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Table of Acronyms

Acronym	Definition
API	Application Programming Interface
BES	Building Energy Simulation
BMS	Building Management System
CPT	Change Point Temperature
DEPC	Dynamic Energy Performance Certificate
DHW	Domestic Hot Water
EPC	Energy Performance Certificate
ES	Energy Signature
HVAC	Heating Ventilation and Air Conditioning
IoT	Internet of things
KPI	Key Performance Indicator
NZEB	Nearly Zero Energy Building
PG	Performance Gap
SH	Space Heating
WAN	Wide Area Network

Executive Summary

The objective of this deliverable 5.5 is to present the establishment, monitoring, and results of the Danish demonstrator. It supplements the deliverable 5.1, which is focused on a general cross-comparison of approaches to monitoring the demonstrators of E-DYCE, by providing more in-depth information about the Danish pilot cases. Moreover, it precedes D5.6 which will focus on the demonstration results, and will propose policy contributions at the end of the project.

The Danish demonstration focused on shared residential buildings, with 3 apartment blocks being investigated in the northern part of the country (2 in Aalborg and 1 in Frederikshavn). These buildings are owned and operated by three different housing associations; they were built between 1964 and 1972 and were renovated between 2010 and 2012. In all 3 sites, the heat supply for space and water heating was provided by district heating from the municipal utility.

Establishing data collection centrally in the buildings has been a relatively straightforward process, based upon Neogrid's extensive experience, known hardware, and pre-existing contact with the building operators. There was only one major challenge in the Frederikshavn building, where connection to an old legacy ventilation system turned out to be impossible, due to missing documentation of its interface and settings.

At apartment level however, a main bottleneck identified was the need for engagement with the tenants and obtaining their consent, in order to collect apartment-level data. This has been a part of the process where the resource usage has been considerably higher than expected, without fully reaching the coverage that was initially envisioned. Luckily, enough apartments were equipped to generate the required data to progress in the project. The level of instrumentation per apartment was varied across the three pilots, from a minimal level (indoor climate, radiator sensors, and window opening) to medium and high (indoor climate and window opening, and energy metering), to reflect different monitoring possibilities on different buildings.

The data collected was automatically transferred to Neogrid's PreHEAT cloud platform via a gateway placed in the buildings, and then processed, structured and uploaded further to EMTECH's FusiX platform, wherefrom it will be made available to the E-DYCE services.

A structured inspection protocol was carried out in each of the buildings. Additionally, some of the tenants were interviewed to evaluate their experience of living in the building, usage of the apartment, acquaintance with energy matters, as well as their perception of the additional sensing equipment that was installed in their homes.

Regarding novel methods for analysis, AAU developed two data-drive assessment methods to improve KPI evaluation. First, a disaggregation methodology for space and water heating, which can reduce sensing needs. Second, a method for performance evaluation based upon building energy signature was developed, to carry out effective cross-comparison of buildings.

All three of the Danish demonstrators will potentially have an excellent coverage of KPIs monitored and assessed by the model. However, the success will highly depend on the model and monitoring quality and will first be evaluated when all modules of E-DYCE are fully integrated and running.

1 Introduction and context of the Danish pilot

This report presents the Danish pilot in more detail, focusing on the context, the characteristics of the building and their systems, as well as monitoring, simulations, and performance analysis.

1.1 Buildings within the demonstrator

The Danish demonstrator consists of 3 apartment blocks, focusing on the residential sector for this demonstration. These buildings were built in the 1960s and early 1970s, and later they were renovated in the early 2010s. All three are owned and managed by three different housing associations, wherefrom tenants rent the apartments. Tenants have varied backgrounds, ages, and situations, so there is no real 'typical tenant' profile for those.

Housing associations in Denmark operate in a democratic manner, where important decisions are taken at board meetings where tenants have a possibility to influence the choices that are being made. Given that most tenants have little to no technical knowledge about building energy systems, this means that board decisions will often not be grounded in deep expertise and understanding. However, these three housing associations have full-time personnel focusing on energy optimisation, as they have a sufficient volume of buildings for such a position to pay off.

1.2 The Danish climate

The three demonstration buildings are located in northern Denmark, within a region called North Jutland. Two demonstration sites are located in Aalborg, while the last one is in Frederikshavn (the position shown on the map below in Figure 1). Both cities have similar climate and weather patterns.

Figure 1: Geographical situation of the buildings of the demonstrator

The region's climate is strongly influenced by its proximity to the North Sea on the western side and the Baltic Sea on the eastern side. This results in mild temperatures and low amplitude of temperature change between seasons (see Figure 2 and Figure 3).

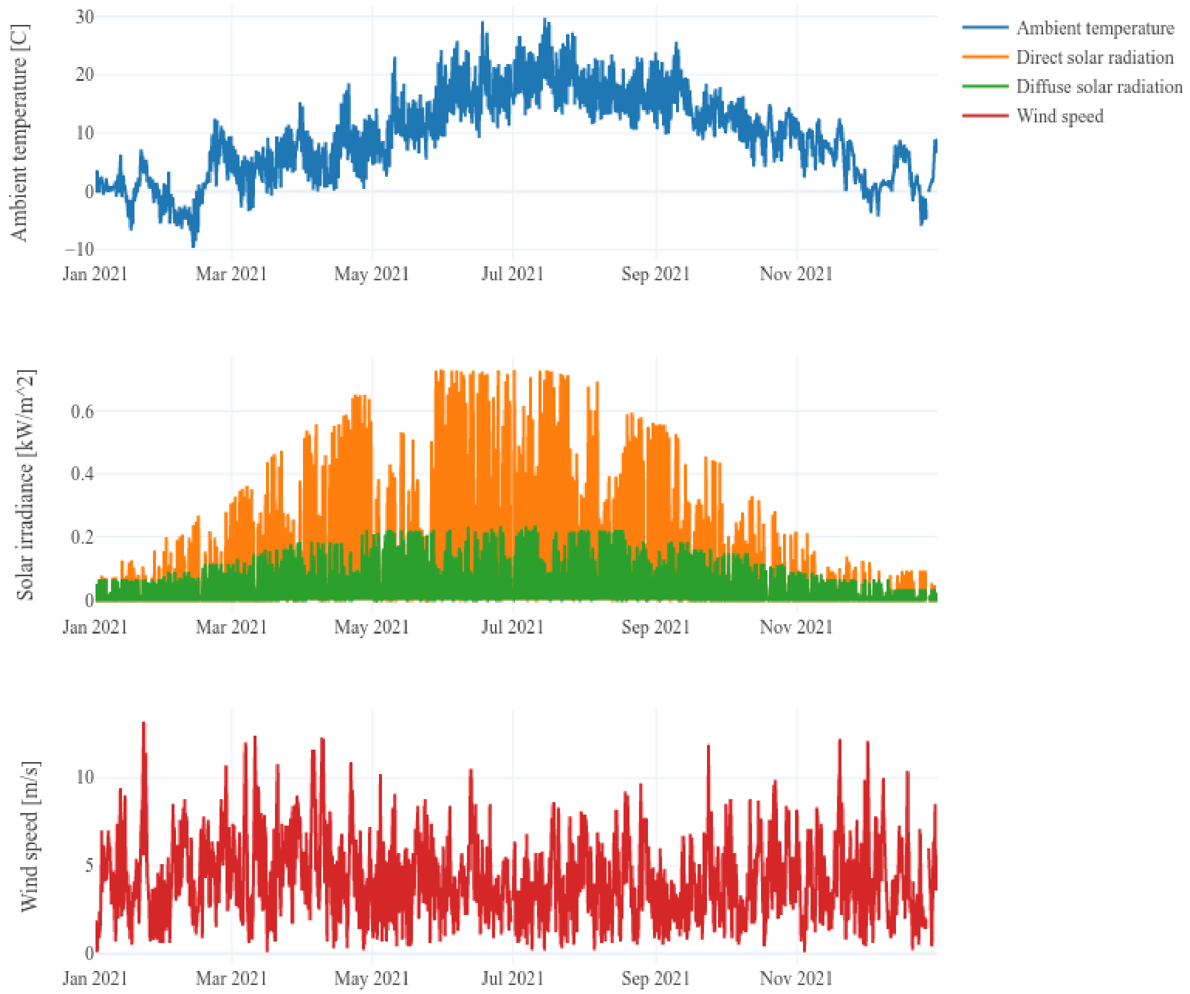

Figure 2: Weather pattern for 2022 (hourly data from Aalborg)

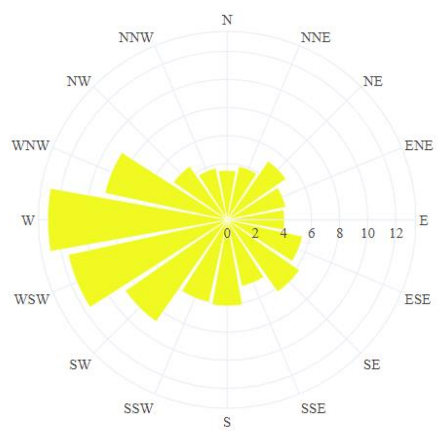

Figure 3: Windrose for Aalborg in 2021 (hourly data in percentage of hours), illustrating the prevalence of wind from west

1.3 Building regulations in Denmark

Compared to other countries, Denmark has a relatively regulated building sector, with strong requirements in the building codes (Bolig og Planstyrelsen, 2022) to ensure a healthy, safe, reliable, and resource-efficient building stock. These building codes were introduced in the 1960s and have been regularly updated to apply to all new constructions, extensions, and renovations. In case construction companies do not meet the requirements of this code, significant fines can be imposed on them.

In the context of our pilot buildings, the relevant building codes were those from the period 1964-1972 for construction and 2010-2012 for renovation.

2 The demonstrators

This chapter presents in detail the three Danish buildings that are used as pilot cases. For each location, the buildings' graphical presentation and the envelope elements' thermal properties are presented. The detailed composition of each envelope element is provided in Appendix A.

2.1 Haanbaek (Frederikshavn)

This subsection presents the Haanbaek pilot building, which is located in Frederikshavn.

Figure 4: The Haanbaek pilot building

2.1.1 Building situation and structure

This pilot building is located on Højrupsvej 48, as presented in Figure 5. The building has a total of 28 apartments and a heated area of 3 120 m^2. It consists of 3 staircases (street numbers 46, 48, and 50), four floors, and two apartments on each staircase and on each floor (8 apartments in each staircase for 48 and 50, 12 for number 46). All monitored apartments are located in staircase 48.

Figure 5: Situation plan for the Haanbaek building

2.1.2 Properties and systems of the building

The building was built in 1972 and has undergone renovation since 2011. It is heated by the city's district heating (*Frederikshavn Forsyning*), and the local distribution grid supplies the electricity.

The characteristics of its envelope are given below in Table 1.

Table 1: Thermal properties of the Haanbaek envelope elements

Haanbaek pilot building		U-value [W/m²K]
Opaque	External wall with cavity - 35 cm brick/light concrete -insulated at construction	0,29
	Facade element - concrete/concrete -50 mm insulation	0,69
	Massive external wall - 19 cm light concrete and 100 external insulation	0,26
	Floor against unheated basement - 50 mm insulation	0,59
	Roof - 275 mm insulation	0,15
[redacted]		

		U-value [W/m²K]	g - value [-]
Windows	Window type -2 layer window with cold edge	1,5	0,63
	Glass element/ terrace door - 2-layer glass with cold edge	1,42	0,63
	Skylight	1,8	0,6

In this building, space heating is realized by a single mixing loop supplied by district heating and located in the technical room in the basement of the block. It supplies all apartments with the same temperature (although these might receive varying lower temperatures due to line losses within the building). The building also has mechanical ventilation with heat recovery (one unit per stairwell), which has a heating coil also supplied by the main mixing loop.

Hot-water production is also realized centrally, with a single heat exchanger supplying a circulation loop to all apartments, which are fitted with a flow meter each to evaluate their demand.

Both central space and water heating are controlled by a Danfoss ECL 310 controller, which Neogrid is interfacing to via a Modbus connection, and is able to read data from and write setpoints back to it.

The ventilation system of the building is a legacy Exhausto unit, which has proven very challenging and resource-intensive to interface to, as it only supported communication over the LON protocol. We found an adapter to Bacnet (which our gateway supported) and requested extensive support from its provider. Still, it was not possible to configure the data acquisition from it, as the unit was so old and installed so long ago, that the documentation of its LON interface was no longer available. Therefore, we are still working on alternatives, to obtain useful context data for the ventilation system in this building.

2.1.3 Monitoring at the apartment level

This demonstrator was the one equipped with the highest resolution of sensing at the apartment level, to represent a 'best-case' situation for monitoring. As shown in Figure 6 below, indoor climate data was metered in every room (including CO_2 in some of them), while window opening was also measured, together with electricity, space, and water heating demand at the apartment level. Lastly, contact temperature sensors were also installed on some radiators, to measure their usage and heat delivery.

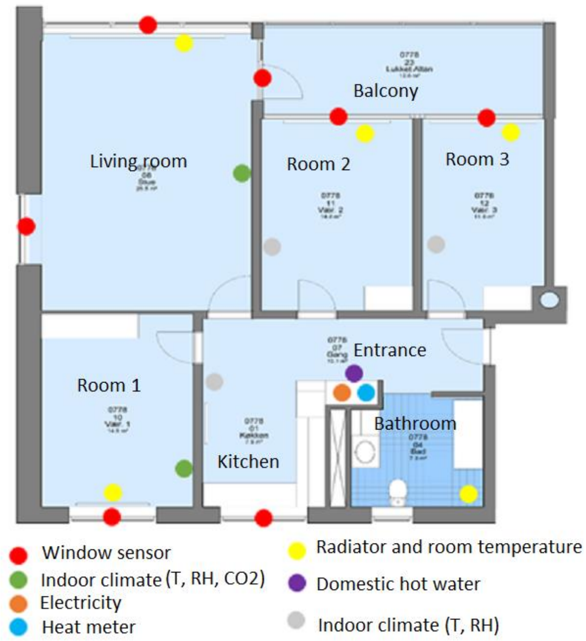

Figure 6: Monitoring plan at apartment level for Haanbaek

2.2 Magisterparken (Aalborg)

This subsection presents the Magisterparken pilot building in Aalborg.

Figure 7: The Magisterparken pilot building[1]

2.2.1 Building situation and structure

The pilot building is located on Magisterparken 415, as presented in Figure 8. The building consists of three staircases 415, 417, and 419, has three floors and two apartments on each staircase and on each

[1] note: the tall building in the background is a separate building, which is not part of the pilot)

floor (6 apartments on each staircase). All monitored apartments are located in staircase 415. In total, it has 18 apartments with a combined heated area of 1 515 m^2.

Figure 8: Situation plan of the Magisterparken building (415, 417, 419)[2]

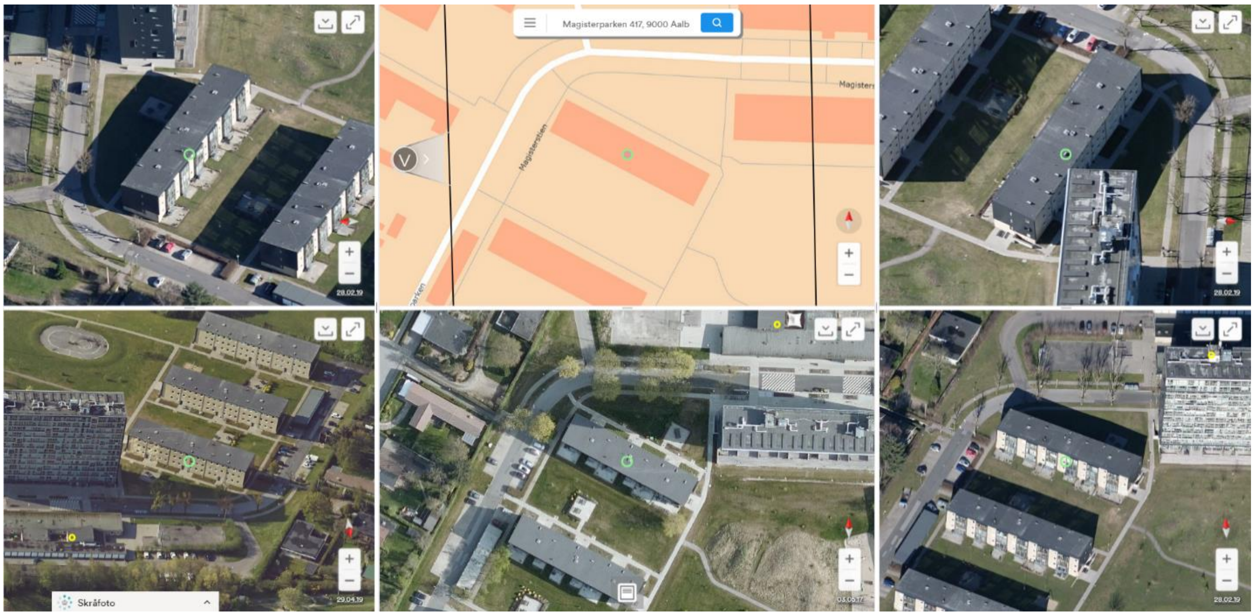

Figure 9: View of the Magisterparken pilot case seen from different orientations and angles

[2] From http://kort.matrikel.dk/spatialmap

2.2.2 Properties and systems of the building

The building was built in 1964 and renovated in 2012. It is supplied by district heating from the city's network (*Aalborg Forsyning*) and electricity from the local distribution grid.

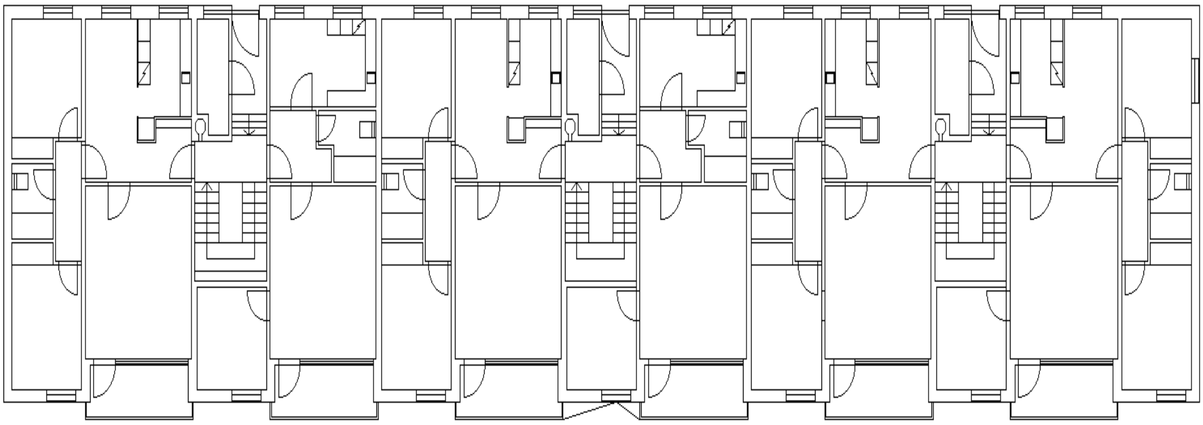

Figure 10: Magisterparken 415-419, plan view of the floors

Table 2: Thermal properties of the envelope of the Magisterparken demonstrator

Magisterparken		U-value [W/m²K]	
Opaque	External wall South & North – as built	1,29	
	External wall East & West (gable wall) – renovated in 2012	0,09	
	Roof	0,38	
	Floor against unheated basement - 50 mm insulation	0,55	
		U-value [W/m²K]	**g - value [-]**
Windows	New windows	1,2	0,64
	Old windows	2,3	0,7
	Entrance door	1,2	0,64

The Magisterparken building also has a single central mixing loop providing a common supply temperature for the heating of the whole building. However, contrary to Haanbaek, it does not have mechanical ventilation implemented.

For water heating, a tank is installed in the building and is connected to the district heating (upstream), as well as to a hot-water circulation loop (downstream) towards the apartments.

Both central space and water heating are controlled by a Danfoss ECL 210, where Neogrid has the possibility to overwrite the setpoints and reading signals back via a Modbus interface.

2.2.3 Monitoring at the apartment level

In the Magisterparken demonstration building, the monitoring strategy at the apartment level is medium, with neither highest resolution sensing (such as in Haanbaek) nor minimalistic sensing (like in Thulevej below). Heat meters provided data about the space and hot water demand of the target apartments, and some windows were equipped with opening sensors, while simple indoor climate sensors (measuring only temperature and humidity) were fitted in the most important rooms of each apartment.

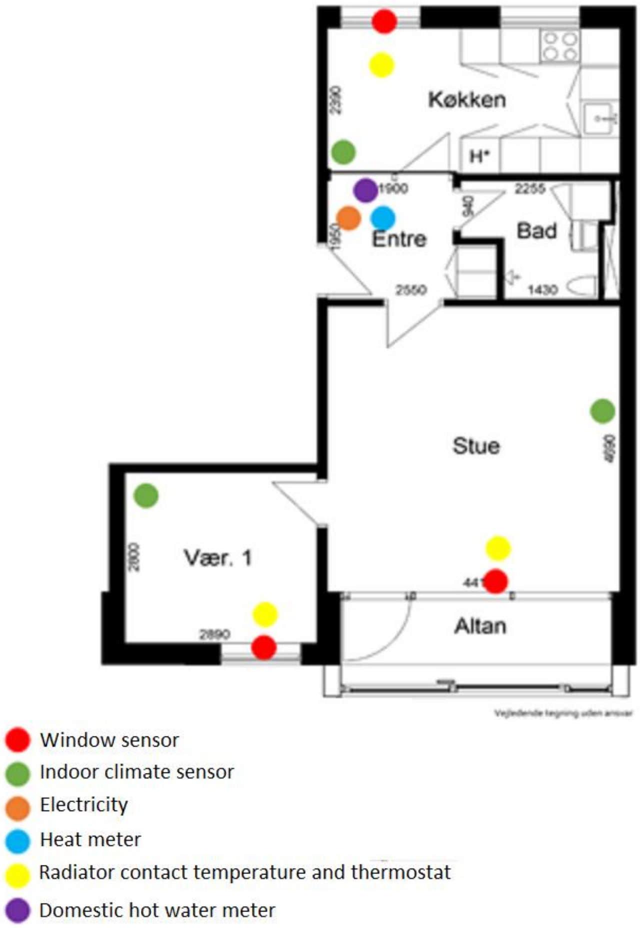

Figure 11: Monitoring plan for Magisterparken apartments

2.3 Thulevej (Aalborg)

This subsection presents the Thulevej pilot building in Aalborg.

