_Buffer_ReturnTemp_(C)	I	1 minute	°C	0.01 °C	02.11.2022
PID_d	2817	HP_Buffer_Volume_(m3)	C	1 minute	m^3	0.01 m^3	02.11.2022
PID_d	2820	HP_Buffer_Flow_(l/h)	I	1 minute	l/h	1 l/h	02.11.2022
PID_d	2818	HP_Buffer_HeatEnergy_(MWh)	C	1 minute	kWh	1 kWh	02.11.2022

PID_d	2819	HP_Buffer_Power_(kW)	I	1 minute	kW	0.01 kW	02.11.2022
PID_e	2847	Supply temperature UFH1	I	1 minute	°C	0.01 °C	02.11.2022
PID_e	2850	Return temperature UFH1	I	1 minute	°C	0.01 °C	02.11.2022
PID_e	2848	Volume UFH1	C	1 minute	m^3	0.01 m^3	02.11.2022
PID_e	2851	Flow UFH1	I	1 minute	l/h	1 l/h	02.11.2022
PID_e	2846	Energy UFH1	C	1 minute	kWh	1 kWh	02.11.2022
PID_e	2849	Power UFH1	I	1 minute	kW	0.01 kW	02.11.2022
PID_f	2853	Supply temperature UFH2	I	1 minute	°C	0.01 °C	09.11.2022
PID_f	2856	Return temperature UFH2	I	1 minute	°C	0.01 °C	09.11.2022
PID_f	2854	Volume UFH2	C	1 minute	m^3	0.01 m^3	09.11.2022
PID_f	2857	Flow UFH2	I	1 minute	l/h	1 l/h	09.11.2022
PID_f	2852	Energy UFH2	C	1 minute	kWh	1 kWh	09.11.2022
PID_f	2855	Power UFH2	I	1 minute	kW	0.01 kW	09.11.2022
Ventilation							
Vent_Gr_a	2835	AHU_Gr_IntakeTemp	I	1 minute	°C	0.1 °C	12.12.2022
Vent_Gr_a	2836	AHU_Gr_SupplyTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_Gr_a	2837	AHU_Gr_ExtractTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_Gr_a	2839	AHU_Gr_ExhaustTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_Gr_a	2840	AHU_Gr_SP_SupplyTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_Gr_a	2838	AHU_Gr_ExtractHumidity_(%)	I	1 minute	%	1 %	12.12.2022
Vent_Gr_a	2841	AHU_Gr_Inlet_FanSpeed_(%)	I	1 minute	%	1 %	12.12.2022
Vent_Gr_a	2842	AHU_Gr_Outlet_FanSpeed_(%)	I	1 minute	%	1 %	12.12.2022
Vent_1st_a	2828	AHU_1st_IntakeTemp	I	1 minute	°C	0.1 °C	12.12.2022
Vent_1st_a	2829	AHU_1st_SupplyTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022

Vent_1st_a	2830	AHU_1st_ExtractTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_1st_a	2832	AHU_1st_ExhaustTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_1st_a	2827	AHU_1st_SP_SupplyTemp_(C)	I	1 minute	°C	0.1 °C	12.12.2022
Vent_1st_a	2831	AHU_1st_ExtractHumidity_(%)	I	1 minute	%	1 %	12.12.2022
Vent_1st_a	2833	AHU_1st_Inlet_FanSpeed_(%)	I	1 minute	%	1 %	12.12.2022
Vent_1st_a	2834	AHU_1st_Outlet_FanSpeed_(%)	I	1 minute	%	1 %	12.12.2022
Temperature heat storage							
PID_g	2843	BufferTank_Temp_Bottom_(C)	I	1 minute	°C	0.01 °C	14.12.2022
PID_g	2844	BufferTank_Temp_Middle_(C)	I	1 minute	°C	0.01 °C	14.12.2022
PID_g	2845	BufferTank_Temp_Top_(C)	I	1 minute	°C	0.01 °C	14.12.2022
Indoor environment							
Sensor_1st_a	2917	IC_Bathroom_First_Floor_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_1st_a	2918	IC_Bathroom_First_Floor_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_1st_a	2919	IC_Bathroom_First_Floor_CO2	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_1st_e	2920	IC_Walk_In_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_1st_e	2921	IC_Walk_In_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_1st_e	2922	IC_Walk_In_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_1st_d	2923	IC_MasterBedroom_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_1st_d	2924	IC_MasterBedroom_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_1st_d	2925	IC_MasterBedroom_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_1st_b	2926	IC_SmallLivingRoom_Humidity	I	5 minutes	%	0.01 %	26.10.2022

