Project no.: **893945**

Project full title: **Energy flexible DYnamic building CErtification**

Project Acronym: **E-DYCE**

Deliverable number:	**D2.3**
Deliverable title:	Smartness scalability report
Work package:	WP2
Due date of deliverable:	M18
Actual submission date:	M18 – 18/02/2022
Start date of project:	01/09/2020
Duration:	36 months
Reviewer(s):	Michele Zinzi (ENEA)
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Dissemination level of this deliverable	**PU**
Nature of deliverable	R

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 893945. Any results of this project reflects only this consortium's view and the European Commission is not responsible for any use that may be made of the information it contains.
Further information is available at www.edyce.eu.

Document history

Version no.	Date	Authors	Changes
0.1	15/01/2022	Olena K. Larsen and Daniel Leiria, AAU	Initial structure
0.2	21/01/2022	Yue Hu, AAU	Description of E+ models
0.3	28/01/2022	Olena K. Larsen, AAU	Updated draft
0.4	03/02/2022	Michal Pomianowski, AAU	Updated draft
0.5	07/02/2022	Daniel Leiria, AAU	Updated draft
0.6	10/02/2022	Yue Hu, AAU	Updated draft
0.7	11/02/2022	All	Final draft
1.0	18/02/2022	Anne Bock, AAU	Final check and submission

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1 Executive Summary

This report is Deliverable 2.3 of the E-DYCE project, summarizing the main outcome of activities in task 2.3, where the smart and dynamic technologies potential is evaluated. Two main objectives were identified within this task:

1. To aid the E-DYCE project by the evaluation and quantification of the effect of smart dynamic technologies on overall building performance, with the specific focus on performance gap (PG) detection, quantification, and its potential elimination.
2. To evaluate the potential of smart-data application for the dynamic energy performance certification.

The first objective of the task and the methodology to reach it are described in chapter 4 of the report. This report focuses on addressing the dynamic technologies for multi-family dwellings located in the Nordic climate (Denmark). The smart and dynamic technologies that can influence building performance are identified as heating, ventilation, and shading. Next, the research question is formulated as follows: *how to set up a credible model for E-DYCE certification procedure that can address the effect of the dynamic technologies on cooling and heating demand in the building, can reasonably well calculate comfort-related KPIs and at the same time have an acceptable level of complexity to ease the roll-out of E-DYCE DEPC concept?*

To answer the research question, a methodology is developed: several models of a case-building are set up with different levels of complexity, ranging from simple to very advanced models. The identification of the credibility of the models is performed in two steps. In the first step, modeling results are compared across the models with different complexity levels and dynamic systems. In the second step, the results of simulations are compared against the monitoring data to identify which simplifications do not significantly interfere with the validity of the results. The hypothesis is that the same methodology can be applied for several buildings of the same building typology (dwellings), then the general conclusions about the acceptable level of model simplification in E-DYCE DEPC can be made, and the resulting model will be able to account for the effect of the dynamic technologies within the building, both in terms of energy and comfort. The initial results from these investigations are organized in section 4.12.3.

Chapter 3 of this report addresses the second objective of the task where the methodology for disaggregation of data from the smart heat meters is developed to assess the operational energy use for domestic hot water. This chapter includes a review of existing disaggregation methods, a suggestion for a new algorithm that is suitable for use in the E-DYCE project but also includes the results of testing this new methodology for a smaller Danish case study and documents its applicability.

2 Introduction

2.1 Objectives of D2.3 report

Smart technologies/smart meters are becoming an integral part of buildings. Smart technologies, in general, are installed to aid users in maintaining certain conditions in the building and, at the same time, can have a significant influence on the energy use in buildings, whether it is intentional or not. For instance, smart meters can offer a significant amount of data. If this data is utilized correctly and turned into knowledge, then this knowledge can become an effective instrument to improve the performance of buildings.

Until the present, the knowledge regarding the influence of smart technologies on the energy performance of buildings has been dispersed. Their effect on overall building energy performance has been difficult to quantify numerically, as the simulations of smart and dynamic technologies are strongly dependent on countless combinations of control settings, which, although very advanced in some software, might have little in common with the real-life operation of these technologies in the buildings. Typically, smart technologies are characterized by their dynamic nature, which does not make it easier to quantify the stand-effect of their application, but also makes it more challenging to quantify their combined effects when more than one technology is present in the building.

E-DYCE, Energy flexible Dynamic building Certification, focuses on the development of a dynamic certification of buildings, supporting real-time optimization of energy consumption and comfort. Importantly, the E-DYCE logical approach combines smart technologies with low-tech solutions, where the quantification of the effect that these technologies have on building performance becomes essential, as neither the effect of smart- or low- technologies are properly rewarded in present steady-state EPC schemes.

Reasoning from the above-stated task 2.3 of the project must aid the E-DYCE project by the evaluation and quantification of the effect of smart technologies on overall building performance, with the specific focus on performance gap (PG) detection, quantification, and its potential elimination. Further explanation to this objective is given in section 4 and the methodology to meeting the objective is provided in section 4.4 of this report.

Looking upon the role of the smart meters in WP 2 of E-DYCE, the smart dimension of buildings will be illustrated for both simple but smart metering and actuating of building systems. In the grant agreement of E-DYCE, it is indicated that the diffusion of smart metering systems in the building stock is a recent phenomenon. Moreover, until recently, the possibility to use a dynamic approach to energy label buildings was complex and difficult for the computational capabilities available in the past.

In this regard, the Directive 2018/844 of the European Parliament and of the Council amending EPBD has introduced the provision to define a Smart Readiness Indicator (SRI) able to rate buildings with respect to their smart readiness (The European Parliament and the European Council, 2018). The SRI is described in deliverable 1.2 of E-DYCE in line with the EU Delegate Act, where SRI is characterized as an indicator defining and informing end-users about the smart readiness of a building/building unit, including rating systems and sub-scorings related to predefined issues faced in the rating methodology. In light of this definition, the smart readiness indicator allows, for example identifying the smart meters (and technologies) present within the building, yet it does not address to what degree the data and the functionality provided by these technologies are utilized in practice.

E-DYCE Dynamic Energy Performance Certification (DEPC) concept, described in the grant agreement, is centred on the fact that the assessment methods should increasingly take into account output measures of performance, making use of an available and increasing number of building energy-related data from sensors, smart meters, connected devices, etc. as the diffusion of smart metering systems in the building stock experiences rapid development, but its potential is not being exploited. Accordingly, the E-DYCE approach to smart meters can be considered as a qualitative supplement to quantitative SRI, where the application of smart meter data is integrated into E-DYCE DEPC.

The other important objective of E-DYCE task 2.3 “Smart technologies potential estimation” is to evaluate the potential of smart-data application for the dynamic energy performance certification.

This objective is then further specified in deliverable 2.4 of the project, where it is explained that E-DYCE DEPC is dedicated to detecting the causes of the performance gap and supporting potential improvements for PG elimination and the energy need reduction. Correspondingly, the total energy demand in E-DYCE DEPC approach becomes 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. At present, only the energy demand for heating, cooling, and lighting can be modeled dynamically. Meanwhile, the solution to dynamically modeled demands for domestic hot water remains unknown, although DHW represents a significant share of the energy use in dwellings. To overcome that limitation, this task aims to develop a methodology to quantify the energy need for the domestic hot water in dwellings dynamically by utilizing the data from the smart meters that measure the total need for heat.

Meeting both of the above-stated objectives in this task will allow for a better comparison between simulation results and the real building operation due to a detailed simulation approach and the adoption of learning algorithms connected with smart metering. The activity in this task will provide inputs to the WP3-6.

The overall purpose of this report is to explain how the above-stated objectives of task 2.3 are being addressed in the project, to explain the methodology behind the investigations carried out, and to present the main findings made during this work.

3 Smart technology potential for estimation of SH and DHW

According to [1], since 2020, it has been obligatory in the European Union (EU) that newly installed district heating and cooling meters are remotely readable. From 2027 and on, this rule will also apply to all meters installed before that date. The resolution of the remotely readable meters, also called “smart meters”, is normally at hourly and, in some cases, at even sub-hourly temporal rate. Moreover, in ten EU countries, more than 20% of the heating demand of the residential sector is covered by district heating [2]. While, in Denmark, 64% of the housing stock is connected to the district heating (DH) network already. High smart heat meter adoption and the hourly resolution of remotely readable meters create a strong basis for a theoretical potential for the new data-driven approaches that could serve for assessment of the building energy performance, with a primary focus on space heating and domestic hot water energy use. In general, a wide deployment of metering devices opens new possibilities for further development of building assessment with respect to not only smartness readiness but also towards operational smartness of respective building systems.

Today’s methods used for assessing and optimizing building performance and evaluating smart readiness are steady-state [3], [4]. While space heating demand is well modeled, and a significant number of validated models can tackle this issue, to the authors’ best knowledge, none of the compliance tools or whole energy building simulation tools are capable of properly or at all quantifying energy use for domestic hot water. Even if tapping profiles are known, which is very seldom, and in most cases based on questionable assumptions, tools typically do not have proper models to quantify energy balances in the domestic hot water distribution system. Consequently, energy use for domestic hot water is often defined as a static value for specific building topology or a very simple correlation to some other parameters, such as a heated floor area.

What is more, as indicated in [5], it can be read that the share of energy dedicated to DHW in total energy use in buildings has been increasing over the last years, and this trend is going to be continued and propagated in the future. This tendency is not due to DHW use having significantly increased but because energy use for other building operations has decreased. Measurement campaigns reflect that the typical Danish dwellings dedicate between 20% to 35% of their total energy need to DHW production and operation [6], [7]. This share increases even up to 40 - 50% in recently built energy-efficient dwellings [6]–[8]. In general, this tendency can be assumed similar in other countries.

Further on, there are significant differences to what reason and how much energy is used for respectively space heating and domestic hot water. Energy for space heating is primarily dependent on building characteristics (envelope insulation level, tightness, etc.), heating source efficiency, and users’ preferences for indoor climate. At the same time, domestic hot water is more dependent on DHW system design/layout, system operation, users number, and their routines to use domestic hot water. Usually, only the total heat (combined energy for space heating and domestic hot water) is metered, and reasons for the building performance gap are difficult to attribute to either space heating or domestic hot water.

To conclude, current modeling methods and knowledge regarding tapping profiles reflect several limitations:

- Modeling tools are not suitable
- Models are too simple
- Model results are heavily assumption dependent

- Models that are able to simulate dynamic DHW system behavior are too complex for broad application/building certification
- Tapping profiles are heavily user-dependent, and there is a general scarcity of measuring campaigns in the field

Therefore, it can be concluded that currently, the best, if not the only possibility, to assess energy use for DHW is the operational one that can be derived from the heat measurements. Still, the "smart heat" meters are installed for billing purposes mainly, and therefore they measure total heat for space heating and domestic hot water together. In order to identify the share that goes to domestic hot water and respectively space heating, the disaggregation algorithms have to be applied.

Firstly, this part of the report identifies and reviews disaggregation methods found in the literature. Secondly, a new algorithm is developed and proposed that could serve the purpose of EDYCE and deliver valuable results to the DEPC protocols. The proposed algorithm targets smart heat meters. The algorithms consider parameters that are available from these meters and their frequency rate.

3.1 Problem description

As mentioned, the installed smart heat meters only measure the total households heating usage. The total gathered values do not differentiate between space heating (SH) and domestic hot water (DHW). Therefore, the following method is proposed to estimate these two heating appliances per household where the smart meter is installed.

The method estimates these energy shares using 1-hour resolution measurements, which is argued in [9], [10] that this measurement frequency is susceptible to inaccurate estimations when applied to some of the methods described in the literature review. Another problem that the present methodology seeks to address is its non-dependence on other sources of information. Some of the exposed methods in the literature review require other information regarding the building (e.g., thermal envelope properties) and people (e.g., consumption habits) to predict the energy shares. This information is often hard to obtain. Therefore, the present methodology was developed only to require the smart meters' hourly total heating values and historical household's location weather data (outdoor temperature and global radiation).

3.2 Brief description of other existing disaggregation methods

One of the first methods to tackle the disaggregation problem is [10], which describes a mathematical time-series approach to detect the DHW data points and predict the space heating from the total measurements. Its method assumes that the space heating demand variates smoother due to minor external temperature variations than the DHW usage, which is more erratic with peaks due to the occupants' actions. The method estimates the SH demand by employing a kernel smoother to the total values, where all measurements above the smoothed generated values are due to DHW usage. This methodology appears promising, and the authors formulated different kernel functions to improve the prediction accuracy. However, it is still missing validation with separated SH and DHW usage measurements, which the authors did not have at the time. Another drawback of this method is the necessity of high-resolution data (10-minutes frequency) to detect the erratic peaks from DHW production. Unfortunately, most installed smart meters do not have this type of resolution.

In [11], a more straightforward method is proposed to separate the smart meters data by considering that the total values from the meters are equal to the DHW usage alone during Summer, i.e., no space heating demand. Based on this idea, their approach is not to estimate the different household heating utilities during the whole year but to identify the household average DHW load profile. This profiling approach provides useful information concerning the customers' DHW tendencies if identified correctly. Regarding the method's accuracy, it is disclosed that it performs well for new-built households with a large DHW usage share. However, the authors also argue that several houses use space heating during summer, which undermines their initial hypothesis and significantly decreases its accuracy.

Comparably, in [12], a method is proposed to disaggregate SH and DHW usage from total measurements. The proposed methodology is titled *hybrid summer signature*. Considering the external temperature (instead of the summer season), the method finds the DHW patterns when the total heating is equal to the DHW usage (no space heating demand). When the DHW profiles are identified, the SH usage equals the subtraction of the total measurements and the DHW daily profiles. The method's validation was performed with several Norwegian buildings (apartments and hotels) and compared with previously existing methods.

Following the study above, [13] also proposes a distinct method that separates the different measurements and validates it with a hotel's dataset in Norway. The authors present and compare two methodologies. Both approaches start by assessing the space heating demand by linearly correlating with the external temperature. The difference between the methods is that the first one determines the DHW needs by subtracting the estimated space heating from the total measured energy. And the second approach, before calculating the DHW usage, the space heating (already calculated by its outdoor temperature correlation) is corrected by employing a singular spectrum analysis (SSA) algorithm. The second methodology had the greatest accuracy in predicting both heating demands according to the validation. Differently, [9] uses grey-box models to predict the SH and DHW usage week-profiles. Their study showed that the calculated values were slightly overestimated compared to the actual measurements. However, the method is precise, and the authors endorse that the models should be improved. Also worth citing is the developed method in [14]. In the study, a methodology based on pattern recognition was applied to separate space heating from other utilities in two households in the UK. However, the heating system used in the houses is gas-based instead of water-based.

As one can see, various methods were created to distinguish the SH and DHW production from the total measurements of the smart heating meters. The importance of having an efficient methodology to disaggregate these values is immense when considering the saved investment in not installing an extra meter per household. Furthermore, respecting energy savings, by distinguishing both energy shares, a more detailed assessment can be done to improve the heating efficiency per household and grid.

3.3 Methodology

The methodology assumes that the space heating system is constantly running. At the same time, the DHW usage is expected only to be used occasionally throughout the day. Thus, during a day (which has 24 recorded data points), only a few of these points will consist in SH and DHW usage, whereas the other measurements will be SH usage alone. To corroborate this hypothesis is used [15] and [16], where authors state that the DHW usage in residential buildings has a share of 14–26% of the total daily heating usage. Thus, only some measurements during the day correspond to most of the DWH demand, whereas the other data points are space heating demand alone. Based on this idea, the present methodology separates and estimates the heating shares. In Figure 1, one can see the method's algorithm.

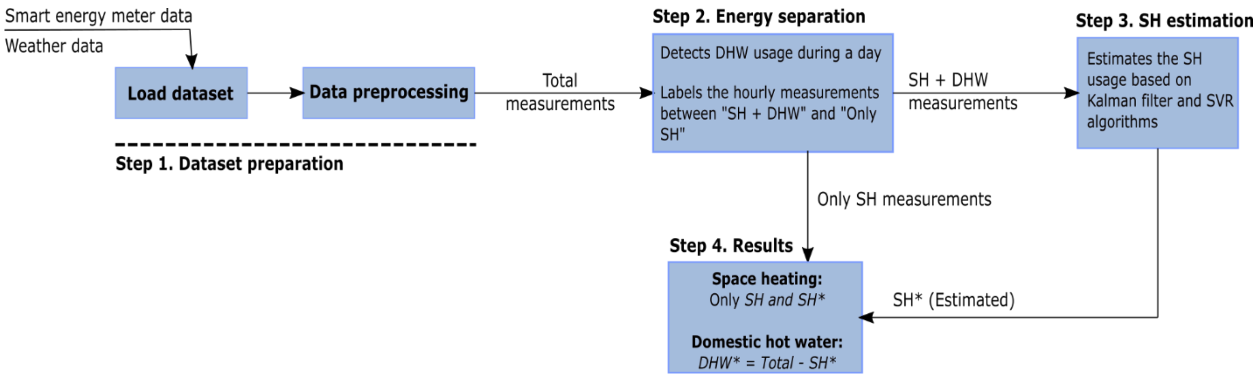

Figure 1: Algorithm's flowchart.

In Figure 1, step 1 refers to loading the datasets (total energy and weather measurements) and pre-processing them. The energy separation, in step 2, identifies and labels all hours where the tenants are using DHW. In step 3, the points labeled as not having DHW (Only SH demand) will be used to estimate the SH share from the points labeled with DHW usage. In the last step (4), the new estimated SH values are integrated into the dataset and used to estimate the DHW demand from the total heating measurements.

3.3.1 Energy separation

The assumption of the SH system being in constant operation while the DHW demand is erratic during the day is the basis of this specific step because it permits categorizing which hourly measurements have DHW usage from those only measuring SH usage.

The external temperature usually has small variations throughout the day, causing smooth fluctuations of the SH demand if operating continuously. Thus, all large variations in the measured total values by the meters are due to DHW production. Hence, the algorithm identifies all daily peaks on the data and considers them as DHW production ($E_{Total} = E_{SH} + E_{DHW}$). If a measurement is not one of the maximum values, it labels the point as only space heating being used ($E_{Total} = E_{SH}$). The seventh-highest measurements are counted as DHW production for each day, while the other 17 hours are space heating alone. To increase the labeling accuracy, it is also considered that from 1:00 - 4:00 AM corresponds to a sleeping period; therefore, the measured data is respecting only space heating, and the peaks during this period are due to low outdoor temperatures. In Figure 2, one can see a representation of the separation method during a day for a single household.

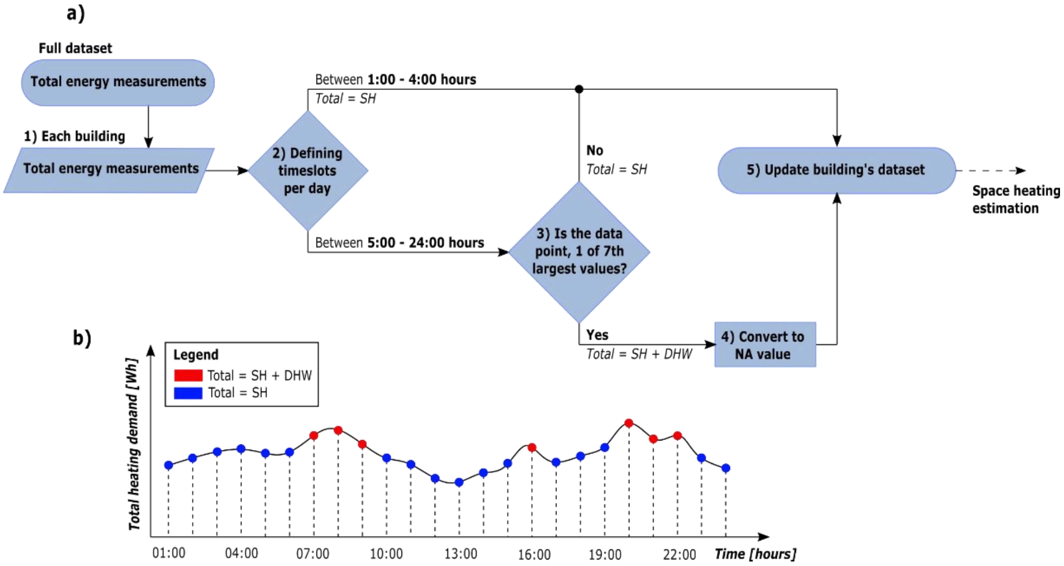

Figure 2: a) Flowchart: Maximum peaks approach; b) Method representation.

After labeling all measurements accordingly, those identified as having DHW usage are converted into NA-values.

3.3.2 SH and DHW demand estimation

At this algorithm stage, the DH dataset consists of NA-values and total values labeled as only space heating usage (ETotal = ESH). From it, the NA-values are estimated, taking into account the only SH usage data points. These new estimated values are also space heating usage only (ESH*) therefore, the DHW usage is predicted by the formula: EDHW* = ETotal – ESH*.

The overall formulation is given by:

$$E_{Total} = \begin{cases} E_{SH}, & \text{If labeled as “only SH” point} \\ E_{SH}^{*} + E_{DHW}^{*}, & \text{If labeled as “SH + DHW” point} \end{cases}$$

To calculate the new space heating values (ESH*), a combination of two different mathematical approaches is used. The first approach is a smoothed Kalman filter estimation algorithm, which predicts the NA-values based on the dataset's existing measurements (only SH points). The Kalman filter is based on a linear Gaussian state-space model for univariate time-series with smoothing characteristics [17]. This method alone is the most accurate of the two approaches. However, there is the risk from the separation step to create large NA-value intervals, which decreases the smoothed Kalman filter estimator accuracy. Therefore, for NA-gaps larger than 2 hours, the points are estimated with a support vector regressor (SVR).

In contrast with the first method, this estimator takes into account other information to predict the SH besides its neighboring points. The method is a machine learning model trained with the total measurements labeled as “only SH” to estimate the “SH + DHW” (NA-values) labeled points. As input to predict the SH at hour i (ETotal[i] = ESH[i]), it uses the external temperature and global radiation measured an hour before the hour i (Tout[i-1] and R[i-1]) and the total heating measured before and after the hour i (ETotal[i-1] and ETotal[i+1]). For SVR, it is also selected a radial kernel function with the parameters C (cost) and γ (gamma) equal to 7 and 0.01, respectively [18], [19].

3.4 Results and discussion

In this section is described a part of the validation results from another overlapping project that AAU is currently working on called PRELUDE [20]. To validate the methodology and assess its performance, a small dataset of 28 apartments located in Aalborg was used. This dataset is a subset of the household data used in the publication [11]. The dataset consists of the total energy, the space heating demand, and domestic hot water production measurements. All these values are recorded hourly, and the measurement period per dwelling is on average 9-months.

The separation approach identifies the daily peaks and labels them as points with simultaneous SH and DHW usage had 20% of wrong labeling in all apartments. This means that 20% of all hourly data points are wrongly identified as "SH + DHW" or "only SH". Most of these wrong attributed data points have a total of energy usage below 2.0 kWh. The total percentages of the separation process validated in the 28-apartment dataset can be consulted in Table 1:

Table 1: Separation approach - Results

Correct label	
Real measurement: "Only SH" Label attributed: "Only SH"	58.1 %
Real measurement: "SH + DHW" Label attributed: "SH + DHW"	22.0 %
Incorrect label	
Real measurement: "Only SH" Label attributed: "SH + DHW"	8.7 %
Real measurement: "SH + DHW" Label attributed: "Only SH"	11.2 %

From the table, it is seen that 22% of the measurements are labeled correctly as "SH + DHW". On the other side, 8.7% are incorrectly considered as DHW being produced. The main reason behind this wrong categorization is that the measured peaks are caused only by the space heating system operation. The sum of these two percentages (30.7%) represents the number of points converted into NA-values, which are estimated in the estimation stage. The other points (58.1% and 11.2%) are used as training data for the model used to estimate the space heating.

The next step of the methodology is the application of the estimators to predict the space heating in the "SH + DHW" labeled points. After using the estimation algorithm described above, it is also calculated the domestic hot water demand in the same labeled points. These estimations are compared with the annual energy usages measured by the apartment to determine the method's overall performance. In Figure 3, one can see the annual heating usage per building regarding space heating and DHW.