Figure 12: The Thulevej pilot building

2.3.1 Building situation and structure

Figure 13: Building Thulevej 42, 44, 46, 48[3]

[3] From : http://kort.matrikel.dk/spatialmap

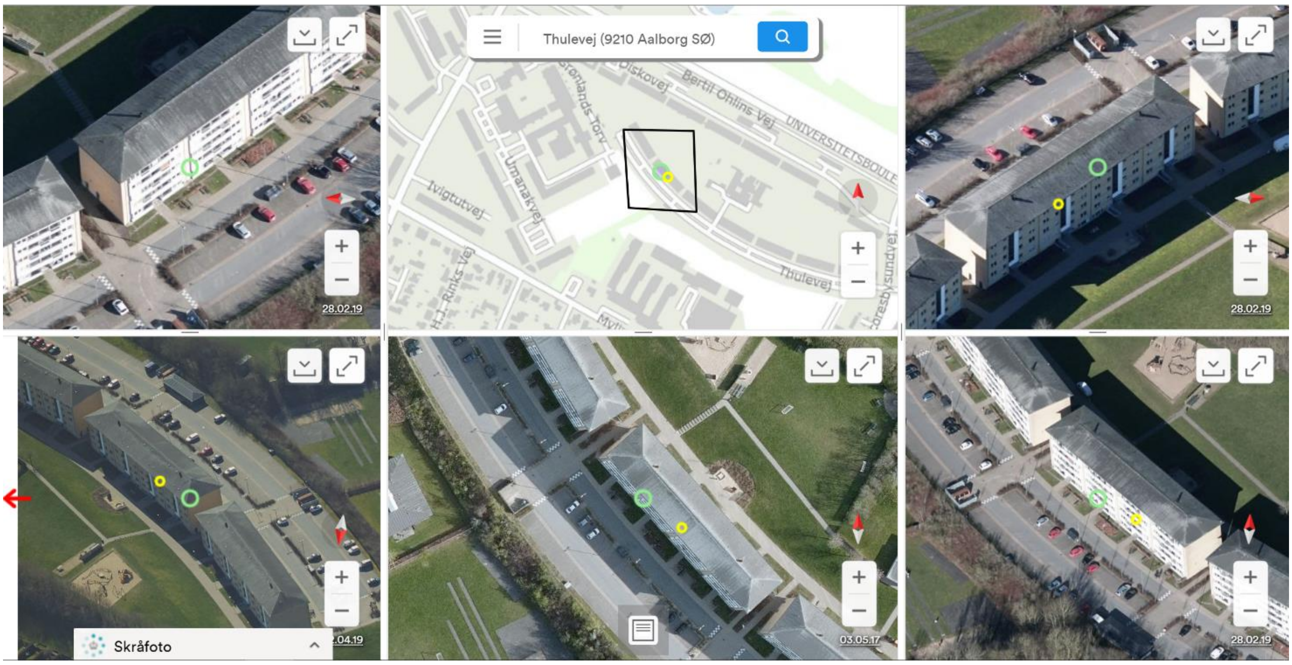

Figure 14: View of the Thulevej pilot case seen from different orientations and angles

2.3.2 Properties and systems of the building

The building was built in 1969 and renovated in 2010. Its heat supply is from the district heating of the city's network (*Aalborg Forsyning*), and the power supply is from the local distribution grid.

Table 3: Thermal properties of Thulevej envelope elements

Thulevej		U-value [W/m²K]	
Opaque	External sandwich wall (brick/insulation/brick)	0,18	
	South facing outer wall	0,19	
	Basement outer wall	0,4	
	Terrace outer wall	0,26	
	Stairway outer wall	0,4	
	Roof	0,16	
	Floor on the ground	0,55	
		U-value [W/m²K]	**g - value [-]**
Windows	Window South	1,3	0,65
	Window North	1,3	0,65

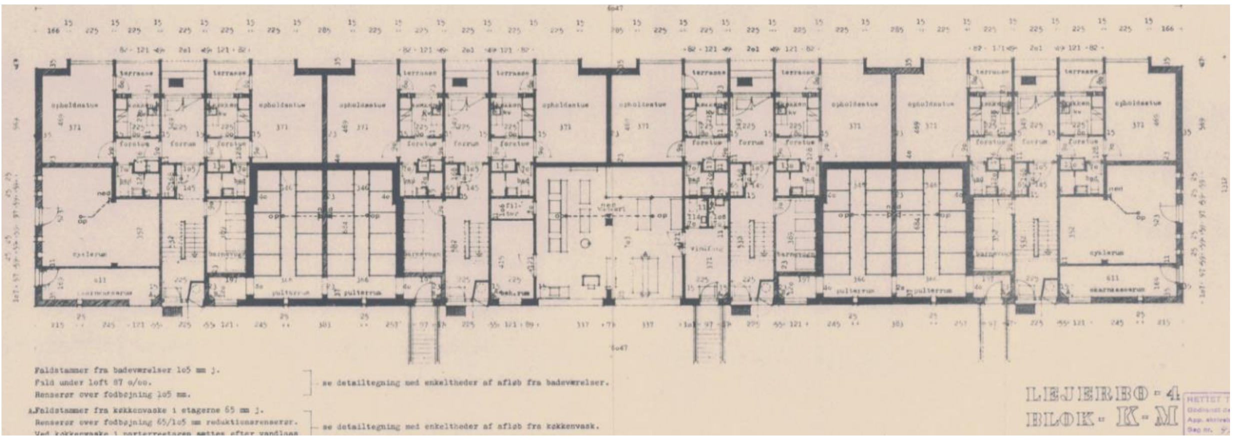

Figure 15: Thulevej 42-48, plan view of the ground floor

Figure 16: Thulevej 42-48, plan view of floors 1-4

Similar to the two other demonstrators, the Thulevej building has a single central mixing loop providing a common supply temperature for the heating of the whole building. It does not have mechanical ventilation implemented.

For water heating, the setup is similar to Magisterparken, as hot water is produced via a tank and sent further via a circulation loop.

Both central space and water heating are controlled by a Danfoss ECL 310, whose setpoints can be overwritten by Neogrid, and signals can be read remotely.

2.3.3 Monitoring plan at apartment level

Among all three Danish demonstrators, Thulevej is the one with the most reduced monitoring infrastructure. The sensing there is dimensioned to reflect a case, where available data for performance evaluation would be limited to a minimum of easy-to-add wireless sensors.

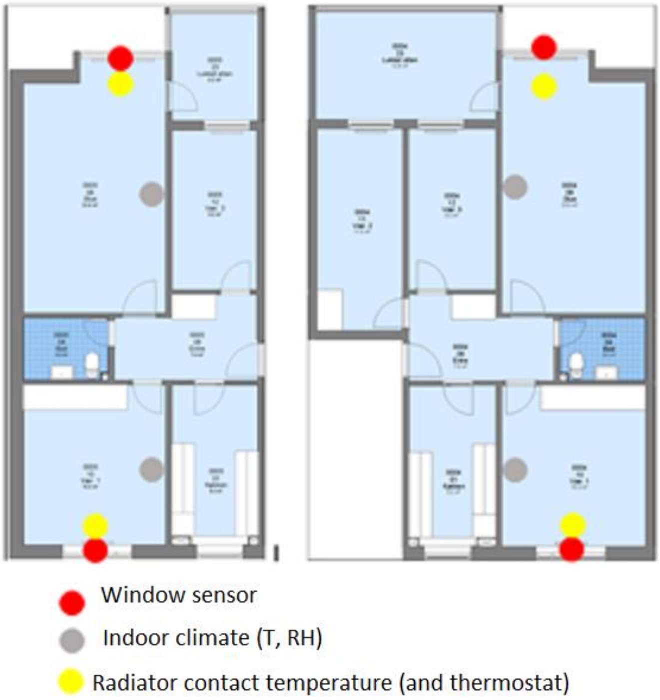

Figure 17: Monitoring plan for apartments on Thulevej

3 Use of "Inspection Protocol"

The EPC models of the Danish pilot buildings were developed before the EDYCE inspection protocol was ready. Therefore, in the Danish case the aim is to identify convergence between current Danish inputs collected either in EPC labels or in compliance models (these two are compatible) and the E-DYCE inspection protocol. This exercise aimed to test to what extent protocols could be filled with information about the building already being available, either from the Danish EPC label (file in XML format) or from the compliance calculation tool Be18 (file in TXT format). The input parameters found in EPC and Be18 are the same, although the data format is slightly different for EPC and the compliance tool. Both TXT and XML formats reflect the potential for automatic input data conversion into inspection protocol. However, this is not done, as the task is not to automate the process but rather to identify the potential for input collection and standardization across different countries. At present, it is concluded that the compatibility between input parameters in Danish EPC/compliance and inspection protocol is limited, and valid only for some input parameters.

In the process of filling in the inspection protocols developed and presented in D2.1, it was noticed that some static information about the buildings (areas, envelope elements, etc.) could be retrieved from Danish EPC or Danish compliance tool Be18. During the process of completing inspection protocols, several alignments and gaps have been observed. These are reported in detail in this chapter.

The "Zone dynamic" has been filled in with the best knowledge from the Haanbaek building and with the local practice of conduct support. Zones Dynamic (Sheet 5) is filled for two apartments.

Detail feedback on the use of sheets in inspection protocol with regards to Danish EPC and compliance calculation input availability, are listed below:

Sheet 1: General Information

No comments

Sheet 2: Building's assignment

This sheet allows the individual definition of the use of specific zones in the building.

"Surface" – requires specification of what surface shall be considered.

"Supplement for room temperature" – not clear from the Danish context.

"Annual energy needs" – would require elaboration on what annual energy needs are considered.

Sheet 3: Global surfaces

This sheet is found to be moderately useful for DEPC assessment. Data are not directly available from the Danish EPC. Still, this sheet gives a good overall understanding of building's size.

The naming of areas is too specific for the Swiss approach and might be difficult to insert for other countries.

Sheet 4: Energy surfaces and envelope

Walls orientation is neither considered in Danish EPC nor compliance calculation. However, this is useful information for creating a dynamic model.

Only windows orientation is provided in Danish EPC and compliance calculation.

The possibility of defining multiple construction elements facing the same boundary condition but having different properties should be considered. For example, different outer walls have different U-values facing outdoor.

Sheet 5: Zones dynamic

Physical properties of the construction elements

In the Danish case, the Danish pilot buildings have been renovated over the years, and each apartment can have windows with different orientations and properties (u-value, g-value, etc.). The sheet works well for the simple case selected but can be challenging to fit a complex case, i.e., three windows with different properties and orientations.

Regarding the thermal capacity of the room, this part can probably be omitted if EnergyPlus or a similar tool is used.

Occupants

Several cells depend on the number of occupants. It is suggested to add a cell that allows specifying a standard number of occupants in the room. If the room is an office, then working hours would mean a period of the room with the occupation. If room is an apartment, then the working hours is the period when the occupants are absent.

Surface per person (B44), clarify if this is heated floor area.

Several inputs are left missing.

Sheet 6: Zones description

This sheet can provide detailed information on the composition of building construction. This sheet supports Sheets 8, 9,10, and 11 when building dynamic models. The naming of construction could be linked between Sheet 6 and Sheet 8-11.

Sheet 7: Monitoring

No comment.

Sheet 8: Roof and ceiling

This sheet is almost to the entire extension compatible with Danish input, which can be found either in EPC or compliance calculation.

Compared to the Danish approach, the deviation is that roof construction is under the same sheet together with walls and floors.

Sheet 9: Walls

This sheet is almost to the entire extension compatible with Danish input, which can be found either in EPC or compliance calculation.

The main deviation is that Danish input does not provide an orientation of walls, construction type (heavy, light, etc.), and insulation position (interior, exterior, etc.). All suggested additional inputs are evaluated positively, as they would support the correct development of dynamic models.

Sheet 10: Windows and doors

This sheet is almost to the entire extension compatible with Danish input, which can be found either in EPC or compliance calculation.

The calculation of shadow proportion is unclear and not fully compatible with the Danish approach. However, it indicates shadow presence, which can be taken into account in dynamic models' development.

Factors "b, g, the proportion of glass" are directly compatible with Danish input found in EPC or compliance calculation.

Sheet 11: Floors and basement

This sheet is almost to the entire extension compatible with Danish input, that can be found either in EPC or compliance calculation.

Compared to the Danish approach, the deviation is that floor constructions are under the same sheet together with walls and roofs.

Sheet 12: Thermal bridges

This sheet is almost to the entire extension compatible with Danish input, which can be found either in EPC or compliance calculation.

Thermal bridges assessment has not been input to the Danish EPC for the assessed building (Haanbaek). If the values were given, they could be implemented in the inspection protocol.

Sheet 13: Heating means

Some requested inputs can be specified based on input available in Danish input that can be found either in EPC or compliance calculation.

Mismatch between inspection protocol and Danish EPC/compliance can be observed for the following issues:

- The share of fossil fuels in the district heating provider's production is neither possible to be stated in the Danish EPC nor in the compliance calculation tool.

- Thermal efficiency is only applicable to the indirect system with heat exchanger, else for direct system efficiency is 100%.

- Domestic hot water efficiency is provided in a different manner than in the inspection protocol.

- With respect to heating location, the Danish input distinguishes between heated and unheated spaces, which is more indicative than solely providing the name of the space as is currently possible in the inspection protocol.

Sheet 14: Annual heat consumption

For the analysed building (Haanbaek), the annual heat consumption is unknown from the performed EPC. However, the Danish EPC method can accommodate this information if it is available and also if the assessor has implemented it in the assessment. Metered heat use can be provided in Danish EPC but does not influence the building label. It can only be provided as a comment to the EPC label report.

Sheet 15: Heating distribution

Heating distribution inputs are provided differently in Danish EPC and compliance calculation than in inspection protocol. Direct filling of inspection protocol based on input form EPC/compliance is not possible.

The Danish method's distribution system considers the following parameters: pipe length, loss (W/m.K), location of pipes (heated/unheated), weather compensation, and summer stop of operation. Space heating, domestic hot water, and circulation pipes should be considered separately.

Sheet 16: DHW distribution

The same comment as for Sheet 15.

Sheet 17: Lighting

Danish EPC and compliance do not include information about lighting quality in the same manner as it is provided in the current version of the inspection protocol. Nevertheless, this information can be translated, to some extent, by the assessor from one format (EPC/compliance) to another (inspection protocol).

Danish EPC and compliance do not include information about the proportion of electricity tariffs, as indicated in the inspection protocol. Instead, Danish EPC and compliance provide a few other inputs such as load [W/m^2], lux levels, daylight factor, light control (from manual to automatic), utilization factor with respect to building operation time, and standby effect [W/m^2].

Sheet 18: Ventilation

Several input parameters can be imported from Danish EPC and compliance to the inspection protocol. These are Fresh air flow rate (although the Danish approach allows adjusting between summer and winter and day and night) and heat recovery efficiency.

The inspection protocol can accommodate inputs which are not present in Danish EPC and compliance calculation. These inputs are: electricity tariffs, airflow is requested in total flows whereas in EPC with regards to floor area, electricity need in kWh (it is not clear for what).

Moreover, the Danish EPC/compliance distinguishes between natural and mechanical airflows and infiltration.

Sheet 19: Annual electricity use

Metered electricity use can be provided in Danish EPC but does not influence the building label. It can only be provided as a comment to the EPC label report.

4 Establishing the demonstrator

This section presents the work done with regard to establishing the demonstrators.

4.1 *Engaging with the building owner*

Engaging with the building owners has been relatively straightforward in the context of the Danish demonstrator, as the three housing associations were already collaborating with Neogrid (in the form of commercial service delivery for control of a number of their buildings) and had already declared their support to the project in the grant application phase. This part of the work has therefore been less demanding than it would be on a future E-DYCE deployment with a new actor who does not have a pre-existing relationship with the service provider.

In practice, getting an agreement in place in the context of a housing association in Denmark can be a long process, as such decisions are made at general assemblies, which only happen once, or a few times a year. On top of this, a trusting relationship needs to be built with key personnel within the association and its facility management, which further increases the start-up time of such projects. All in all, it is, therefore, not uncommon to wait, at least for a year, between the first contacts and the establishment of the monitoring.

4.2 *Accessing central systems in the building*

Accessing the central systems in the technical room of the building has also been relatively straightforward in this project, given that Neogrid had extensive experience in interfacing with the systems used by these housing associations (Danfoss ECL), and with some pre-existing hardware installed in the buildings where it was operating the control, prior to the start of the project.

Suppose the equipment in place relies upon standard communication protocol (such as a BMS using Bacnet or Modbus – or equipment with a Modbus interface, such as the above-mentioned Danfoss controller). In that case, the establishment of the data collection is typically a straightforward process.

However, establishing a data connection can be a major hurdle if the equipment does not support such open protocols. This happened in the Haanbaek demonstrator, where the legacy ventilation system relied upon the LON protocol for communication, which required an adapter that was initially difficult to get to work. Later it could not be set up in any way (as the register documentation for the ventilation system was missing). This issue ended up costing significant time and equipment budget resources, unfortunately not ending with a satisfactory outcome.

4.3 *Engaging with tenants*

Tenants of all apartments participating in E-DYCE monitoring campaign have been first informed about the project, its motivation and objectives, through a brochure that was specially prepared for tenants; then they were asked to sign informed consent, see Figure 18. Both brochure and informed consent have been prepared in Danish, in order to secure that tenants consciously sign the agreement.

Figure 18: Brochure for tenants informing about the project (left), informed consent (right)

Engagement with the tenants has nevertheless been a very demanding step, as it was hard to get in contact with them. They were often not home at times when we were visiting the building, and they were not necessarily checking their mailbox on a regular basis[4]. Another lesson learned was that tenants should be engaged in a way that they do not need to be proactive in order to participate in the project (e.g., expecting them to call back after receiving a flyer was not realistic). Since tenants' consent was a fundamental requirement to get access to apartment data, this difficulty has had a strong implication for the number of apartments we managed to access.

4.4 Accessing apartment-specific information and interviews with tenants

Several detailed telephone interviews have been conducted with tenants of one pilot building in Haanbaek. The detailed information collected during individual interviews is presented in Table 4. The interview is divided into five sections: i) occupants, ii) air quality, iii) thermal comfort, iv) use of shadings, v) E-DYCE sensor installation, and energy-saving motivation. Based on the interview, some general conclusions can be drawn:

- Most of the time, apartments are occupied, but the exact location of occupants inside the apartments remains unknown. The interview provided information about actual people load that can be used to replace standard loads. The spatial distribution of the loads remains for the expert to decide.

- Occupants are satisfied with the air quality.

- All occupants declare to vent their apartments rather often and be conscious of the purpose of venting. Based on interviews, elevated air change rates thanks to natural ventilation, especially in

[4] Here, it is worth knowing that a significant amount of the administrative communication in Denmark happens via an electronic mailbox. Materials sent by regular mail are therefore typically more of lower priority.

summer, should be considered to reflect user behaviour and interaction with openable windows. The tenants have indicated that the primary motivation for opening windows is for fresh air and the removal of moisture, and when experiencing elevated indoor temperatures. The setting of natural ventilation activation in models remains for the expert to decide. The task of mimicking opening windows and scheduling them in the models seems challenging

- Occupants express that they are rather satisfied with the thermal comfort in their apartments. However, some tenants report signs of elevated temperature and draught from windows. These are indicated as minor problems.

- Occupants, although they are satisfied with thermal comfort, are not able to explicitly answer about maintained indoor temperature. Adaptation of model set points, for example, for heating must rely on measured indoor temperatures.

- Setting on radiators can be expected to be different. Lower settings are, in general, reported in bedrooms. This indicates that lower temperature set points for bedrooms could be worth considering in adapted models.

- Except for one apartment, there is no clear indication if the temperature within each apartment is uniform.

- All tenants that agreed to host E-DYCE answered that they positively experienced the installation of indoor sensors.

- When asked about spending on energy, tenants indicated that either not much or a little too much is spent. This is also reflected in their relatively low motivation to save energy, where they declare rather low flexibility for change. Tenants indicated that they could consider energy-saving actions, but only if they would receive explicit advice on what to change.

