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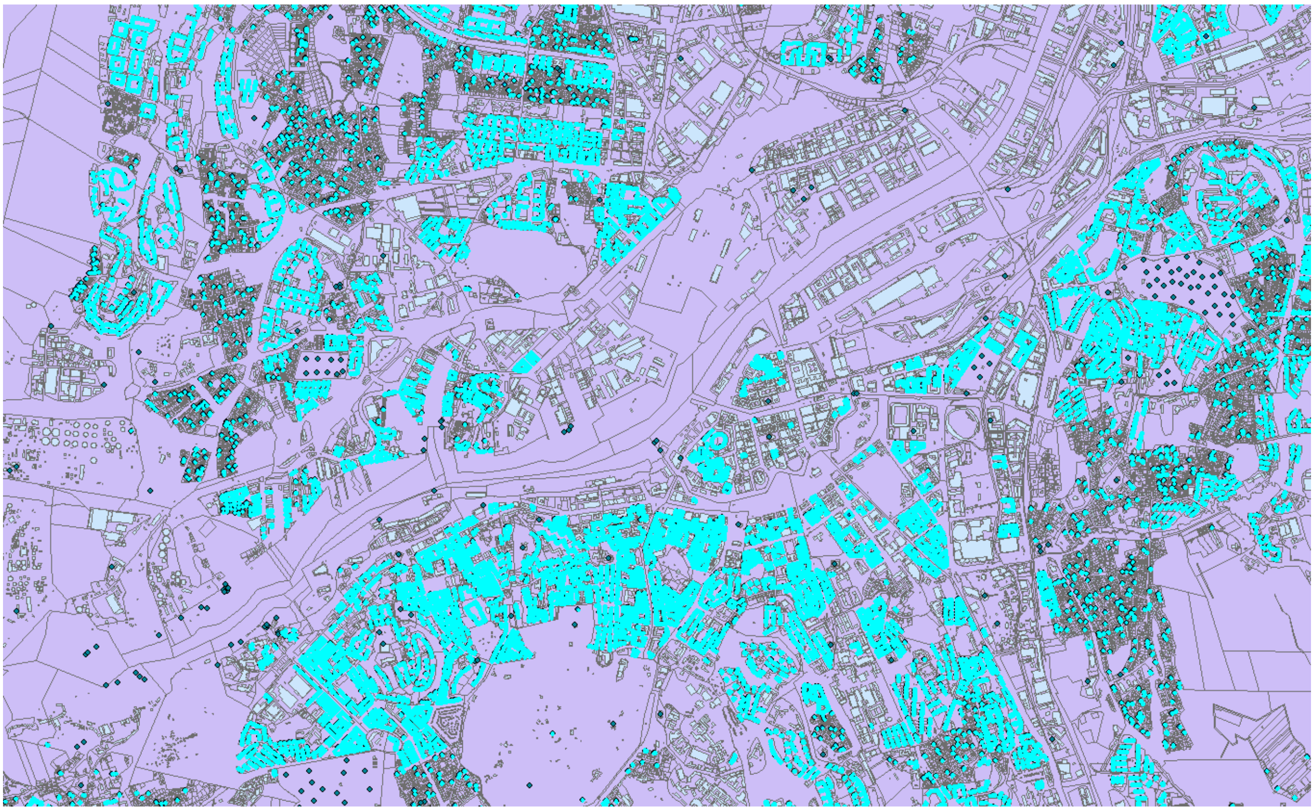

Exploring data flows for building modelling at urban level

Case study of Gothenburg residential buildings

Master's thesis in the Master's Program Sustainable Energy Systems

BAYU ARDIYANTO

Department of Architecture and Civil Engineering

Division of Building Technology

Sustainable Building

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Cover:
Interface of spatial join in GIS map, showing the selected building results from the spatial join
Department of Architecture and Civil Engineering. Göteborg, Sweden, 2018

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ABSTRACT

Building sector was acknowledged as a priority to reduce energy consumption and GHG emissions due to its high potency in energy reduction. With the increasing complexity, especially with respect to the energy supply and demand, building stock needs an update of knowledge to understand the building stock performance better. At the city level, building stock model is a tool to assess the energy performance, therefore assisting the formation of a proper strategy to reduce the energy demand. This thesis aims to evaluate the information flow between different building models used on the urban scale and to explore mechanisms for continuous update of the modelling inputs.