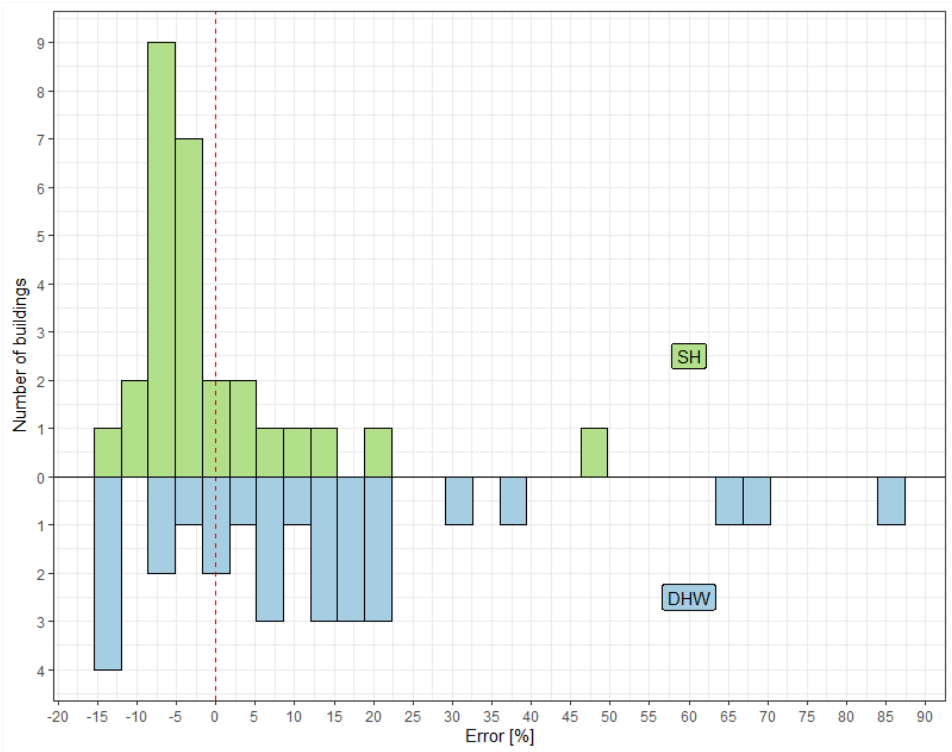

Figure 3: Annual estimation error per apartment

According to Figure 3, the annual SH error is primarily negative, with 16 apartments between -10% and 0%. This means that the estimator is sub-estimating annual SH usage by less than 10%. Furthermore, the dwellings with the extreme error values are one apartment with less than -15% error and another with almost 50% error. The meaning of a household with a 50% error is that the estimator is overpredicting 50% more SH usage than the actual measurement.

Regarding the DHW prediction (in blue), the error distribution is wider than SH. In this case, there are 5 apartments with an annual overestimation of the DHW demand above 25%. The extreme DHW estimations are one dwelling with an overestimation of 85% and 4 apartments with an underestimation slightly higher than 10%. In order to understand more the extreme cases found in this validation, three households were selected, and their measurements are plotted with their estimations over the measurement's timeframe. The selected dwellings are seen in Table 2:

Table 2: Estimation results of the selected apartments.

Apartment ID	Measurement period	Heating utility	Annual energy usage (share) [kWh]	Annual estimated energy usage (share) [kWh]	Annual error (share) [%]
666	April – July	SH	1514.9 (0.65)	1511.3 (0.65)	-0.24 (0)
		DHW	816.4 (0.35)	820 (0.35)	0.44 (0)
699	March – December	SH	1185.4 (0.22)	1746.7 (0.32)	47.3 (45.5)
		DHW	4234.4 (0.78)	3673.1 (0.68)	-13.3 (-12.8)
700	April – December	SH	5688.2 (0.93)	5327.7 (0.87)	-6.3 (-6.5)
		DHW	425.3 (0.07)	785.8 (0.13)	84.8 (85.7)

Apartment 666 is from the 28 cases, the one with the lowest error percentage. Because of its outstanding prediction performance was one of the selected apartments to be analysed. Household 699 was selected because of its high error in the SH estimation (47.3%). In contrast, apartment 700 was selected due to its overestimation of the DHW demand (84.8%). In the table, it is also represented, in parenthesis, the total consumption shares of the SH and DHW. The following figures are the display of the different heating usage per household.

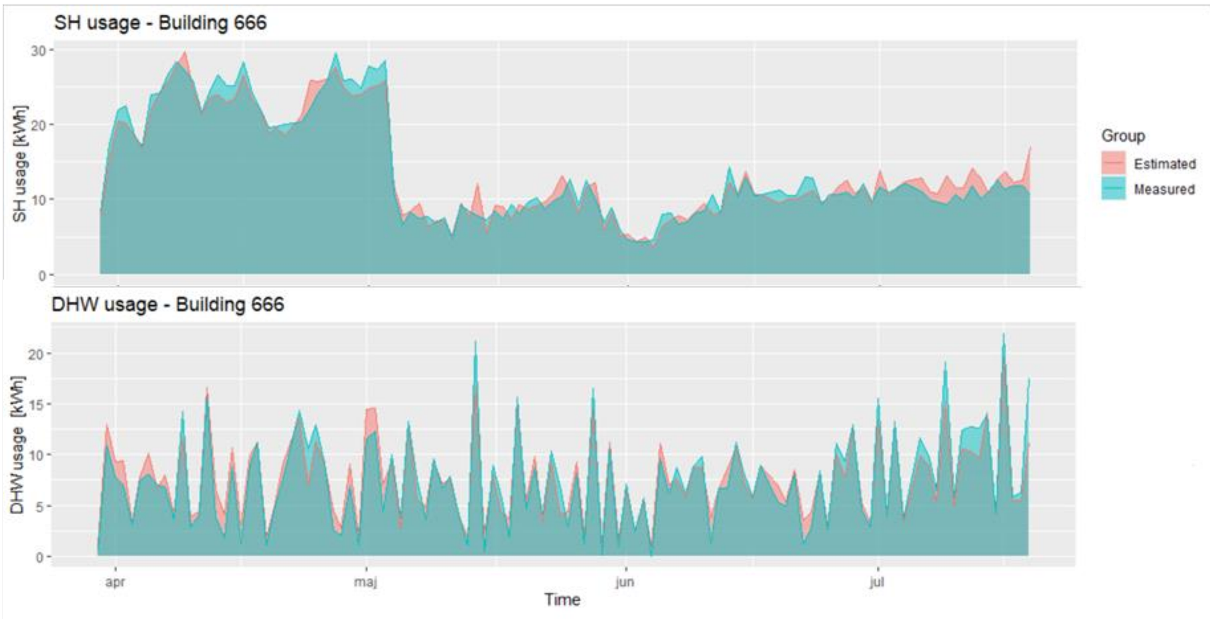

Figure 4: SH and DHW daily usage in household ID:666

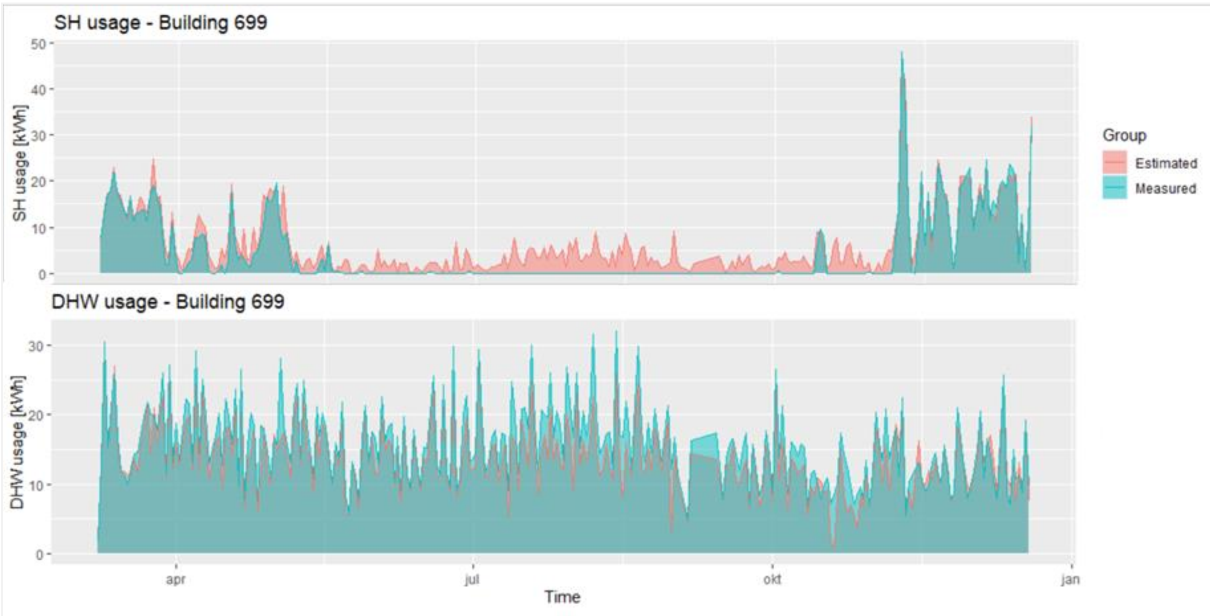

Figure 5: SH and DHW daily usage in household ID:699

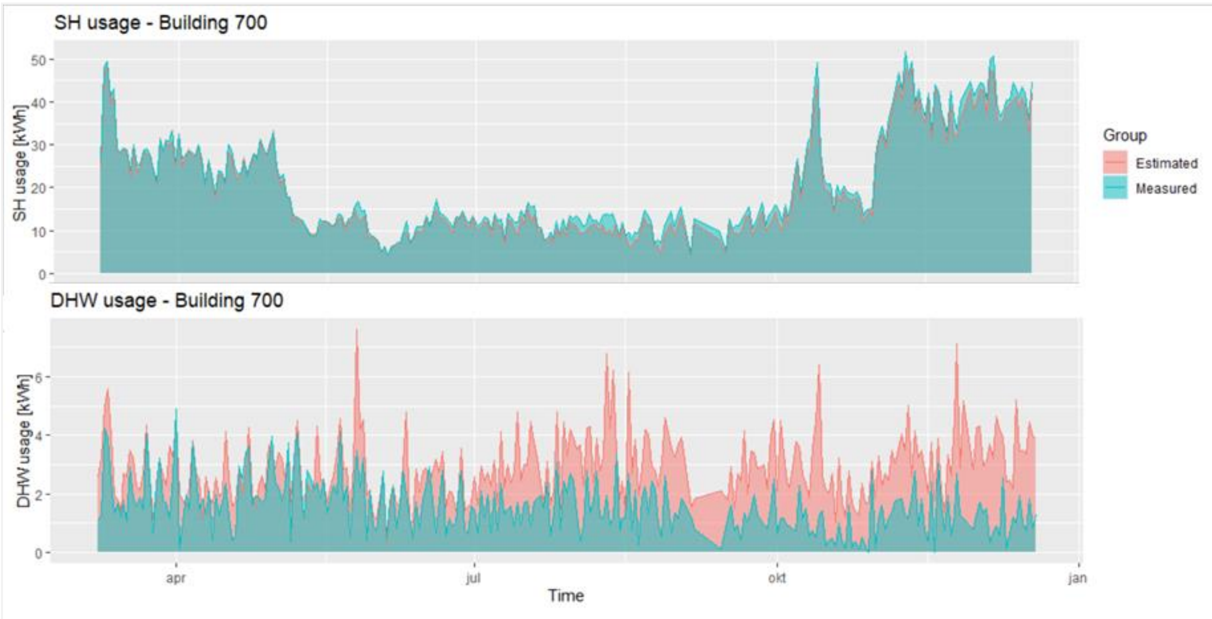

Figure 6: SH and DHW daily usage in household ID:700

In Figure 4, there is no particularity to be highlighted in the graphs. As mentioned above, this specific apartment has the best estimation performance and can be seen by its plotted daily heating usage. In Figure 5, apartment 699 is displayed because its space heating is greatly overestimated. From the plot, it is deduced that the overestimation is due to the method attributing SH usage in the no-heating season when in reality, no space heating was demanded. In Figure 6, the dwelling 700 is also displayed regarding its SH and DHW usage. This apartment has the highest error in the DHW estimation. This difference is due to the overall low consumption of DHW in the dwelling. In Table 2, one can see that its total DHW consumption is 425.3 kWh, which represents only 7% of the total heating consumption.

As one can see, this method performs quite well for some of the apartments. Nevertheless, there are some cases where the error is too high to be neglected. This is because the initial assumption of 7 hours during the day with DHW usage might be too small (few people in a household) or too large (e.g., many people in a household or the DHW is more distributed during the day). Another factor that might generate high inaccuracies is the estimation models used to determine the space heating. The application of the Kalman filter or SVR might not be appropriate for some datasets, negatively affecting the methodology performance. Even though the method might seem too simplistic or have a poor performance for some cases. It can be argued that its simplicity allows it to be applied in several dwellings without depending on more building information that often cannot be retrieved or measurement resolution that the current installed meters do not have.

3.5 Conclusion

The lack of disaggregated data from the households' smart meters and the scarcity of building information to be applied in modeling have catalysed the need to develop a methodology to separate the space heating and domestic hot water demands from the total hourly measurements. The resulting methodology from this task is straightforward and does not depend on numerous inputs, allowing its integration in various projects. Also, the method aims to be applied in 1-hour resolution measurements, allowing it to be used with the retrieved datasets from the current installed smart energy meters.

Relating to the task 2.3 from this project, the methodology itself can be applied to extract more accurate information concerning DHW usage. Due to the absence of information regarding DHW consumption habits in the households, the current energy performance certificates (EPCs) estimate the DHW energy share based on building standards. These standards are based on generalizations that often do not correspond to the actual energy usage and do not consider the dwellers' routines and practices, generating consequently inaccurate results on the energy certificate. Therefore, the results from this methodology can be used to estimate the space heating demand and the domestic hot water production for the operational dynamic certification (DEPC) and consequently decrease the performance gap.

4 Dynamic technology potential for building energy performance evaluation

E-DYCE project aims at the detection of the performance gap (PG), its quantification and elimination as a part of E-DYCE DEPC. Furthermore, the optimization of the building energy performance via utilization of the information generated in E-DYCE DEPC is another objective in the project. Both objectives can be met if the effect of smart and dynamic technologies in the building can be accounted for in the tools used for the certification process. In E-DYCE, the Energy Plus is selected as a suitable tool for that purpose, being an open-source software able to perform dynamic simulation of building performance.

4.1 Problem description

It is of common knowledge that the quality of model results, also in terms of the effect that the dynamic systems have on overall building performance, is highly sensitive to the way the model is developed and to the level of detail and quality in the input data (building and system properties, operational conditions, etc.). The absence of the input data is often addressed by sensitivity and uncertainty studies, meanwhile, the reliability of the model is typically addressed by model validation against the monitoring data. The sensitivity studies and the empirical validation are equally complex procedures suitable for the research purposes but potentially difficult to implement as a part of the routine in an energy certification process. It is, therefore, of key importance in the E-DYCE project to find an approach that allows reasonably accurate quantification of the effect of the dynamic technologies while maintaining simulation efforts at a level that is reasonable for the certification process.

E-DYCE project addresses several building typologies, and the approach to simulate those may vary depending on the typology, climatic conditions, or the dynamic technologies available in the building. This report focuses on addressing the dynamic technologies for multi-family dwellings located in the Nordic climate (Denmark). However, relevant findings for other building typologies from WP3-6 will be integrated into this report by the end of the task. In this way, the outcomes of task 2.3 will support the identification of the level of the credible model for E-DYCE DEPC, and the work in WP3 will build on top of that by addressing the system-related parameter variation (PRE-DYCE) to assess the potential of the dynamic technology.

4.2 Dynamic technologies in E-DYCE

Dynamic or smart technologies in E-DYCE are considered to be the technologies that are or can be present within a building, and these are the technologies whose performance can be modified either by the BMS system or by the occupant to adjust the indoor environmental conditions and/or to obtain a certain energy-saving effect.

Since this report addresses dwellings in Denmark, the dynamic technologies characteristic for these types of buildings must be identified for the assessment of their singular or combined effects. In Denmark, nearly all multi-family dwellings are equipped with a heating system, with the controllable setpoint, and typically there is no cooling installed. The northern latitude is the main reason for the majority of dwellings to have installed internal shading of a light color. Finally, the main differences in the dynamic systems among the buildings in this group belong to the ventilation, as both natural and hybrid ventilation principle is used. There are no other dynamic systems that must be considered for the dwellings, and the following dynamic systems must be selected for the evaluation:

- Heating system
- Ventilation system
- Internal shading system

These are also the systems present in the demonstration buildings in E-DYCE.

4.3 Brief description of existing studies within the area

A brief description of existing works within this area can be provided by the end of WP2.

4.4 Methodology

How to set up a credible model for E-DYCE certification procedure that can address the effect of the dynamic technologies on cooling and heating demand in the building, that can reasonably well calculate comfort-related KPIs and at the same time have an acceptable level of complexity to ease the roll-out of E-DYCE DEPC concept? This section introduces the initial methodology to be able to answer that question.

The core idea of this methodology is to set up several models of a case-building, where the models vary in their level of complexity, ranging from simple to very advanced models. The identification of the credibility of the models is performed in two steps. In the first step, modeling results are compared across the models with different complexity levels and dynamic systems, see Table 3. In the second step, the results of simulations are compared against the monitoring data to identify which simplifications do not significantly interfere with the validity of the results. The hypothesis is that the same methodology can be applied for several buildings of the same building typology (dwellings), then the general conclusions about the acceptable level of model simplification in E-DYCE DEPC can be made, and the resulting model will be able to account for the effect of the dynamic technologies within the building, both in terms of energy and comfort.

Accordingly, this methodology requires a set of monitoring data to evaluate the credibility of a model and to disqualify those with unsatisfactory performance. The limited availability of the monitoring data until the present is the reason why this methodology has not been tested in full, and only limited conclusions can be made. In this report, only the initial results of the method application are described. Meanwhile, the final conclusions will be made when a sufficient amount of the monitoring data has been acquired.

The realization of the methodology in practice requires that the dynamic technologies relevant to consider in the models are identified, and the KPIs for evaluation of each individual model validity, including the energy- and comfort-related KPIs are selected.

The dynamic technologies relevant for the investigation are selected in 4.2. There are several ways how these technologies can be modeled in Energy Plus. They range from the simplistic system models (i.e., using ideal loads) to more advanced ones with a very specific application range and many input properties to be provided. Often, they also require additional care to the combination of system-related models within one thermal zone to avoid conflicts during simulation.

The geometry of the model is another critical aspect to be considered. The definition of thermal zones within the model influences comfort-related properties but also determines how detailed the model results will be. E-DYCE DEPC approach aims at evaluation of comfort as one of the determinants for the performance gap existence. Thus, the zoning of the model can play a significant role when looking for a trade-off between the model simplicity versus model validity.

Finally, the models of different complexity levels that express both the system- and the geometry-complexity must be set up.

4.5 *Definition of complexity levels*

The model complexity study aims to explore the necessity of building modeling in a very complex way and to simplify the building modeling process with the lowest complexity within the acceptable error range, including both building energy simulation and indoor thermal comfort with different building facilities/HVAC systems. The modeling complexity study includes parameter study of the smart/dynamic technologies: the *shading complexity levels*, the *mechanical ventilation complexity levels*, and the *heating system complexity levels*.

Moreover, it was identified that model complexity study of dynamic technologies must also take account for the *zoning -complexity levels* as these might shift results, and wrong conclusions could be drawn in case the spectrum of zoning possibilities was not taken into account in the analysis.

Table 3 presents the summary of the complexity levels for the identified smart/dynamic facilities and zoning methods. The internal mass is added to complexity level 1-4 for the missing internal floors and internal walls. This means that the thermal mass is equally accounted in all of the models, but its definition varies between the simplified and detailed models.

Table 3. Overview of the complexity levels

	Complexity level	
Zoning methods	1	One zone per staircase
	2	Two zones per staircase
	3	One zone per apartment
	4	2 zones per apartment (west rooms as one zone, east rooms as another zone)
	5	One room as a zone
Facility 1 (shading)	1	Simple shading, controlled based on either room air temperature or solar radiation, shadow calculation method: Periodic
	2	Shadow calculation method: timestep
Facility 2 (ventilation)	1	Zone ventilation, not considering wind speed and wind direction
	2	Fan ventilation, no fan curve, and pressure curve
	3	Airflow network, fan exhaust, wind pressure on each external surface
	4	Balanced ventilation with heat recovery
Facility 3 (heating)	1	Ideal loads, district heating energy demand
	2	Convector heating system (electricity heating)
	3	District heating + radiator (Figure 16)

Consequently, the system for model names has been developed to monitor a large number of models developed for different complexity levels of facilities and zoning methods. The methodology for model names is presented in Table 4.

Table 4. Definition of model names.

A_B_C-zoningD	Example: 1_2_3 –zoning3
A- Shading complexity level	Shading complexity level 1
B- Ventilation complexity level	Ventilation complexity level 2
C- Heating complexity level	Heating complexity level 3
D- Zoning method	One zone per apartment

4.6 KPIs for model evaluation

The number of KPIs are used to compare models results across defined in previous Chapter 4.5 complexity levels. Model results are separated by heating season and cooling season. Moreover, KPIs used in this study are to a high extent aligned with the KPIs identified for the DEPC protocol in D2.4 and cover focus areas: energy (heating and cooling, energy signature), thermal comfort, atmospheric comfort. It is necessary to mention that KPIs in this report differ from those identified in Deliverable 2.4 of the E-DYCE project. It is due to the fact that the purpose for the KPIs application in this report is different from the Deliverable 2.4. In this work, the KPIs are used to verify and select appropriate models, meanwhile, in Deliverable 2.4, the KPIs are identified to provide the user with specific information.

Heating season KPIs:

- **Free_running_h (free-running hours)** for the whole building, calculated as 1-hour intervals, when the heating system does not call for heat in the heating season. It is calculated for the whole building, thus in multizone models, it is expected that none of the zones call for heating. Note that this parameter is not representative of the actual free-running potential in a mechanically heated building. Here the duration of the heating season, as well as the need for fictitious cooling/heating are the important parameters. Still, the free-running time is included in the evaluation, as it is critical that the selected simplification approach can predict the free-running potential.
- **Heating** (heating energy) **kWh/week, kWh/m²/year** – heating demand of the building, weekly values, calculated only for the heating season. The cooling season is defined when the heating load of the staircase is less than 10% of the maximum heating load for no less than 3 days. When the cooling season is identified, then the rest of the year is accounted for as the heating season. The cooling season, in this case, is understood as the period when no heating is present. Additionally, it must be mentioned that no active cooling systems are used in the Danish demo sites.
- **H_26_heating** Hours/Minutes of zone operative temperature out of range (T_{avg} < 20 °C or T_{avg} > 26 °C, where T_{avg} is the volume average temperature of the zone. Please note that the name of this KPI will be changed in the final report.
- **CO2_900+_heating** Hours/Minutes of CO2 concentration above 900 ppm. For multizone models, CO2 concentration for the whole building is defined as a volume-averaged value for all zones.

- **CO2_600-_heating** Hours/Minutes of CO2 concentration below 600 ppm. For multizone models, CO2 concentration for the whole building is defined as a volume-averaged value for all zones.
- **PMV1_heating** Hours/Minutes of zone thermal comfort in the category I ((-0.2) <= PMV <= 0.2).
- **PMV2_heating** Hours/Minutes of zone thermal comfort in the category II ((-0.5) <= PMV <= 0.5).
- **PMV3_heating** Hours/Minutes of zone thermal comfort in the category III ((-0.7) <= PMV <= 0.7).
- **PMV_out_heating** Hours/Minutes of PMV out of range (PMV >= 0.7 or PMV <= (-0.7)).