Table 4: Detailed answers collected from interviews with tenants of the Haanbaek pilot case

Question	Apartment A	Apartment B	Apartment C	Apartment D
OCCUPANTS				
Number of adults	1	3	2	1
Number of children	0	2	0	0
Number of people primarily staying home (not going to work)	1 (retired person)	2	2	1 (retired person)
Staying at home	Not at home 9-12 and Thursdays 12-15	2 at home always, children at school 8-15	Always	Out of apartments in the middle of the days and afternoons

AIR QUALITY				
Are you satisfied with the indoor air quality in the apartment?	Yes	Yes	Yes	Yes
How often do you ventilate (open windows) and where?	Every day both summer and winter. All rooms	Every day/2-3 times a day/All rooms	Every day, bedroom and bathroom, all internal door open at all time	Every day, bedroom all day, living room in summer
How long and when do you ventilate apartment?	Each day bedroom and bathroom, living room and one small room 2-3 times a week. Long venting in summer (all days) and short in winter (10 minutes)	Summer- all day/Winter 1-2 h mornings	Summer and winter, 1-2 h in winter	All day in summer, 3-4 hours in morning in winter
Motivation for ventilating?	To remove moisture all year, summer to decrease temperature	Fresh air/Summer when too hot	Fresh air, to remove moisture, never because of temperature, not when too hot outside	It is too hot
THERMAL COMFORT				
Are you satisfied with thermal comfort?	Yes	Yes and no. Problems with draught (under windows). In bathroom constant extraction causes heat removal	Draught from windows (living room)	Too hot in living room
What temperature do you maintain (summer/winter)?	Summer and winter 22-24	Do not know	Do not know	Do not know
What is the setting on radiator thermostats?	Bedroom is set to be cold (setting 1). Bathroom set on 2.	Different - because radiators do not give the same heat	Only radiator in living room is open (setting 4-5), floor heating in bathroom (do not know settings)	All radiators set on 3. In bedroom, radiator is not used and the bathroom always used
Is temperature in the apartment uniform?	No answer	Yes, except one bedroom (here no heating is used)	Yes, because open indoor doors	No answer

USE OF SHADING				
How often are shadings used?	Shading available in all rooms (but different, more shading in living room and bedroom). Shading is used every day in summer and few times a week in winter	Every day, both summer and winter	Every day, both summer and winter	Shading available in all rooms, but used only in living room. Summer every day, Winter few times a week
Purpose of use of solar shadings	For sleeping (to get sleeping rooms dark), to protect from glare from sun (both winter and summer)	For sleeping (to get sleeping rooms dark), to protect from glare from sun (both winter and summer)	For sleeping (to get sleeping rooms dark) both summer and winter, in summer because it gets too hot, in winter because it gets too cold (solar shading to prevent heat to escape apartment)	Summer: sun glare and too hot. Winter: sun glare
SENSOR INSTALLATION AND ENERGY SAVING MOTIVATION				
How did you perceive EDYCE sensor installation?	Positive	Positive	Positive	Positive
Do you pay too much for energy?	Yes, but only little too much	Yes, a little too much. Apartment is "warm" not much heat is used	No	No
Would understanding of your energy use make you save energy?	No. Essential is to know what to change. Tenant does not worry about it.	Yes, if get advice on how to do it!	Rather not, but depends if they know what, do not see possibility to change temperature and light	No. The tenant thinks uses little energy

In contrast to the Haanbaek pilot case, no interviews were conducted with tenants of the two other pilot cases. Here, the modelling approach will have to be solely supported by measurements of the indoor environment and based on national guidelines, or eventually on standard load profiles.

5 Dynamic model development

In this chapter are presented models of Haanbaek and Magisterparken pilot cases. Thulevej model is to be developed at a later stage, as first, the correctness and operability of Haanbaek and Magisterparken are proven with PREDYCE and FusiX while developing this report. The motivation for this approach is to reduce resource spending for debugging models and use lessons learned in the first two demo cases.

5.1 Internal load

The internal loads are equal for all developed models; only appliances and occupants were considered. The operation time, occupancy density, and appliance density were based on DS/EN 16798-1, 2019. A summary is shown in Table 5. Equation 1 calculates the activity level per person based on Table 5, showing occupancy density and occupants' heat release. This activity level of about 119 W/person corresponds to approximately 1.2 met (depending on the used body surface area). It should be noted that the reference area changes for the different zoning complexities because internal walls and ceilings are not or only partially modelled. Additionally, for models where the whole staircase is represented by one zone, the internal gains are adjusted by multiplying them by the number of floors. An overview of the resulting internal loads is given in Table 6.

Table 5: Parameters and setpoints for the energy calculations

	Parameter	Value	Unit	Source
Operation time	Hour at day, START	0	hour	DS/EN 16798-1, 2019
	Hour at day, END	24	hour	DS/EN 16798-1, 2019
	Breaks, inside range	0	hours	DS/EN 16798-1, 2019
	days/week	7	days	DS/EN 16798-1, 2019
	hours/day	24	hours	DS/EN 16798-1, 2019
	hours/year	8760	hours	DS/EN 16798-1, 2019
Internal gains	Occupants	28,3	m^2/pers	DS/EN 16798-1, 2019
	Occupants (Total)	4,2	W/m^2	DS/EN 16798-1, 2019
	Appliances	3	W/m^2	DS/EN 16798-1, 2019

	CO_2 production	0,66	$l/(m^2h)$	DS/EN 16798-1, 2019
HVAC setpoints	Min T,op	20	°C	DS/EN 16798-1, 2019
	Max T,op	26	°C	DS/EN 16798-1, 2019
	Ventilation rate	0.5	ACH	Expert knowledge

$$\text{Activity level} = 28.3\ \text{m}^2/\text{person} \times 4.2\ \text{W/m}^2 = 118.86\ \text{W/person} \quad (1)$$

Equation 1: Activity level per person.

Table 6 Resulting internal loads and ventilation rate due to the changing reference area

Zoning type	**Occupied area** m^2	**Occupied volume** m^3	**Appliances** W	**Occupants** W	**Ventilation rate** l/s	**CO_2** l/h
Haanbaek						
Model A	732.3	1827	2196.9	3072.6	255.6	483.4
Model B	194.5 (778)	2119.1	2334.0	3226.6	271.5	513.9
Difference (A-B)/A	-6.2%	-16%	-6,2%			
Magisterparken						
Model A	381.0	975.3	1143	1598.6	135.6	251.5
Model B	130.7 (392.1)	1037	1176.3	1646.7	139.5	259.0
Difference (A-B)/A	-2.9%	-6.3%	-2.9%			

For occupants and appliances used, schedules are shown in Figure 19 and are based on DS/EN 16798-1, 2019.

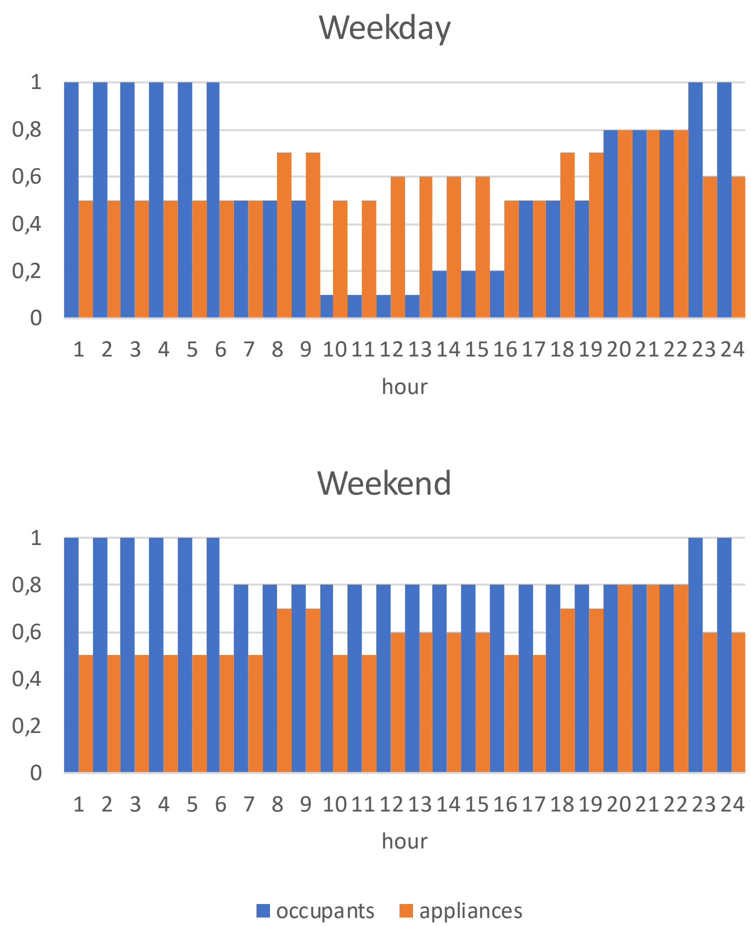

Figure 19: The schedule of the internal loads for the simulation[5]

The occupants' clothing was defined following the method shown in Olesen et al., 2020 who based the clothing on the 3-day outdoor running mean temperature (ORM_3). They used 1clo in winter when ORM_3 < 10°C, 0.5clo when ORM_3 > 15°C and 0.75clo in-between. This approach was simplified based on a visual inspection of the ORM_3 of the Danish design reference year (DRY) to allow for a simple definition of connected periods. The result is shown in Figure 20.

[5] Based on DS/EN 16798-1, 2019 (Residential, apartment)

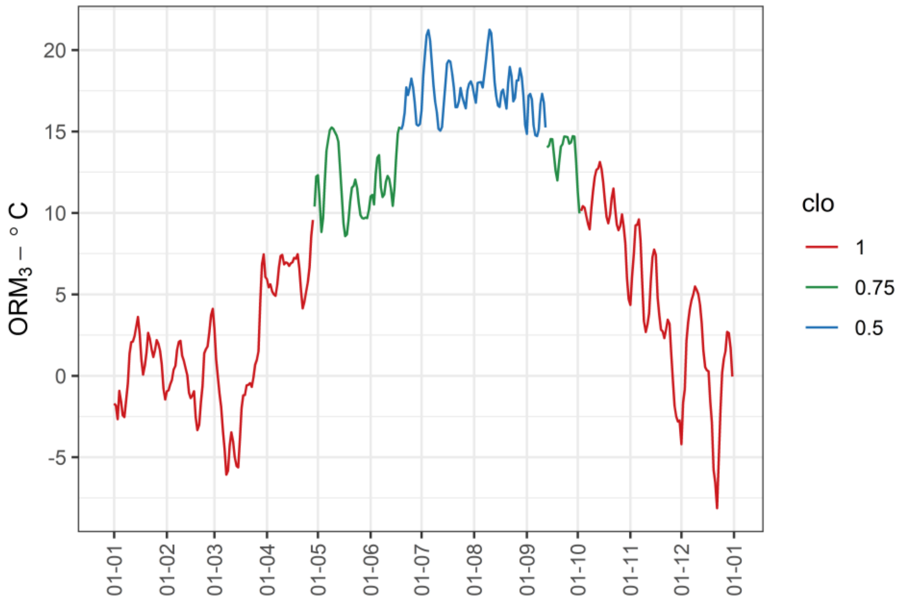

Figure 20: Clothing level based on the ORM_3 of the Danish DRY, simplified by visual inspection[6]

5.2 HVAC

5.2.1 Ventilation rate

The ventilation flow rate was for all models defined as 0.5 ACH, following the idea that this was a typical standard value in the past for ventilation systems in Denmark. To be able to adjust the ventilation rate to the different levels of detail of the models, the flow rate was based on the clear floor height. For models where the whole staircase is represented by one zone, it is otherwise adapted in the same way as the internal loads. The resulting total ventilation rate is given in Table 6.

5.2.2 Heating period definition

The definition of heating/non-heating season strongly influences energy consumption and thermal comfort (Olesen et al., 2020). For this work, the definition was based as suggested by Olesen et al., 2020 on the ORM_3. Heating is available until the ORM_3 surpasses 15°C for the first time and again available when the ORM_3 falls below 10°C for the first time. The resulting definition, based on the Danish DRY, is shown in Figure 21. It is to be noted that the first peak of the ORM_3 in May was disregarded, due to the substantial decrease afterward below 10°C.

[6] Based on the approach of Olesen et al., 2020.

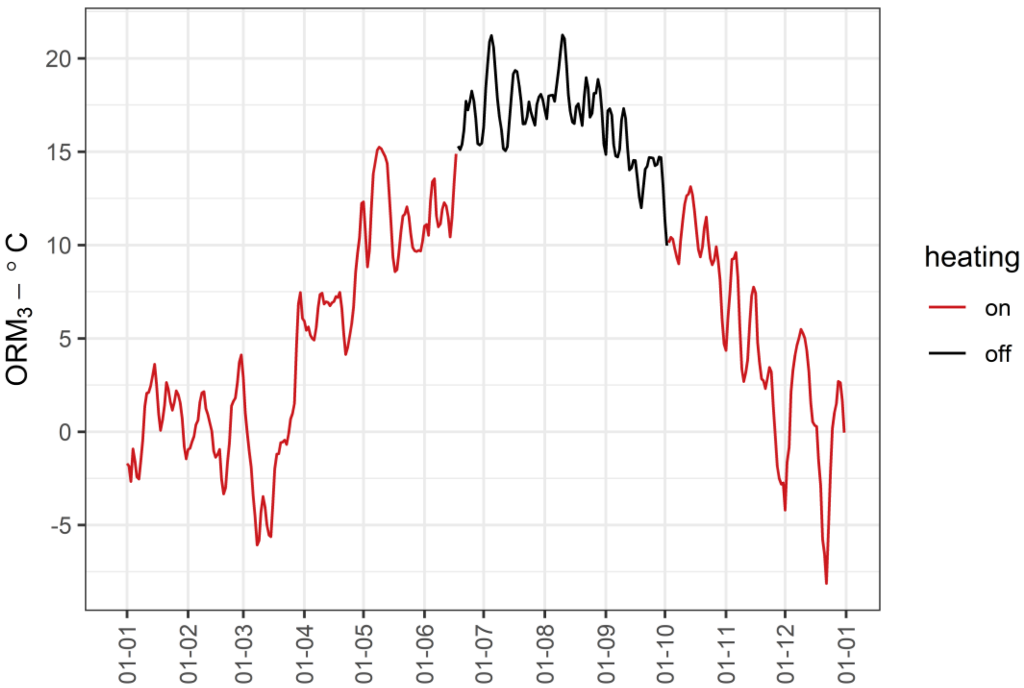

Figure 21: Definition of the availability of heating as suggested in Olesen et al., 2020[7]

5.3 Haanbaek

The building is assumed to be North-south oriented with a 2° rotation anticlockwise. The north and south façades of the staircase are external walls and are exposed to the outdoor environment, while the east and west façades are modelled as adiabatic since they face their neighbouring staircases. The balcony, corridor/stairway, attic, basement, and loggia were modelled as not conditioned for both models since they are neither heated nor ventilated. Additionally, in the more detailed model (model B), the technical shafts were modelled as not conditioned. The windows in the basement were disregarded, as their influence was deemed low. The windows and entrance doors in the stairway were simplified.

5.3.1 Model A

For model A, each room was modelled as a separate thermal zone. Model A represents a detailed approach for geometry consideration and is presented in Figure 22.

[7] Heating is available until the ORM_3 surpasses 15°C for the first time and again available when the ORM_3 falls below 10°C for the first time. The first peak of ORM_3 in May was disregarded due to the substantial decrease in temperature afterwards.

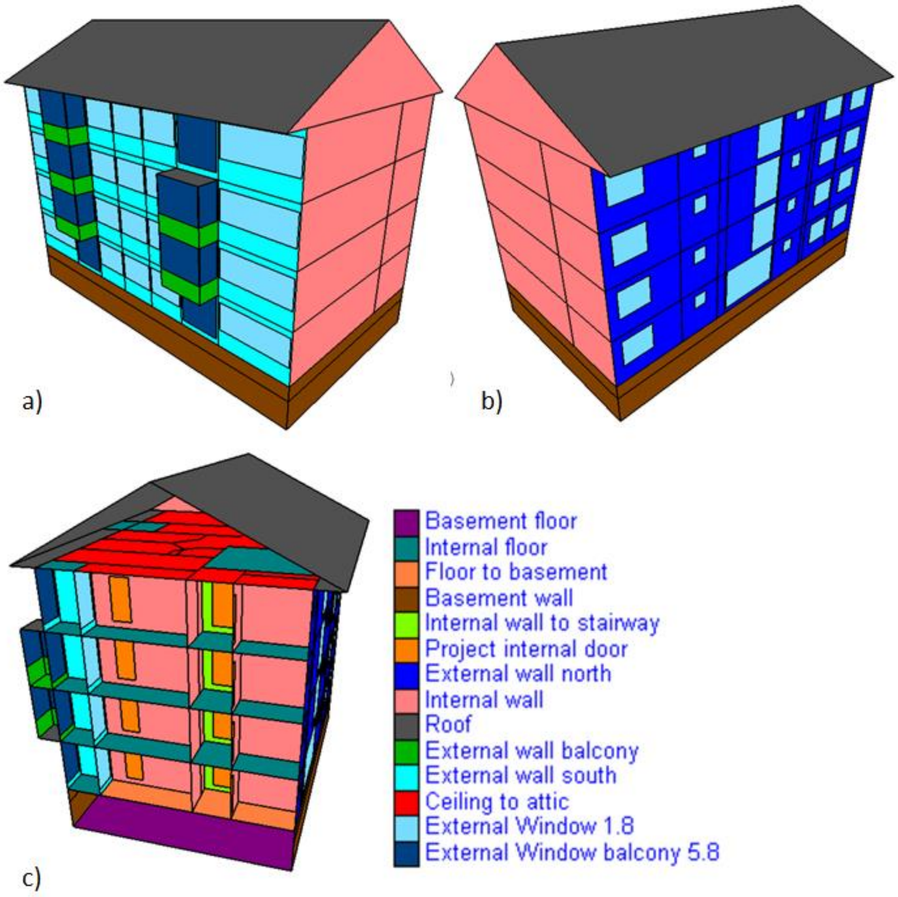

Figure 22: Model type A of Haanbaek demonstration building – each room as a thermal zone, a) South façade, b) North façade, c) Vertical section view through the model.

5.3.2 Model B

For model B, the whole staircase was modelled as one zone. All unconditioned parts were modelled as their own thermal zones. Model B represents a very simplified approach for geometry consideration and is presented in Figure 23.

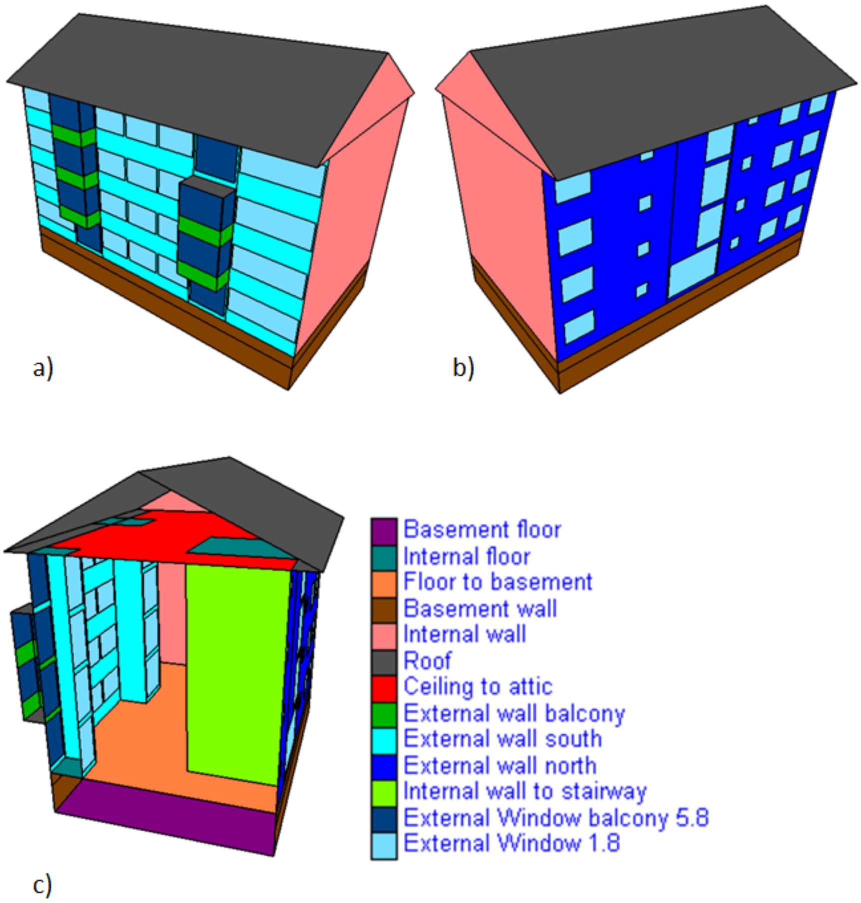

Figure 23: Model type B of Haanbaek demonstration building – whole staircase as thermal zone, a) South façade, b) North façade, c) Vertical section view through the model.

5.4 Magisterparken

The model has a boundary to the ground. The staircase's north, south, and west façades are exposed to external walls since they face outdoor conditions. The east façade is modelled as adiabatic. The balcony, corridor/stairway, attic, and basement are not conditioned and thus always are modelled as their own separate zones. The windows in the basement were disregarded, as their influence was deemed low.

5.4.1 Model A

Each apartment was modelled as a separate thermal zone for model A. his model represents a moderately detailed approach for geometry consideration and is presented in Figure 24.