Sensor_1st_b	2927	IC_SmallLivingRoom_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_1st_b	2928	IC_SmallLivingRoom_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_1st_c	2929	IC_BigLivingRoom_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_1st_c	2930	IC_BigLivingRoom_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_1st_c	2931	IC_BigLivingRoom_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_GR_c	2932	IC_Bathroom_Ground_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_GR_c	2933	IC_Bathroom_Ground_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_GR_c	2934	IC_Bathroom_Gr_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_GR_e	2935	IC_Bedroom2_S_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_GR_e	2936	IC_Bedroom2_S_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_GR_e	2937	IC_Bedroom2_S_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_GR_b	2938	IC_Bedroom1_F_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_GR_b	2939	IC_Bedroom1_F_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_GR_b	2940	IC_Bedroom1_F_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_GR_d	2941	IC_DinningArea-Corridor_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_GR_d	2942	IC_DinningArea-Corridor_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_GR_d	2943	IC_DinningArea-Corridor_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022
Sensor_GR_a	2944	IC_Kitchen_Humidity	I	5 minutes	%	0.01 %	26.10.2022
Sensor_GR_a	2945	IC_Kitchen_Temperature	I	5 minutes	°C	0.01 °C	26.10.2022
Sensor_GR_a	2946	IC_Kitchen_C02	I	5 minutes	ppm	0.01 ppm	26.10.2022

DVI heat pumps

Table 55: Heat pump parameters logged by DVI API. The parameters are available in FusiX.

Location	FusiX ID	Parameter name	Category	Type	Time Resolution	Unit	Value Resolution	Start Period
HP_AW_a	2858	AW_SH_SupplyTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_AW_b	2859	AW_SH_ReturnTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
	2860	AW_DHW_SupplyTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	18.02.2023
HP_AW_g	2861	AW_SH_TankTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_AW_e	2862	AW_Evaporator_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_AW_f	2863	AW_OutdoorTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_AW_c	2864	AW_HighPressureTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_AW_d	2865	AW_LowPressureTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
	2866	AW_Defrosting_Relay	Relay	I	1 minute	-		18.02.2023
	2867	AW_FluidInjection_Relay	Relay	I	1 minute	-		18.02.2023
	2868	AW_SH_MixingValve_Open_Relay	Relay	I	1 minute	-		18.02.2023
	2869	AW_SH_MixingValve_Close_Relay	Relay	I	1 minute	-		18.02.2023
	2870	AW_SH_Pump_Relay	Relay	I	1 minute	-		18.02.2023
	2871	AW_Error_Relay	Relay	I	1 minute	-		18.02.2023
	2872	AW_SoftStart_Compressor_Relay	Relay	I	1 minute	-		18.02.2023
	2873	AW_DHW_PriorityValve_Relay	Relay	I	1 minute	-		18.02.2023
	2874	AW_ExpansionValve_Relay	Relay	I	1 minute	-		18.02.2023
	2875	AW_HeatingElement_Relay	Relay	I	1 minute	-		18.02.2023