Cooling season KPIs:

- **H_26** (Hours/Minutes of zone operative temperature out of range (T_{avg} < 20 °C or T_{avg} > 26 °C, where T_{avg} is the volume average temperature of the zone)).
- **CO2_900+** (Hours/Minutes of CO2 concentration above 900 ppm.
- **CO2_600-** (Hours/Minutes of CO2 concentration below 600 ppm.
- **CEN1** (Hours/Minutes of zone thermal comfort in category I) is defined by T_{avg} >= 0.33*T_o+18.8-3 and T_{avg} <= 0.33*T_o+18.8+2, where T_{avg} is the volume average temperature of the zone, and T_o is the running mean outdoor air temperature.
- **CEN2** (Hours/Minutes of zone thermal comfort in category II) is defined by T_{avg} >= 0.33*T_o+18.8-4 and T_{avg} <= 0.33*T_o+18.8+3.
- **CEN3** (Hours/Minutes of zone thermal comfort in category III) is defined by T_{avg} >= 0.33*T_o+18.8-5 and T_{avg} <= 0.33*T_o+18.8+4.
- **CEN_out** (Hours/Minutes of zone thermal comfort out of the category III) is defined by T_{avg} < 0.33*T_o+18.8-5 or T_{avg} > 0.33*T_o+18.8+4.

4.7 Demonstration sites

4.7.1 Demo 1- Magisterparken 415, Aalborg

The buildings were built in 1964 and renovated in 2012. The heated area is 2398m². The analysed building is Magisterparken, staircase 8, and it belongs to the complex of 10 buildings called Magisterparken. This case-building will be referred to in this report as Magisterparken.

Figure 7. Building number 415 on Magisterparken. Image from Krak.dk

The major orientation of the building is north/south. The building is far away from other buildings from all orientations and not influenced by the shadow of other buildings.

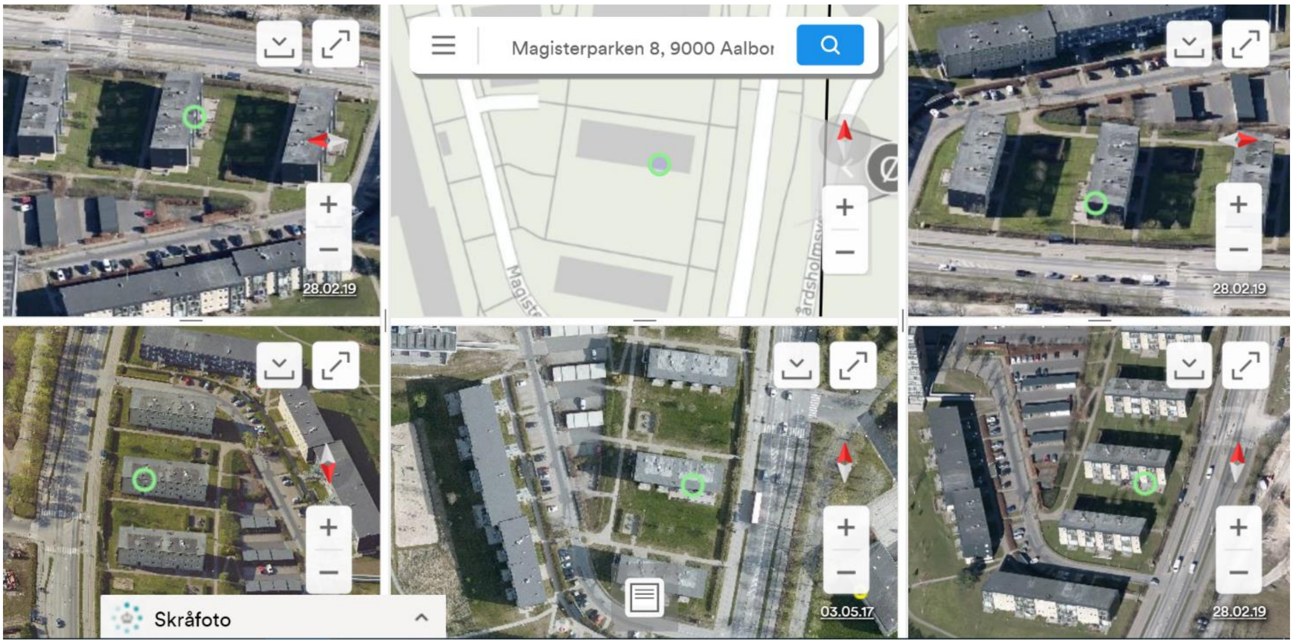

Figure 8. Magisterparken 415, 9000 Aalborg. https://skraafoto.kortforsyningen.dk/

The building has 3 floors, 2 staircases, and 12 apartments (6 apartments on each staircase and 2 apartments per floor). The west apartment is 87 m^2 and has 1 living room, 2 bedrooms, a kitchen, a bathroom, a balcony, and an entrance. The east apartment is 73.2 m^2 and has 1 living room, 2 bedrooms, a kitchen, a bathroom, a balcony and an entrance.

The roofing is made of wood. The external wall is built by 2 layers of bricks and one layer of air gap between the 2 bricklayers. The ground floor is made of 140 mm concretes. More details can be found in Appendix C.

The ventilation system consists of exhaust fans in the kitchen and bathroom. The inlet air is going through building cracks and window/door openings.

4.7.2 Demo 2 - Højrupsvej 48, Hånbæk Fredrikshavn

The buildings were built in 1972 and renovated in 2011. The total heated area is 4756m^2. The analysed building is Højrupsvej 48, and it belongs to a complex of 15 buildings called Hånbæk. This case-building will be later referred to in this report as Hånbæk.

Figure 9. Building number 48 on Koktvedvej and Højrupvej. Image from Krak.dk

The major orientation of the building is north/south. The building is far away from other buildings from the south, east and west orientations, and not influenced by the shadow of other buildings, see Figure 10.

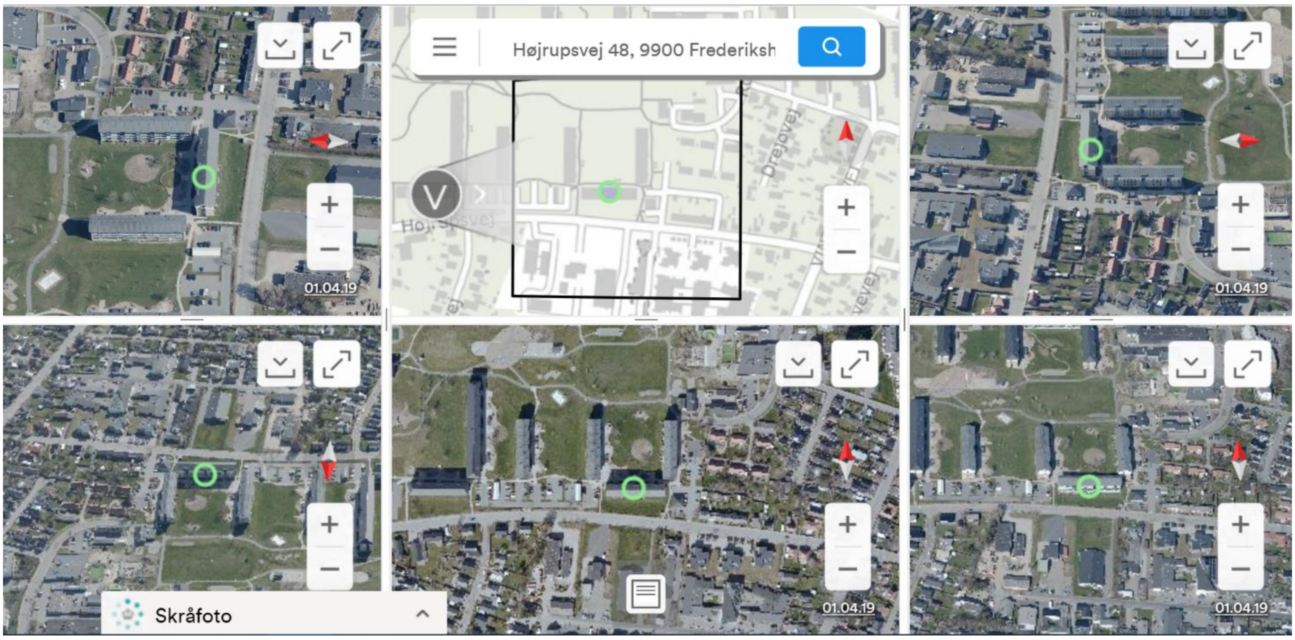

Figure 10. Afd 12 Hånbæk, Højrupsvej 48, 9900 Frederikshavn.

The building has 4 floors, 3 staircases, and 24 apartments (8 apartments on each staircase and 2 apartments per floor). Each apartment is 118 m^2 and has 1 living room, 3 bedrooms, a kitchen, a bathroom, a balcony, and an entrance.

The roofing consists of shingles. The external layer of the external wall is built of yellowish bricks, partly with cement plates. The inner layer of the external wall is built with 190 mm concrete. The middle layer of the wall is insulated with 90-210mm insulation. More details can be found in Appendix C.

The ventilation system is balanced ventilation with heat recovery. The ventilator is Exhausto BESB 315 MGE. The constant air volume meets the requirements of the building regulations with 15 l / s from the bath and 20 l / s from the kitchen. The heating system is district heating with water radiators. Solar curtains are installed by individual residents in each apartment.

4.7.3 Demo 3 - Thulevej 50-56, Aalborg

The buildings were built in 1969 and renovated in 2010. The heated area is 3262m², including 39 apartments in total. The building has a southwest orientation.

Figure 11. Building number on Thulevej 2-56. Krak.dk

The building has 4 floors, 5 staircases, and 39 apartments. For each staircase, the 0 floor has 2 apartments of the size 38 m², consisting of a living room, a bathroom, a kitchen, and a locked balcony. The 1-4 floors have an 86 m² apartment and a 100 m² apartment for each floor. The 86 m² apartment has a living room, 2 bedrooms, a kitchen, and a locked balcony. The 100 m² apartment has a living room, 3 bedrooms, a kitchen, and a locked balcony. The external walls consist of 2 layers of brick and a layer of wool insulation in the middle.

4.8 *Models - B*asic settings and *zoning of demonstration cases*

4.8.1 Geometry

The geometry of Magisterparken is shown in Figure 12. It has an unconditioned underground basement, which is simulated as a building component for heat transfer calculation and is separated from building zones. The balcony and corridor are not conditioned, thus are also separated from building zones. The west, north, and south façades of the staircase are external walls and are exposed to sun and wind. The east façade is made of internal walls adjacent to another staircase.

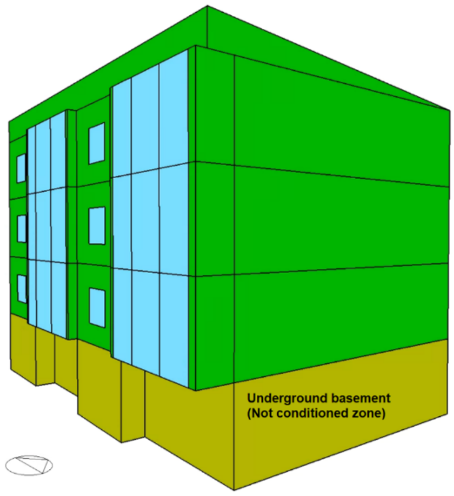

Figure 12. Geometry of Magisterparken 415, 9000 Aalborg.

The geometry of Hånbæk is shown in Figure 13. It has a boundary to the ground. The west, north, and south façades of the staircase are external walls and are exposed to sun and wind. The east façade is made of internal walls adjacent to another staircase. The balcony and corridor are not conditioned, thus are separated from building zones.

The geometry of Thulevej is under development, and further work will proceed once conclusions are drawn for the first two models, Magisterparken and Hånbæk.

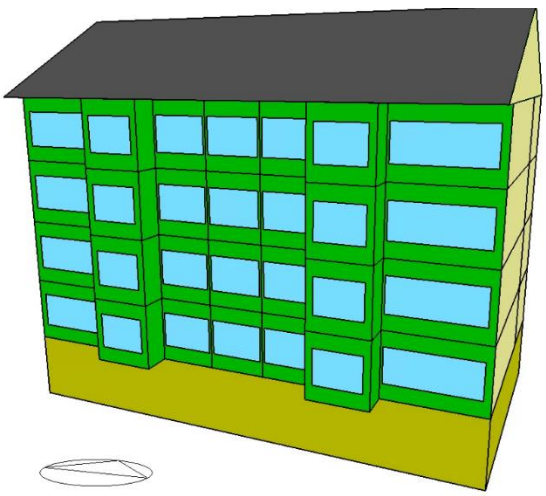

Figure 13. Geometry of Afd 12 Hånbæk, Højrupsvej 48, 9900 Frederikshavn.

4.8.2 *Constructions (opaque, transparent, adiabatic, internal/external etc.), thermal bridges*

For Magisterparken, the U values of the constructions are listed in Table 5. The materials and structures of the constructions are shown in Appendix C. For Hånbæk, the U values of the constructions are listed in Table 6. The details of the materials and layers of the constructions are shown in Appendix C.

Table 5. The U values of the different constructions in Magisterparken.

Construction	U value (W/m²K)
External wall	1.11
Roof	0.37
Ground floor	0.30
Basement wall	0.42
Basement floor	0.43
Window	2.80

Table 6. The U values of the different constructions in Højrupsvej 48.

Construction	U value (W/m²K)
Roof	0.12
Gable	0.22
Remaining exterior wall	0.35
Window	1.5

The thermal mass of the buildings in building simulation includes the internal walls, floors, partitions, etc. the thermal mass of the furniture is not included.

4.8.3 *Internal loads*

The internal loads and schedules are taken from DS EN 16798-1 standard [21], including the occupants, appliances, and lighting. Presented in Figure 14-15 and

Table 7 schedule and parameter setpoints are common for all developed models.

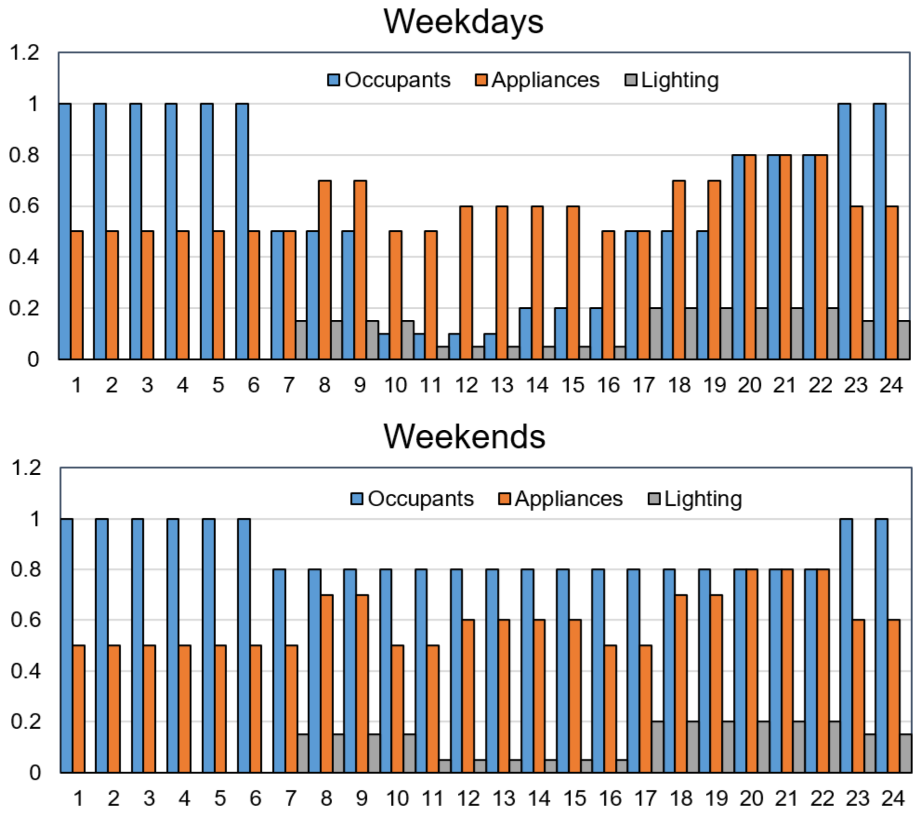

Figure 14. The schedule of the internal loads for the simulation. Source from DS EN 16798-1 standard [21]**.**

The clothing schedule is shown in Figure 15.

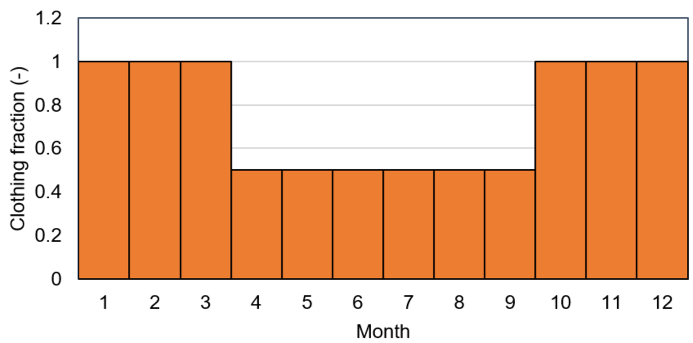

Figure 15. The clothing schedule of the residential occupants.

Table 7. Parameters and setpoints usage schedule for energy calculations. Source from DS EN 16798-1 standard [21].

	Parameter	Value	Unit
Operation time	Hour at day, START	0	hour
	Hour at day, END		24 hour
	Breaks, inside range	0	hours
	days/week	7	days
	hours/day	24	hours
	hours/year	8760	hours
Internal gains	Occupants	28,3	m2/pers
	Occupants (Total)	4,2	W/m^2
	Occupants (Dry)	2,8	W/m^2
	Appliances	3	W/m^2
	Lighting		
	Moisture production	2,12	g/(m2, h)
	CO_2 production	0,66	l/(m2, h)
Setpoints	Min T,op in unoccupied hours	16	°C
	Max T,op in unoccupied hours	32	°C
	Min T,op	20	°C
	Max T,op	26	°C
	Ventilation rate (min.)	0,5	l/(s m2)
	Ventilation rate for CO2 emission	0,28	l/(s m2)
	Max CO2 concentration (above outdoor)	500	ppm
	Min. relative humidity	25	%
	Max. relative humidity	60	%
	Lighting, illuminance in working areas	0	lux

The activity level of the occupants is calculated as Equation (1).

$$\textit{Activity level} = 28.3\ m^2/person * 4.2\ W/m^2 = 118.86\ W/person \qquad (1)$$

Of which fraction of radiation is 0.3.

4.9 Dynamic systems

In this Chapter are described dynamic facilities: shading, ventilation, heating that are taken into account in the study. Detail description of each facility model set up in EnergyPlus can be found in Appendix B.

4.9.1 Shading

The shading properties for all windows are defined in Table 8. In the first round, these properties were assumed, but for the model verification, these will be modified according to actual shading properties in the buildings. Reflectance and emissivity properties are assumed to be the same on both sides of the shade. Shades are considered to be perfect diffusers (all transmitted and reflected radiation is hemispherically-diffuse) independent of angle of incidence. Moreover, shading is turned on when there is high solar on a window (I>150W/m2).

Table 8. Specifies the properties of window shade materials.

Field	Units	Obj1
Name		20020
Solar Transmittance	dimensionless	0.65
Solar Reflectance	dimensionless	0.25
Visible Transmittance	dimensionless	0.65
Visible Reflectance	dimensionless	0.25
Infrared Hemispherical Emissivity	dimensionless	0.9
Infrared Transmittance	dimensionless	0
Thickness	m	0.003
Conductivity	W/m-K	0.1
Shade to Glass Distance	m	0.05
Top Opening Multiplier		1
Bottom Opening Multiplier		1
Left-Side Opening Multiplier		0
Right-Side Opening Multiplier		0
Airflow Permeability	dimensionless	0

Table 9. The complexity level of shading.

Complexity level	Description
1	Calculating sun position every 20 days (EnergyPlus default)
2	Calculating sun position every timestep

4.9.2 Ventilation

The ventilation airflow rate for all the models is q = 30 m^3/h/person. The ventilation modeling complexity is listed in Table 10. The subsections describe the principle of each ventilation model.

Table 10. The complexity level of ventilation.

Complexity level	Description
1	Zone ventilation, not considering wind speed and wind direction
2	Fan ventilation, Design Specified Outdoor Air
3	Airflow network, fan ventilation
4	Balanced ventilation with heat recovery

The fan ventilation has a similar principle as the zone ventilation and results in similar values for the KPIs, thus being down prioritized.

The EnergyPlus airflow network consists of a set of nodes linked by airflow components. Therefore, it is a simplified airflow model compared to detailed models such as those used in computational fluid dynamics (CFD) models. The node variable is pressure, and the linkage variable is airflow rate.

When working together with AirflowNetwork, the zone inlet air doesn't need extra settings in Design Specification Outdoor Air and ZoneVentilation objects.

In Hånbæk, the ventilation system is balanced ventilation with heat recovery. The air loop AHU is used for the whole staircase, which consists of an outdoor air mixer, a supply fan, a return fan, and a heat recovery unit. The fans are constant air volume fans. The heat recovery unit is an air-to-air heat exchanger using effectiveness relationships. The sensible effectiveness is 0.75, and the latent effectiveness is 0.

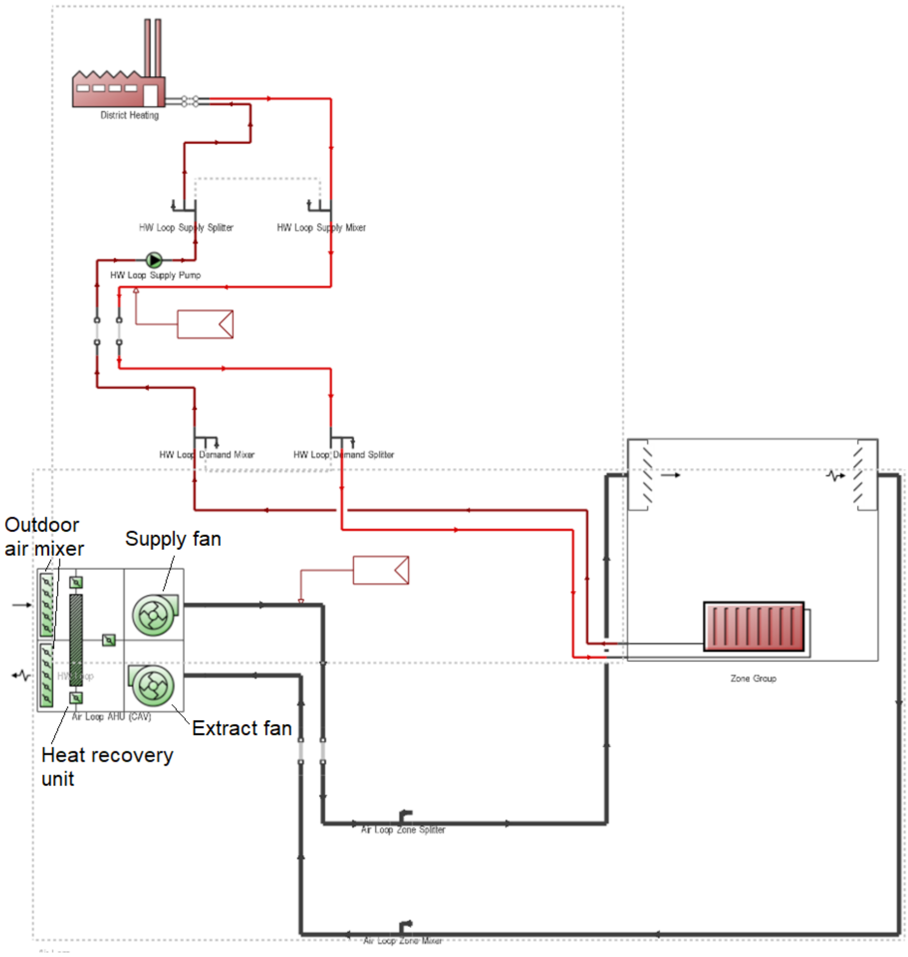

Figure 16. The balanced ventilation system with heat recovery unit.

Ideal loads HVAC system with heat recovery and zone ventilation is not representable for the system because the ideal loads HVAC provides no heat recovery for the zone ventilation, as shown in Figure 17.