The data flow for building stock modelling in Gothenburg residential buildings is developed by integrating the dataset from EPC, Land survey and property map. The archetypes are constructed from historical architecture data and BETSI database to classify the individual building information data. The integrated dataset along with assigned archetype was screened and modelled on ECCABS (Energy, Carbon and Cost Assessment for Building Stocks). ECCABS is a building stock model with a bottom-up perspective that calculates energy use based on the physical properties of the buildings. Two inputs are modelled in ECCABS based on their assigned archetypes; 1) Typology based on historical architecture data and 2) Typology based on BETSI database. The modelling result on total energy delivered was then validated with the measured data taken from Energy Performance Certificate (EPC). The results show that the total energy demand calculated in ECCABS performed better in the input with BETSI archetype (R^2 = 0,92) compared to historical data input archetype (R^2 = 0,71).

Key words: Building stock model, energy performance certificate, GIS, residential, energy

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Göteborg, September 2018

Bayu Ardiyanto

Notations

Abbreviations and translated terms

BABS	Building code
BBR	National board of building, housing and planning's construction rules
BETSI	Building energy use, technical status and indoor environment
Boverket	National Board of Housing, Building, and Planning
BSM	Building Stock Model
CSV	Comma separated value
ECCABS	Energy, Carbon and Cost Assessment for Building Stocks
EPC	Energy Performance Certificate
GHG	Greenhouse gasses
GIS	Geographic Information System
Lantmäteriet	Swedish Land Survey
MFB	Multi-family building
NR	New construction rules
SBN	Swedish Building Code
SFB	Single-family building
SHP	Shape file
WWR	Windows to wall ratio

1 Introduction

This chapter introduces the background of the thesis, followed by the aims and research question as well as the scope of the study, and the structure of the thesis.

1.1 Background

In Europe, building stock was acknowledged as a priority to decrease the energy consumption and GHG emission due to high energy demand and a high potential for energy reduction (Commission of the European Communities, 2006). On the Swedish building sector, there is an energy and climate target which is 20% energy efficiency improvement by 2020 and 40% reduction of GHG emission compared to the 1990 level (IEA, 2016). Additionally for the city of Gothenburg, as the case study for this thesis, has its own target to reach 30% energy reduction in household compared to 1995 baseline as stated on the Covenant of Mayors (Gothenburg, 2014). The current energy demand for the Swedish residential and services sector accounted for 143 TWh in 2015, or 39% of the total energy consumption where most of the total energy goes to the building stock. In addition, nearly half of the demand goes to the heating, both for space heating and domestic hot water production hence, building stock is an important sector for Sweden to reach the climate and energy target (Swedish Energy Agency, 2017). Since building has a long lifetime, approximately until 50 years, aside from the potential energy reduction, a risk also appears to avoid the energy lock-in. Therefore, multiple strategies and measures are needed to avoid the intensive energy lock-in (IPCC, 2014). As the old building-age is still in use today, most of the energy usage from the residential building sector comes from the old buildings. Renovating and retrofitting the building stock, therefore, is essential to reduce the energy demand on building sector (Johansson, Olofsson, & Mangold, 2017).

The increasing complexity of the building stock, especially regarding the energy demand and supply, would need an update of knowledge on the building stock data with high-resolution data quality (Perez, 2014). In this case, building stock modelling (BSM) is a powerful tool to perform and assess the building datasets regarding the energy demand in disaggregated level, quantify the effect of different building regulations, and measure the energy reduction strategies aiming for the energy efficiency and renewable energy technologies (Buffat, Froemelt, Heeren, Raubal, & Hellweg, 2017) (Kavgic et al., 2010). At the city level, building-stock models exist to assess the energy performance of the building-stock to form renovation strategies to lower the energy demand (Érika Mata, Kalagasidis, & Johnsson, 2013).

In the building stock modelling, bottom-up approach uses results of a heat balance model to estimates the energy consumption for individual buildings and then extrapolated to the city level. By utilizing this model, it is possible to optimize real estate portfolios, neighbourhoods, and entire cities for their economy, energy, maintenance, and environmental impact (Érika Mata, Sasic Kalagasidis, & Johnsson, 2013). The increasing availability to access the dataset for a modelling purpose gives a chance for updating the knowledge on building stock performance. For example, with the introduction of Energy Performance Certificate (EPC) in 2006, there was much information regarding the energy demand of individual building that can be used for a research purpose (Boverket, 2010). On the other hand, the large amount of dataset available could be overwhelming, and potentially arising uncertainties from the various data sources which could be ambiguous for the modelling (Booth, Choudhary, & Spiegelhalter, 2012; Perez, 2014).