	2876	AW_CondenserCircuitPump_Relay	Relay	I	1 minute	-		18.02.2023
	2877	AW_Fan_Relay	Relay	I	1 minute	-		18.02.2023
	2878	AW_Compressor_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2879	AW_DHW_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2880	AW_HeatingElement_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2881	AW_SH_State	Setting	I	1 minute	-		18.02.2023
	2882	AW_SH_Offset_HeatCurve_(C)	Setting	I	1 minute	°C		18.02.2023
	2883	AW_SH_SetPoint_Curve_(C)	Setting	I	1 minute	°C		18.02.2023
	2884	AW_SH_SetPoint_Constant_(C)	Setting	I	1 minute	°C		18.02.2023
	2885	AW_DHW_State	Setting	I	1 minute	-		18.02.2023
	2886	AW_DHW_SetPoint_(C)	Setting	I	1 minute	°C		18.02.2023
	2887	AW_DHW_ClockControl	Setting	I	1 minute	-		18.02.2023
Ground soure heat pump								
HP_WW_c	2888	WW_SH_SupplyTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_d	2889	WW_SH_ReturnTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_i	2890	WW_DHW_SupplyTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_h	2891	WW_SH_TankTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_g	2892	WW_OutdoorTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_e	2893	WW_HighPressureTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_f	2894	WW_LowPressureTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
HP_WW_b	2895	WW_BrineSupplyTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022

HP_WW_a	2896	WW_BrineReturnTemp_(C)	Sensor	I	1 minute	°C	0.1 °C	30.11.2022
	2897	WW_BrinePump_Relay	Relay	I	1 minute	-		18.02.2023
	2898	WW_SH_MixingValve_Open_Relay	Relay	I	1 minute	-		18.02.2023
	2899	WW_SH_MixingValve_Close_Relay	Relay	I	1 minute	-		18.02.2023
	2900	WW_SH_Pump_Relay	Relay	I	1 minute	-		18.02.2023
	2901	WW_Error_Relay	Relay	I	1 minute	-		18.02.2023
	2902	WW_SoftStart_Compressor_Relay	Relay	I	1 minute	-		18.02.2023
	2903	WW_DHW_PriorityValve_Relay	Relay	I	1 minute	-		18.02.2023
	2904	WW_ExpansionValve_Relay	Relay	I	1 minute	-		18.02.2023
	2905	WW_HeatingElement_Relay	Relay	I	1 minute	-		18.02.2023
	2906	WW_CondenserCircuitPump_Relay	Relay	I	1 minute	-		18.02.2023
	2907	WW_Compressor_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2908	WW_DHW_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2909	WW_HeatingElement_RunTime_(h)	Timer	I	1 minute	h		18.02.2023
	2910	WW_SH_State	Setting	I	1 minute	-		18.02.2023
	2911	WW_SH_Offset_HeatCurve_(C)	Setting	I	1 minute	°C		18.02.2023
	2912	WW_SH_SetPoint_Curve_(C)	Setting	I	1 minute	°C		18.02.2023
	2913	WW_SH_SetPoint_Constant_(C)	Setting	I	1 minute	°C		18.02.2023
	2914	WW_DHW_State	Setting	I	1 minute	-		18.02.2023
	2915	WW_DHW_SetPoint_(C)	Setting	I	1 minute	°C		18.02.2023
	2916	WW_DHW_ClockControl	Setting	I	1 minute	-		18.02.2023

Table 56: PV system parameters logged by Fronius API. The parameters are available in FusiX from June 2023.

Location	Parameter name	Type	Time Resolution	Unit	Value Resolution	Start Period
PID_b	Energy inverter	I	5 minutes	Wh	0.00001 Wh	15.02.2022
PID_b	Direct consumption	I	5 minutes	Wh	0.01 Wh	15.02.2022
PID_b	Energy from battery	I	5 minutes	Wh	0.01 Wh	15.02.2022
PID_b	Energy from grid	I	5 minutes	Wh	1 Wh	15.02.2022
PID_b	Energy to battery	I	5 minutes	Wh	0.01 Wh	15.02.2022
PID_b	Energy to grid	I	5 minutes	Wh	1 Wh	15.02.2022
PID_b	Consumption	I	5 minutes	Wh	0.01 Wh	15.02.2022
PID_b	PV production	I	5 minutes	Wh	0.01 Wh	15.02.2022
PID_b	Charging status	I	5 minutes	%	1 %	15.02.2022

APPENDIX D: Electricity prices in Denmark

This appendix should support the PRELUDE technologies working with load shifting and the potential for economic savings for the demo cases in Denmark. The analysis performed is only to show the potential, and a more thorough analysis should be performed to conclude the economic savings.