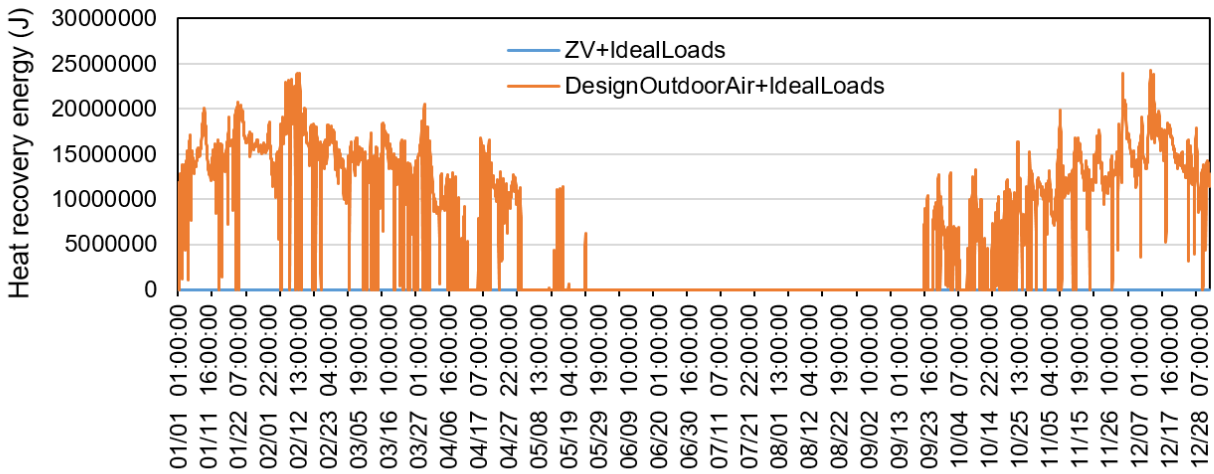

Figure 17. The heat recovery energy of the zone ventilation+ ideal loads HVAC stem compared to design outdoor air + ideal loads HVAC system.

While the design outdoor air with ideal loads HVAC provides heat recovery for the ventilation but only when the ideal loads HVAC is active (heating demand is not 0), which is shown in Figure 18.

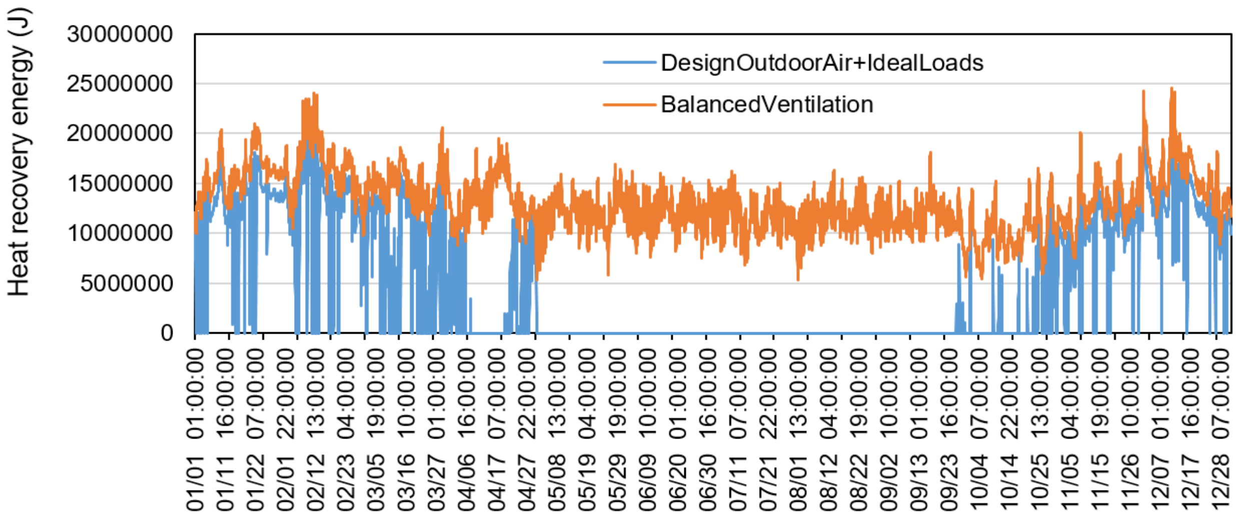

Figure 18. The heat recovery energy of design outdoor air + ideal loads HVAC system compared to balanced ventilation + heat recovery system.

In Magisterparken, the mechanical ventilation is exhaust ventilation without heat recovery, thus facility 2 has only 3 complexity levels: i) zone ventilation, ii) ideal loads, iii) airflow network.

4.9.3 Heating

The operative temperature heating setpoint is 20°C for the whole staircase. The non-heating season is defined when the heating load of the staircase is less than 10% of the maximum heating load for no less than 3 days. No cooling is available for all the thermal zones. The complexity level of the heating system is shown in Table 11. The subsections explain the modeling principles of the different heating models.

Table 11. The complexity level of the heating system.

Complexity level	Description
1	Heating: ideal loads
2	Heating: convector heating
3	Heating: district heating+ water radiator

4.10 Zoning complexity levels

Requires further elaboration as the task 2.3 progresses.

Table 12. The descriptions of 4 zoning complexity levels.

Level	Zoning methods	People method	Equipment level
1	One zone per staircase	Number of people per floor area, 9.4333 m^2/person for Magisterparken, 7.075 m^2/person for Højrupsej	3*nr_of_floor W/m^2
2	Two zones per staircase	Number of people per floor area, 28.3 m^2/person	3 W/m^2
3	One zone per apartment	Number of people per floor area, 28.3 m^2/person	3 W/m^2
4	2 zones per apartment (west rooms as one zone, east rooms as another zone)	Number of people per floor area, 28.3 m^2/person	3 W/m^2
5	One room as a zone	Number of people per floor area, 28.3 m^2/person	3 W/m^2

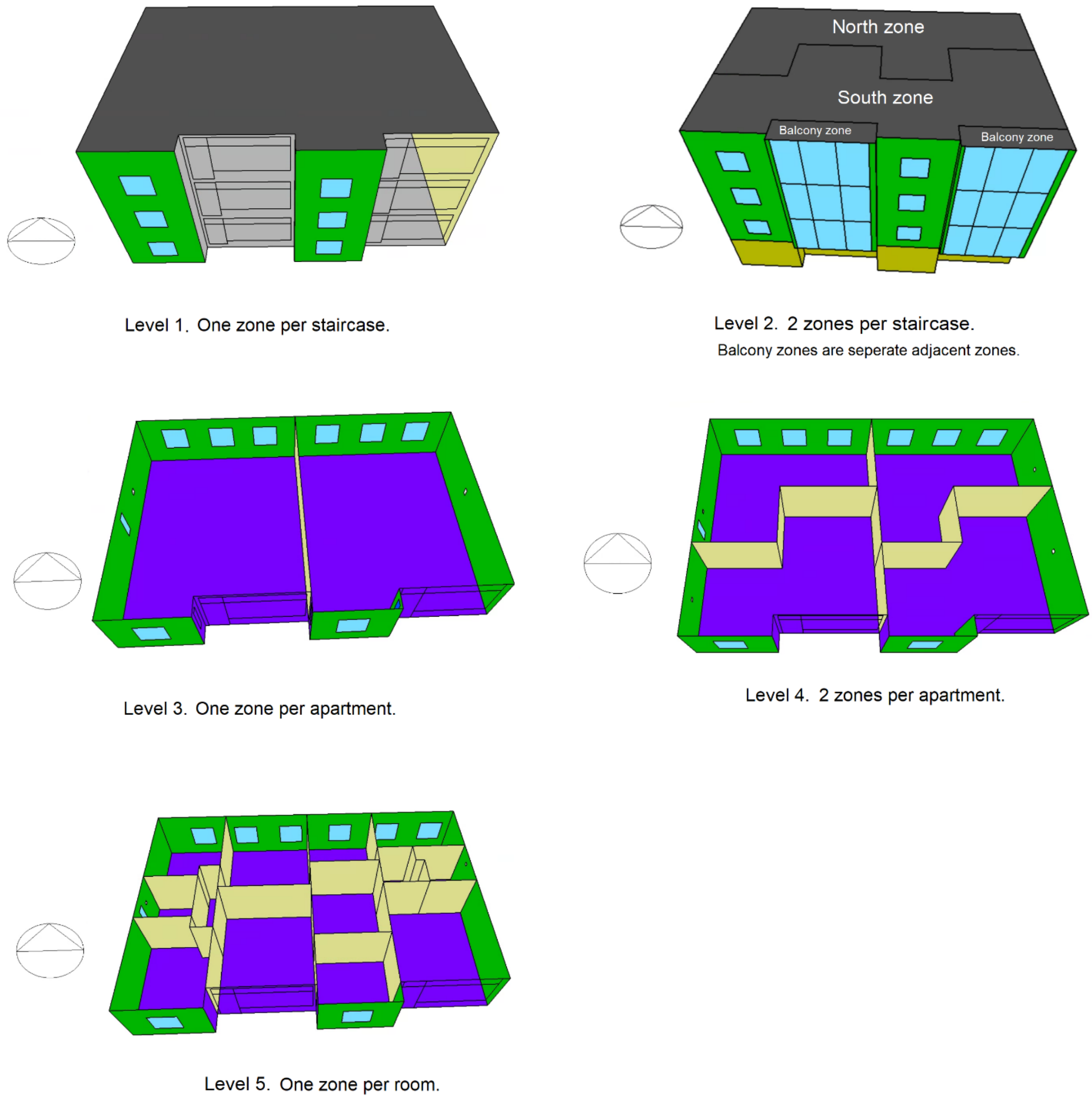

Figure 19. The 4 levels of zoning complexity of Magisterparken.

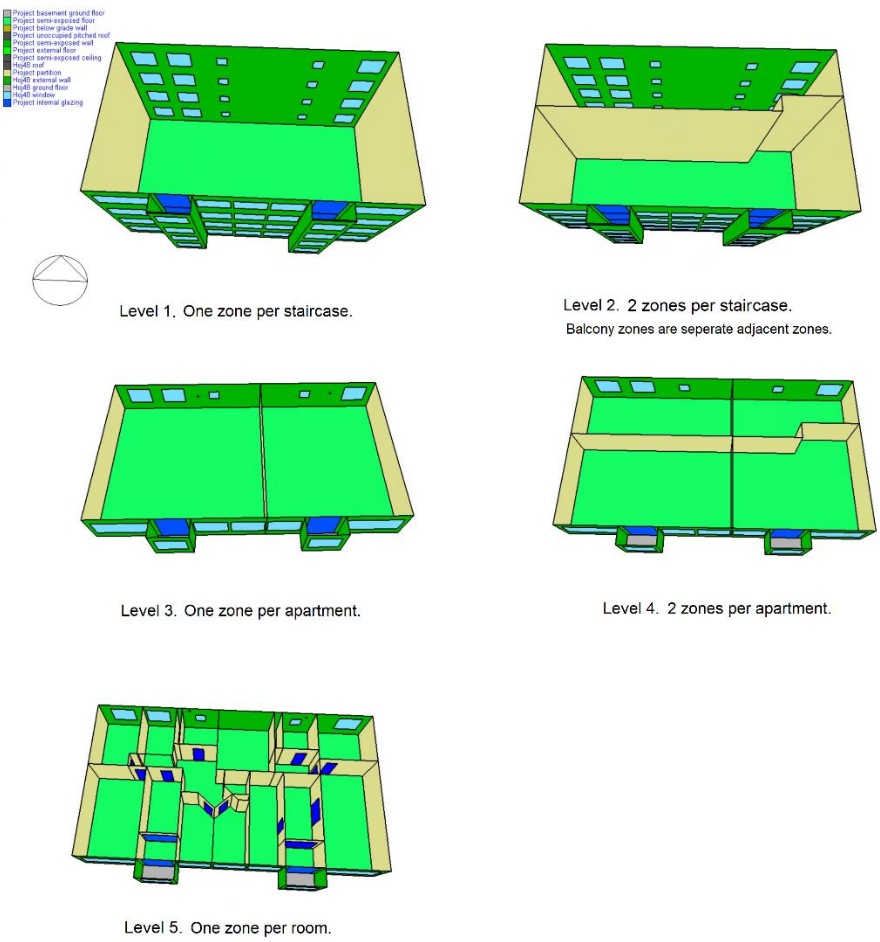

Figure 20. The 4 levels of zoning complexity of Hånbæk

4.11 Definition of the heating/cooling season

In this work, the definition of the cooling and heating season becomes critical, as only for the flexible season definition the free-running potential of the building can be fully explored. Therefore, a common methodology for the definition of the seasons must be established and used identically for all of the demo buildings when evaluating the model complexity.

The heating season is defined as follows: the season ends when 3 days in a row the peak hourly energy demand is below 10% of the heating load and ends when in 3 days the peak hourly energy demand is above 10% load for the highest energy consumption model. To find out the highest energy consumption model, all the models are running through entire year calculation with standard weather condition with heating system running the whole year. The 10% heating load of the total heating load is shown in Figure 21 for Magisterparken and Figure 22 for Hånbæk. The resulting cooling and heating seasons for both buildings are provided in Table 13.

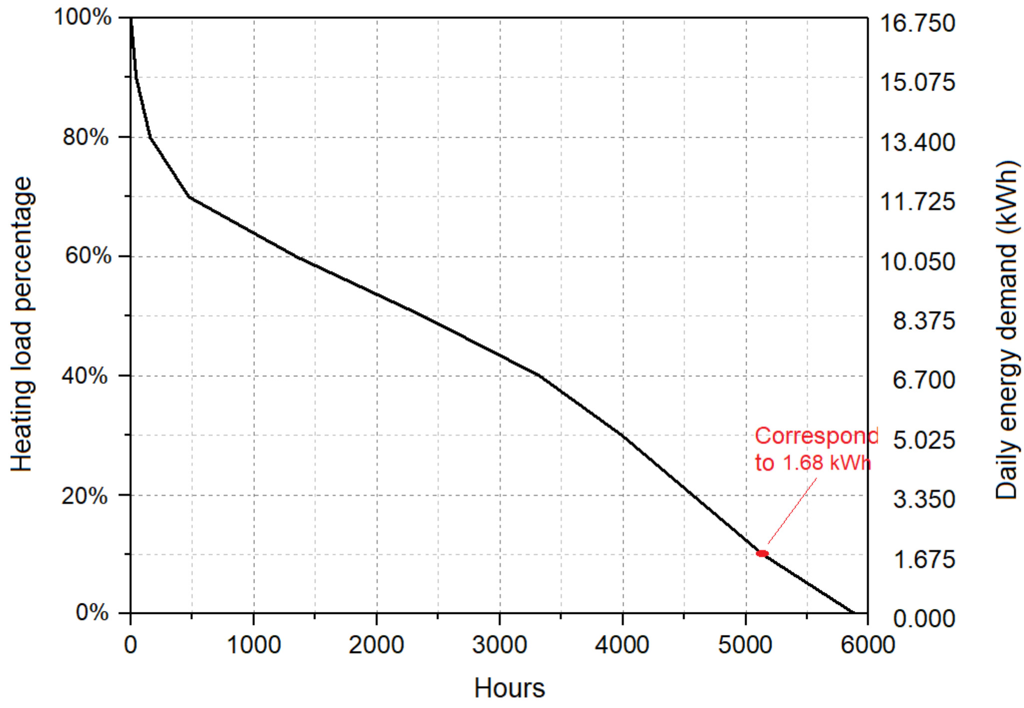

Figure 21. Magisterparken. The accumulated hours of the heating load percentage of the modeling with heating system running the whole year.

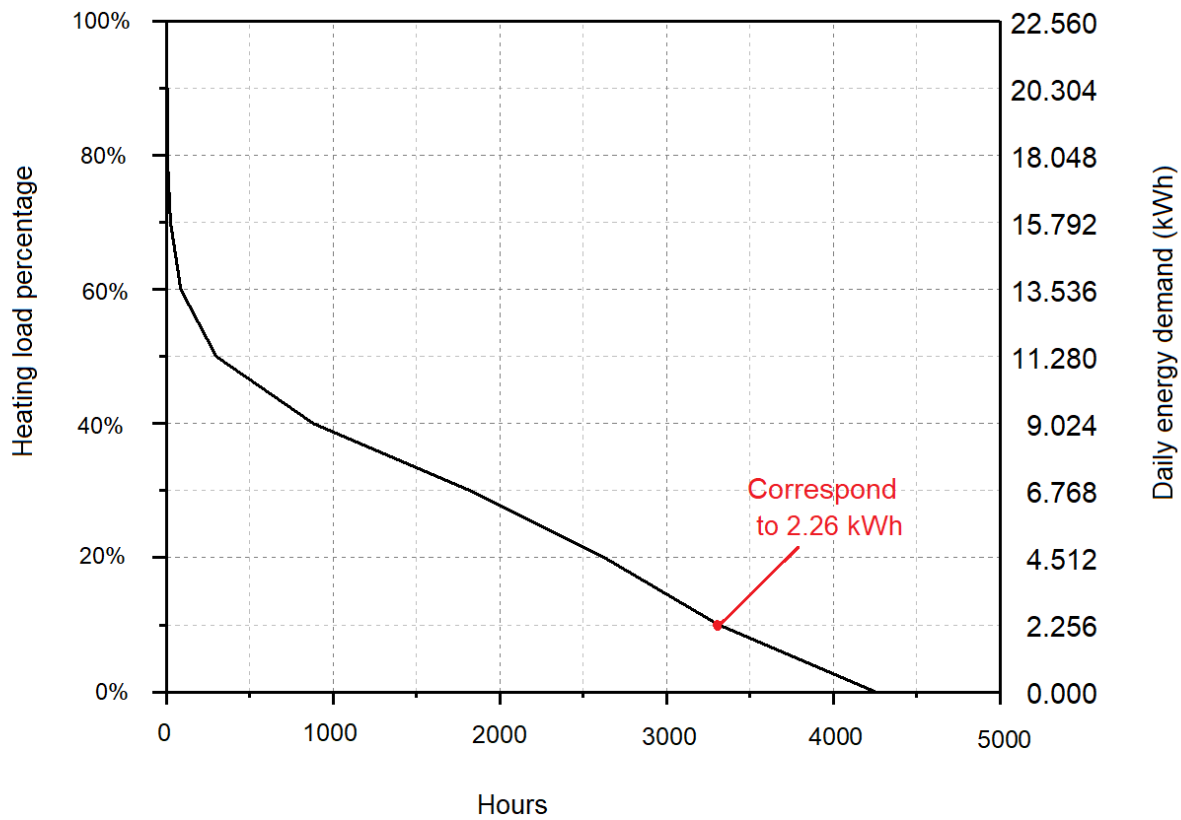

Figure 22. Hånbæk. The accumulated hours of the heating load percentage of the modeling with heating system running the whole year.

Table 13. Heating and cooling season duration.

	Magisterparken	Hånbæk
Cooling season	3rd May - 19th September	7th April - 17th October
Heating season	19th September - 3rd May	17th October - 7th April

4.12 Preliminary results and discussion

This section introduces the initial results of the model complexity study. These include results for two cases: Magisterparken and Hånbæk. The models for Thulevej are under development, and further work will proceed once conclusions are drawn for the first two cases.

The results include a number of KPIs described in section 4.6. Only selected KPIs are included in this report, as the remaining ones require an additional processing time and will be integrated into the final version of this report. The results are mainly annual values split into two groups: for the heating season and cooling season. KPIs with better resolution, for example, weekly values, are not yet processed and therefore not included in this report.

It has to be mentioned that for the summer (cooling season) conditions, the heating system is not activated, and several figures in the report will be simplified in the future.

4.12.1 Demo 1- Magisterparken

In Magisterparken, the mechanical ventilation is exhaust ventilation without heat recovery, thus facility 2 has 3 complicity levels, which are shown in Table 14. The names of the models are defined using the principle described in section 4.5.

Facility 1 level 2 gives very similar results to facility 1 level 1. The results of this investigation will be added to the Annex of this report in the future. Accordingly, the results of facility 1 level 2 are not included in the studies.

Facility 2 level 2 gives very similar results as facility 2, level 1. This is explained by similarities in models in Energy Plus. Therefore, the results of facility 2, level 2 simulations are also omitted in this report.

Table 14. Model complexity levels of Magisterparken 415.

	Complicity level	
Facility 1 (shading)	1	Simple shading, controlled based on either room air temperature or solar radiation, shadow calculation method: Periodic
	2	shadow calculation method: timestep
Facility 2 (ventilation)	1	Zone ventilation, not considering wind speed and wind direction + ideal loads HVAC system
	2	Ideal loads HVAC system+ design outdoor air
	3	Airflow network, exhaust ventilation, air intake is covered by defining the size and location of leakages and wind pressure on each external surface.
Facility 3 (heating)	1	Ideal loads, district heating energy demand
	2	Electric convector
	3	District heating + water radiator
Zoning methods	1	One zone per staircase
	2	2 zones per staircase (divide the staircase by south zone and north zone)
	3	One zone per apartment
	4	2 zones per apartment (south rooms as one zone, north rooms as another zone)
	5	One room as a zone

4.12.1.1 Heating season

Figure 23 shows the yearly modeling results of all the models with different complexity levels in the heating season. It shows a large deviation in heating demand among the models. The thermal comfort for PMV1 and PMV3 are in good agreement between all models, while PMV2 is split into two groups. Overventilation (CO2_600-) is in good agreement among all the models, while underventilation (CO2_900+) is split into two groups.

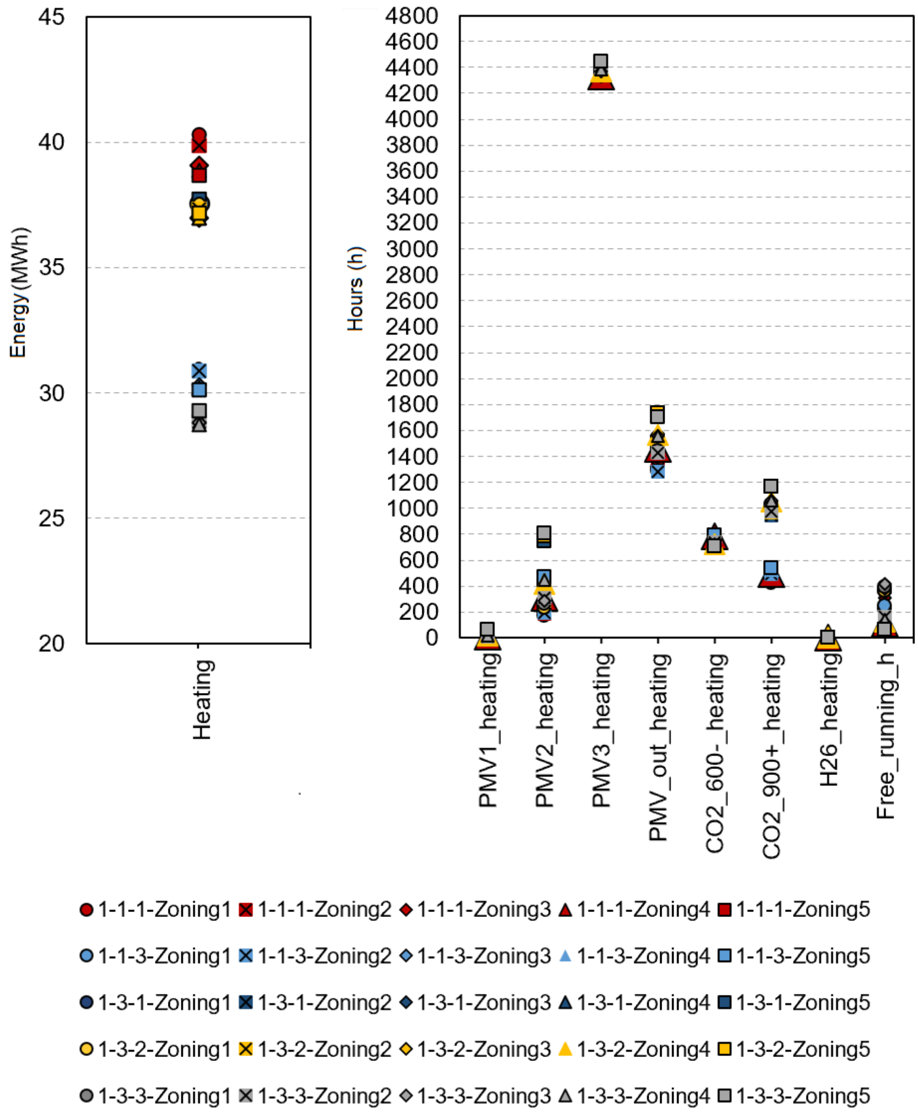

Figure 23. The yearly modeling results of all the models with different complicity levels in the heating season.