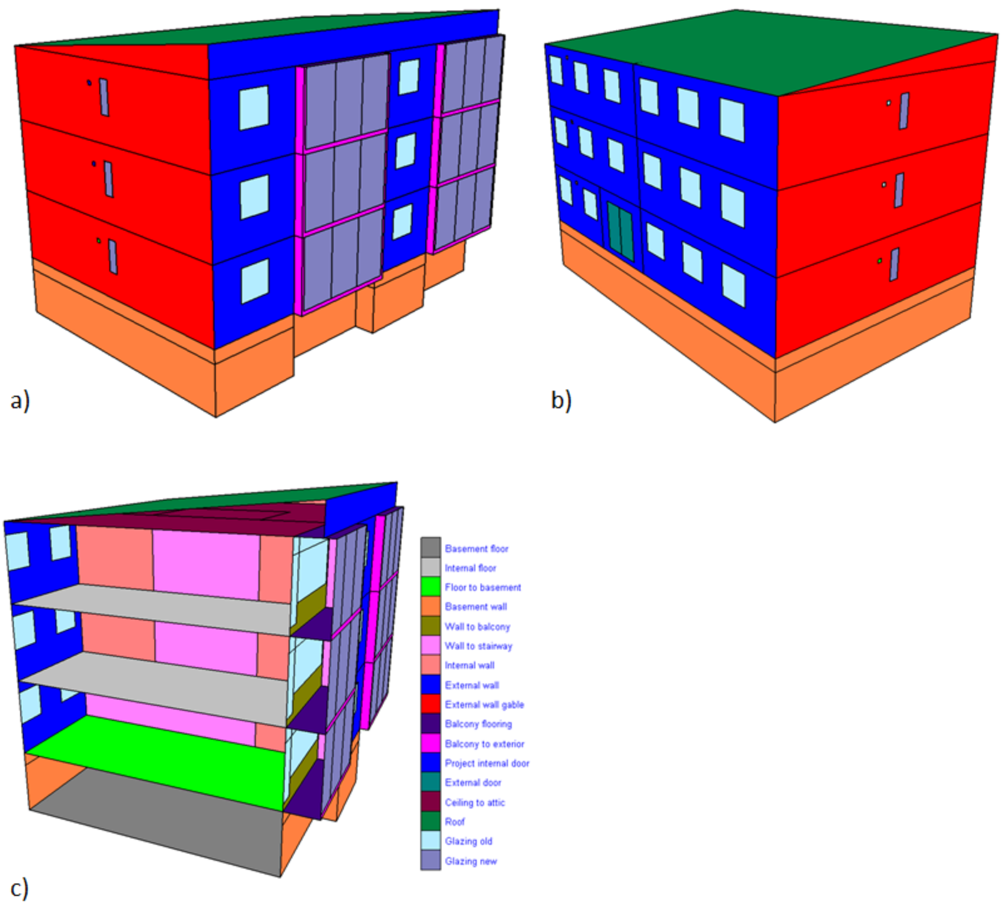

Figure 24: Model type A of Magisterparken demonstration building – each apartment as a thermal zone, a) South façade, b) North façade, c) Vertical section view through the model.

5.4.2 Model B

For model B, the whole staircase was modelled as one zone. All unconditioned parts were modelled as their own thermal zones. Model B represents a very simplified approach for geometry consideration and is presented in Figure 25.

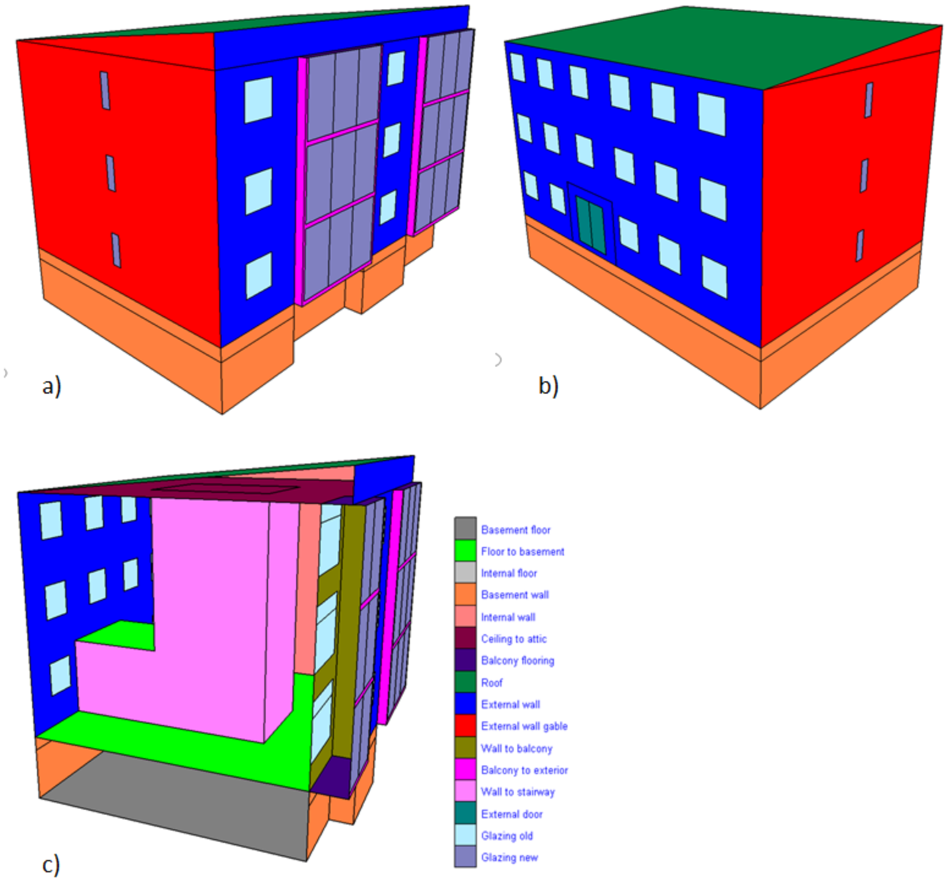

Figure 25: Model type B of Magisterparken demonstration building – whole staircase as thermal zone, a) South facade, b) North facade, c) Vertical section view through the model.

5.5 Monitoring plan

The monitoring systems installed in the demonstration pilots essentially operate on two levels. Centrally, the data from the meters, the mixing loop, and heat exchangers are collected in the technical room via wired connections and open BMS protocols (Modbus and Bacnet). For apartment and other decentralized sensing, wireless-Mbus-based "Internet of things" (IoT) sensors were used.

5.5.1 Central monitoring

The objective of the central monitoring was to build an in-depth understanding of the energy usage of the building for space and water heating (as well as ventilation in Haanbaek) and the effectiveness of the hydronic system and exchangers (which is an essential parameter in district heating).

At the central level, data is therefore acquired from the main heat meter (covering the whole heat demand of the building, as it measures demand at the point of connection with the district heating network) and a sub-meter (typically to the hot water part). It is, therefore, possible to indirectly evaluate the space heating demand by subtracting the readings from the two meters.

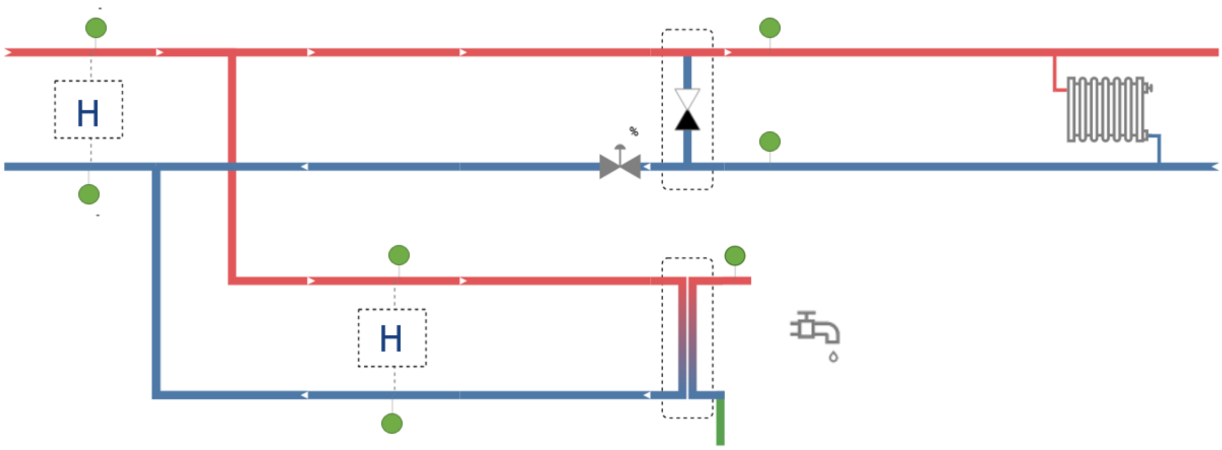

Figure 26: Sensors installed at the central level on the space heating and hot-water conversion[8]

On the Haanbaek demonstrator, a flow meter is also installed on the cold-water supply to the hot-water loop, which quantifies the tapping at the building level.

5.5.2 Apartment monitoring

The objective of the apartment monitoring was to get more detailed information on indoor climate (comfort) and energy demand at the household level, which can later be used to investigate actionable feedback to tenants and user behaviour.

[8] 'H' indicates a heat-meter, where the leftmost is the 'main' meter and the lower one is the sub-meter to hot-water, while green rounds indicate temperature sensors.

The configurations of sensors used in apartments for the three pilots are presented above (Figure 6, Figure 11, and Figure 17) and condensed in a cross-visualization in Figure 27 and equipment inventory in Table 7 below.

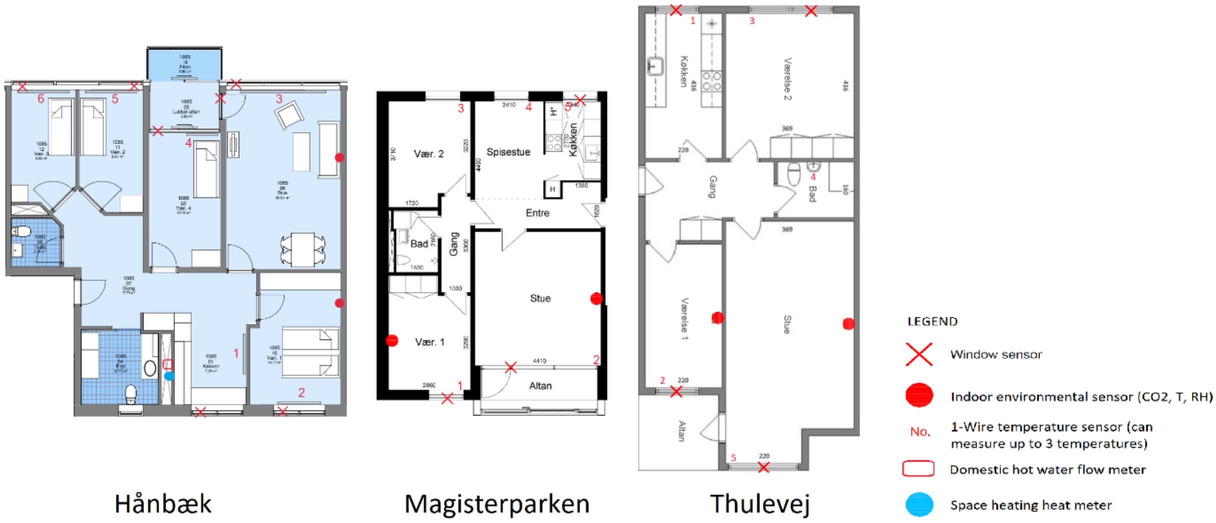

Figure 27: Overview of monitoring equipment installed in Danish demonstration buildings - example at apartment level for each location

Table 7: Overview of sensors and meters installed in the apartments of the three pilots

Sensor type	Haanbaek	Magisterparken	Thulevej
1 -wire (for indoor temperature and humidity)	9	1	2
1-wire (for common pipe measurements)	0	2	0
1-wire (for radiator measurements)	18	1	12
Indoor environmental sensor (T, CO_2, RH)	8	4	8
Window sensor (open/closed)	25	8	17
Domestic hot water flow meter (apartment level)	4	0	0
Space heating meter (apartment level)	4	0	0

Obtaining this data collection in apartments has taken longer than expected, for the reasons above in 2.1.3. The apartment monitoring has therefore started in the three pilots as follows (dates of first sensor installation): Haanbaek on 12/08/2021, Magisterparken on 25/10/2021, and Thulevej on 08/09/2021.

5.6 Cloud-based data acquisition and transfer to FusiX

The data is connected by an electronic gateway that communicates with the building equipment using the protocols mentioned above. Once it has fetched the data from them, it forwards it to Neogrid's cloud (a solution called PreHEAT) via an encrypted MQTT channel. This process is described in Figure 28 below.

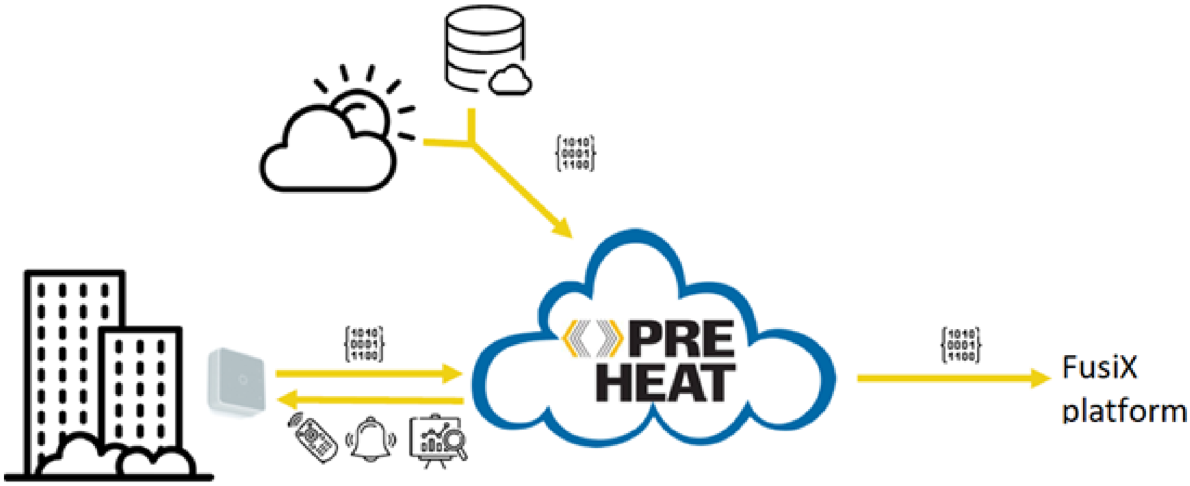

Figure 28: Data communication concept for the demonstrator

The cloud platform has a mechanism to map the signals into a building model, allowing structured analysis and visualization of the data on complex building structures. This structuring of the raw sensor data was carried out manually by Neogrid for the E-DYCE pilot buildings.

The PreHEAT platform provides a possibility to access the data directly via a REST API. This option was, however, not used in E-DYCE, as specific filtering of the data to be exported to FusiX had to be applied, which was not possible within this API. Therefore, a specific exporter was designed and applied for the project.

This automatic export was made via secure FTP, which was set from Neogrid's PreHEAT platform to EMTECH's FusiX platform. It exports data for all three pilots (both at the central and apartment levels) with a 5-minutes resolution once a day. From there, the data ingestion mechanism of the FusiX platform takes care of the data structuring and conversion, to make it usable within the E-DYCE tool.

At a later stage, a data pipeline back from FusiX to the PreHEAT platform might be implemented, in order to provide feedback to the users. This is, however, still under discussion and will be clarified in a later phase of the project, once the analysis system is fully operational.

5.7 Sensor technologies used in the demonstration

The sensors used for indoor climate monitoring were typical industrial IoT sensors for temperature, humidity, and CO_2 in indoor conditions, designed by the Swedish company Lansen Systems[9]. These sensors communicate via Wireless Mbus (which is a common protocol for IoT systems).

Four types of sensors were used:

- Indoor climate sensors measure CO_2 concentration, indoor temperature, and relative humidity (see Figure 29)
- Contact sensors to measure window/door opening (see Figure 30)
- Simple indoor climate sensors measuring indoor temperature and relative humidity
- Simple indoor climate sensors to measure indoor temperature and relative humidity with added external probes (see Figure 31 and Figure 32). These were used both on apartments' radiators and central levels to add different temperature measurements on pipes to the stairwells.

Figure 29: Indoor climate sensor with CO_2 measurement

[9] https://www.lansensystems.com/

Figure 30: Contact sensor measuring door/window opening

Figure 31: Simple indoor climate sensor (temperature & humidity) with external probes for pipes

Figure 32: Contact sensor mounted on a radiator pipe in the apartment

Due to range constraints, wireless-Mbus repeaters are also typically installed in the buildings to ensure communication between the basement (where the gateway is mounted) and the sensors out in the apartments. Other protocols, such as LoRa WAN, allow getting around this issue, as they are designed for a longer range. Although such equipment has not been evaluated in these pilots, it might be worth considering in future applications.

These IoT sensors are often not of research-grade quality. However, they provide a strong opportunity for cost-effective sensing of temperature and indoor climate measurements, which should facilitate the economic feasibility of the E-DYCE solution in the long run.

6 Use of DEPC protocol

The application of the E-DYCE DEPC protocol for the Danish demonstrators is described in this chapter. In contrast to Deliverable 2.4, this chapter addresses the specifics and particularities of the E-DYCE procedure within the Danish national context of dwellings. This chapter does not provide the results of the completed E-DYCE DEPC certification, but only outlines the strategy for implementing the E-DYCE DEPC certification for the selected demonstrators.

6.1 DEPC protocols for the demonstrators

The overall E-DYCE DEPC approach is the same for all demonstrators. Nonetheless, this approach's flexibility allows a spectrum of adjustments to ensure its applicability and customer-tailored service, independent of the building typology and national legislation. Five key aspects of the E-DYCE DEPC protocol can vary significantly among the demonstrators.

1. The dynamic model of the building (or part of the building) is developed using a BES tool, and is generally sensitive to the modeler's expertise, the inspection protocol's quality, and the information availability.

   The aspects of the dynamic model and the monitoring plan are already addressed in the previous chapters of this report. In this regard, the use of the DEPC protocol depends on a zoning approach within the model. Haanbaek and Magisterparken demonstration cases are modelled with multi-zone and single-zone approaches. Therefore, KPIs calculated at the apartment or room level are expected to be available for both demonstrators. Finally, the DEPC analysis can therefore include:

   - KPIs in the static EPC for the building (or part of the building) (EPC),
   - KPIs in the standard dynamic model (DEPC- AS),
   - KPIs in the adapted dynamic model, where the inspection and the results of the monitoring are applied to adapt the model to the actual building use (DEPC-AA),
   - KPIs are calculated based on the monitoring data (DEPC-O).

   These KPIs will be combined into information packages (sections 6.4 and 7.1 of this report), to support the extraction of specific information about the building performance, the presence of the PG, and the identification of options for its elimination.

2. The monitoring plan, its implementation, monitoring resolution, and continuity.

   The Danish demonstrators' expectation for determining these KPIs is summarized in deliverable D5.1. Meanwhile, these are quoted here for the Haanbaek demonstrator to illustrate the availability of KPIs for this demo case (Table 8). The operational KPIs that can be derived in demonstration cases depend on the installed sensors and the measured parameters. The next step will be to illustrate the information packages introduced in Deliverable 2.4, that can be generated for the given demonstrators based on KPI availability. Selected examples of relevant information packages for the Haanbaek demonstrator are provided in section 7.1.

3. Potential gaps in the monitoring plan for the realization of E-DYCE DEPC.

   The implementation of the monitoring plan matters not only in terms of availability of the operational KPIs, but also in terms of their correctness, as many E-DYCE KPIs must be calculated as annual, monthly, or weekly values, and the gaps in the data acquisition may have severe consequences for the reliability of the operational KPIs. Any gaps in the monitoring plan or its realization will lead to a deficiency of data for determining KPIs and will reduce the quality of generated information packages.

4. The availability of the EPC certificate of the demonstrator.

   All Danish demonstrators hold an EPC certificate; therefore, this is not an issue for the Danish demonstrators.

5. The motivation of the building energy professional and tenants.

   The status of the tenant's motivation is already explained in section 4.3 of this report. Their motivation plays a role in evaluating the actual/potential value of the E-DYCE DEPC for specific tenants. Low engagement among some tenants, can potentially diminish the value of the E-DYCE analysis for their dwelling. At the same time, it can have added value for the whole housing complex and society. On the contrary, the motivation among the professionals is the engagement to process all information delivered by E-DYCE analysis and to act accordingly.