The total electricity prices in Denmark for imported electricity from the grid can be disaggregated into six components as shown in Table 57. The two components, "raw electricity" and "network tariff", are variable depending on the building owner's contract with the electricity supplier (grid).

Table 57: The six price components of the total electricity price in zone DK1.

Components	Estimated share of total price [%]	Fixed or variable
Raw electricity	52.6	Variable
Network tariff	9.4	Variable
Network subscription		Fixed
Transmission	2.4	Fixed
Electricity tax	15.6	Fixed
VAT	20	Fixed

For the PRELUDE actions the clarification of the variable prices is very interesting, as it formulates the background knowledge for the potential of the load shifting in the building. In the following, the variability of the network tariff and raw electricity price is described.

Network tariff

There are several network companies in Denmark covering the electrical grid. The network companies own each a part of the electrical grid, and the building's address determines what company to pay the network tariff. The individual network company sets the network tariffs, and the price is depending on different loads and season periods. The network is calculated according to the consumption in kWh. The Danish demo cases are covered by two different network companies with variable tariffs. The network tariffs are described below for the two demo cases.

<u>Ry</u>

The network tariff to the network company in Ry operates with one season period and three load prices for private customers. In Table 58, the time for the load prices is shown. The low load price is 0.1224 DKK/kWh, the high load price is 0.1837 DKK/kWh, and the peak load price is 0.4775 DKK/kWh.

Table 58: Times for the network tariffs in Ry. Green = low load price, yellow = high load price, and red = peak load price.

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Egernsund

The network tariff to the network company in Egernsund operates with two season periods and two load prices for private customers. The two season periods are summer (April to September) and winter (October to March). The winter period has two load prices, low load price (0.3268 DKK/kWh) and peak load price (0.8409 DKK/kWh). The summer only has a low load price. In Table 59, the periods are shown.

Table 59: Period and times for the network tariffs in Egernsund. Green = low load price, and red = peak load price.

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Winter																								
Summer																								

Raw electricity price

The raw electricity prices can be variable with hourly prices specified by the power market Nord Pool or a fixed monthly price set by the electrical supplier. The following will analyze the electrical prices for zone DK1 (Ry and Egernsund are included) monthly, daily, and hourly to show price fluctuations and load-shifting potentials. All raw electricity prices depicted in the following graphs are given in EUR/MWh.

In Figure 90, the average raw electricity price per month is depicted. There are shown prices for 5.5 years (2018-2023). From January 2018 to May 2021, the electricity prices did not fluctuate much yearly or monthly. However, from June 2021 to December 2022, the increase in electricity prices has been enormous due to weather conditions in 2021 and the Ukraine-Russia conflict from February 2022. The monthly difference is up to 13 times (August 2020 to August 2022). The 2023 electricity prices show a more stable and slowly falling tendency. In the next graphs, only electricity prices from 2018-2020 are used to show the normal tendencies on a weekly and daily basis.