From Figure 23, the data from all models are combined. It shows the distribution of the results, but it is hard to see the specific model results with deviations in details. In Figure 24, the yearly results of heating demand are sorted based on the zoning methods, which shows that the heating demand is independent of the zoning approach, but the different definition of systems results in two groups of results: heating demand of apx. 30 MWh and above 35 MWh.

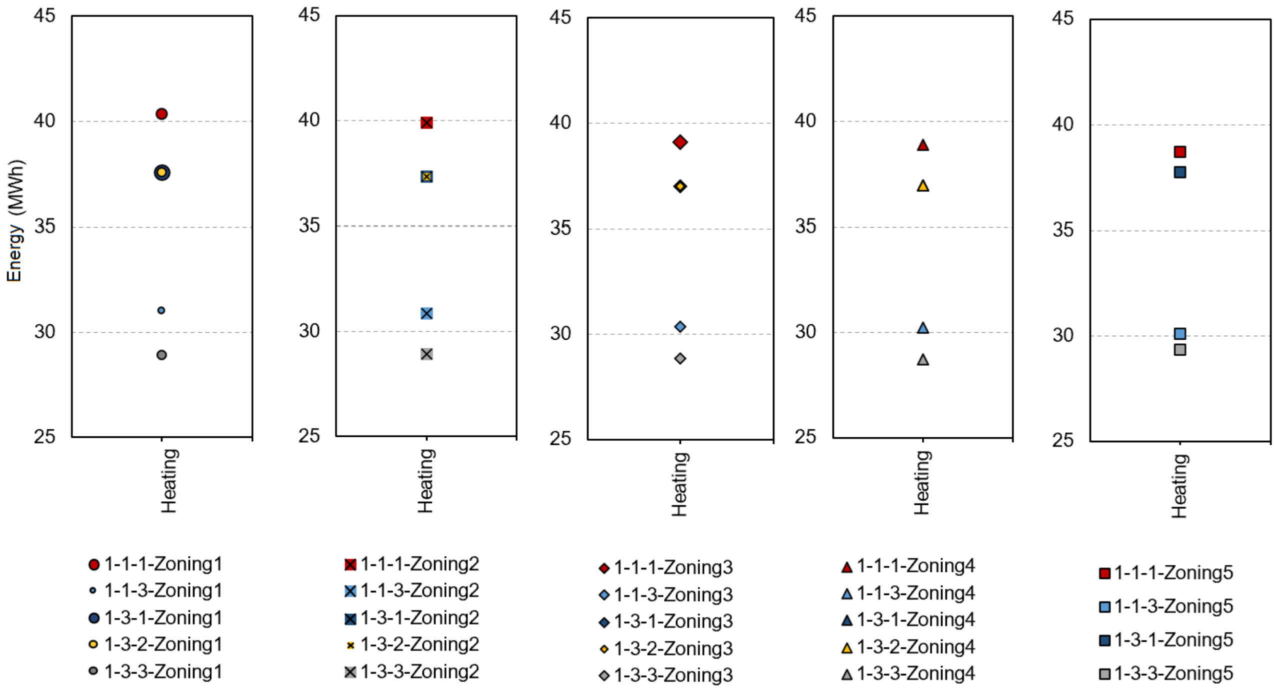

Figure 24. The yearly modeling results of heating demand are sorted based on the zoning methods.

In Figure 25, the yearly results of heating demand are sorted based on the facility modeling methods. When comparing different facility modeling methods, detailed ventilation models have a lower heating demand compared to other ventilation models (for example, 1-3-1-zoing1 is lower than 1-1-1-zoing1), and detailed heating system modeling methods have a lower heating demand compared to other heating system modeling methods (for example, 1-3-3-zoing1 is lower than 1-3-1-zoing1).

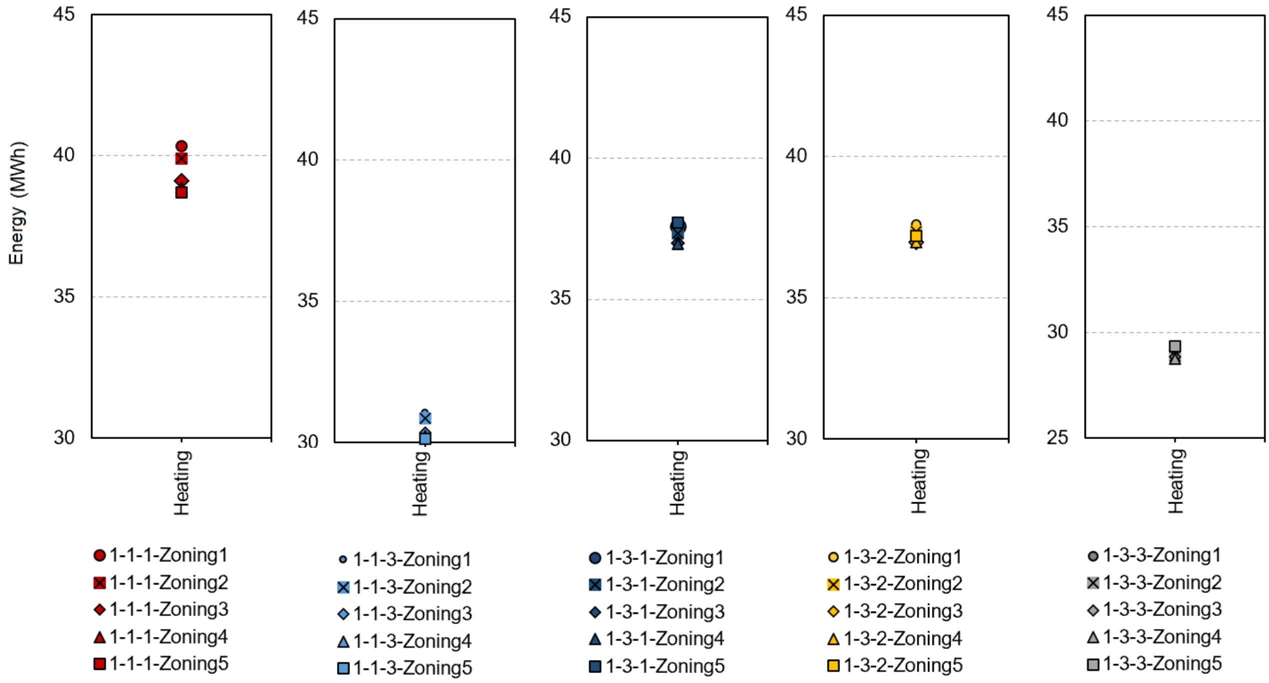

Figure 25. The yearly modeling results of heating demand are sorted based on the facility modeling methods.

The yearly results of the other KPIs in the heating season are sorted based on the zoning methods in Figure 26. It shows that thermal and atmospheric comfort (PMV and CO2) are sensitive to facility modeling and less sensitive to zoning. However, the calculation of the free-running hours is sensitive to the zoning approach.

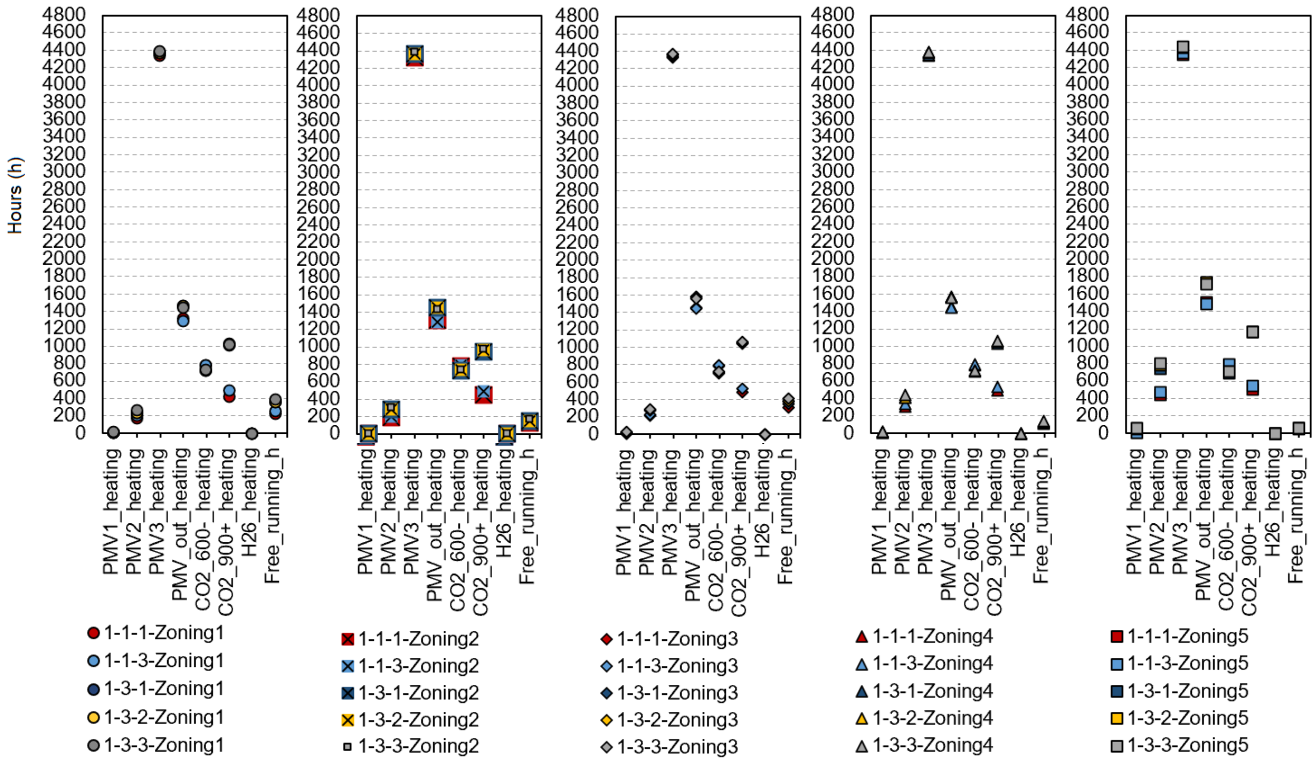

Figure 26. The yearly modeling results of other KPIs are sorted based on the zoning methods in the heating season.

The yearly results of the other KPIs in the heating season are sorted based on the facility modeling methods in Figure 27. It shows that for the models with the same facility complicity, thermal comfort (PMV) is almost the same with different zoning methods. Some exception is present for zoning 5 (one zone per room) with complex ventilation model (airflow network) (for example, PMV2_heating for 1-3-1-zoing5). It is because, for zoning 5, the internal walls and doors are added to the airflow network. The hours are similar for underventilation (CO2_600-) for the models with the same facility complicity. For underventilation (CO2_900+), complex ventilation models (airflow network) have higher values.

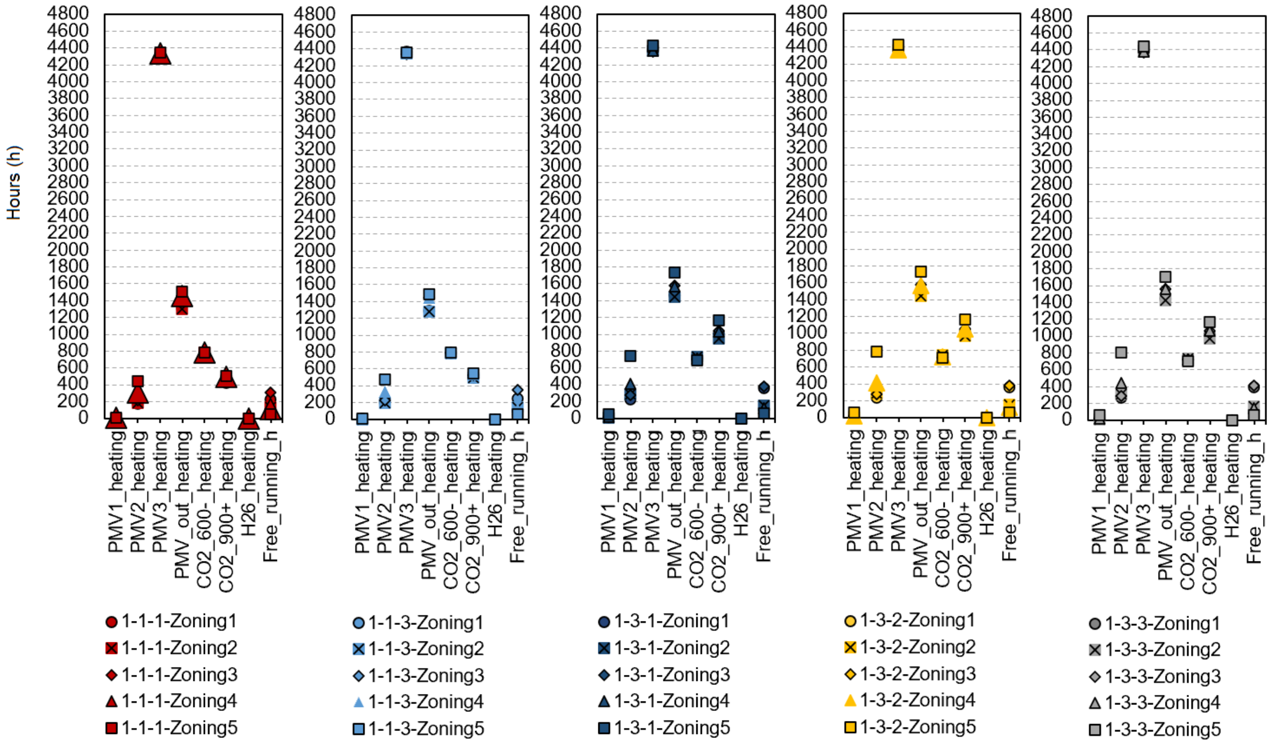

Figure 27. The yearly modeling results of other KPIs are sorted based on the facility modeling methods in the heating season.

4.12.1.2 Cooling season

Figure 28 shows the yearly modeling results for all models sorted according to the complexity levels for the cooling season. It shows that the thermal comfort for all CENs and H26 varies between the models. The zoning level 5 has the lowest CEN values in all categories. There in general are better agreements among model results for under/over ventilation (CO2_900+ and CO2_600-).

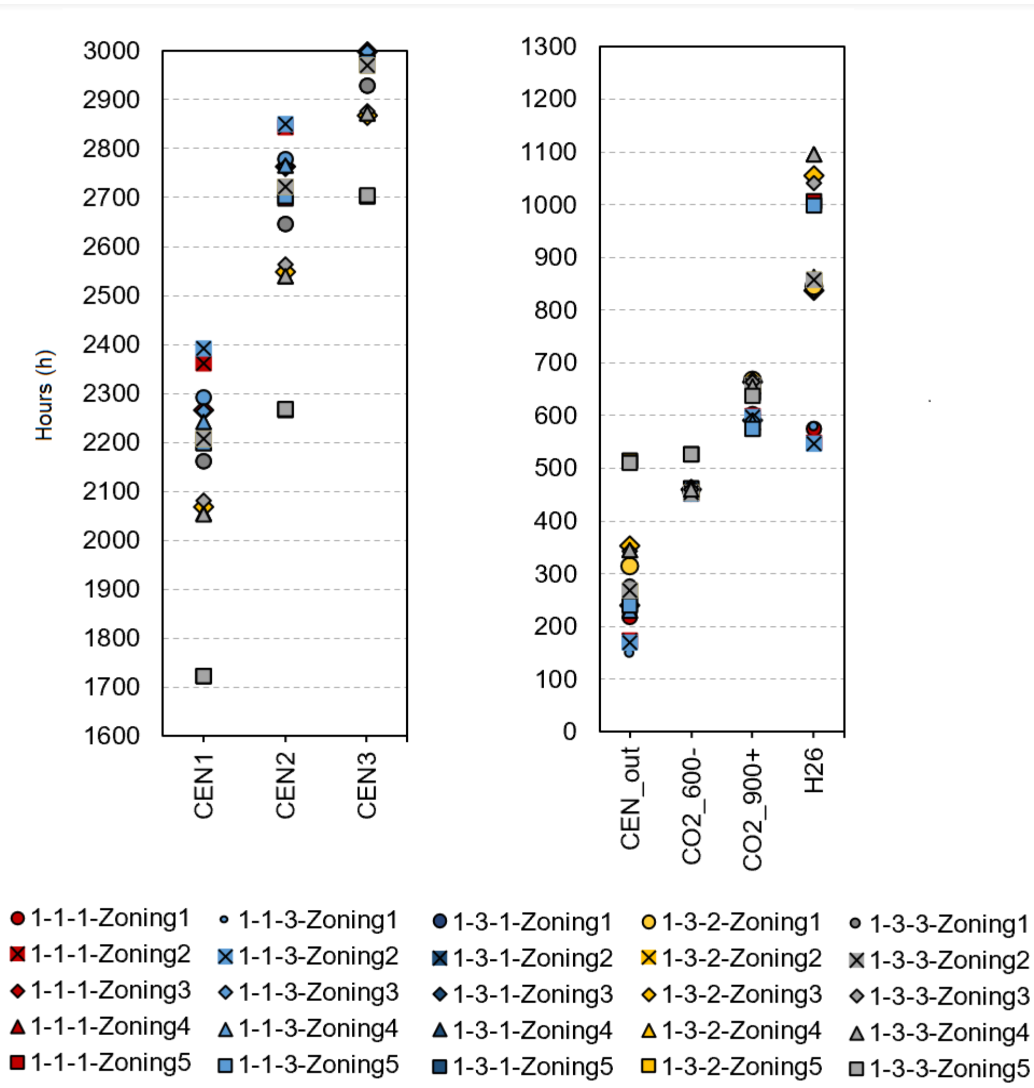

Figure 28. The yearly modeling results of KPIs in the cooling season.

From Figure 28 the data from all models are combined. It shows the distribution of the results, but it is hard to see the specific model results with deviations in details. In Figure 29, the yearly results of thermal comfort are sorted based on the zoning methods. It shows that with the same zoning method, the thermal comfort is mainly split into 2 groups: the ones with the same ventilation model have the same results as CEN.

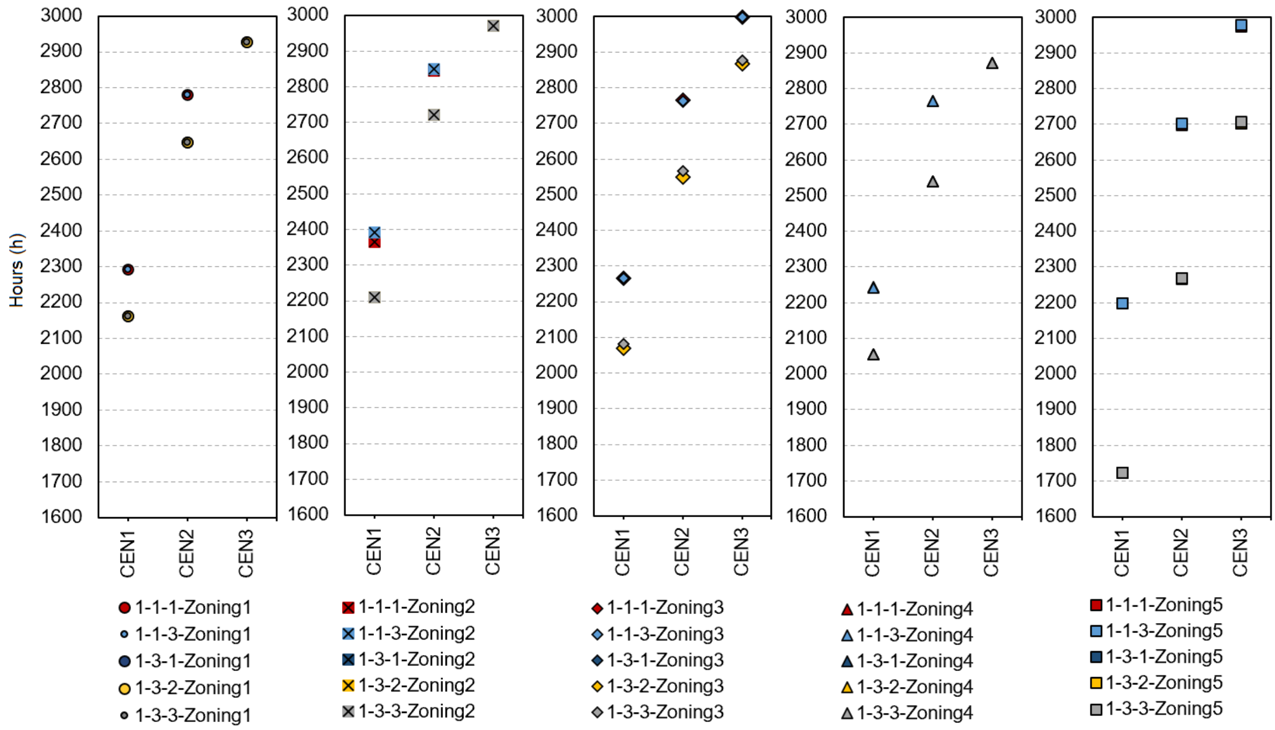

Figure 29. The yearly modeling results of thermal comfort are sorted based on the zoning methods in the cooling season.

The yearly results of thermal comfort are sorted based on the facility modeling methods in Figure 30. It shows that the thermal comfort has a big deviation among the different zoning method; with the detailed ventilation model, the deviation of thermal comfort among different zoning methods are even bigger.

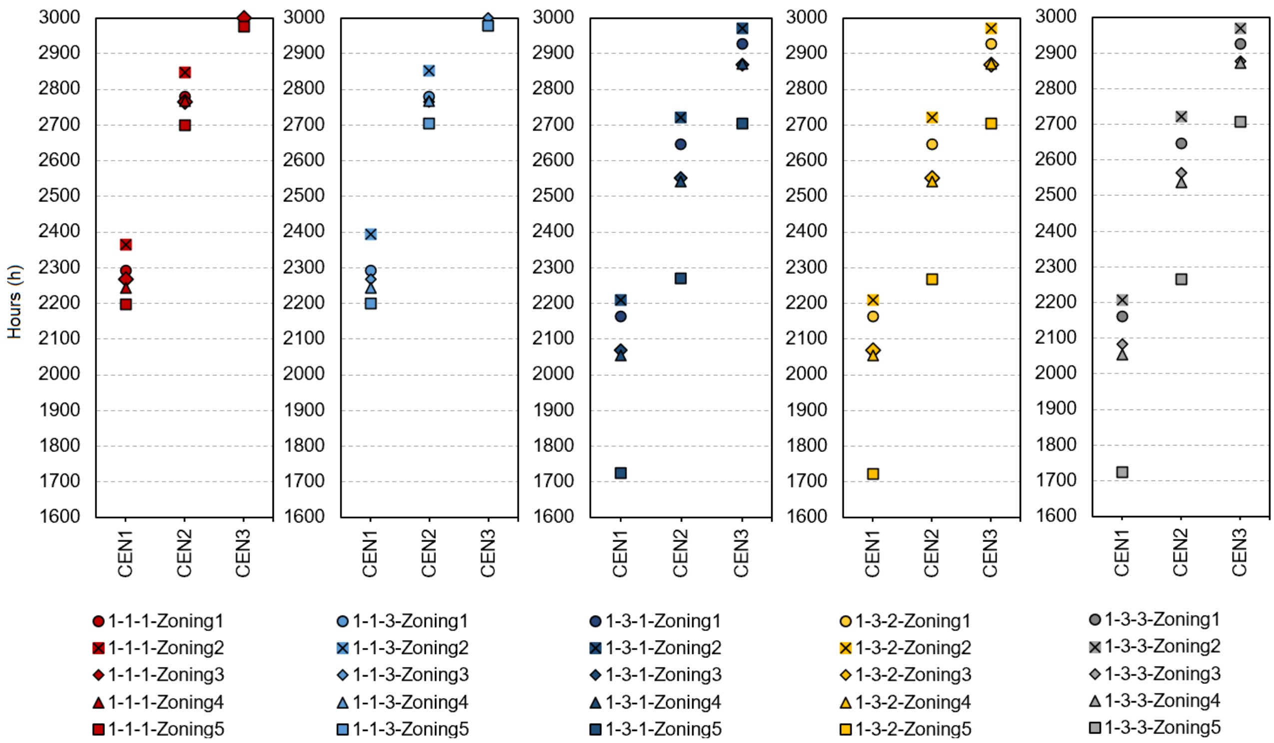

Figure 30. The yearly modeling results of thermal comfort are sorted based on the facility modeling methods in the cooling season.