Table 8 : Coverage of KPIs for Haanbaek

For tenants							
KPI	Symbol	Assessment schema				Evaluation period	
		EPC	DEPC-AS	DEPC-AA	DEPC-O	Min	Max
Global energy performance index	Q_gl			✗	✗	month	year
Final energy need for heating	f_Q_h			✓	✓	week	year
Final energy need for cooling	f_Q_c			✓	✓	week	year
Final energy need for DHW	f_Q_dh			✗	✓	week	year
Final energy need for heating for an average space in the building	f_Q_h_av			✓	✓	week	year
Final energy need for cooling for an average space in the building	f_Q_c_av			✓	✓	week	year
Operative temperature	t_op_i			✓	✓	week	
CO_2 concentration	CO2			✓	✓	week	

Fore certification party/Energy service specialist								
KPI	Symbol	Assessment schema				Evaluation period		Supporting statement
		EPC	DEPC-AS	DEPC-AA	DEPC-O	Min	Max	
Global energy performance index	Q_gl	✓	✗	✗	✗	month	year	
Primary energy need for heating	Q_h	✓	✓	✓	✓	week/month	year	[1]
Primary energy need for cooling	Q_c	✓	✓	✓	✓	week/month	year	[5]
Primary energy need for DHW	Q_dh	✓	✗	✗	✓	week/month	year	[2]
Primary electricity need for running technical installations	Q_tech	✓	✓✗	✓✗	✗	week/month	year	
Primary electricity need for lighting (if relevant)	Q_l	✓	✓	✓	✗	week/month	year	
Primary energy need for heating for an average space in the building	Q_h_av	✗	✓	✓	✓	week/month	year	[3], [4]
Primary energy need for cooling for an average space in the building	Q_c_av	✗	✓	✓	✓	week/month	year	[5]
Primary energy need for heating for the critical zone	Q_h_cr	✗	✓	✓	✓	week/month	year	[3], [4], [10]
Primary energy need for cooling for the critical zone	Q_c_cr	✗	✓	✓	✓	week/month	year	[5]
Energy signature, global solar correlated	EN_SIG_2D		✓	✓	✓	month	year	[11]
Energy signature, global solar correlated for the critical zone (heating)	EN_SIG_2D_h		✓	✓	✓	week/month	year	[10], [11]
Energy signature, global solar correlated for the critical zone (cooling)	EN_SIG_2D_c		✓	✓	✓	week/month	year	[5]
Fictious Energy need for free-running mode (cooling)	FICT_COOL	✗	✓	✓		week/month	year	[9]
Fictious Energy need for free-running mode (heating)	FICT_HEAT	✗	✓	✓		week/month	year	[9]
Number of free-running hours (cooling season)	n_fr_c	✗	✓	✓	✓	week/month	year	[9]
Number of free-running hours (heating season)	n_fr_h	✗	✓	✓	✓	week/month	year	[9]
Number of free-running hours for critical room (cooling season)	n_fr_cr_c	✗	✓	✓	✓	week/month	year	[9]
Number of free-running hours for critical room (heating seson)	n_fr_cr_h	✗	✓	✓	✓	week/month	year	[9]
Number of hours when CO2 level is below category I, for heating season	n_co2_h_bI	✗	✓	✓	✓	week/month	year	[6], [8]
Number of hours when CO2 level is below category I, for cooling season	n_co2_c_bI	✗	✓	✓	✓	week/month	year	[6], [8]
Number of hours when CO2 level is above category III, for heating season	n_co2_h_aIII	✗	✓	✓	✓	week/month	year	[6], [8]
Number of hours when CO2 level is below category I for the zone with maximum heating/cooling demand	n_co2_cr_bI	✗	✓	✓	✓	week/month	year	[6], [8]
Number of hours when CO2 level is above category III for the zone with minimum heating/cooling demand	n_co2_cr_aIII	✗	✓	✓	✓	week/month	year	[6], [8]
Operative temperature in the critical zone for heating season	T_op_cr_h_i	✗	✓	✓	✓	week	year	[6], [7]
Operative temperature in the critical zone for cooling season	T_op_cr_c_i	✗	✓	✓	✓	week	year	[6], [7]
Operative temperature in the critical zone in free-running for heating		✗	✓	✓	✓	week	year	[6], [7]
Operative temperature in the critical zone in free-running for cooling		✗	✓	✓	✓	week	year	[6], [7]

6.2 An adapted dynamic model for the demonstrators

The standard dynamic model (DEPC-AS) setup is described in chapter 5 of this report. The adapted model (DEPC-AA) represents a model of the building (or its part), adapted to approach actual building use and operation, and therefore differs from the DEPC-AS model. The adapted conditions can include such aspects as loads, set points, and schedules, which typically relate to building users and systems, as explained in the deliverable D2.4. The adapted conditions can be established in different ways. The inspection, long-term monitoring, and interviews are the main methods for identifying the adapted conditions.

For the Danish demonstrators, the inspection (Deliverable 5.1), the monitoring (section 6.5), and the interview with the tenants for four apartments in Haanbaek, four apartments in Thulevej, and two apartments in Magisterparken can allow an expert to adapt the model with regards to:

- The operative temperature in a room or apartment,
- The occupancy (number and an approximate schedule),
- The ventilation/Infiltration schedule with regards to the venting habits of the occupants,
- The assumptions for the shading properties in the model.

Section 7.2 provides an example of adapting the model for Haanbaek. For the other two buildings, the adapted conditions will be identified in the following stages of the project.

6.3 Determination of DHW use for the demonstrators

E-DYCE DEPC is dedicated to detecting the causes of the performance gap and supporting potential improvements for PG elimination and energy need reduction. Correspondingly, the total energy demand in E-DYCE DEPC approach is less important, as the focus in the E-DYCE DEPC methodology is shifted towards the distributed demands, such as energy demand for heating, cooling, domestic hot water, artificial lighting, etc.

The smart heat meters used for billing purposes in Denmark usually measure only the total heat consumed, and do not allow the split between the space heating and domestic hot water use. This challenge is resolved for one of the demonstrators Haanbaek, where the monitoring plan has determined the energy usage for space and water heating at the building and apartment level (section 6.5). For the other two demonstrators where this information is absent, a new methodology to dynamically quantify the energy need for domestic hot water in dwellings by utilizing the data from the smart meters that measure the total need for heat, is developed and described in Deliverable 2.3. Some additional information is also given below in subsection 7.1.2.

6.4 Information packages for the Danish demonstrators

The families of KPIs and their expected availability are shown in section 6.1. Meanwhile, the general families of KPIs are repeated here:

- Energy operation KPIs – precisely, the energy needs in the building support the identification of the performance gap.
- The energy signature KPIs – to ease the evaluation of the performance gap of a building/zone due to the operational thermal conditions.
- Comfort/quality KPIs – to support detecting causes for the performance gap.
- Free-running operation KPIs – to address issues in the certification of low-tech buildings and support passive strategies application in buildings.

The availability of KPIs can now be translated to the information packages that can target the withdrawal of specific information from a selected group of KPIs. Thus, the information packages are nothing other than selected specific KPIs, which are defined beforehand as a part of the E-DYCE project or can be identified later in the process, according to the user group demands.

Two main user groups identified for the demonstrators, require different degrees of detail in the information being produced. These are:

- Tenants can benefit from the information available about the performance of their own space, compared to an average apartment in the same building.

- Building energy professionals, which include: (1) the energy certification party– who materially performs energy certification analyses. (2) the professional building owners, and (3) the professional building administrators/operators. This type of user has versatile needs, ranging between the need for certification alone and the need for screening, inspection, optimization, and planning of the energy renovation of the building. For all three Danish demonstrators, this user group is represented by Neogrid, which has the professional building administrator/operator role.

E-DYCE DEPC protocol offers only one information package for the tenants, where they can follow up on the energy performance and comfort of their own space, see section 7.1.3.

The building energy professionals are offered a broad spectrum of possibilities, starting with the information package that can offer a fast screening of the building at the apartment and building level, for the identification of the performance gap and the presence of critical performance outliers within the building (at apartment or room level). Furthermore, the number of KPIs calculated for the Danish demonstrators is considerably high and allows the detection of potential causes for the performance gap. Suggestions for such information packages are described in section 7.1.

In the process of E-DYCE DEPC analysis, the user might also require information to establish the adapted conditions for the model (set-point temperature, duration of the heating season, etc.), as well as information about the effectiveness of the implementation of the adapted conditions and the general model validity. KPIs able to answer those questions will often require customization; therefore, no information is developed for this purpose.

7 Assessment methodologies

This chapter has two focus areas, one is the E-DYCE DEPC building assessment, and the other is the assessment of the model used in E-DYCE DEPC; more specifically, the methodology used for the adaptation of the model for one of the demonstration buildings (Haanbaek), is described in section 5.

The E-DYCE DEPC analysis is performed based on the asset and operational KPIs of the building, which are organized in groups or so-called information packages, to target a specific aspect of building performance. The actual E-DYCE DEPC analysis is not yet initiated. Therefore, this chapter describes only the potential application of relevant KPIs for the Danish demonstrators.

The methods used for the E-DYCE DEPC significantly depend on the measurements still being collected at this stage. Therefore, some new methodologies are developed with other datasets, to be applied afterward to the project's demo cases. The motivation for this approach is to apply the gathered measurements, to have an accurate overview of the energy usage in buildings and calibrate the simulated models. A short explanation of these new methodologies is also included in this chapter.

In the following subsections, the availability of KPIs and the information that can be extracted from the corresponding information packages are provided, with the Haanbaek demo case in mind, as the best-monitored demonstrator with the highest potential.

7.1 Building assessment

E-DYCE DEPC building assessment protocol is described in Deliverable 2.4, where the specifics of the assessment for the Danish demonstrators are highlighted in chapter 7. This section of the report will focus on the expected outcome of such an assessment. It is evident that an increasing number of KPIs, a large number of thermal zones in the model, and advancements in monitoring can result in information overflow. Meanwhile, some critical KPIs can still be missing. Thus, the information packages come in use to reduce this risk, and to offer general or specific information in a structured way.

The information packages addressing user groups and their needs are detailed in the following sections. The packages that introduce novel KPIs are described in more detail to include relevant background information and an explanation of the methodologies used. Meanwhile, those with straightforward content will be briefly mentioned.

7.1.1 Background for disaggregation of SH and DHW

Several methodologies have been developed and applied to different building cases, when considering research in building energy assessment. They span from equations used to estimate a steady-state heating demand, simulation tools that assess the different dynamic dependencies (solar, occupancy, ventilation, etc.) on the energy needs and building standards that enforce good construction practices, to the new trend of data-driven methods applied in the building sector. On the Danish side, energy efficiency has been one of the main drivers of building regulations (Rohde et al., 2020), making Denmark one of the front-runners in the green energy transition. One of the topics of this green transition focuses on building heating usage. This focus is derived from the European Union (EU) building sector accounting for 40% of its total energy (European Commission, 2022), and without reducing it, the EU will not be able to reach its energy goals.

In Denmark, most of the buildings' heating demand is provided by the district heating network, used for space heating (SH) and domestic hot water (DHW) needs. These two types of heating needs are significantly different from each other. The SH primarily depends on the building's thermal characteristics (envelope insulation level, tightness, etc.), heating source efficiency, and users' indoor preferences. While DHW usage is more dependent on its system design/layout, the number of people, and usage routines (e.g., cooking, showering, etc.). Even though the two hot water demands differ from each other, due to billing purposes only the total heat usage (SH and DHW combined) is measured by smart energy meters. Doing so, makes it difficult to assess which of the two heating demands is mainly responsible for the energy performance gap in buildings.

In the following sections, two main methodologies are described to assess energy assessment in buildings. The first part briefly explains a method to separate SH and DHW from the total energy measured by the smart heating meters. The second methodology currently in development, is regarding the application of energy signature models, to infer some of the thermal characteristics of the buildings and the user's behaviours.

7.1.2 SH and DHW disaggregation methodology

As specified in Pomianowski et al., 2020, the share of energy for DHW production in buildings has increased over the years and is expected to continue in the future. As seen in measurement campaigns, typical Danish dwellings dedicate between 20% to 35% of their total energy needs to DHW production and operation (Bøhm et al., 2009 and Bøhm, 2013). This share increases even more to 40 – 50% in recently built energy-efficient dwellings (Bøhm et al., 2009; Bøhm, 2013; and Erhorn and Erhorn-Kluttig, 2014). From these campaigns, it is argued that this increased DHW share is due to overlooked energy-efficiency initiatives, while other heating utilities had their shares reduced due to systems' technology advancements and tighter energy regulations. Moreover, it is also assumed that this tendency is similar in other countries.

It can be concluded that currently, the best way if not the only possible to assess energy use for DHW with measurements, is to derive it from the heat measurements. In order to disaggregate these energy shares from the total measurements, we defined a simple methodology to estimate the hourly heating demand (space heating and DHW) of residential dwellings. The method is a 3-step algorithm, as one can see in Figure 33.

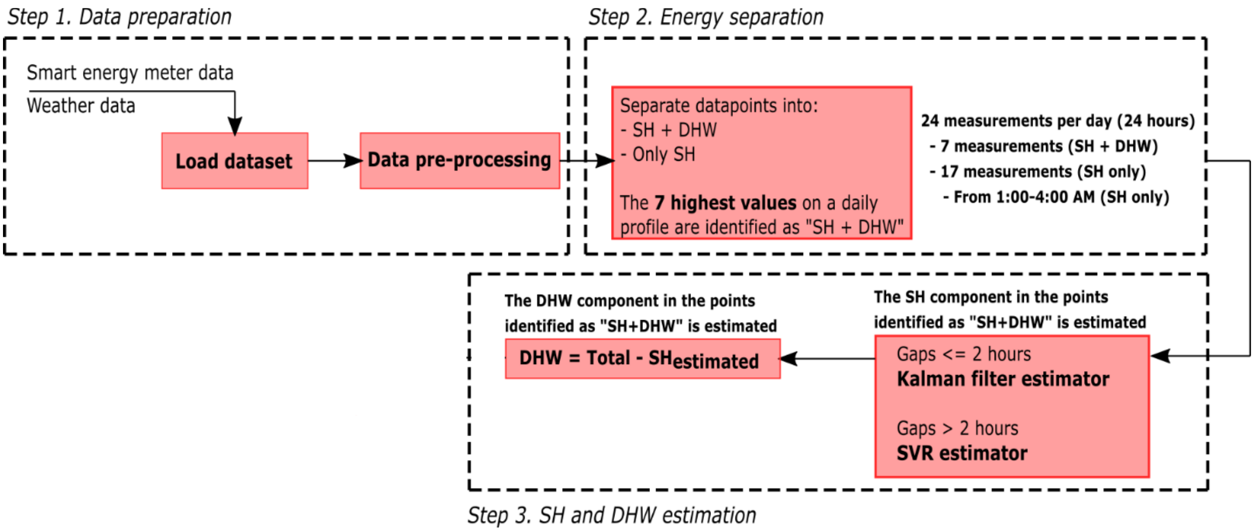

Figure 33: Disaggregation methodology.

The method estimates the space heating and DHW using 1-hour resolution measurements, depending on a few additional information (i.e., weather conditions). The methodology assumes that the space heating system is constantly running in the heating season, while DHW production is more predominant in the warmer months. Regarding the residence's daily heating profiles, DHW is foreseen to be sporadically produced throughout the day. Thus, during a day (which has 24 recorded data points), only a few of these points will consist of combined SH and DHW usage, whereas the other measurements will be SH usage alone. Therefore, after the measurements are pre-processed (step 1), the algorithm attempts to detect the points where the DHW is produced. To accomplish this task, the seven highest points between 5:00 – 24:00h are labelled as "SH + DHW", while the others are space heating (SH) alone (step 2). In step 3, the space heating in the "SH + DHW" labelled points is estimated using different data-driven methods. In contrast, the DHW use is determined a-posteriori, by the difference between the total measured energy and the estimated space heating.

7.1.2.1 Results

To validate this methodology, several datasets with separated heating measurements are used. As explained above, these datasets are not from the pilot cases because their measurements are still being gathered. This validation tries to tackle the robustness of the method, by comparing its performance for different building types (residential and non-residential) located in different countries, with different heating centrals (instantaneous and stored water heaters) and different measurements resolution (decimal and rounded measurements). In Table 9 it is seen the different characteristics of the datasets.

Table 9: Validation dataset of the disaggregation method.

Country	Type of building(s)	Main characteristics	Type of data
Denmark	28 single-family apartments	The measurements correspond to the primary circuit of the heat exchanger of each apartment.	Hourly heating measurements per apartment. The same dataset was tested for

			decimal and rounded measurements.
Switzerland	Multi-family apartments block	The measurements correspond to the primary circuit of the building. The DHW production is through a storage water tank.	Hourly heating measurements of the entire apartment block (aggregated data)
Italy	Theatre	The measurements correspond to the primary circuit of the heat exchanger installed at the substation.	Hourly heating measurements for the theatre
Italy	Rehabilitation institution	The measurements correspond to the primary circuit of the heat exchanger installed at the substation.	Hourly heating measurements for the rehabilitation institution

This work also compares this methodology with each country's annual DHW compliance calculation. These compliance calculations are used to estimate the DHW usage in the current EPCs, and depend on the heated area and/or the number of people. In Table 10, the results from the DHW estimations are given.

Table 10: Comparison of countries' compliance predictions and the method's estimation results[10]

Country	Case building	Error		
		Compliance	Round	Decimal
Denmark	Apart 666	-47%	97%	0%
Denmark	Apart 668	-42%	103%	21%
Denmark	Apart 669	-11%	102%	22%
Denmark	Apart 670	-72%	21%	-6%
Denmark	Apart 671	-34%	108%	20%
Denmark	Apart 697	-76%	12%	-12%
Denmark	Apart 698	-75%	21%	-7%
Denmark	Apart 699	-76%	10%	-13%
Denmark	Apart 700	123%	510%	85%
Denmark	Apart 701	-1%	93%	18%
Denmark	Apart 702	87%	182%	32%

[10] The green-coloured cells indicate the best (orange colour – the worst) performing method between this research's method (rounded and decimal measurements) and the DHW compliance calculations.

Denmark	Apart 724	-28%	89%	11%
Denmark	Apart 726	43%	70%	14%
Denmark	Apart 727	61%	149%	18%
Denmark	Apart 728	11%	152%	37%
Denmark	Apart 729	14%	119%	12%
Denmark	Apart 730	-57%	43%	5%
Denmark	Apart 731	90%	273%	63%
Denmark	Apart 732	-60%	24%	-15%
Denmark	Apart 734	59%	144%	17%
Denmark	Apart 735	-50%	44%	6%
Denmark	Apart 736	-51%	40%	1%
Denmark	Apart 739	-68%	34%	7%
Denmark	Apart 740	1%	75%	-3%
Denmark	Apart 741	-30%	59%	7%
Denmark	Apart 742	0%	121%	15%
Denmark	Apart 743	-64%	29%	-13%
Denmark	Apart 745	78%	265%	69%
Switzerland	Apart. block	4%	-9%	-
Italy	Rehab inst.	-59%	-79%	-
Italy	Theatre	-35%	154%	-

As shown in Table 10, there are three types of values per DHW usage. The error between the actual DHW demand and the compliance calculation (compliance column), the error between the measurements and the estimated DHW from the developed methodology (rounded column), and the error between the measurements and the estimated DHW (decimal column). The table has different colours: green represents the smallest error, and dark orange the largest error. In most apartments, the developed methodology outperforms (green colour) the current compliance calculations. However, the methodology requires decimals values. If not, as the results show, the error between the measurements and estimation increases significantly.

Even though the disaggregation method has a good performance in estimating the DHW usage for most apartments, there are few cases where the error is significant. It might be due to numerous measurement hours missing in the initial dataset, or the lack of dwellers in the households during the measurement period (total heating equal to zero – no consumption). However, from the results it is argued that the method can be applied to predict the household's DHW energy use, instead of what has been used to make the dwelling's energy assessment in Denmark. Also, it is clear that basing the Danish DHW compliance calculations only on the building area, is imprecise; hence the research must shift towards the occupancy number and its behaviour. Compared to the national compliance calculations, the methodology underperformed in the Switzerland and Italy cases (large buildings). In order to improve these cases' results, it is envisioned that by having a DHW schedule to detect "SH + DHW" points, the methodology's performance might increase.

7.1.2.2 Further work

For further work, more datasets must be used for more extensive validation and robustness analysis of the method. Another aspect to consider is the improvement of the separation methodology, for rounded measurements and non-residence buildings. This improvement is expected to be made by developing an algorithm, to convert the rounded heating measurements into decimal values. Moreover, implementing an expected DHW schedule to detect "SH+DHW" data points, might improve the methodology for non-residence buildings. After the pilot cases' datasets are ready, this methodology will be applied to their measurements.

7.1.3 Information package for the tenants

This package (Table 10) includes the final energy for the space heating and DHW (asset and operational), so that the user can follow up if there is any gap regarding the pay bill and the potential for savings. Furthermore, it allows the user to see how good/bad the situation is for this apartment, compared to the rest of the building. The final energy need (not primary) is selected as a relevant KPI for the tenants to avoid any confusion that can take place when the user compares the data from E-DYCE DEPC with the energy bill.

Table 11: Information package for tenants

KPI	Symbol	Unit	Assesment schema
Final energy need for heating	f_Q_h	kWh/m2 per period	DEPC-AA
			DEPC-O
Final energy need for heating for an average appartme	f_Q_h_av	kWh/m2 per period	DEPC-AA
			DEPC-O
Final energy need for DHW	f_Q_dh	kWh/m2 per period	DEPC-AA
			DEPC-O
Final energy need for DHW for an appartment space in	f_Q_dh_a	kWh/m2 per period	DEPC-AA
			DEPC-O
Operative temperature	t_op_i	oC	DEPC-AA
			DEPC-O
CO_2 concentration	CO2	ppm	DEPC-AA
			DEPC-O

7.1.4 Information package for screening (for building professional)

Fast screening can ensure a complete overview of the building performance for all monitored KPIs. Here, the period for which the screening is performed can become essential for the availability of the KPIs, and the short screening periods might be inappropriate. Typically, the screening is to be performed over a longer period, for example a year or a month, and includes all families of KPIs.

The KPIs are provided for:

- The standard and adapted model to evaluate the significance of specific use of building/apartment for the PG.
- The operational data, to establish the actual performance gap concerning the standard and adapted model and to screen the applicability of the adapted model.

The Energy KPIs allow to identify the presence of the energy performance gap, and to map the difference between the average building performance and the presence of outliers within the building (critical apartment), as seen in Table 12.