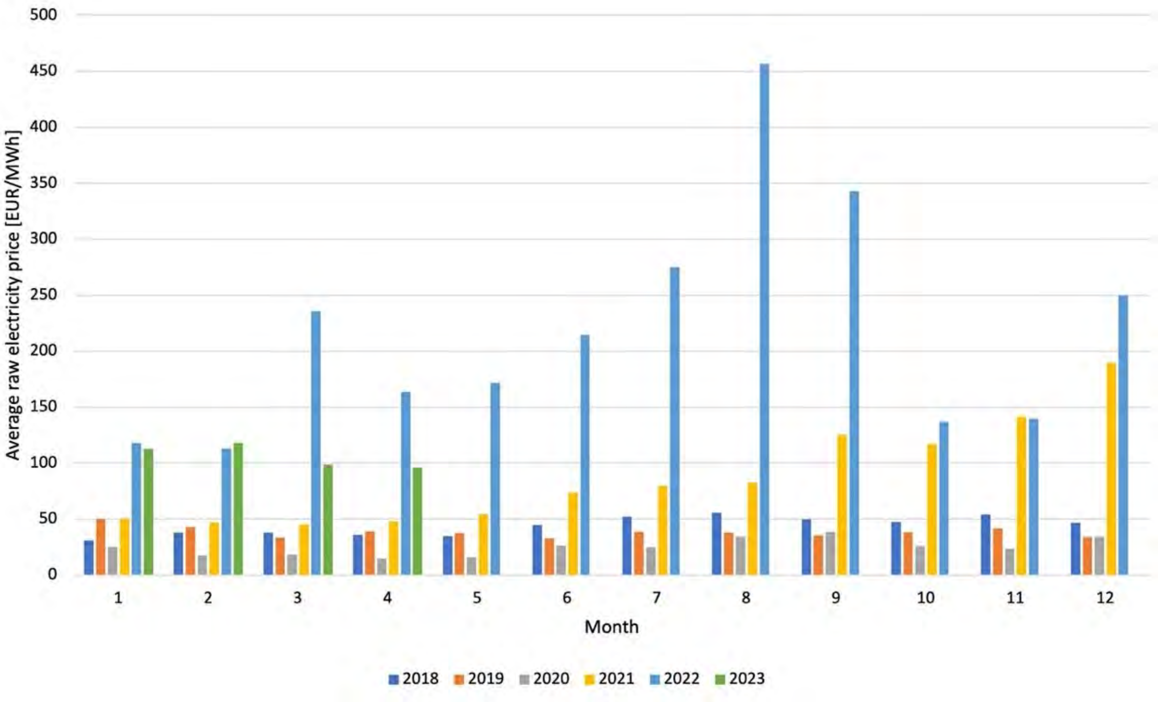

Figure 90: Average raw electricity price per month over 5.5 years (2018-2023).

The average electricity price for average weekdays in 2018-2020 is depicted in Figure 91. As can be seen in all figures in this appendix, the prices in 2020 were generally low. The weekdays (Monday to Friday) are generally stable (differ less than 10 %). However, there is a clear tendency showing that weekend days have cheaper electricity than weekdays. The lower electricity price on weekend days is expected to be because of lower activities in the business and industry. On average, Saturday prices are 18 % cheaper than average weekdays, and Sunday prices are 26 % cheaper. Load-shifting activities that can be moved from weekdays to weekends have a good potential economic savings.