The yearly modeling results of other KPIs sorted based on the zoning methods are shown in Figure 31 because they have similar scales. It shows that with the same zoning method, the thermal comfort is mainly split into 2 groups: the ones with the same ventilation model have the same results of CEN_out. The same conclusion can be conducted for H26, except zoning 5. For overventilation (CO2_600-), there is generally a good agreement among the models, except zoning 5 with detailed ventilation model; while for underventilation (CO2_900+), it seems that the ventilation model can affect it (detailed ventilation model results in higher underventilation), but the affection is smaller than H26.

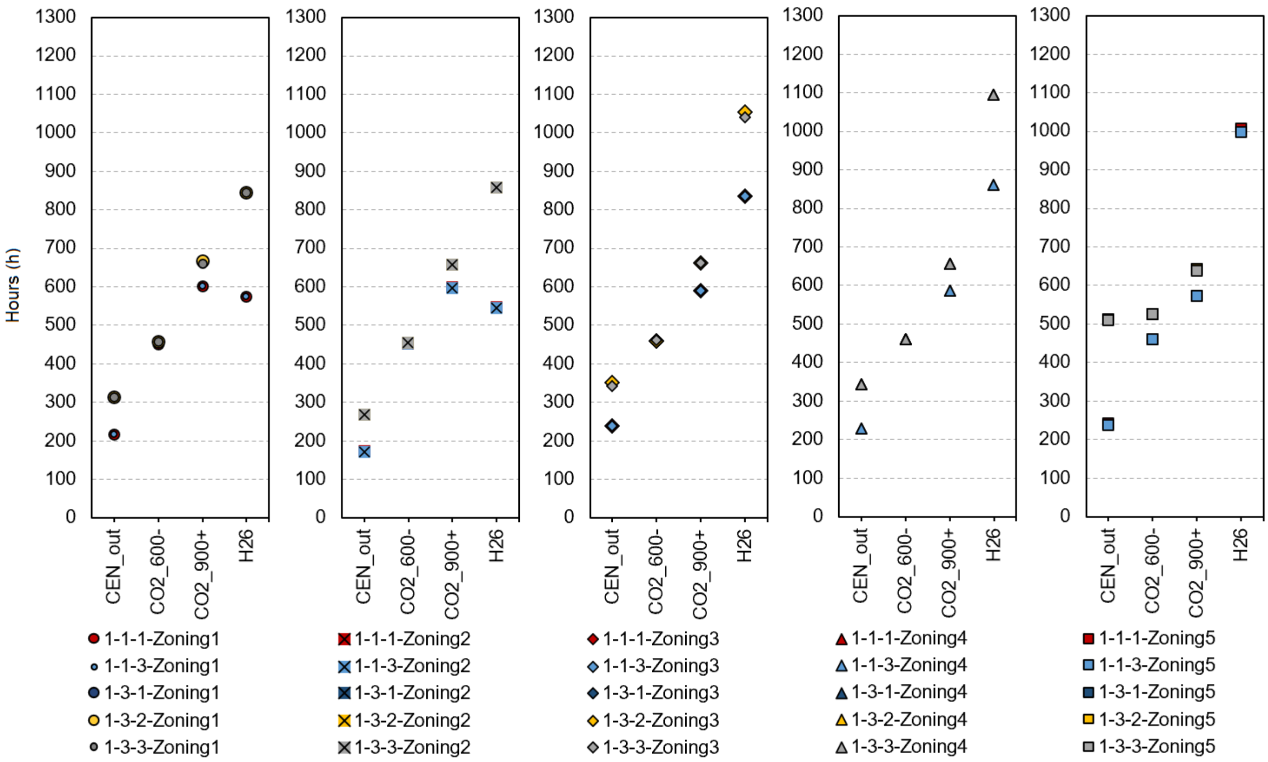

Figure 31. The yearly modeling results of other KPIs are sorted based on the zoning methods in the cooling season.

The yearly modeling results of other KPIs sorted based on the facility modeling methods are shown in Figure 32. It shows that with the same facility modeling method, the H26 is sensitive to the zoning method, as well as the ventilation model. With the detailed ventilation model, the H26 is higher in general. There are generally good agreements among models for overventilation (CO2_600-) except zoning 5 with the detailed ventilation model, and the underventilation (CO2_900+) is less affected by the zoning method.

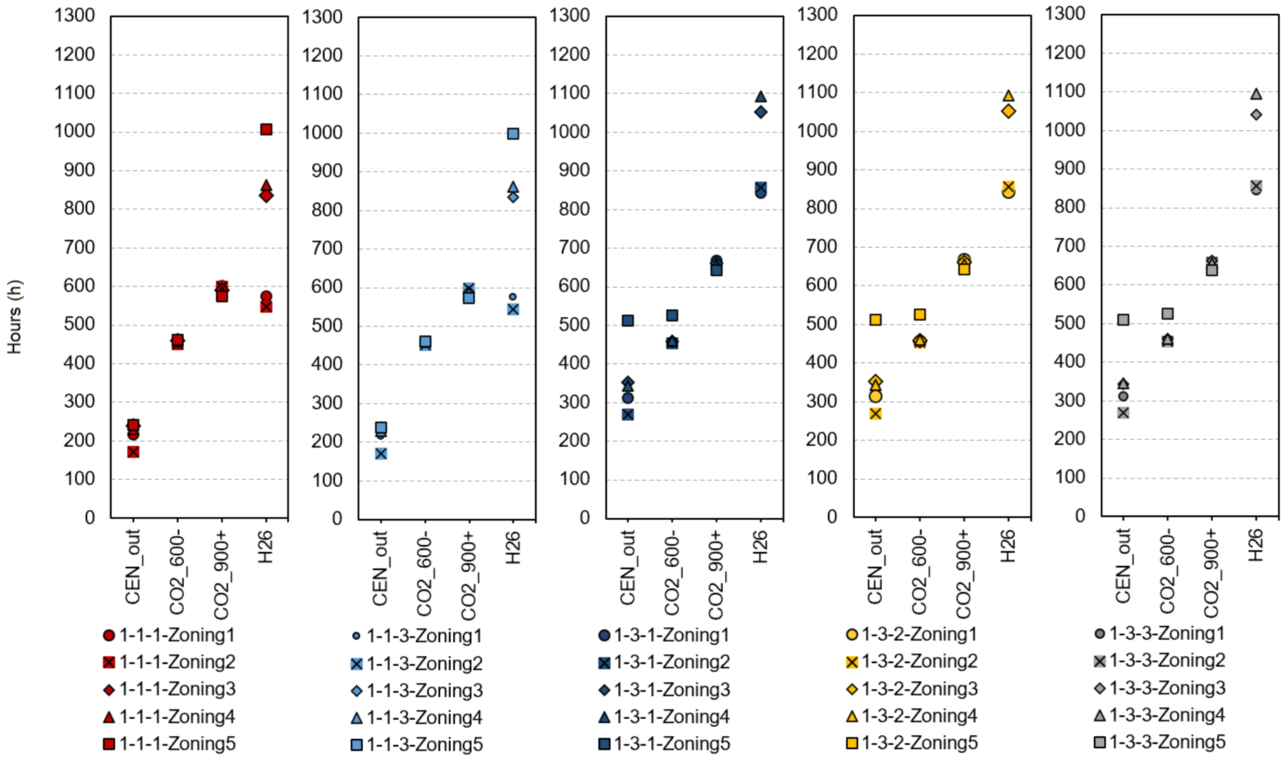

Figure 32. The yearly modeling results of other KPIs are sorted based on the facility modeling methods in the cooling season.

4.12.1.3 Summary of the results for Magisterparken

The modeling of Magisterparken with different facility complicity levels and zoning complicity levels has the conclusion that for heating demand, the zoning method does not seem to have a significant impact on the heating demand; while detailed heating model and ventilation model can have an influence on the heating demand evaluation. The importance of using more complex models is yet to be investigated, as the relative differences between the results of simple and complex models are rather small.

For the heating season, thermal and atmospheric comfort is sensitive to facility complexity.

For the cooling season, thermal comfort is sensitive to both zoning method and ventilation model. With the detailed ventilation model (airflow network), the deviation of thermal comfort among different zoning methods is even bigger. In general, the detailed ventilation model results in lower thermal comfort.

For air quality in the cooling season, the zoning method seems less important, while the ventilation model only affects underventilation, and the detailed ventilation model results in higher underventilation.

4.12.2 Demo 2 - Hånbæk

In Hånbæk, the ventilation system is a balanced ventilation system with a supply fan, an exhaust fan, and a heat recovery unit for the whole staircase, thus it is difficult to simulate the ventilation system in a simple way, due to the incapability of ideal loads HVAC system to represent balanced ventilation with heat recovery. The model complexity levels of Hånbæk are shown in Table 15. The shading complexity is simple shading, which is the same as been described for Magisterparken. Since for Hånbæk other than for

Magisterparken complexity levels were used, the names of the models are slightly different and defined in Table 16.

Table 15. The model complexity levels of Højrupsvej 48.

	Complicity level	
Ventilation and heating	1	Electric convector with balanced ventilation system (supply and return fan, airflow network) and heat recovery
	2	Electric radiator with balanced ventilation system (supply and return fan, airflow network) and heat recovery
	3	District heating with balanced ventilation system (supply and return fan, airflow network) and heat recovery
Zoning methods	1	One zone per staircase
	2	2 zones per staircase (divide the staircase by south zone and north zone)
	3	One zone per apartment
	4	2 zones per apartment (south rooms as one zone, north rooms as another zone)
	5	One room as a zone

Table 16. Definition of model names.

A -zoningB	Example: 1–zoning3
A- Ventilation and heating complexity level	Ventilation and heating complexity level 1
B- Zoning complexity level	One zone per apartment

4.12.2.1 Heating season

The annual results from models of different complexity levels for the heating season are shown in Figure 33. It shows a deviation in heating demand among the models, which are split into 2 groups.

The thermal comfort for PMV1, PMV2, and H26 are in good agreement among all models, while PMV3 and PMV_out have significant differences in the models. Overventilation (CO2_600-) and free-running hours have big deviations among the models, while underventilation (CO2_900+) are in good agreement among all the models.

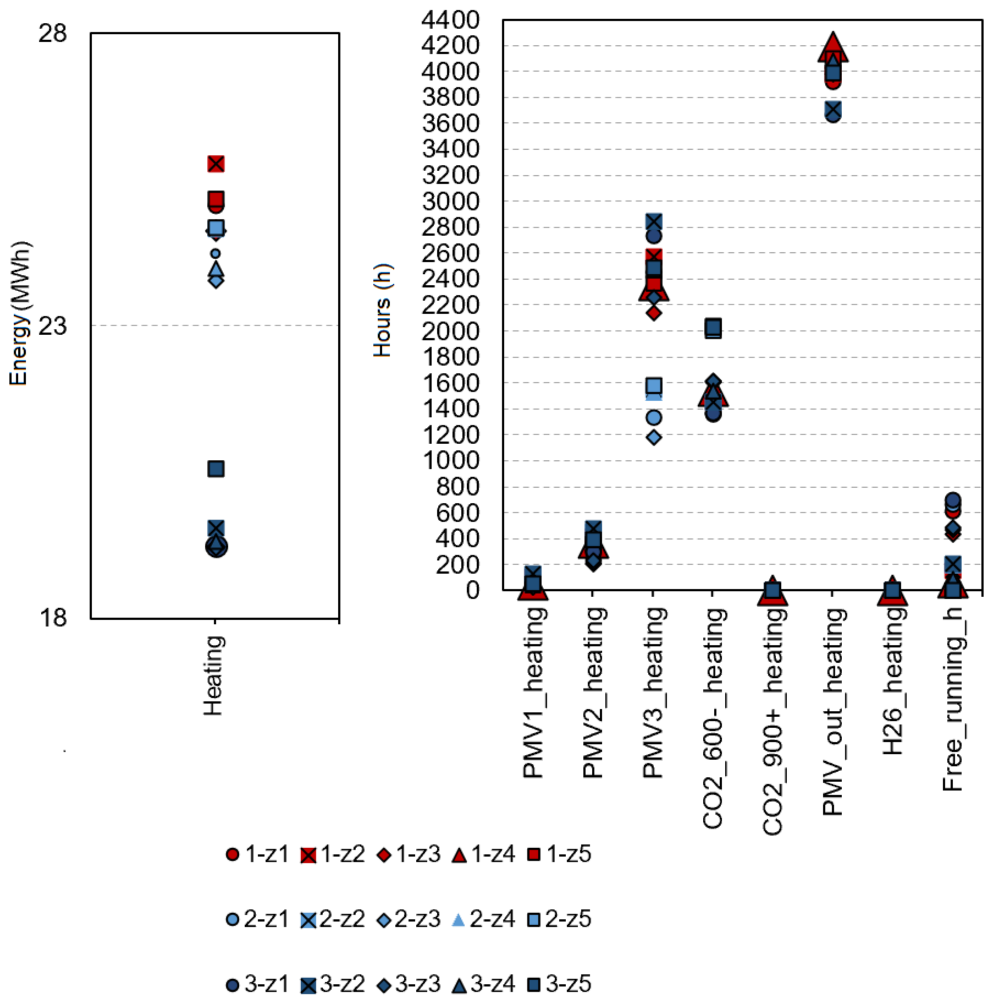

Figure 33. The yearly modeling results of all the models with different complicity levels in the heating season.

From Figure 33, the data from all models are combined. It shows the distribution of the results, but it is hard to see the specific model results with deviations in details. In Figure 34, the yearly results of heating demand are sorted based on the zoning methods. For all zoning models, the results are split into 2 groups: around 20 MWh and around 25 MWh.

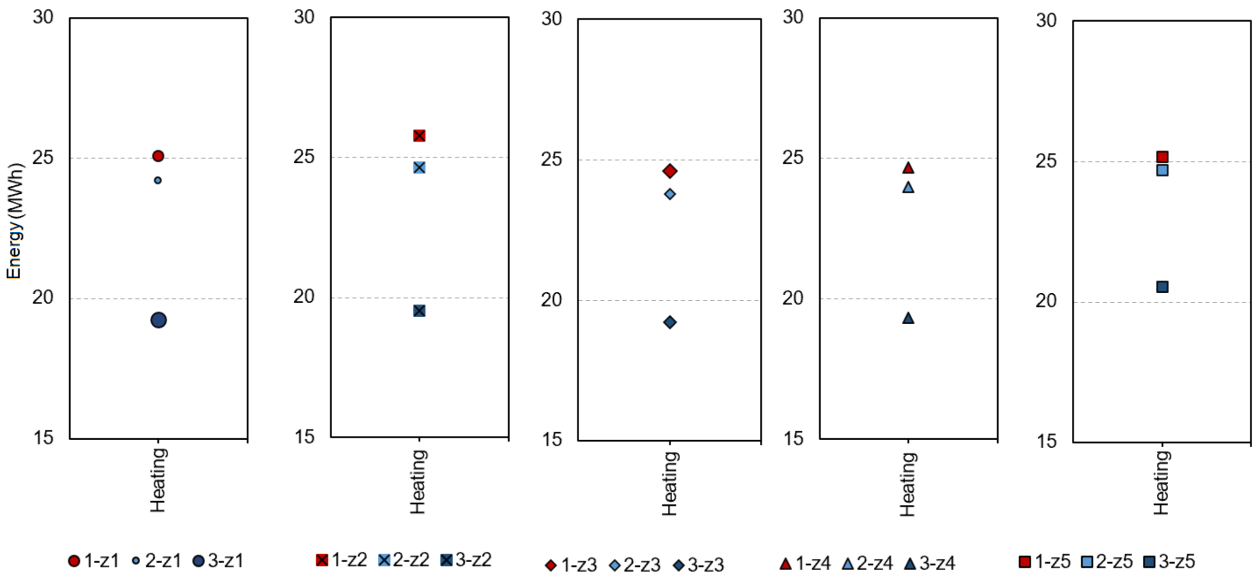

Figure 34. The yearly modeling results of heating demand are sorted based on the zoning methods.

The yearly results of heating demand are sorted based on the facility modeling methods in Figure 35. For the models with the same facility, the 5-zone models have slightly higher heating demand, while other zoning approaches have better agreement with each other. When comparing different facility modeling methods, detailed heating system modeling methods have the lowest heating demand compared to other heating system modeling methods.

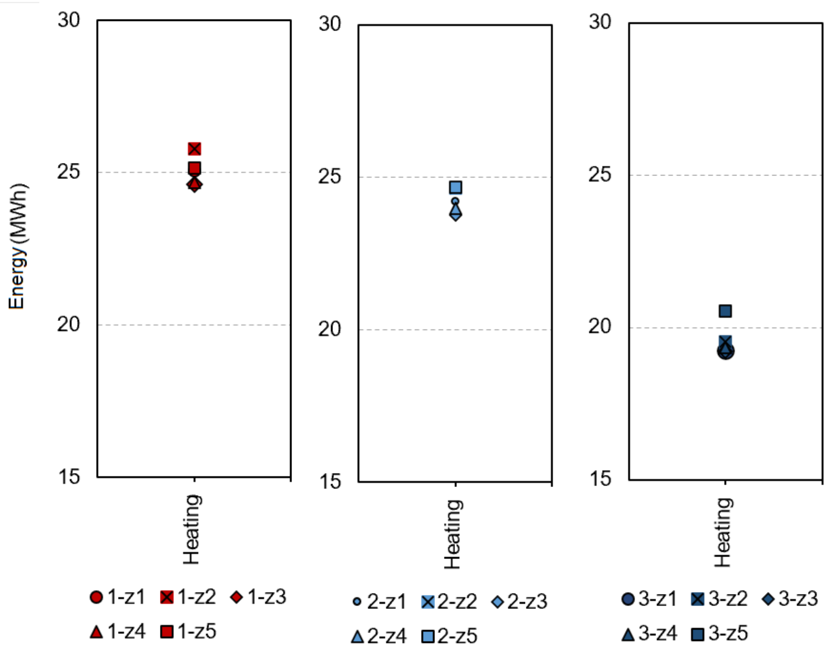

Figure 35. The yearly modeling results of heating demand are sorted based on the facility modeling methods.

The results of the other KPIs are sorted based on the zoning methods in Figure 36. It shows that all the KPIs are slightly sensitive to the zoning method. With the same zoning approach but different facility modeling methods, the KPIs among models tend to be similar.

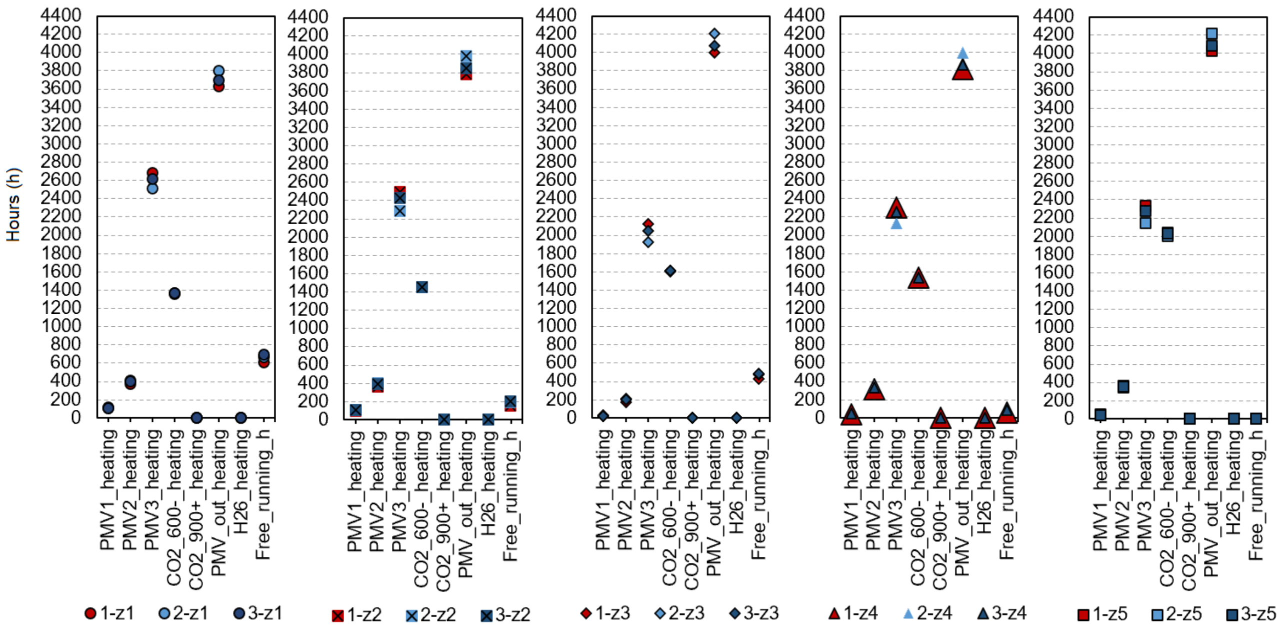

Figure 36. The yearly modeling results of other KPIs are sorted based on the zoning methods in the heating season.

The results of the other KPIs are sorted based on the facility modeling methods in Figure 37. It shows that for the models with the same facility complicity, the KPIs for both thermal comfort and air quality have big deviations. The 1 zone model (whole staircase as 1 zone) seems to have the biggest difference among all the models. For air quality, the overventilation (CO2_600-) highly depends on the zoning method, and zoning level 5 has the highest value; while the underventilation (CO2_900+) has a better agreement among all models.

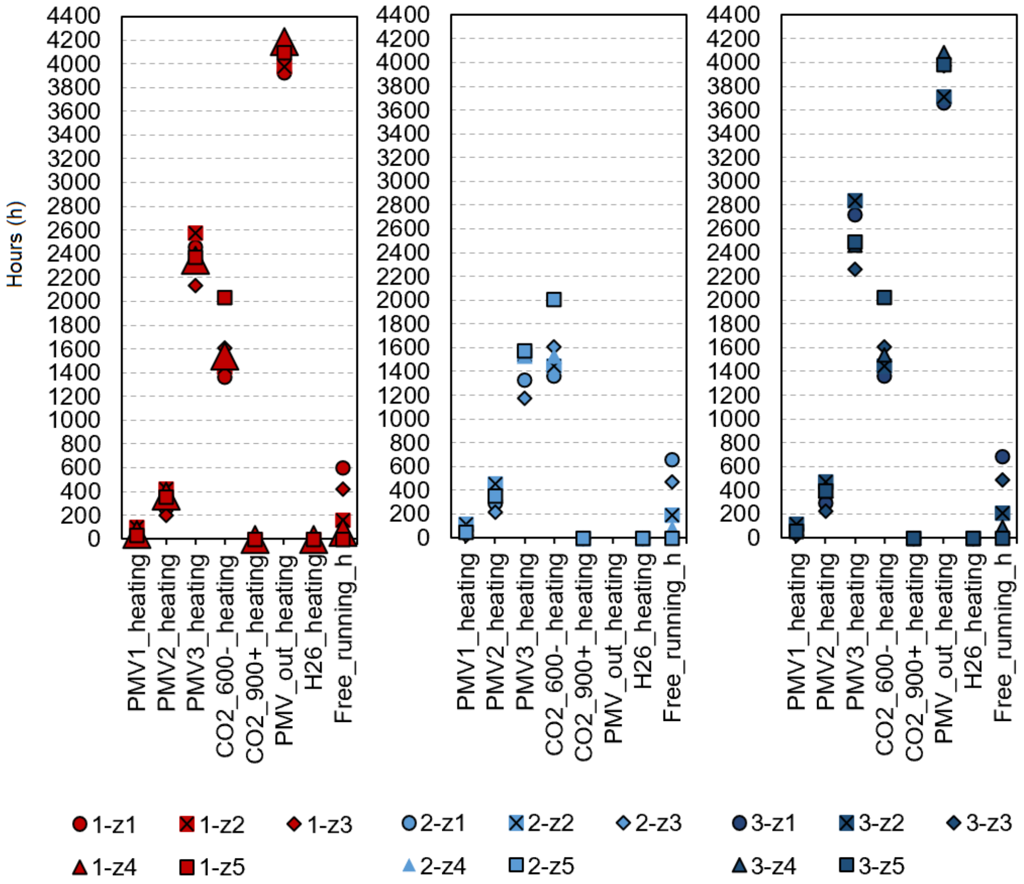

Figure 37. The yearly modeling results of other KPIs sorted based on the facility modeling methods in heating season.