Table 12: Energy KPIs for screening

KPI	Symbol	Unit	Assesment schema
Primary energy need for heating	Q_h	kWh/m2 per period	EPC
			DEPC-AS
			DEPC-AA
			DEPC-O
Primary energy need for DHW	Q_dh	kWh/m2 per period	EPC
			DEPC-AS
			DEPC-AA
			DEPC-O
Primary energy need for heating for a critical zone	Q_h	kWh/m2 per period	EPC
			DEPC-AS
			DEPC-AA
			DEPC-O
Primary energy need for DHW for a critical zone	Q_h	kWh/m2 per period	EPC
			DEPC-AS
			DEPC-AA
			DEPC-O

The comfort/quality KPIs will help to identify if there is any significant overventilation in the building leading to increased heating demand, as well as to identify issues with the thermal comfort, which cause overventilation or simply result in increased heating demand.

Table 13: Comfort KPIs for screening

Number of hours when CO2 level is below category I, for heating season	n_co2_h_I	-	
			DEPC-AS
			DEPC-AA
			DEPC-O
Number of hours when CO2 level is below category I for the zone with maximu	n_co2_h_I	-	
			DEPC-AS
			DEPC-AA
			DEPC-O
Operative temperature in the critical zone for heating season	T_op_cr_h_i	oC	
Average operative temperature in the building during heating season	T_op_av_h_i		
			DEPC-AS
			DEPC-AA
			DEPC-O
Operative temperature in the critical zone for cooling season	T_op_cr_c_i	oC	
Average operative temperature in the building during cooling season	T_op_av_c_i		DEPC-AS
			DEPC-AA
			DEPC-O

Finally, the free-running KPIs which are expressed in the free-running hours and the fictitious energy for free running, can be used to identify whether the passive strategies in the building are adequately engaged, and if there is a potential for optimizing its performance.

Assuming that the adapted model of the building performance is evaluated to be sufficient and the critical zones within the building are properly identified, then the screening of the Haanbaek demonstrator will allow the positioning of the overall building operation against its asset rating. Furthermore, simultaneous screening of all possible thermal zones within the building, will allow identifying areas for further analysis.

7.1.5 Information package for energy signature – total heating usage assessment (for building professional)

As mentioned above, several models and tools exist to assess building energy usage. One of these models is called *energy signature* (ES). The energy signature of a building is the model retrieved from the energy measurements combined with its climate conditions, which in most cases is the outdoor temperature. This model is selected to assess energy usage in the demo cases of this project.

7.1.5.1 Definition of the energy signature model

The ES model takes into account the dependency between the building's energy usage (i.e., heating, cooling, DHW, etc.) and the outdoor temperature. However, some model variations account for other climate parameters, such as solar radiation, wind speed, and humidity. By considering only the external temperature, the definition of ES is derived from the heat balance equation in buildings, as one can see in Equation 2 and Equation 3.

For the heating season (cold months):

$$E_{trans} + E_{vent} - E_{sun} - E_{int} - E_{heat} = \frac{\partial E}{\partial t} \quad (2)$$

Equation 2: Heat balance for the heating season

For the no heating season (warm months):

$$E_{trans} + E_{vent} + E_{sun} + E_{int} - E_{cool} = \frac{\partial E}{\partial t} \quad (3)$$

Equation 3: Heat balance for the no heating season

All the parameters in the equations represent the existing energy gains and losses in buildings and are outlined in Table 14.

Table 14: Heat balance variables definition

Parameter	Definition
E_{trans}	Transmission heat losses/gains through conduction in the building envelope
E_{vent}	Ventilation heat losses/gains through air openings, ventilation supply systems, infiltration
E_{sun}	Heat gains through solar radiation
E_{int}	Internal heat gains through equipment, people metabolism, lighting
E_{heat}	Heating system output
E_{cool}	Cooling system output
$\partial E/\partial t$	Heat variation through time regarding the building's thermal inertia

In this study, the focus is on the heating season (Equation 2). According to Hammarsten, 1987, in order to remove the thermal inertia influence on the measurements, the data granularity must be with a minimum daily resolution. With this condition, Equation 2 is changed to:

$$E_{trans} + E_{vent} - E_{sun} - E_{int} - E_{heat} = 0 \quad (4)$$

Equation 4: Heat balance for the heating season without dynamic effects (daily or lower resolution)

All its parameters express the heat gains and losses on a daily, weekly, or monthly resolution. The outdoor temperature is averaged according to the chosen resolution. The ES model, when expressed linearly (*y = mx + b*), is derived from Equation 4:

$$E_{heat} = -(UA + n\rho c_p)T_o + (UA + n\rho c_p)T_i - E_{gains} \quad (5)$$

Equation 5: ES model (linear regression)

Where the *UA* (overall thermal transmittance in kWh/°C), $n\rho c_p$ (ventilation rate in kWh/°C), T_o and T_i (outdoor and indoor temperatures in °C), and E_{gains} (sum of solar and internal heat gains). The ES equation can be plotted in the cartesian plane, as shown in Figure 34.

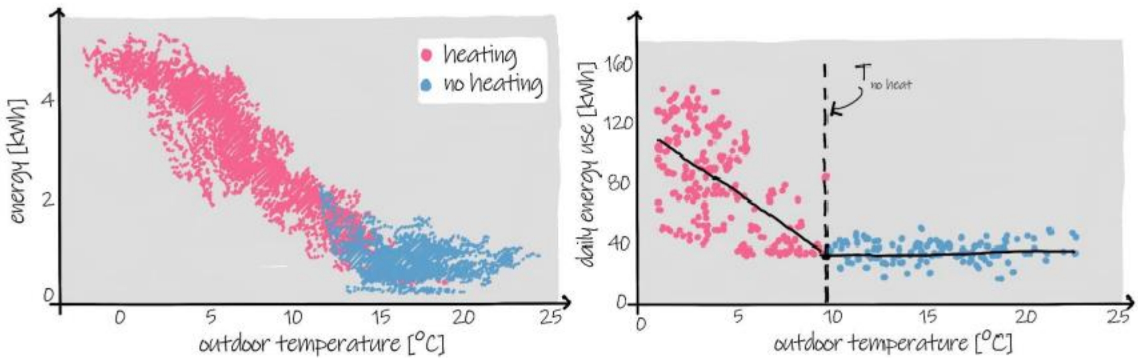

Figure 34: Representation of the linear ES model (Chiesa et al., 2020)

The plot is divided into two areas, heating season (in pink) and no heating season (in blue). The heating season is defined by Equation 5 and characterized as linear regression. The no heating area is described as a horizontal line, demonstrating that outdoor temperature does not influence energy usage. The energy measurements of this dataset in this area are due to the DHW production. Therefore, Equation 5 is adjusted to address this energy usage.

$$E_{DH} = E_{heat}(T_o) + E_{DHW} \tag{6}$$

Equation 6: ES model (linear regression) with DHW production

While analysing Figure 34, specific indicators can be retrieved from it. The heat loss slope (m_{loss}) and the change-point temperature (*CPT*). The m_{loss} defines the heating losses from transmission and ventilation as defined in Equation 5 in kWh/°C.

$$m_{loss} = -\left(UA + n\rho c_p\right) \tag{7}$$

Equation 7: Slope of the ES model

The *CPT* represents the outdoor temperature value separating the heating and no heating areas and is defined in Equation 8 in °C.

$$CPT = \frac{E_{DHW} + m_{loss}T_i + E_{gains}}{m_{loss}} \tag{8}$$

Equation 8: CPT of the ES model

If the heating measurements are only space heating, then $E_{DHW} = 0$, and *CPT* is described as:

$$CPT = T_i - \frac{E_{gains}}{UA + n\rho c_p} \tag{9}$$

Equation 9: CPT of the ES model without DHW production

These are the main equations behind the ES model. Even though this model is simple and applicable for all building cases, it also has its pitfalls. Table 15 lists the benefits and drawbacks of the application of the ES model.

Table 15: List of benefits and drawbacks of the ES model

Benefits	Drawbacks
Highly researched and applied model in the building sector.	It is a static model. Therefore, it does not account for the dynamic thermal behaviour of the buildings (i.e., thermal inertia). Also, if used, the basic ES model (linear dependency only on outdoor temperature) does not describe solar gains, infiltration, and user behaviour.
It can be applied for different measurement resolutions (e.g., daily, weekly, monthly, etc.)	The parameters obtained from the linear regression are more likely to be biased due to multi-collinearity (variables correlated with each other, e.g., solar radiation and outdoor temperature), measurement errors, etc.
Simple to understand and computationally cheap.	It is based on certain constant factors, e.g., indoor temperature.

7.1.5.2 Energy signature analysis

According to the table above, it is seen that the linear parameters retrieved from the model are more likely to be biased. However, the shape of the plot (data points distribution) can be used in the energy assessment, to infer the different household characteristics and compare the residences with each other.

The first characteristic to be investigated is the linear shape of the plots. As seen in Equation 7, the slope is influenced by the ventilation and transmission losses. Because the U-value is constant, then these values are due to the ventilation rate. Therefore, by comparing two buildings, the slopes might indicate which buildings have higher air rates. Another aspect of comparing the plots is their measured energy range. In this case, it is suggested to plot the energy values divided by the heated area of the household. A large energy range comparing similar dwellings, shows that the high energy usage is due to large DHW production or higher SH usage.

Another aspect is the plots' tails (as shown in Figure 35). This hypothesis has already been developed in Westermann et al., 2020 and Nageler et al., 2018, and it is planned to apply these ES model's characteristics in this assessment.

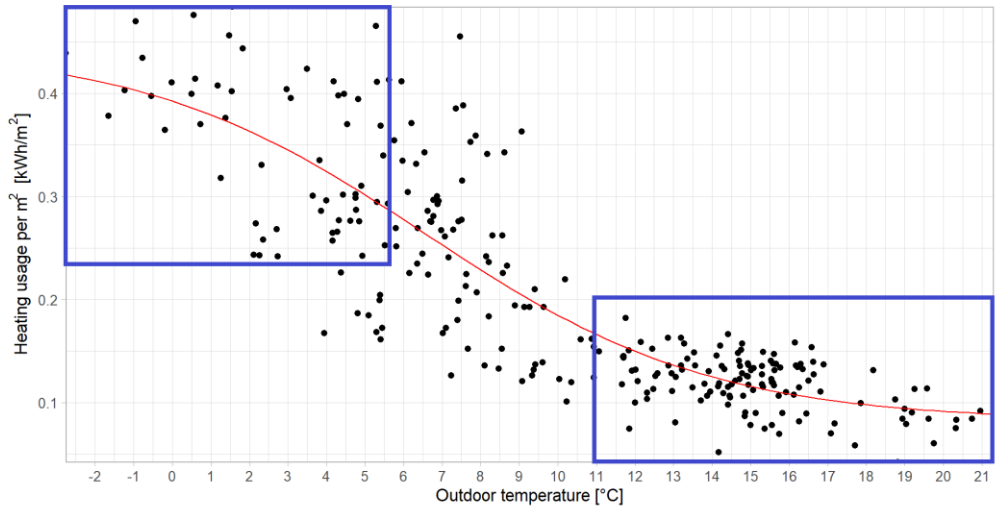

Figure 35: Representation of ES plot for a single-family apartment with its tails (marked in blue)

The right tail of the ES plot is due to the daily energy usage in warmer months (no heating season), where the heating usage is predominantly due to DHW production. The left tail is still unknown, but according to the literature (Westermann et al., 2020), some buildings have this function shape. The same article theorized that this tail is due to other heating systems associated with the main one. However, their primary heating system is from an electric source. Nageler et al., 2018 argues that this curve stabilization is due to the heating reaching its maximum design output. However, it is not likely, because the temperature where the stabilization starts is much higher than the usual external design temperatures. Another hypothesis for the curve is due to the significant reduction of the natural ventilation, when the temperatures decrease below a specific value (i.e., people open their windows less when the outside temperatures are low). From all these possible theories, understanding these shapes can become useful in understanding certain aspects of the building's thermal characteristics and heating systems.

Another aspect of the ES model is the presence of outlier measurements. These values can be measurement errors from the smart heat meters, user behaviour, system faults, etc. Therefore, assessing these data points is necessary to detect possible factors, that increase the building's energy performance gap. In Figure 36, it can be seen an ES plot of a single-family apartment with outliers in the heating measurements.

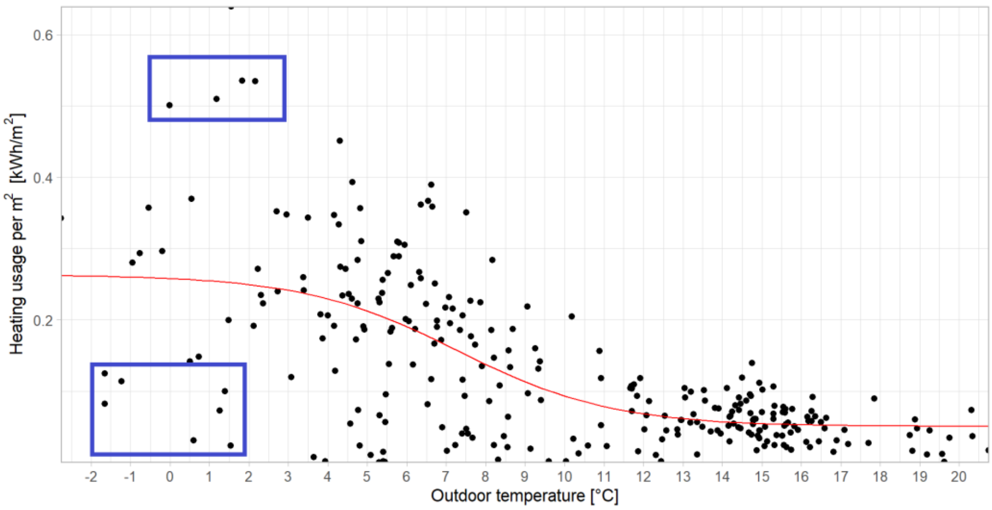

Figure 36: Sigmoid function of the ES model of a single-family apartment with outliers (marked in blue)

One last point of this ES plot assessment is the analysis of the distribution of the different data points in the cartesian plan. This is accomplished by defining the distribution of the data points, measured by the heating meters according to the temperature and energy values and comparing them with other building cases. As shown in Figure 37, the green histograms represent the distribution of the data points, over outdoor temperature (x-axis) and total heating per m^2 (y-axis).

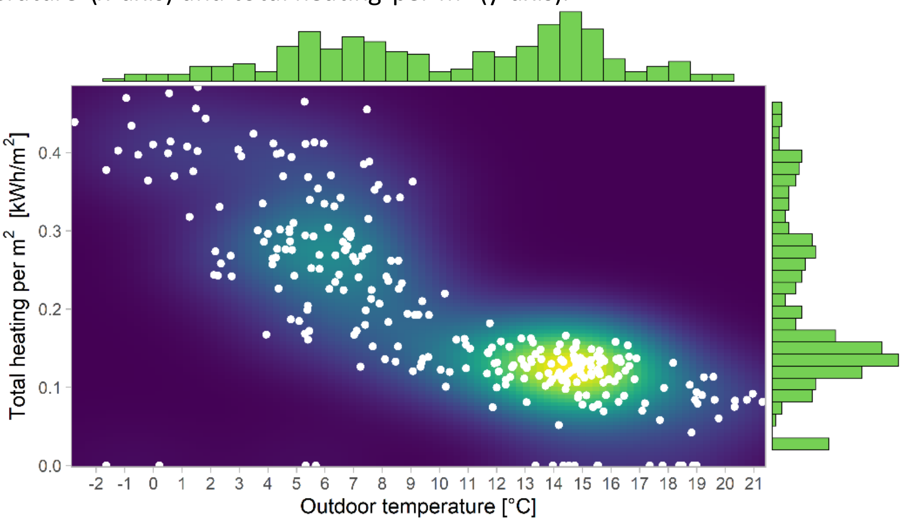

Figure 37: ES plot with its data points distribution (green histograms)

This plot shows how the data points are distributed in the axes; each distribution can be characterized by three main variables: mean value, standard deviation, and skewness. This method aims to calculate all distribution variables (total heating and outdoor temperature) and compare these values between buildings. Accordingly, the outdoor temperature distribution will be similar in buildings located in the same area. However, a building with several missing measurements in the dataset can be spotted through these values. The energy distribution shows the range of heat output measured in the building and its shape. By retrieving the buildings' parameters, it is envisioned that it is possible to cluster them according to their distribution. The clustering process is still under research; however, the preliminary results section shows the current results of applying a principal component analysis (PCA), in the different distribution parameters.

7.1.5.3 Preliminary results

Currently, this methodology is being developed using different building cases, which are not the demo cases from this report. The used dataset is constituted of 28 single-family apartments in Aalborg, Denmark. All apartments are from a social housing complex renovated following the Nearly Zero-Energy Buildings (NZEB) standard. The space heating system includes radiators in the main rooms, and underfloor heating in the hallways and bathrooms. Moreover, the total building's heating demand is provided by the district heating network from *Aalborg Forsyning*.

Regarding the ES model, a piecewise linear regression of two linear equations is implemented for each apartment. These equations refer to the heating season (space heating is predominant), and no heating season (DHW is predominant). The transition point (change-point temperature, *CPT*) defines the separation between these seasons. The energy (y-axis) is the total daily heating usage per m^2, while the x-axis is the external temperature. From the application and visualization of the ES model, it is observed in several dwellings the existence of the tails (stabilization of the measurements on the extreme outdoor temperature values), which makes it possible to characterize the heating output as a sigmoid function as one can see in Figure 38.

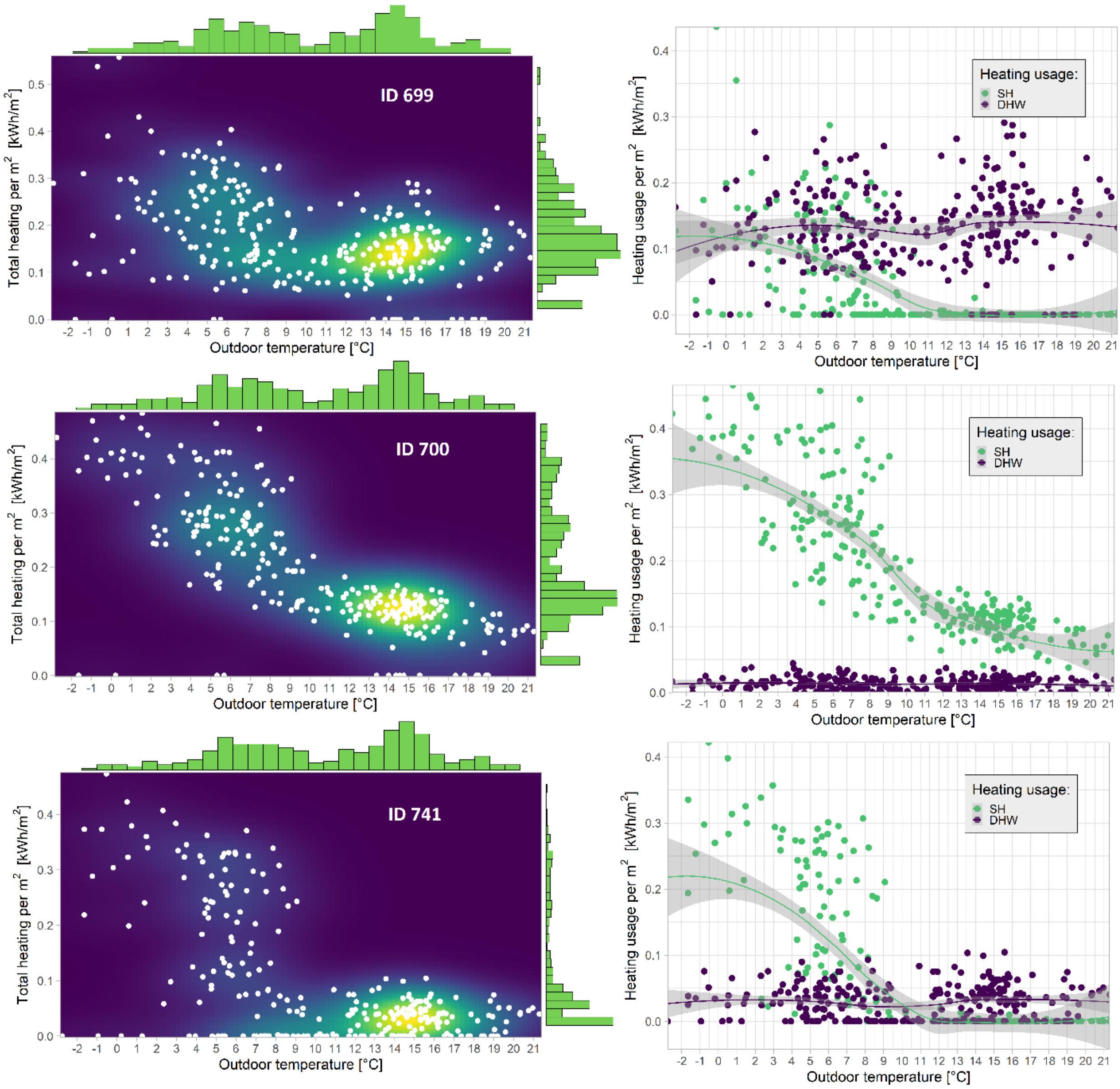

Figure 38: ES plots of three single-family apartments

When the distribution parameters are retrieved from each apartment's ES plots, they are mapped in a PCA plot. The dwellings of this dataset are categorized into three types of buildings, according to the information provided by the building company. The categories are: "Big - renovation", "Standard - renovation", and "Terraced house". The results from the PCA are seen in Figure 39.