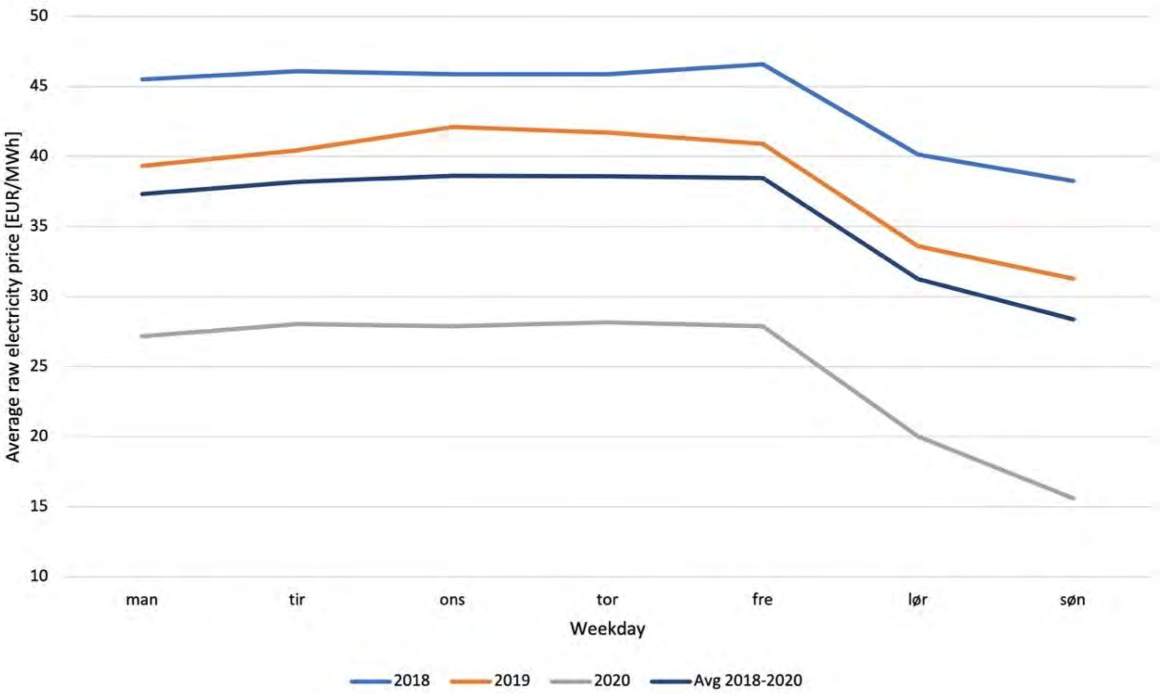

Figure 91: Average raw electricity price per week for the period 2018-2020.

The average hourly price variation for 2018-2020 is shown in Figure 92 for weekdays and weekends. For the weekdays, there are two peaks, the morning peak (7:00 to 9:00) and the evening peak (17:00 to 20:00). The night and early mornings are the cheapest hours on the weekdays. In the weekend, one high peak appears, the evening peak (17:00 to 20:00). It is noticeable that the highest average peak in the weekend is nearly the same as the “midday valley” (13:00 to 16:00) in the weekdays.

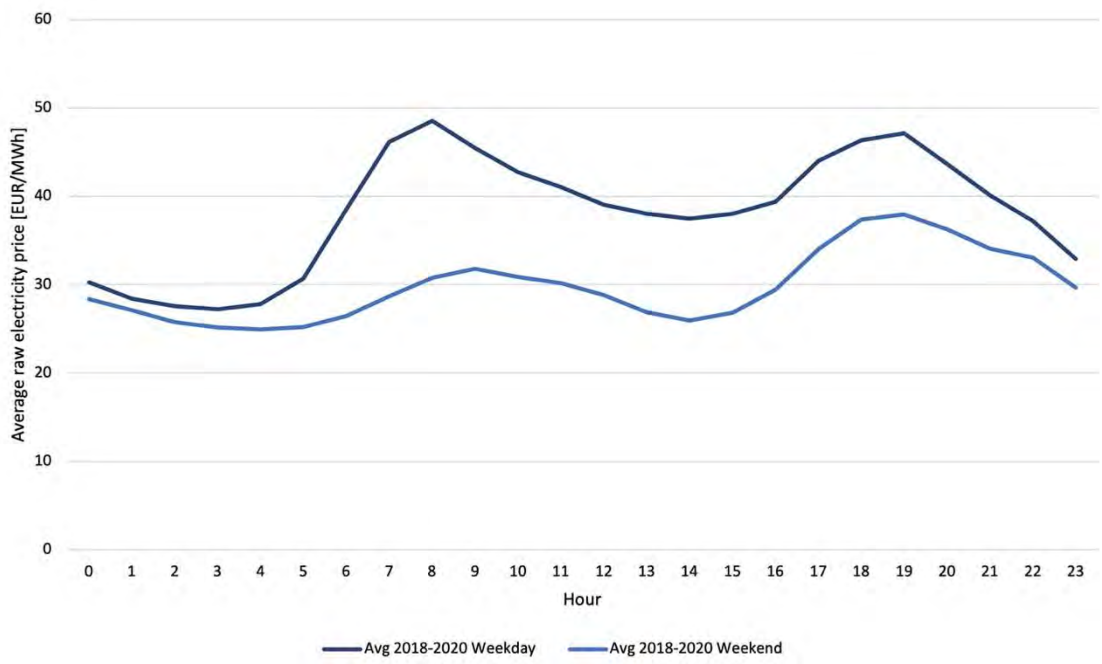

Figure 92: Average raw electricity price for weekdays and weekends in the period 2018-2020.

This short analysis shows that there is a good potential to utilize load shifting for electricity in technical installations and electrical appliances. There are economic savings in moving electrical loads from weekdays to weekends and in the hours of the day.