4.12.2.2 Cooling season

Figure 38 shows the yearly modeling results of all the models with different complexity levels in cooling season. It shows that thermal comfort for CEN3, CEN_out and H26 varies among the models, as well as the overventilation (CO2_600-). There are better agreements among model results for underventilation (CO2_900+). Zoning 1 (one zone per staircase) and zoning 5 (one zone per room) seem to have a bigger influence on the air quality (CO2_600-) than other zoning methods. For zoning 1, the thermal mass fails to represent the real internal partitions and leakages for the airflow network; for zoning 5, the added internal partitions and doors of each room make the model different than zoning 2-4, which only includes partitions of internal walls between apartments.

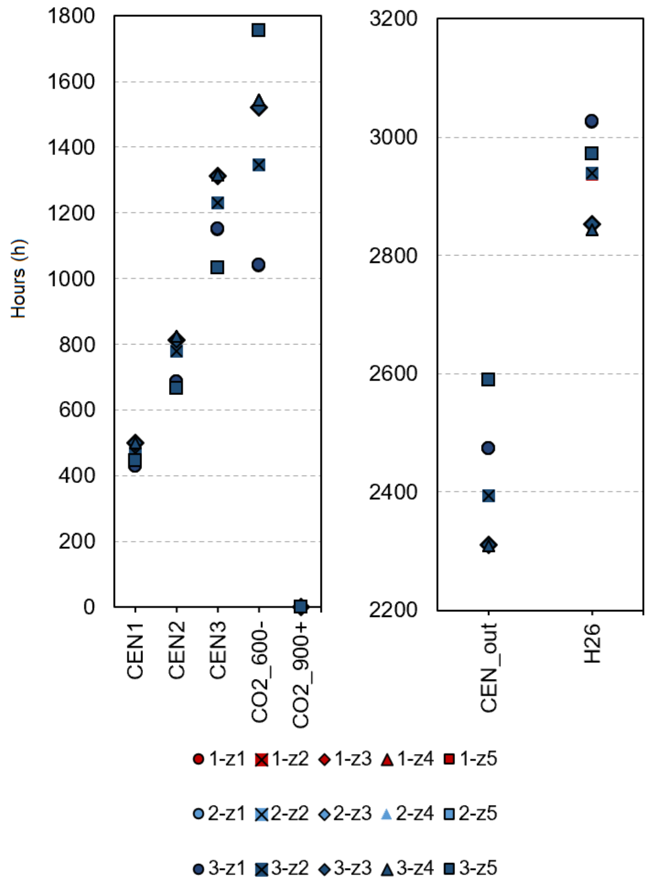

Figure 38. The yearly modeling results of all the models with different complicity levels in cooling season.

The yearly modeling results of thermal comfort and air quality are sorted based on the zoning methods in Figure 39. It shows that with the same zoning method and different heating models, the thermal comfort and air quality tends to be the same.

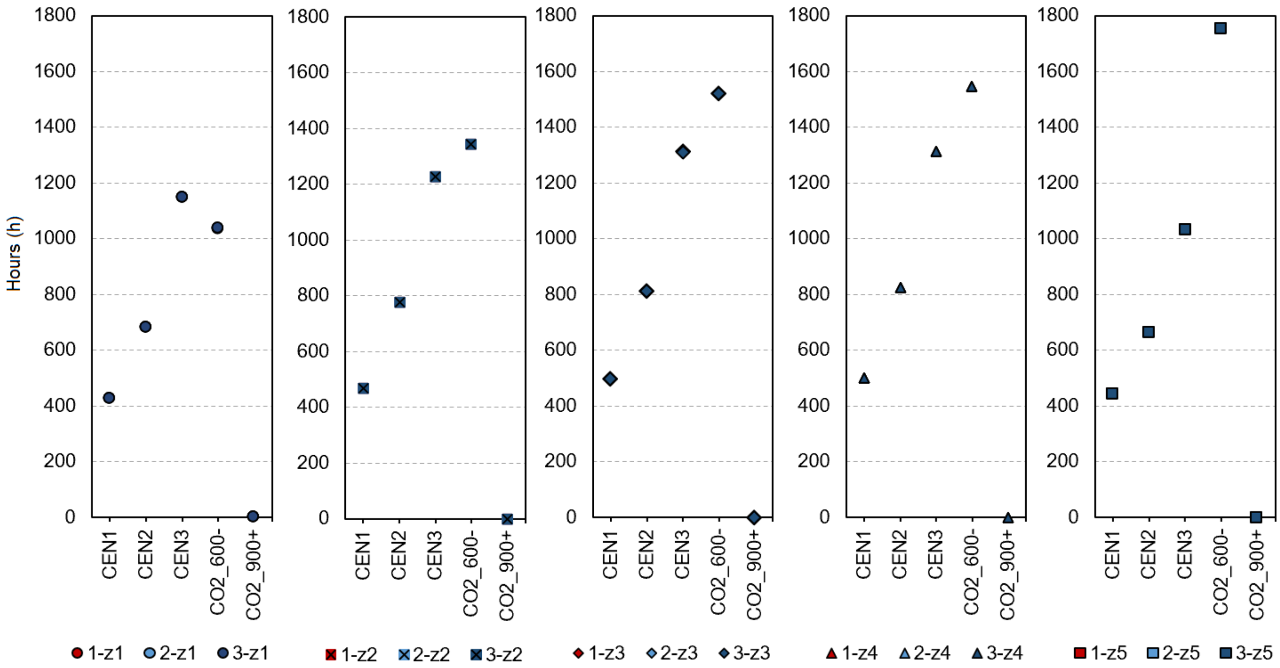

Figure 39. The yearly modeling results of thermal comfort and air quality sorted based on the zoning methods in cooling season.

The yearly modeling results of thermal comfort and air quality are sorted based on the facility modeling methods in Figure 40. With the same heating model and different zoning methods, the thermal comfort and air quality both have big deviations, except CEN1 and CO2_900+. Zoning 1 result in low overventilation (CO2_600-) but zoning 5 results in high overventilation (CO2_600-).

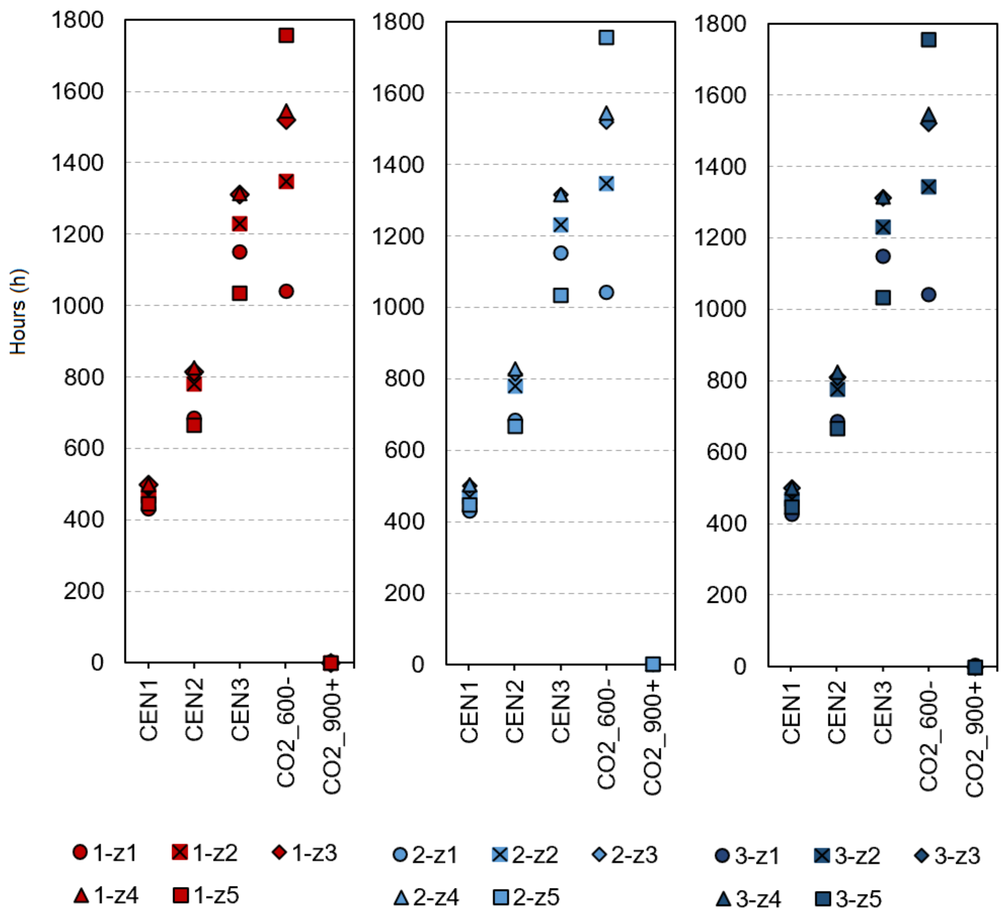

Figure 40. The yearly modeling results of thermal comfort and air quality sorted based on the facility modeling methods in cooling season.

The yearly modeling results of other KPIs are sorted based on the zoning methods in Figure 41 because they have similar scales. Similar to Figure 39, with the same zoning method and different heating models, the thermal comfort and air quality tends to be the same.

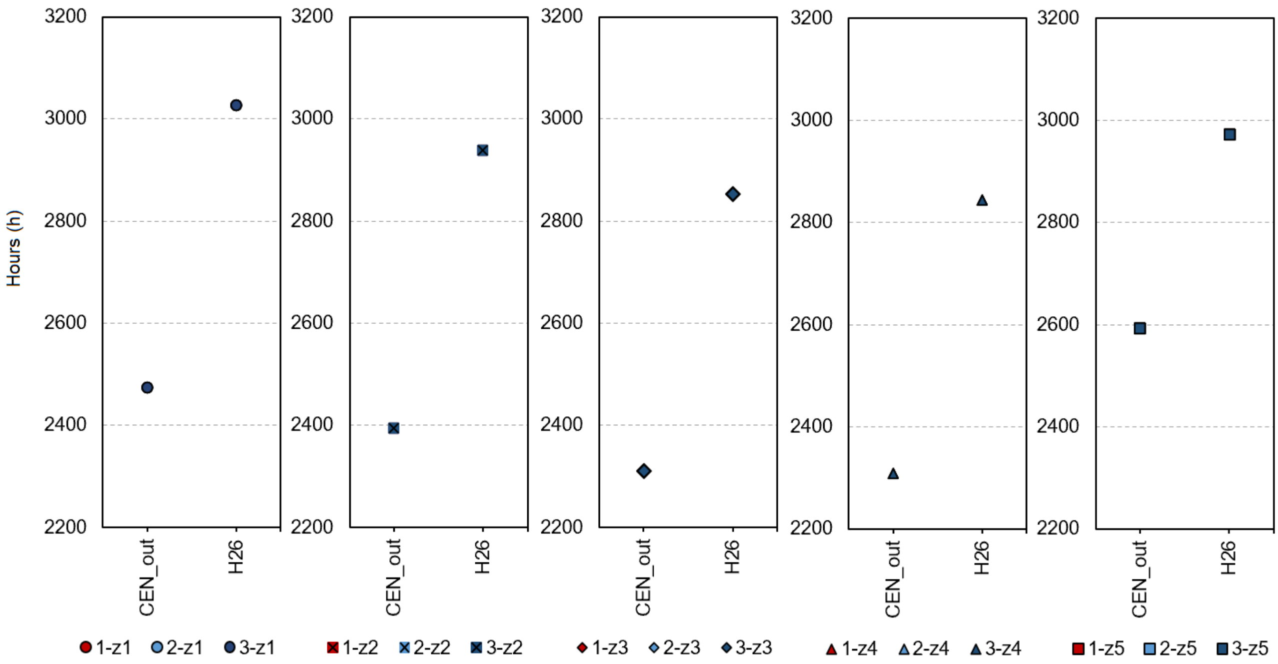

Figure 41. The yearly modeling results of other KPIs sorted based on the zoning methods in cooling season.

The yearly modeling results of other KPIs are sorted based on the zoning methods in Figure 42. Similar to Figure 40, With the same facility model and different zoning methods, the CEN_out and H26 both have big deviations. The biggest deviations come from zoning 1 and zoning 5. Both zoning 1 and zoning 5 result in high CEN_out and H26.

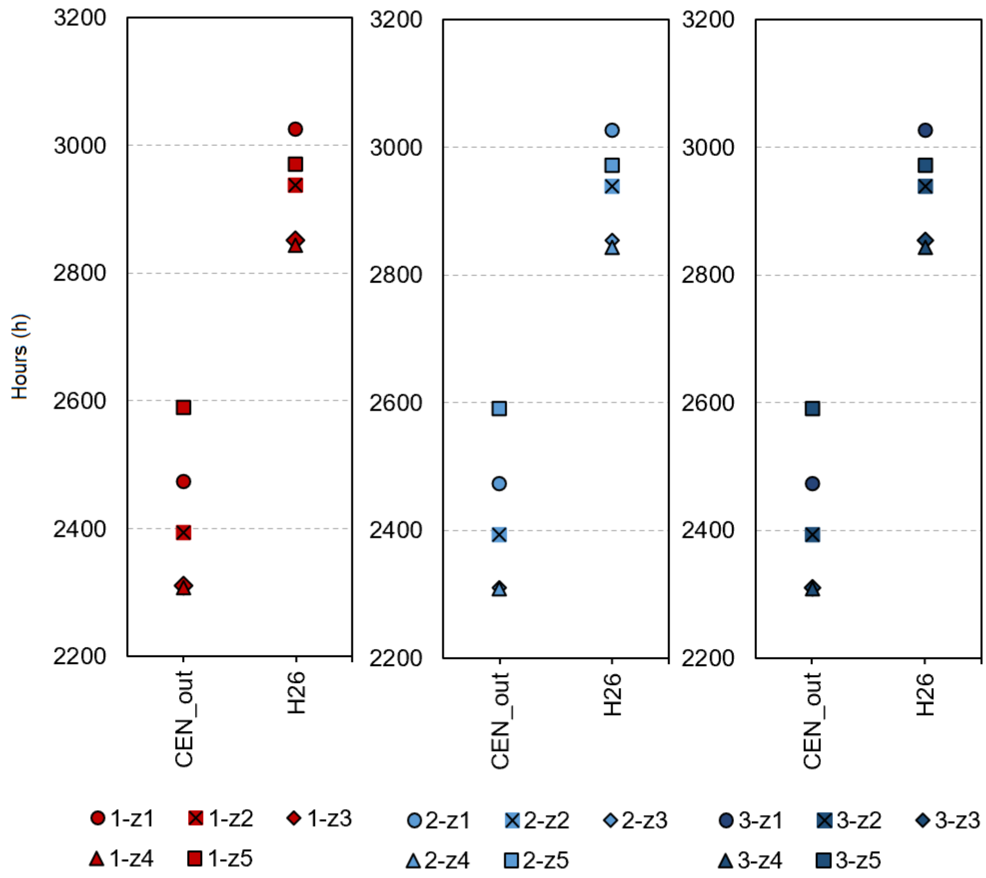

Figure 42. The yearly modeling results of other KPIs sorted based on the facility modeling methods in cooling season.

4.12.2.3 Summary of the results for Hånbæk

The modeling of Hånbæk with different facility complicity levels and zoning complicity levels has the conclusions that for heating demand in the heating season, the zoning method seems to have little impact on the heating demand of the staircase; while detailed heating model gives lower value, due to the share of radiative heating direct to zone and occupants.

Zoning 1 (one zone per staircase) and zoning 5 (one zone per room) seem to have a bigger influence on both the thermal comfort (CEN3) and the air quality (CO2_600-) than other zoning methods in the cooling season. For zoning 1, the thermal mass fails to represent the real internal partitions and leakages for the airflow network; for zoning 5, the added internal partitions and doors of each room make the model different than zoning 2-4, which only includes partitions of internal walls between apartments. In general, the thermal comfort and the air quality are sensitive to facility modeling in the heating season, meanwhile, during the cooling season, the zoning approach becomes influential.

4.12.3 Discussion of the results.

The results integrated into this report are preliminary and address only the annual performance of the models. Since this study aims at supporting the dynamic energy certification, addressing the free-running potential, and also informing users dynamically about the building performance, then final conclusions cannot be drawn based on the annual data only. At least weekly values must be scrutinized for the selection of appropriate model complexity. These will be added in the final version of the report.

Looking upon the annual results following early indication to model applicability can be made:

Table 17. Initial findings from model complexity studies

	Magisterparken	**Hånbæk**
Heating demand	Heating demand is independent of the zoning approach Heating demand is sensitive to systems: • detailed ventilation models have a lower heating • detailed heating system modeling methods have a lower heating demand	Heating demand is independent of the zoning approach Heating demand is sensitive to systems: • District heating with a balanced ventilation system (supply and return fan, airflow network) and heat recovery results in the lowest demands
Thermal comfort in the heating season	The facility model is important, zoning has a small impact	The facility model is important, zoning has a small impact
Thermal comfort in the cooling season	Zoning and ventilation approaches are important	Zoning is important, but not the facility
Air quality in the heating season	Air quality is not very sensitive to the zoning method, but there is some sensitivity to facility modeling	Both the facility and zoning are important
Air quality in the cooling season	The zoning method seems less important, while the ventilation model has an effect	Zoning is important, but not the facility
Free running hours	Both zoning and facility are important	Both zoning and facility are important

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6 Annex A – Weather data

Figure 43, Figure 44, and Figure 45 show the weather data in Denmark from the EnergyPlus Weather data website, including the solar radiation, dry-bulb temperature, wind speed, and wind direction. They are used in building simulation for the two building sites.

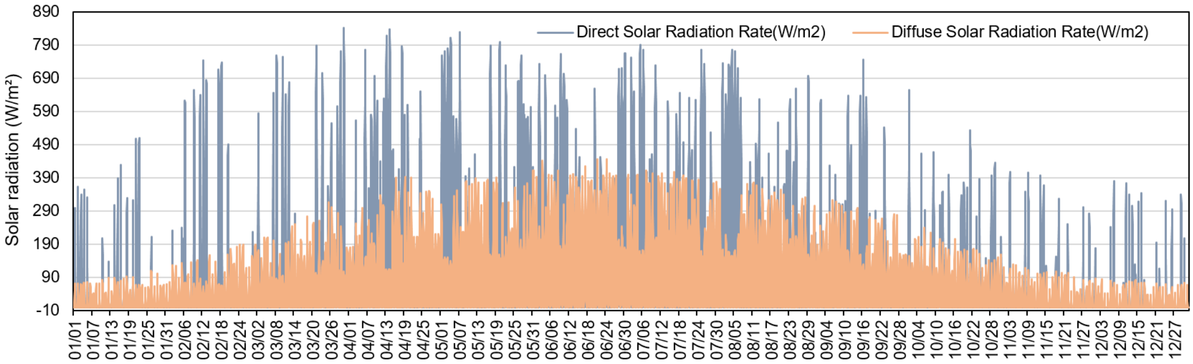

Figure 43. Solar radiation used in building simulation.

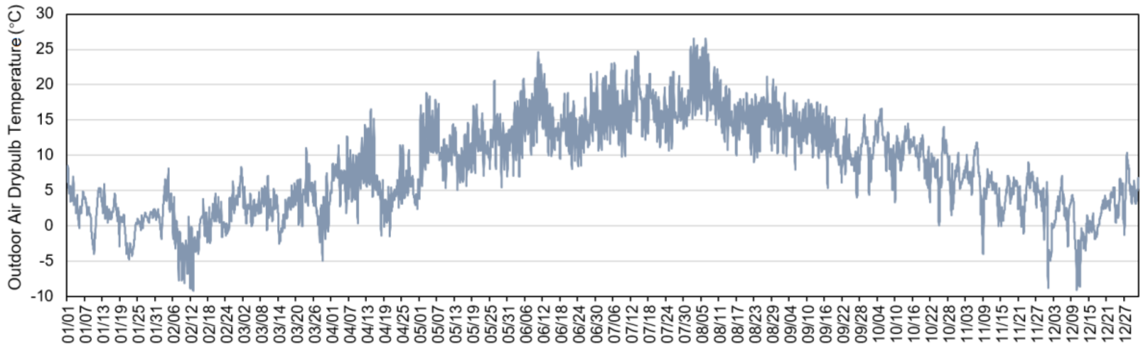

Figure 44. Outdoor air dry-bulb temperature used in building simulation.

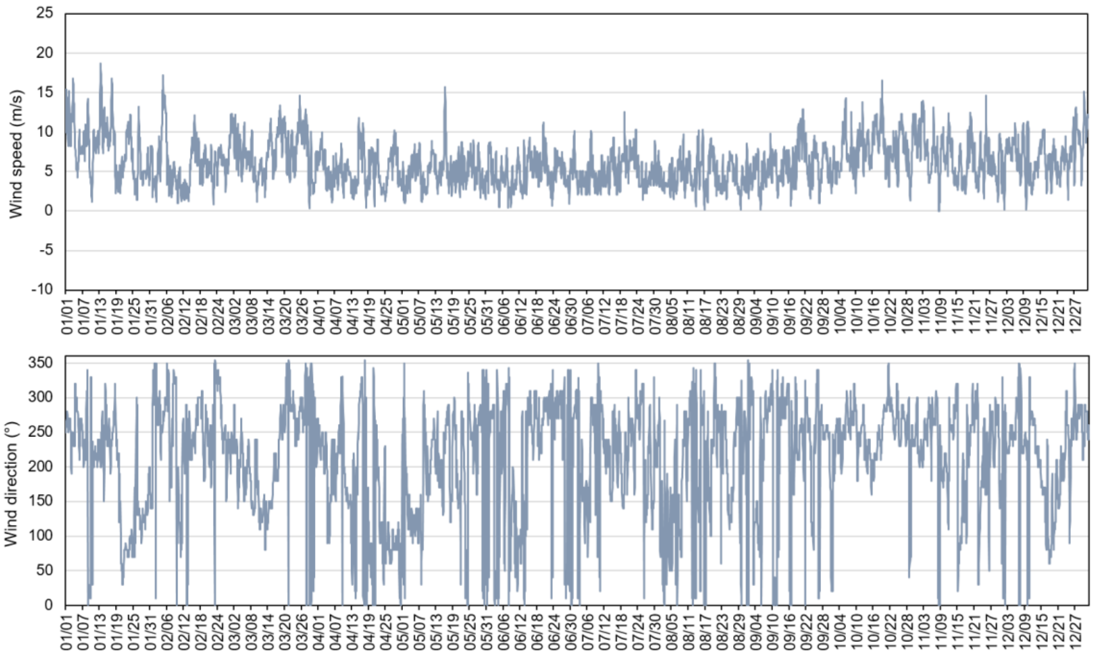

Figure 45. Wind speed and wind direction used in building simulation.

7 Annex B – Dynamic systems specification in models

7.1 Shading

Table 18. The complexity level of shading.

Complexity level	Description
1	Calculating sun position every 20 days (EnergyPlus default)
2	Calculating sun position every timestep

ShadowCalculation object is used to control some details of EnergyPlus's solar, shadowing, and daylighting models. There are two basic methods available for the calculations. To speed up the calculations, shadowing calculations (sun position, etc.) for the default method are performed over days. Note that this value may be very important for determining the amount of sun entering your building and, by inference, the amount of cooling or heating load needed for maintaining the building. Though termed "shadowing" calculations, it in effect determines the sun position for a particular day in a weather file period simulation. (Each design day will use the date of the design day object). Even though weather file data contains the amount of solar radiation, the internal calculation of sun position will govern how that affects various parts of the building. By default, the calculations are done for every 20 days throughout a weather run period; an average solar position is chosen, and the solar factors (such as sunlit areas of surfaces) remain the same for that number of days. When more integrated calculations are needed for controlling dynamic windows or shades, a second method is available where solar calculations are performed at each zone timestep.