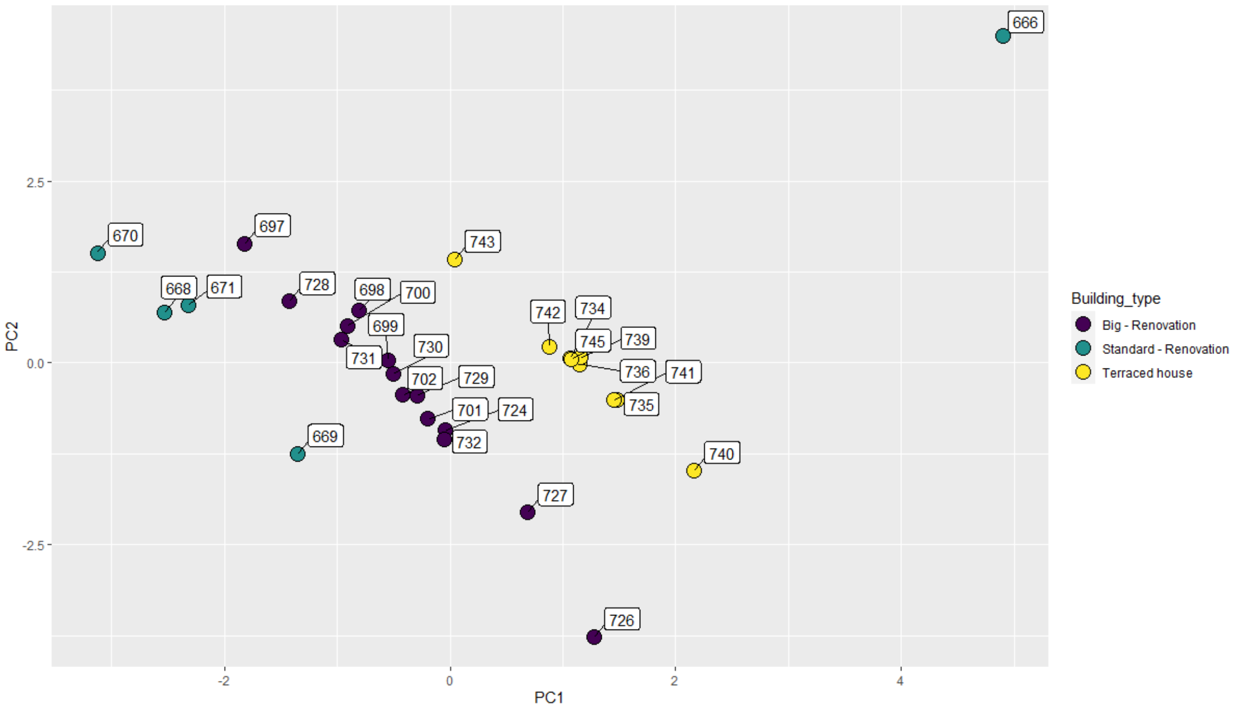

Figure 39: PCA of 28 single-family apartments according to their distribution parameters

The different categories can be easily identified in the plot. These apparent clusters seem accurate due to the buildings being so similar in terms of construction layout, heating systems, etc. In the plot, it is also possible to observe the buildings that are outliers, according to their ES model. The most extreme case is apartment ID 666, the only one of the 28 dwellings with significantly fewer measurements.

More research must be done on how to use the heating measurements to comprehend the assessed buildings more. Besides the methodology for separating the space heating and domestic hot water usage in total energy measurements, a larger step must be taken to unravel the buildings' thermal properties. For the current project, it is envisioned to use the energy signature model as a characterization methodology to correlate the measurements of the outliers, the function shape, and the data points distribution, with the ventilation and solar radiation impact on the heating demand, and the influence of the user's behaviour on the overall consumption.

7.1.6 Information package for inspection of the energy use

If the user wishes to inspect the primary energy use in the building in detail, all KPIs in the energy family become useful (Table 16), in addition to the energy signature described in the previous section.

The energy use inspection is typically necessary when the screening (section 7.1.4) is completed and it is established that there is a performance gap present. The screening is typically performed over a longer time-period (a month or year) and therefore it can be difficult to conclude about the cause for the PG.

In order to identify the cause of PG, or specify the period of time it occurs or identify the zone where PG is prevailing, the inspection of the energy use is carried out. This action can be successfully combined with the inspection of zones in the buildings, to identify those with the highest heating demand, their set-point temperatures, heating season duration, etc.

The main difference in this step from the ones described in section 7.1.4 is the time-resolution of KPIs, which must be higher, for example weekly values, to identify when and where the PG appears or using the timeseries to zoom in on the problem.

Table 16: Energy-related KPIs.

Global energy performance index	Q_gl
Final energy need for heating	f_Q_h
Final energy need for cooling	f_Q_c
Final energy need for DHW	f_Q_dh
Final energy need for heating an average space in the building	f_Q_h_av
Final energy need for cooling an average space in the building	f_Q_c_av

If the space heating PG is present, but its causes are not fully identified. Then, with a short time resolution, the comfort family of KPIs can be analysed, with the focus on over- and under-ventilation of the dwelling. An example of this analysis is given in Figure 40 below, where specific periods (spring and autumn) are characterized by significantly different atmospheric comfort in the monitored dwellings.

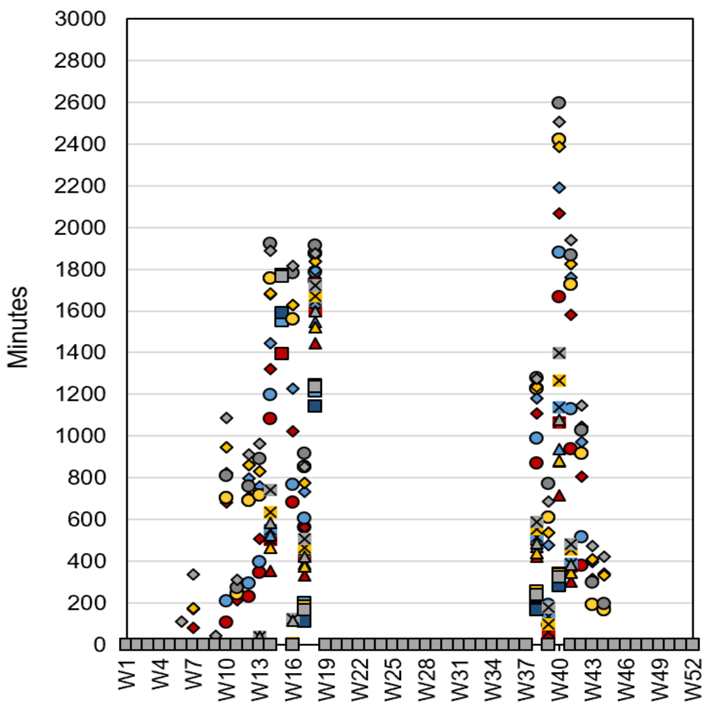

Figure 40: An example plot of under-ventilation during the year for different zones in the building

In addition to the actual energy use, the building can be inspected in terms of the fictitious energy use for cooling or heating in the free-running mode. Too high fictitious energy use would signify a low level of comfort in the occupied spaces, and the potential need for further inspection to evaluate whether the passive strategies in the building are less efficient than they are assumed to be in the model, or if the occupant's behaviour is the main cause for the PG or other issues are present. The user must be helped in assessing all this information by an efficient graphical interface, for example as in Figure 41, that illustrates a large amount of data in one plot, supported by the data provided as the time series.

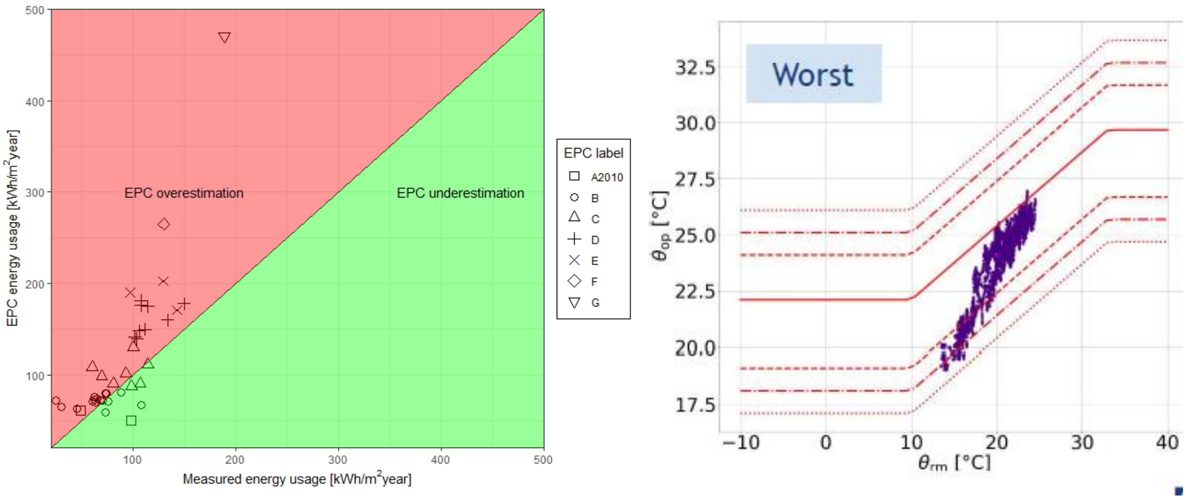

Figure 41: Example of graphics for plotting KPIs

7.2 Adapted model assessment

The standard dynamic models for Haanbaek and Magisterparken demonstrators are briefly described in chapter 5. At this stage, it is essential to mention that these models correspond to the DEPC-AS assessment scheme, and do not consider any specifics of the actual building operation.

The adapted models (DEPC-AA) are therefore compulsory for the E-DYCE project, as they are meant to address the actual building performance, addressing the actual dynamic capabilities of the building (i.e., dynamic solar shading) or non-standard user behaviour, occupancy, or comfort-preferences, etc.

This chapter provides an initial example of model-adaption, performed for several models for the Haanbaek demonstrator models. The overall schema for this process is shown in Figure 42 below. The example includes an adaptation of the model with regards to:

- The weather data (the monitoring data replaces standard weather file),
- The heating set-point adjustment according to monitored data,
- The adaptation of the ventilation rate from DS/EN 16798-1, 2019 to correspond to 0.5 [1/h], as prescribed minimum ventilation by the Danish Building Regulation for residential buildings.

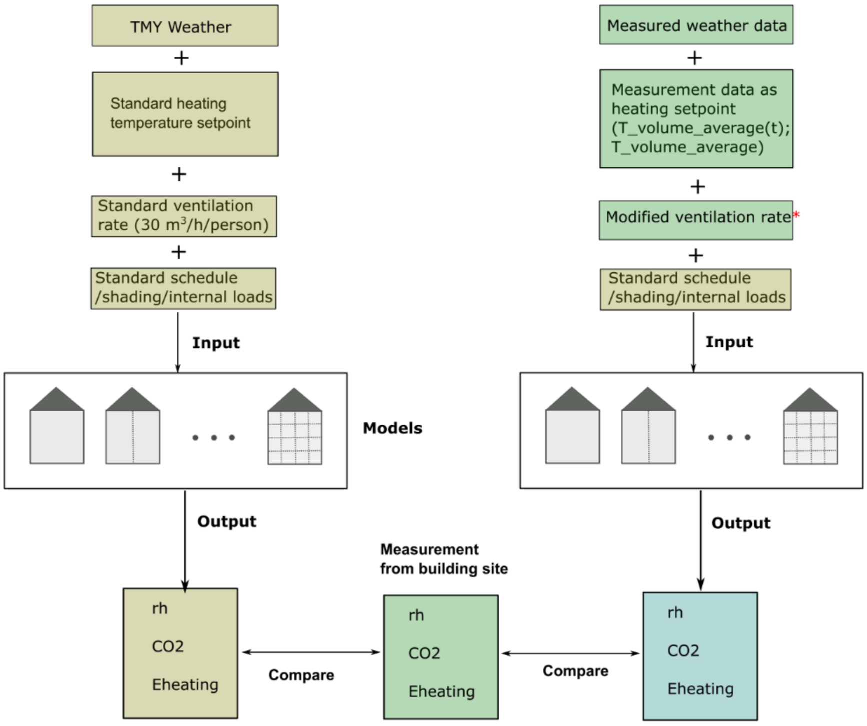

Figure 42: Process of model adaptation.

The results of the adapted model, in terms of the space heating demand and the atmospheric comfort (CO2), are then compared with the monitored data to evaluate the effect of the model adaptation and its applicability for E-DYCE purposes. These can be seen in Figure 43 – Figure 46. It is necessary to mention that this work was carried out in the past, when the acceptable model complexity for E-DYCE was not settled, as discussed in Deliverable 2.3. Therefore, the figures include multiple lines, where each line represents a separate model of the same building.

In Figure 43, the space heating energy demand assessed according to DEPC-AS models is plotted against the monitoring data, illustrating a significant performance gap. Similarly in Figure 44, the atmospheric comfort assessed and monitored is expressed as the number of hours when the CO2 level is below 600 ppm (overventilation) showing significant disbalance.

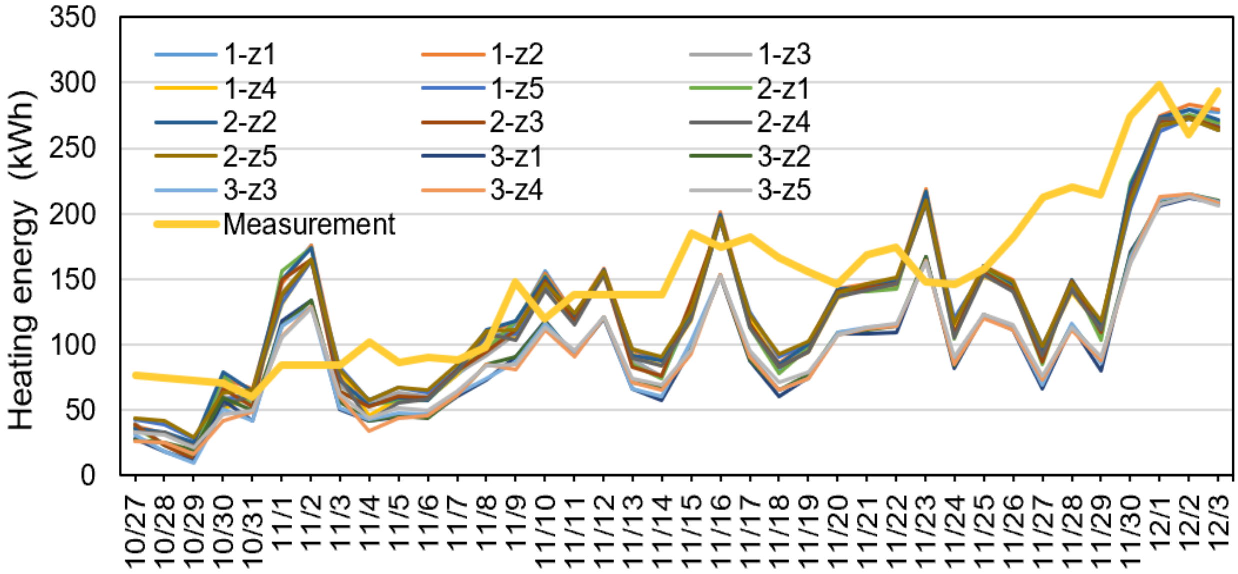

Figure 43. Space heating demand for the DEPC-AS model.

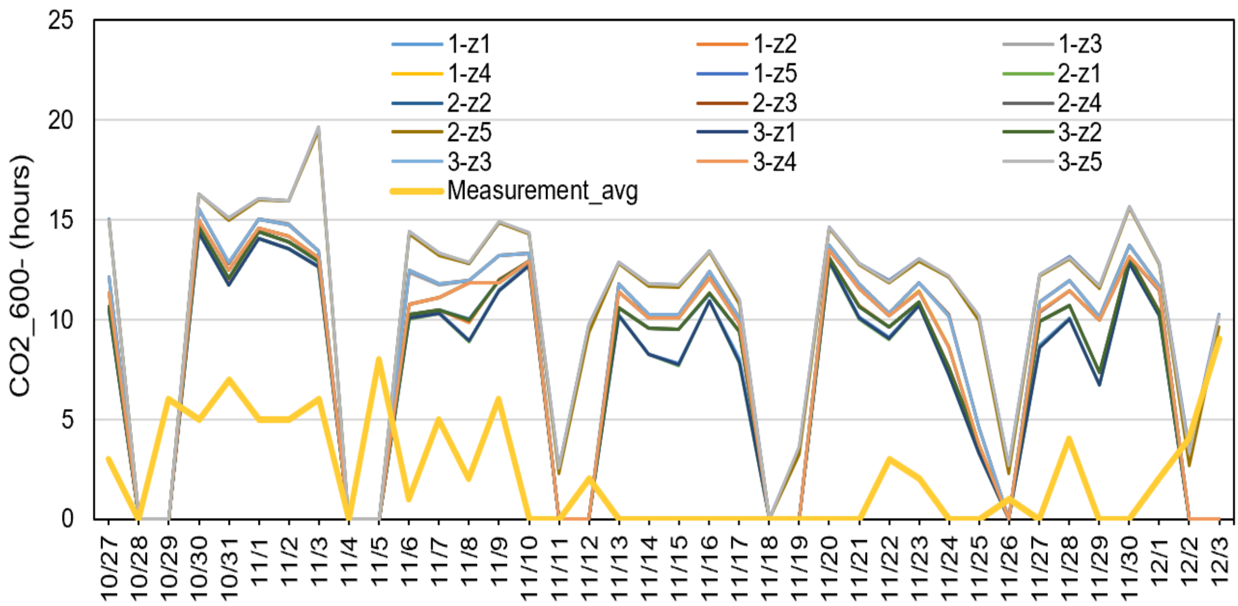

Figure 44. Hours of over-ventilation for the DEPC-AS model.

Next in Figure 45 – Figure 46, the same KPIs are provided for the adapted model, showing the improvement of the models in terms of energy performance, but not in terms of atmospheric comfort, as the adaption of the ventilation rates was relatively insignificant, and the adaption of the occupancy rate and occupant schedules based on the inspection plan, is necessary.

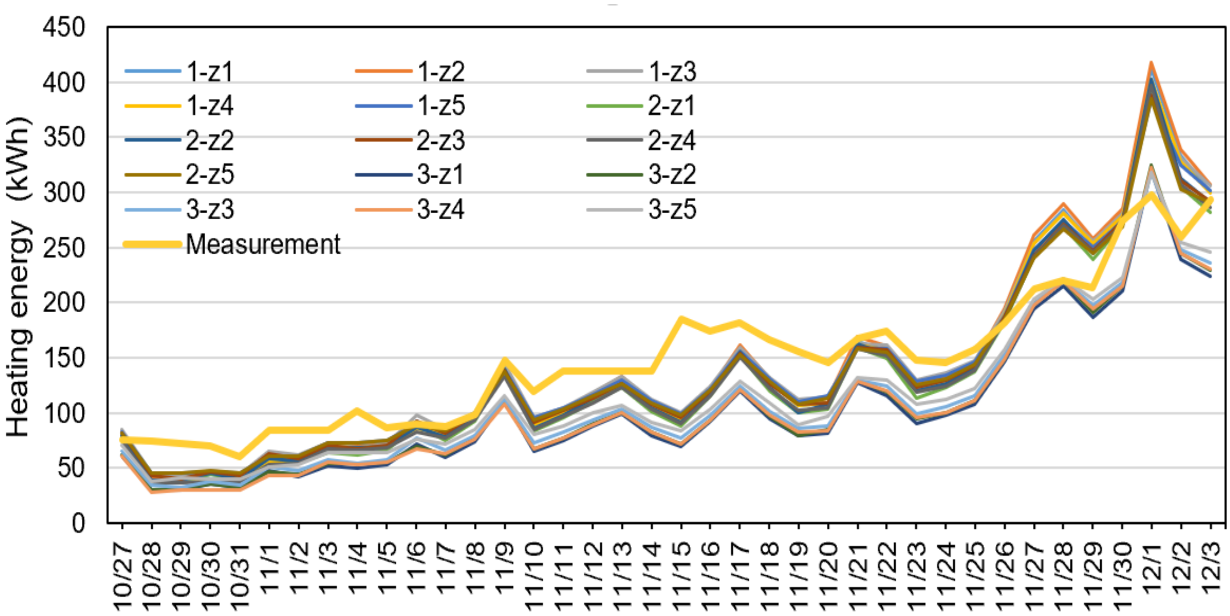

Figure 45: Space heating demand for the DEPC-AA model.

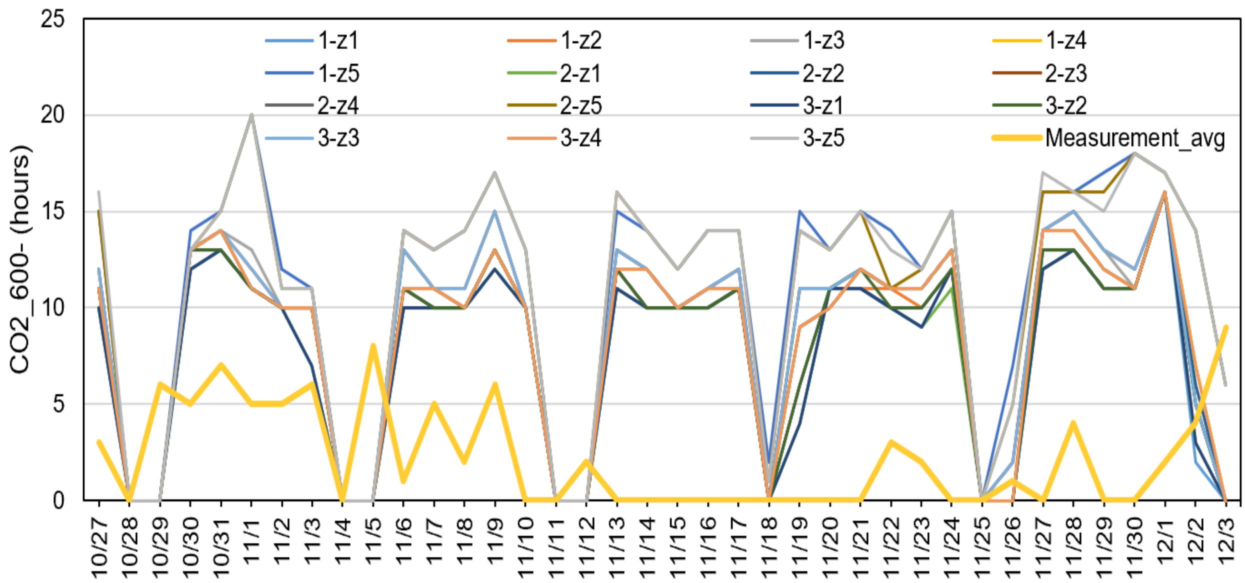

Figure 46: Hours of over-ventilation for the DEPC-AA model.

In general, the exercise with the model adaptation illustrates some efficiency of the procedure and certain capability of the models developed, but at the same time requires consideration in their adaptation for application within E-DYCE DEPC. It is also necessary to mention that the adaptation of the Haanbaek models is still at its initial stage, to be completed upon the availability of an adequate monitored dataset.

8 Conclusion

This report presented the Danish pilot buildings' establishment, structure, and already applied models.

Data collection has been established both centrally and in some apartments for each pilot, with varying resolutions from building to building to reflect different practical realities. Accessing apartments and obtaining tenant consent has been the biggest bottleneck in this process. This is expected to be a specificity of the residential sector in shared housing. However, it might have substantial implications for the feasibility of the E-DYCE solution in such a context.

An inspection protocol has been developed and carried out on the buildings, to allow identifying opportunities for value creation from analyses and dynamic simulations. As the pilot is now ready to be actively used in simulations coupled with the FusiX platform, we have paved the way to the last phase of the project in its final year.

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9 Appendix A

This appendix presents additional details about the envelope of the pilot buildings.

9.1 Haanbaek - Building envelope details

Outer wall - north

Material	Thickness [m]	Thermal conductivity, λ [W/(m K)]	Thermal resistance, R [(m2 K)/W]	References	Density	Specific heat cap. (J/kg.K)
R in			0,130	[1]		
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
lightweight concrete	0,190	0,180	1,056	[1]	535	1000
Insulation	0,050	0,030	1,667		30	1000
Bricks	0,110	0,550	0,200	[1]	1400	1000
R out			0,040	[1]		
Total Thickness	0,360					
	Total Thermal resistance, R		3,12			
	U-value, [(W/m² K)]		**0,32**	[0,29]		

Outer wall - south and to loggia

Material	Thickness [m]	Thermal conductivity, λ [W/(m K)]	Thermal resistance, R [(m2 K)/W]	References	Density	Specific heat cap. (J/kg.K)
R in			0,130	[1]		
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
Concrete (high density)	0,095	2,000	0,048	[2]	2400	1000
Insulation	0,050	0,042	1,190		30	1000
Concrete (high density)	0,095	2,000	0,048	[2]	2400	1000
R out			0,040	[1]		
Total Thickness	0,250					
	Total Thermal resistance, R		1,48			
	U-value, [(W/m² K)]		**0,68**	[0,69]		

Floor to basement						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,170	[1]		
Timber	0,01	0,160	0,063	[2]	700	1600
Airgap (Strøer)	0,05		0,210	[3]	-	-
Mineral wool	0,05	0,042	1,190		135	1000
Concrete (high density)	0,185	2,000	0,093	[2]	2400	1000
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R out			0,100	[1]		
Total Thickness	0,305					
	Total Thermal resistance, R		1,85			
	U-value, [(W/m² K)]		**0,54**	[0,59]		

Roof (attic to exterior)						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,040	[1]		
Bitumen	0,01	0,230	0,043	[2]	1100	1000
Timber	0,025	0,130	0,192	[2]	500	1600
R in			0,100	[1]		
Total Thickness	0,035					
	Total Thermal resistance, R		0,38			
	U-value, [(W/m² K)]		**2,66**			

Ceiling to attic						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R out			0,040	[1]		

Mineral wool	0,275	0,042	6,548		30	1000
Concrete (high density)	0,185	2,000	0,093	[2]	2400	1000
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R in			0,100	[1]		
Total Thickness	0,470					
	Total Thermal resistance, R		6,81			
	U-value, [(W/m² K)]		**0,147**			

Outer wall - balcony						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Cement bonded particle board	0,030	0,230	0,130	[2]	1200,000	1500
R out			0,040	[1]		
Total Thickness	0,030					
	Total Thermal resistance, R		0,30			
	U-value, [(W/m² K)]		**3,33**			

Internal floor						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,170	[1]		
Timber	0,01	0,160	0,063	[2]	700	1600
Airgap (Strøer)	0,05	-	0,160	[3]	-	-
Mineral wool	0,05	0,042	1,190		135	1000
Concrete (high density)	0,185	2,000	0,093	[2]	2400	1000
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R in			0,100	[1]		

Total Thickness	0,305					
	Total Thermal resistance, R		1,80			
	U-value, [(W/m² K)]		**0,56**			

Internal wall						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Gypsum plasterboard	0,025	0,21	0,119	[2]	700,000	1000
Air gap	0,1		0,180	[3]		
Gypsum plasterboard	0,025	0,21	0,119	[2]	700,000	1000
R in			0,130	[1]		
Total Thickness	0,150					
	Total Thermal resistance, R		0,68			
	U-value, [(W/m² K)]		**1,47**			

Internal wall against staircase						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
Concrete (high density)	0,095	2,000	0,048	[2]	2400	1000
Insulation	0,050	0,042	1,190		30	1000
Concrete (high density)	0,095	2,000	0,048	[2]	2400	1000
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R in			0,130	[1]		
Total Thickness	0,260					
	Total Thermal resistance, R		1,60			
	U-value, [(W/m² K)]		**0,63**			

Floor against ground

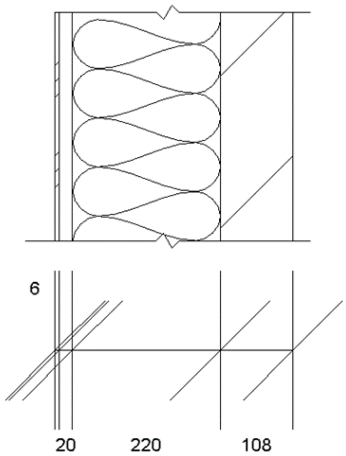
Material	Thickness [m]	Thermal conductivity, λ [W/(m K)]	Thermal resistance, R [(m2 K)/W]	References	Density	Specific heat cap. (J/kg.K)
R in			0,170	[1]		
Concrete (high density)	0,12	2,000	0,060	[2]	2400	1000
R out			1,500	[1]		
Total Thickness	0,120					
	Total Thermal resistance, R		1,73			
	U-value, [(W/m² K)]		**0,58**			

Wall against ground						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Concrete (high density)	0,2	2,000	0,100	[2]	2400	1000
R out			1,500	[1]		
Total Thickness	0,200					
	Total Thermal resistance, R		1,73			
	U-value, [(W/m² K)]		**0,58**			

9.2 Magisterparken - Building envelope details

External wall (gable wall) to the east and west

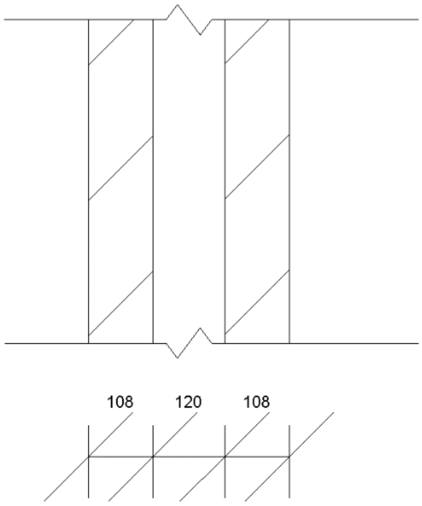
The external gable wall consists of 1 layer of brick on the inside, 220mm of insulation, and aluminium panels on the outside. This wall had undergone a renovation in 2012, where the original wall, which consisted of brick, cavity, and brick layer, was improved by demolishing the outer layer of brick, adding 220mm insulation, and covering it with aluminium panels, leaving an air gap to ventilate the moisture away. It had been assumed that renovating only gable walls was profitable.



Outer wall - Gabel						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
Bricks	0,110	0,550	0,200	[1]	1400	1000
Insulation	0,120	0,035	3,429		30	1000
Bricks	0,110	0,550	0,200	[1]	1400	1000
Insulation	0,250	0,035	7,143		30	1000
R out			0,040	[1]		
Total Thickness	0,600					
	Total Thermal resistance, R		11,17			
	U-value, [(W/m^2 K)]		**0,09**	[0,69]		

External wall to the south and north (as built, not renovated)

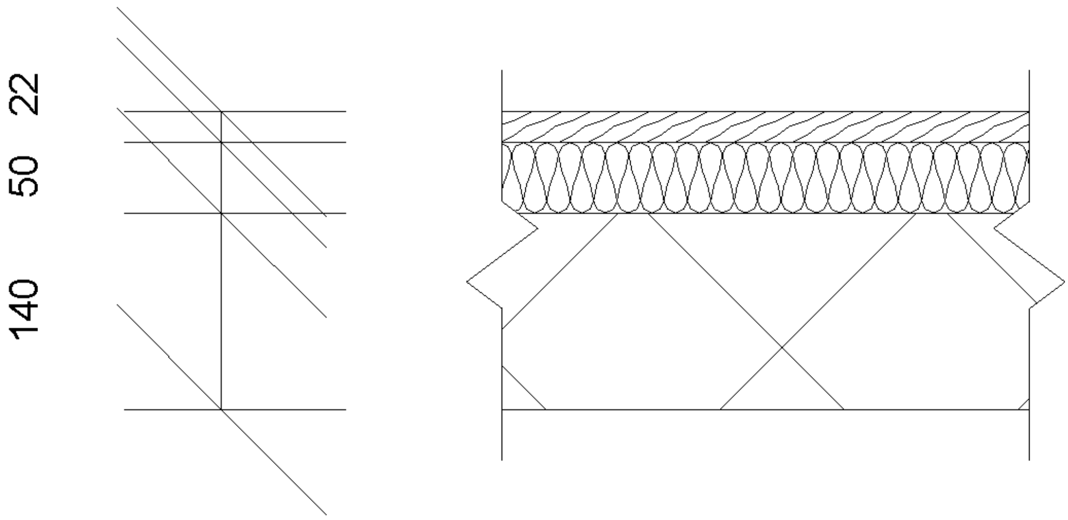
The external façade wall consists of 2 layers of brickwork, 108mm each, and a cavity in between 120mm. It has not been renovated since 2012.



Outer wall						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
Bricks	0,110	0,550	0,200	[1]	1400	1000
Cavity	0,120		0,180		30	1000
Bricks	0,110	0,550	0,200	[1]	1400	1000
R out			0,040	[1]		
Total Thickness	0,350					
	Total Thermal resistance, R		0,78			
	U-value, [(W/m² K)]		**1,29**	[0,29]		

Floor against unheated basement

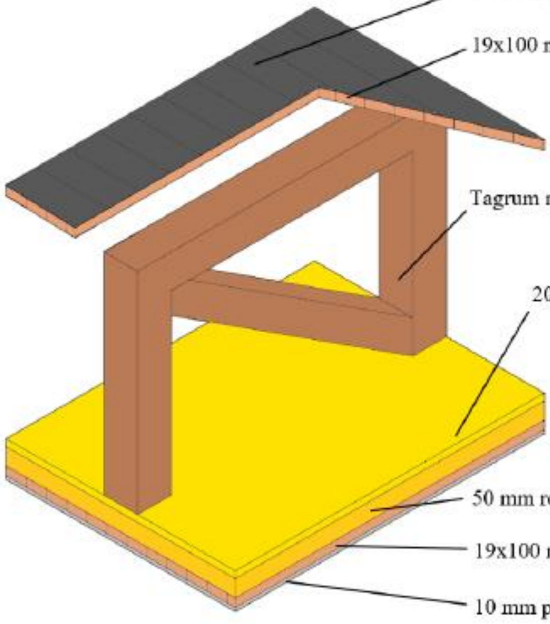
The construction of the ground floor was determined based on an earlier inspection documented in 2012 when the building was renovated. It was shown to include 22mm of wooden flooring, above 50mm of insulation, and a 140mm concrete slab.



Floor to basement						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,170	[1]		
Timber	0,022	0,160	0,138	[2]	700	1600
Mineral wool	0,05	0,042	1,190		135	1000
Soft woodfibre panel	0,0125	0,07	0,160	[2]	250	1700
Concrete (reinforced 2%)	0,14	2,500	0,056	[2]	2400	1000
R out			0,100	[1]		
Total Thickness	0,225					
	Total Thermal resistance, R		1,81			
	U-value, [(W/m² K)]		**0,55**	[0,59]		

Roof and ceiling to the attic

The roof had undergone a renovation in 2012, where the original roof consisted of gips, wooden decking, insulation, arkimåtte (a material made of seaweed grass), and a bituminous finish. Technical documentation from the renovation process highlight that only a bituminous finish has been replaced with a new one.



The roof structure consists of (from the bottom):

1. Gips (0,010 m)
2. Wooden deck (0,10 m)
3. Old Insulation (0,05 m)
4. Arkimåtte (0,02 m)
5. Wood strut
6. Wooden rafter
7. Roof finishing, bituminous

Roof (attic to exterior)						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,040	[1]		
Bitumen	0,01	0,230	0,043	[2]	1100	1000
Timber	0,025	0,130	0,192	[2]	500	1600
R in			0,100	[1]		
Total Thickness	0,035					
	Total Thermal resistance, R		0,38			
	U-value, [(W/m² K)]		**2,66**			

Ceiling to attic						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R out			0,040	[1]		
Straw (Arkimåtte)	0,02	0,03	0,667		30	1600
Mineral wool	0,05	0,04	1,250		30	1000
Timber	0,02	0,130	0,154	[2]	500	1600
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R in			0,100	[1]		
Total Thickness	0,100					
	Total Thermal resistance, R		2,24			
	U-value, [(W/m² K)]		**0,447**			

Internal floor

Internal floor						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,170	[1]		
Timber	0,022	0,160	0,138	[2]	700	1600
Airgap (Strøer)	0,05	-	0,160	[3]	-	-
Soft wood fibre panel	0,0125	0,07	0,160	[2]	250	1700
Concrete (reinforced 2%)	0,14	2,500	0,056	[2]	2400	1000
Gypsum plastering	0,01	0,4	0,025	[2]	1000	1000
R in			0,100	[1]		
Total Thickness	0,235					
	Total Thermal resistance, R		0,81			
	U-value, [(W/m² K)]		**1,24**			

Basement floor against ground

Basement floor against ground						
Material	Thickness [m]	Thermal conductivity, λ [W/(m K)]	Thermal resistance, R [(m2 K)/W]	References	Density	Specific heat cap. (J/kg.K)
R in			0,170	[1]		
Plastic flooring	0,02	0,25	0,080	[2]	1700	1400
Concrete (high density)	0,1	2,000	0,050	[2]	2400	1000
R out			1,500	[1]		
Total Thickness	0,120					
	Total Thermal resistance, R		1,80			
	U-value, [(W/m² K)]		**0,56**			

Basement wall

Basement wall						
Material	Thickness [m]	Thermal conductivity, λ [W/(m K)]	Thermal resistance, R [(m2 K)/W]	References	Density	Specific heat cap. (J/kg.K)
R in			0,130	[1]		
Concrete (high density)	0,35	2,000	0,175	[2]	2400	1000
R out			1,500	[1]		
Total Thickness	0,350					
	Total Thermal resistance, R		1,81			
	U-value, [(W/m² K)]		**0,55**			

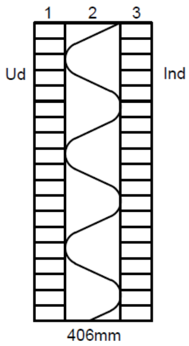
Wall to balcony

Wall to balcony						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,130	[1]		
Gypsum plasterboard	0,01	0,21	0,048	[2]	700	1000
Mineral wool	0,1	0,04	2,500		30	1000
Cement bonded particle board	0,005	0,230	0,022	[2]	1200	1500
R out			0,040	[1]		
Total Thickness	0,115					
	Total Thermal resistance, R		2,74			
	U-value, [(W/m² K)]		**0,37**			

Balcony flooring

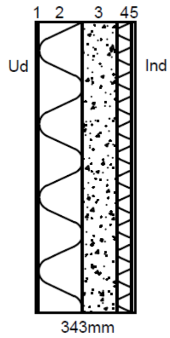
Balcony flooring						
Material	**Thickness [m]**	**Thermal conductivity, λ [W/(m K)]**	**Thermal resistance, R [(m2 K)/W]**	**References**	**Density**	**Specific heat cap. (J/kg.K)**
R in			0,170	[1]		
Plastic flooring	0,02	0,25	0,080	[2]	1700	1400
Concrete (reinforced 2%)	0,14	2,500	0,056	[2]	2400	1000
R out			0,100	[1]		
Total Thickness	0,160					
	Total Thermal resistance, R		0,41			
	U-value, [(W/m² K)]		**2,46**			

9.3 Thulevej - Building envelope details



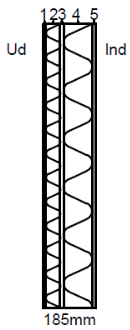
Generel outer wall
1. Layer: 108mm
   Bricks 1800 kg/m^3
2. Layer: 190mm (inhomogent)
   Insulation: Rockwool A-murbatts
   Solid masonry binders: Stainless steel Ø4mm
3. Layer: 108mm
   Bricks: 1800 kg/m^3

Collective U-value
U = 0,18 W/m^{2}K



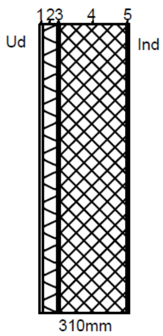
South facing outer wall
1. Layer: 10mm
   Exterior plaster
2. Layer: 150mm (non-homogenous)
   Insulation: Rockvision Facadebatts 37
   Solid masonry binders: Stainless steal Ø4mm
3. Layer: 120mm
   Reinforced concrete 2% steel: 2400kg/m^3
4. Layer: 50mm (non-homogenous)
   Insulation: Mineral wool 39
   Solid masonry binders: Stainless steel Ø4mm
   Wood: 450kg/m^3
5. Layer: 13mm
   Plasterboard

Collective U-value
U = 0,19 W/m^{2}K



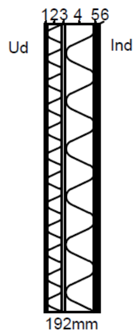
Stairway outer wall
1. Layer: 10mm
   Exterior plaster
2. Layer: 50mm (non-homogenous)
   Insulation: Rockvision Facadebatts 37
   Solid masonry binders: Stainless steel Ø4mm
3. Layer: 12mm
   Fiberboard
4. Layer: 100mm (non-homogenous)
   Insulation: Mineral wool 37
   Solid masonry binders: Stainless steel Ø4mm
   Wood: 450kg/m^3 (6,33%)
5. Layer: 13mm
   Plaster

Collective U-value
U = 0,40 W/m^{2}K



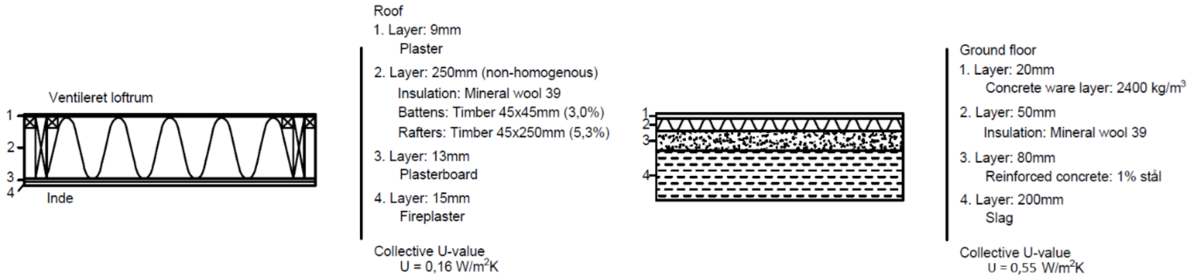
Basement outer wall
1. Layer: 10mm
   Exterior plaster
2. Layer: 50mm (non-homogenous)
   Insulation: Rockbase Facadebatts 37
   Solid masonry binders: Stainless steel Ø4mm
3. Layer: 10mm
   Exterior plaster
4. Layer: 230mm
   LECA-blocks 600
5. Layer: 10mm
   Interior plaster

Collective U-value
U = 0,40 W/m^{2}K



Terrase outer wall
1. Layer: 10mm
   Exterior plaster
2. Layer: 50mm (non-homogenous)
   Insulation: Rockbase Facadebatts 37
   Solid masonry binders: Stainless steel Ø4mm
3. Layer: 12mm
   Fiberboard
4. Layer: 100mm (non-homogenous)
   Insulation: Mineral wool 37
   Solid masonry binders: Stainless steel Ø4mm
5. Layer: 10mm
   Fiber board
6. Layer: 10mm
   Interior plaster

Collective U-value
U = 0,26 W/m^{2}K



Source: https://www.weblager.dk/app