Using the ShadowCalculation object, you can set how often the shadowing calculations are performed. Calculating every timestep (Timestep frequency option) is obviously the most accurate but is also the most time-consuming. Using a greater length of time (number of days) before calculating again can yield speedier results. For lengths of time greater than one day, the solar position values (e.g., equation of time, sun position angles) are averaged over that time period for the shadowing calculations. For dynamic shading, Timestep frequency is required to capture changes in shading transmittance.

7.2 Ventilation

Table 19. The complexity level of ventilation.

Complexity level	Description
1	Zone ventilation, not considering wind speed and wind direction
2	Fan ventilation, Design Specified Outdoor Air
3	Airflow network, fan ventilation
4	Balanced ventilation with heat recovery

7.2.1 Zone ventilation

Zone Ventilation (Ref Object: ZoneVentilation:DesignFlowRate) is the purposeful flow of air from the outdoor environment directly into a thermal zone to provide some amount of non-mechanical cooling and/or to reduce indoor pollution concentration. Ventilation, as specified by this input syntax, is intended to model “simple” ventilation as opposed to the more detailed ventilation investigations that can be performed with the AirflowNetwork model. Simple ventilation in EnergyPlus can be controlled by a schedule and through the specification of minimum, maximum, and delta temperatures. The temperatures can be either single constant values for the entire simulation or schedules which can vary over time. As with infiltration, the actual flow rate of ventilation can be modified by the temperature difference between the inside and outside environment and the wind speed.

The zone ventilation energy use has an output of Zone Ventilation Fan Electricity Energy, which calculates the fan’s electrical consumption for Intake or Exhaust ventilation types (for ZoneVentilation:DesignFlowRate objects only). The fan is defined by fan pressure rise and fan total efficiency; in this case, they are set as 5 and 0.6, respectively.

In this simulation case, zone ventilation gives constant flow for all the thermal zones, which is 0.008333 m^3/s/person. The fan energy consumption is not a part of KPIs for model comparison, thus is not calculated and compared.

7.2.2 Fan ventilation

The zone exhaust fan (Fan:ZoneExhaust) is a simple model to account for the fan electric energy use and impact on central air handlers from the bathroom and hood exhaust. Because the fan only extracts air from the zone, it doesn't directly impact the zone itself.

The supply air to the zone is either from the ZoneHVAC:IdealLoadsAirSystem: Design Specification Outdoor Air Object, or from ZoneVentilation(where the ventilation type= natural, Fan pressure rise = 0) or ZoneInfiltration. The flow rate is 0.008333 m^3/s/person for both cases.

The fan ventilation has a similar principle as the zone ventilation and results in similar values for the KPIs, thus being down prioritized.

7.2.3 Airflow network + exhaust fan

The AirflowNetwork model provides the ability to simulate the performance of an air distribution system, including supply and return leaks, and calculate multizone airflows driven by outdoor wind and forced air during HVAC system operation. The airflow leaks in the building constructions are defined by surface crack linkage and detailed opening of windows and doors where the airflow goes through

The EnergyPlus airflow network consists of a set of nodes linked by airflow components. Therefore, it is a simplified airflow model, compared to detailed models such as those used in computational fluid dynamics (CFD) models. The node variable is pressure, and the linkage variable is airflow rate.

When working together with AirflowNetwork, the zone inlet air doesn't need extra settings in Design Specification Outdoor Air and ZoneVentilation objects.

7.2.4 Balanced ventilation with heat recovery

In Hånbæk, the ventilation system is balanced ventilation with heat recovery. The air loop AHU is used for the whole staircase, which consists of an outdoor air mixer, a supply fan, a return fan, and a heat recovery unit. The fans are constant air volume fans. The heat recovery unit is an air-to-air heat exchanger using effectiveness relationships. The sensible effectiveness is 0.75, and the latent effectiveness is 0.

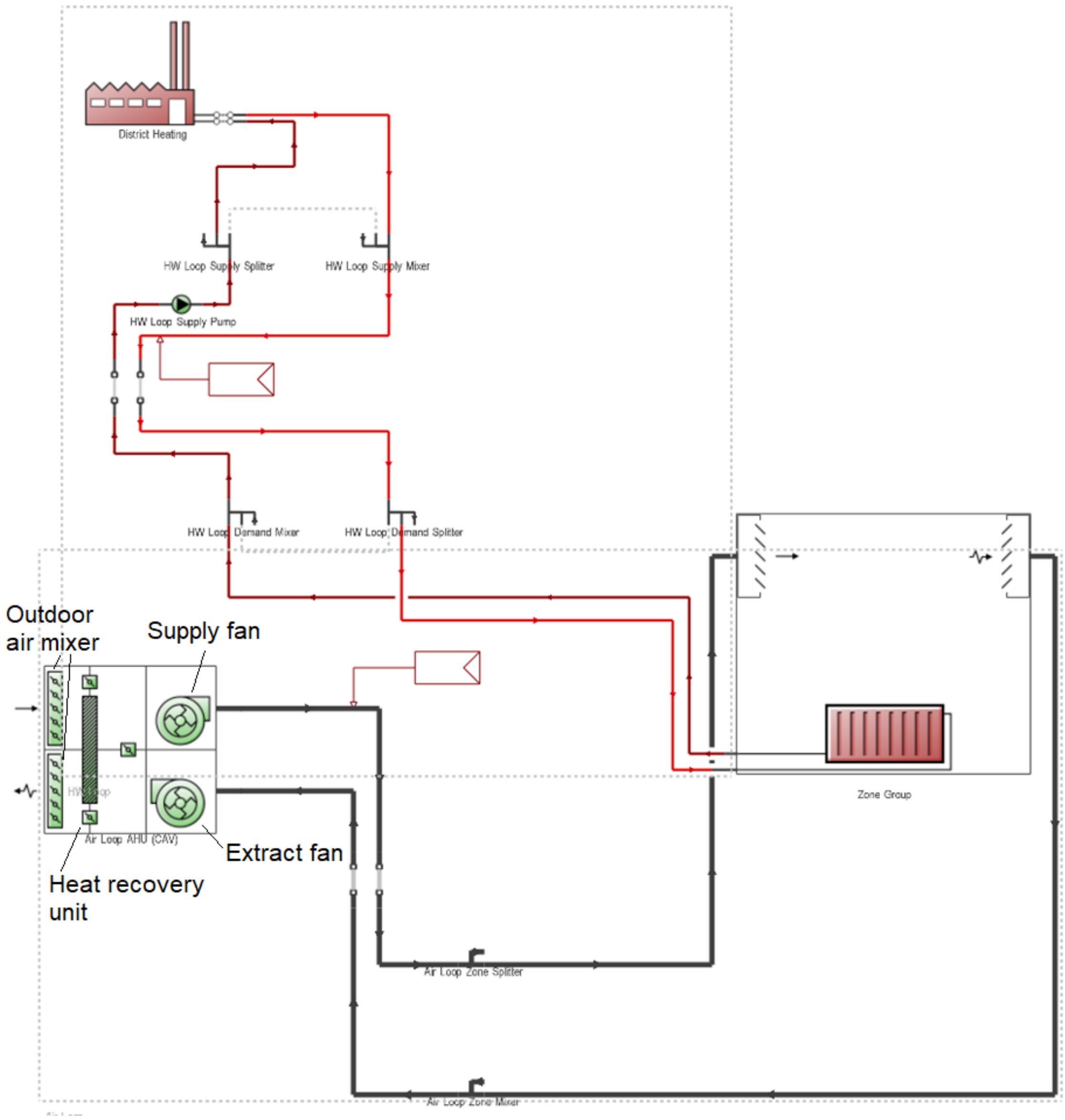

Figure 46. The balanced ventilation system with heat recovery unit.

Ideal loads HVAC system with heat recovery and zone ventilation is not representable for the system because the ideal loads HVAC provides no heat recovery for the zone ventilation, as shown in Figure 47.

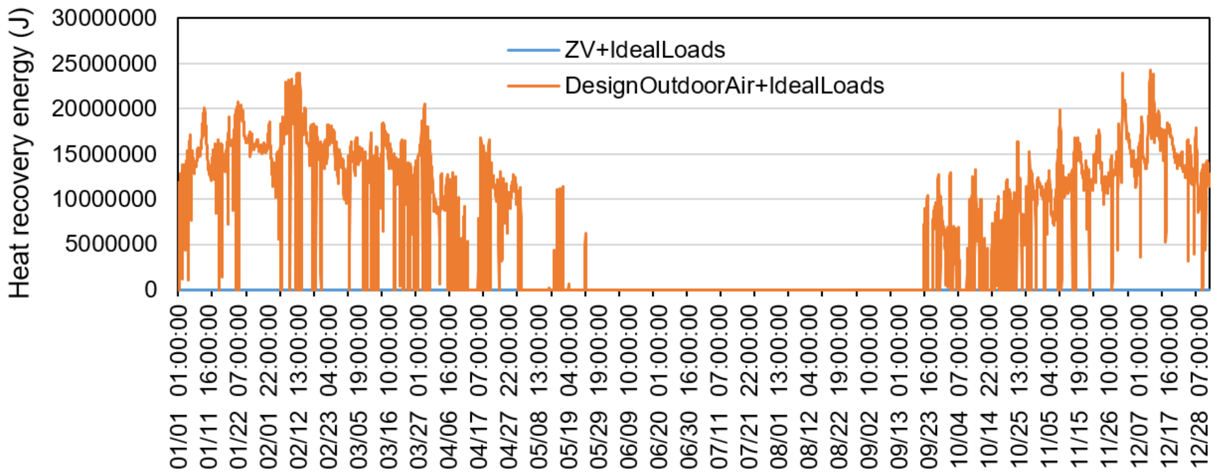

Figure 47. The heat recovery energy of the zone ventilation+ ideal loads HVAC stem compared to design outdoor air + ideal loads HVAC system.

While the design outdoor air with ideal loads HVAC provides heat recovery for the ventilation but only when the ideal loads HVAC is active (heating demand is not 0), which is shown in Figure 48.

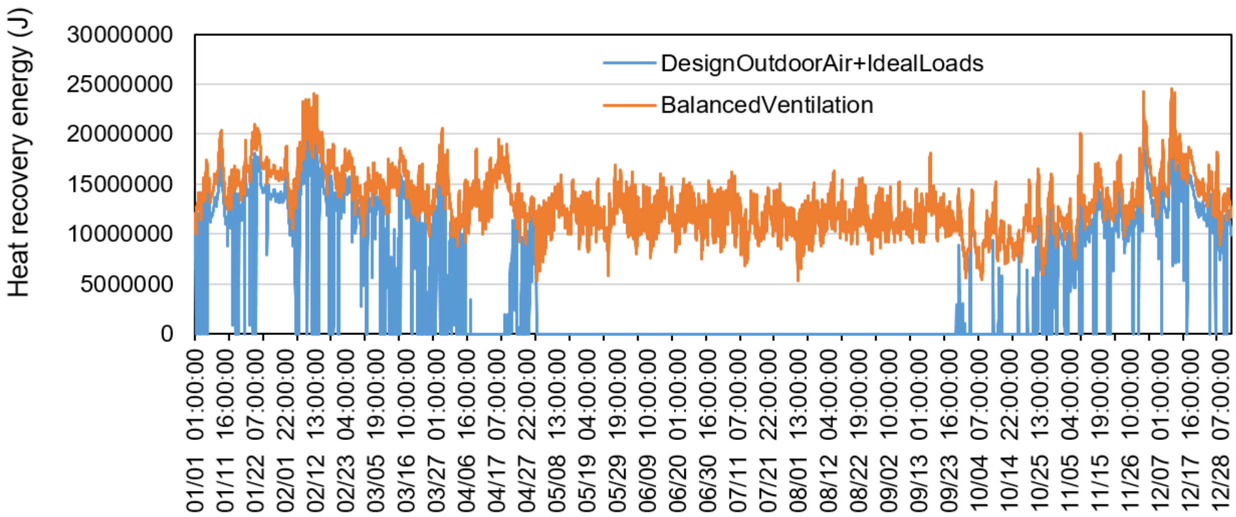

Figure 48. The heat recovery energy of design outdoor air + ideal loads HVAC system compared to balanced ventilation + heat recovery system.

7.3 Heating

The subsections explain the modeling principles of the different heating models.

Table 20. The complexity level of the heating system.

Complexity level	Description
1	Heating: ideal loads
2	Heating: convector heating
3	Heating: district heating+ water radiator

7.3.1 Heating: ideal loads

The ideal system is used to calculate loads without modeling a full HVAC system. All that is required for the ideal system are zone controls, zone equipment configurations, and the ideal loads system component. This component can be thought of as an ideal unit that mixes zone air with the specified amount of outdoor air and then adds or removes heat and moisture at 100% efficiency to meet the specified controls. Energy use is reported as DistrictHeating and DistrictCooling.

7.3.2 Heating: convector heating

The input object ZoneHVAC:Baseboard:Convective:Electric is used to define an electric baseboard heater that assumes only convective heat addition to a zone from the unit. In most situations, the baseboard heater does give a significant amount of heat off via natural convection, but some heat is given off via radiation. In this model, the radiant component is ignored and all heat is assumed to be delivered to space via convection. The baseboard heater provides heat to the zone via electric resistance heating and thus consumes electricity rather than be supplied with hot water. EnergyPlus then assumes that this heat is evenly spread throughout the zone thus having an immediate impact on the zone air heat balance which is used to calculate the mean air temperature (MAT) within the space.

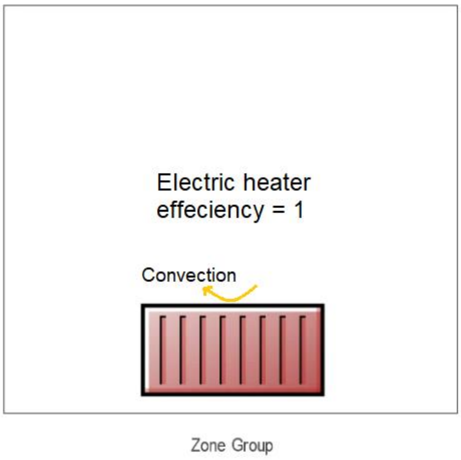

Figure 49. The electric heater of convector heating.

7.3.3 Heating: district heating

The input object ZoneHVAC:Baseboard:RadiantConvective:Water is used to model a hot water baseboard unit that transfers heat to the zone air via convection and to the surfaces and people via radiation. The actual system impact of the baseboard heater on the zone is the sum of the convective heat transfer to the zone air, the additional convective heat transfer from the surfaces to the zone air after they have been heated, and the radiant heat transferred to people which is assumed to be added to the zone air heat balance by convection from people to the zone air. This actual convective power is used to directly meet any remaining heating requirement in the zone based on the thermostatic controls. The model thus improves the accuracy of thermal comfort predictions by allowing the impact of radiation from the baseboard unit to people in the zone to be considered while better accounting for the actual effect of the radiation from the baseboard unit to surfaces.

The baseboard heater is supplied with hot water from the district heating water which is circulated through the inside of a finned tube within the space. This could also be used to model a hot water radiator (convector in the UK). Heat is transferred from the water inside the pipe, through the tube and fins. It is also not only convected to the surrounding air but also radiated to the surfaces and people within the zone. The user is allowed to specify the percentage of radiant heat from the heater to the surfaces as well as how that radiation is distributed to individual surfaces using radiant distribution fractions. In addition, the user has the option to define what fraction of radiation leaving the heater is incident directly on a person within the zone for thermal comfort purposes. This amount of heat is then used in the thermal comfort models in the same way that radiation from a high-temperature radiant heater is utilized.

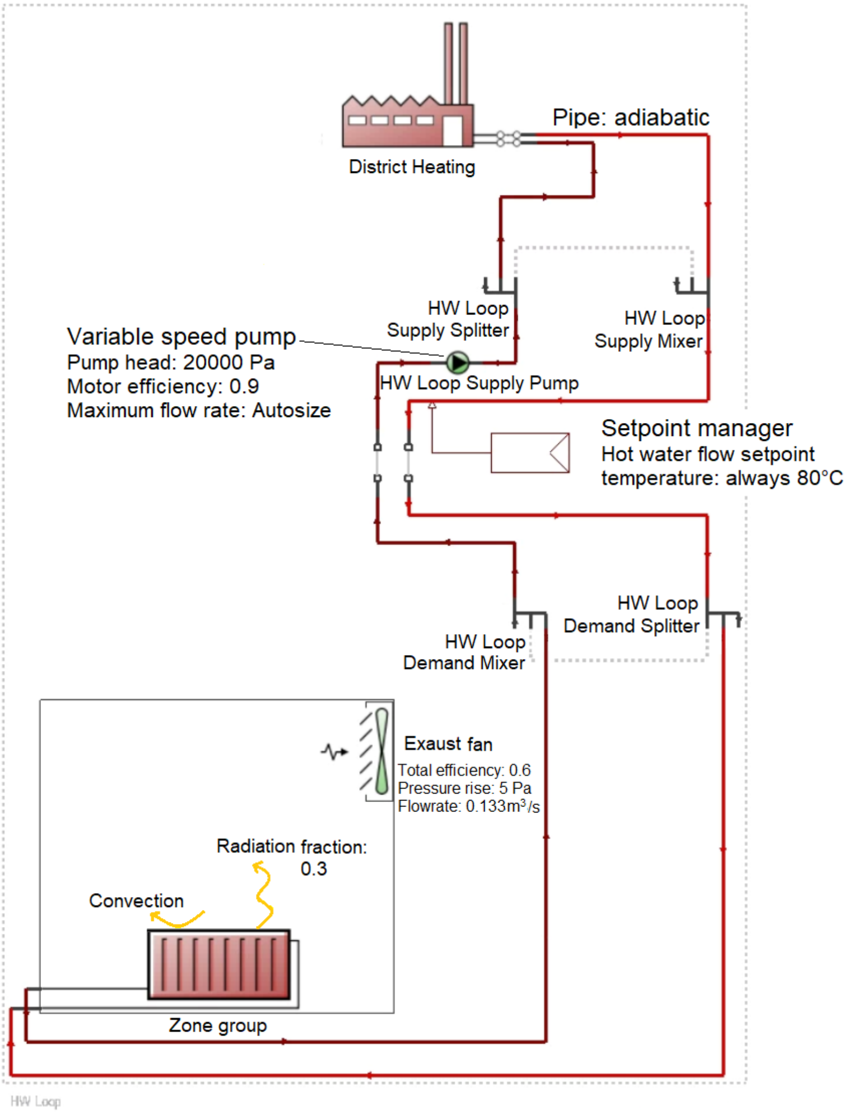

Figure 50. The schematic diagram of district heating and water baseboard heater.

8 Annex C – Construction details

8.1 Magisterparken

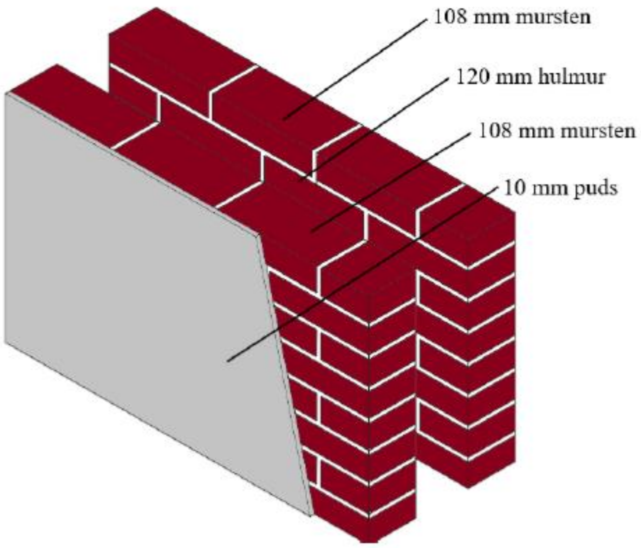

Figure 51. The details of roof construction in Magisterparken 415.

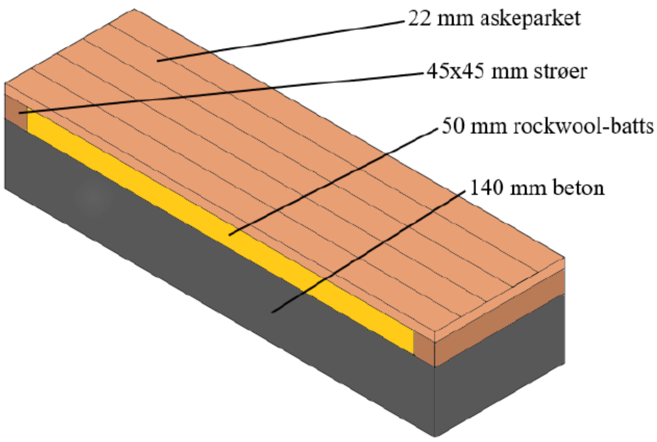

Figure 52. The details of the ground floor in Magisterparken 415.

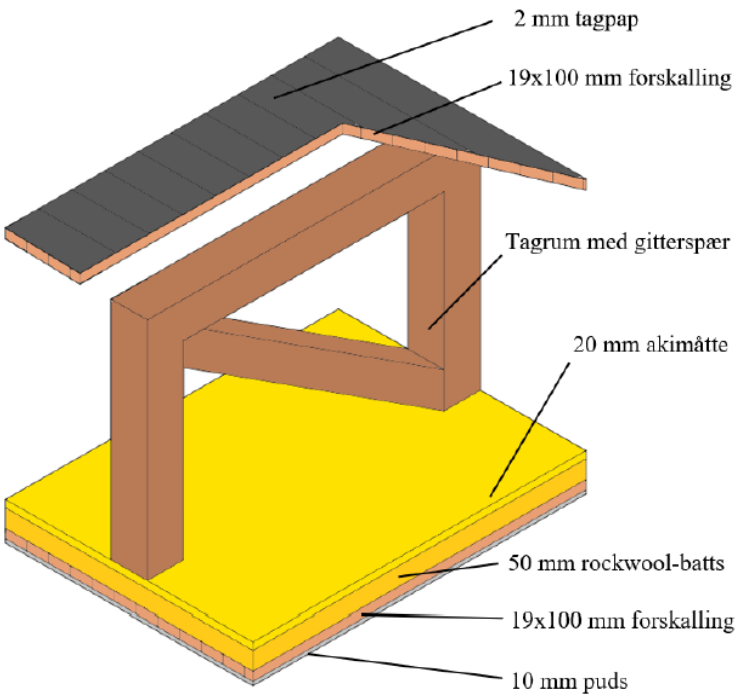

Figure 53. The details of roof construction in Magisterparken 415.

8.2 Hånbæk

Table 21. The details of roof construction in Højrupsvej 48.

Material	Thickness (m)	Thermal conductivity (W/m·K)	Thermal resistance (m²·K/W)
R_{se} (ude)			0.04
Isolering	0.12	0.037	3.24
Isolering /spærfod	0.15	0.042	3.56
Dampspærre	0.0002	0.25	0.01
Isolering	0.045	0.045	0.99
Forskalling	0.022		0.16
Loft	0.02	0.15	0.08
R_{si} (inde)			0.1
R_{total}			8.19

Table 22. The details of gable construction in Højrupsvej 48.

Material	Thickness (m)	Thermal conductivity (W/m·K)	Thermal resistance (m²·K/W)
R_{se} (ude)			0.04
Mursten/puds	0.11	0.55	0.20
Isolering	0.15	0.037	5.68
Beton	0.19	2	0.1
R_{si} (inde)			0.13
R_{total}			4.52

Table 23. The details of rest external wall construction in Højrupsvej 48.

Material	Thickness (m)	Thermal conductivity (W/m·K)	Thermal resistance (m²·K/W)
R_{se} (ude)			0.04
Mursten/puds	0.11	0.55	0.20
Isolering	0.09	0.037	2.43
Beton	0.19	2	0.1
R_{si} (inde)			0.13
R_{total}			2.89