This thesis presents a methodology to assess the information flow of the available data input for building stock modelling. In this case, ECCABS (Energy, Carbon and Cost Assessment for Building Stocks) (Érika Mata & Kalagasidis, 2009) would serve as the modelling and simulation tools from the input built. Different databases categories for the residential building are compiled and structured in order to comply with the model, and the results would be validated with the corresponding measures. In this case, the result is focused on the energy and heat demand of the building stock and validated with the measured data from EPC.

1.2 Aim and research questions

This thesis aims to present a methodology for assessing the information flow for building stock modelling by exploring the mechanism of modelling inputs from the existing datasets and how they affect the results.

The specific research questions that this study aims to answer are:

1. How to assess the information flow of data input from various datasets in a structured framework for building stock modelling?
2. How the validation from building stock model result performed with the measured data?

In the end, this thesis intended to explore the next step of the building stock model which is to continuously update the knowledge of the building stock performance and implement it on the building stock model.

1.3 Scope

This thesis work specified on the residential building (single-family buildings and multi-family buildings) in Gothenburg. Therefore, the datasets also limited to only for Gothenburg city. Existing building stock model used in this thesis is ECCABS. The validation for the model result is compared to EPC data.

1.4 Structure

The content for each chapter of the thesis would focus on the following aspects:

Chapter 1 – Introduction

This chapter introduces the background of the thesis, followed by the aims and research question as well as the scope of the study, and the structure of the thesis.

Chapter 2 – Literature Study

This chapter aims at introducing a relevant concept and review of previous work related to the thesis.

Chapter 3 –Methodology

The chapter explains all the preparation and workflow for the input building and modelling the datasets into ECCABS. The collected datasets are merged and aggregated into one big data that is ready to build and modelled. Two archetypes approaches are developed and modelled to understand how the importance of archetypes in the building stock model.

Chapter 4 – Result

This chapter presents the result of the thesis work. The result from this work discussed mainly focused on two topics: the input data building result from dataset linking and the ECCABS model result regarding the energy output.

Chapter 5 – Discussion

This chapter presents the discussion regarding limitation on the data integration process and reflection on the building stock modelling results

Chapter 6 – Conclusion

This chapter presents the conclusion of this thesis work answering the aim and research question and also provide some possibilities for future work in this topic

2 Literature Studies

This chapter aims at introducing a relevant concept and review of previous work related to the thesis.

2.1 Literature used

There are numerous literature and models available regarding energy model on various levels. However, the approach of each model is generally different and heavily depends on the objective of the study conducted (Mastrucci, Pérez-López, Benetto, Leopold, & Blanc, 2017). The literature reviewed in this chapter is analysed based on four relevant topics implemented in this thesis, which are

a. Application of bottom-up building physics models
b. Data processing in building stock models
c. Implementation of GIS in building stock models
d. Characterization of building archetype for building stock models

Table 2.1 summarized the literature studied, including a review of the aggregation level, existing dataset usage, and parameter, which is relevant for this thesis.

Table 2.1 Summary of studied literature

Reference	**Aggregation level**			**Dataset investigated**	**Output**	**Building stock modelling system**
	Area - Type	**n-building**	**Resolution**			
(Érika Mata & Kalagasidis, 2009)	SE - R	1 400	Hourly, one-zone	Archetypes (BETSI)	Net energy Delivered energy, Annual cost, CO2 emission	ECCABS
(Érika Mata, Kalagasidis, et al., 2013)	UK, SP, GR, FR - R	212	Hourly, one-zone	Archetypes (sampling)	Energy consumption	ECCABS
(Cerezo Davila, Reinhart, & Bemis, 2016)	Boston, US - R	83 541	Hourly, one-zone	GIS Data (Tax Parcels, Building Shape, Tax record lite), Tax record full	Energy consumption	US DOE EnergyPlus
(Österbring et al., 2016)	Gothenburg, SE - MFB	433	Hourly, one-zone	EPC, Property Register, GIS Data	Space heating + domesting hot water demand	ECCABS
(Buffat et al., 2017)	St. gallen and Zernez, SW - R	1 965	Monthly, one-zone	Building Footprints, Digital elevation models, Climate data, Buildings and dwellings statistics	Space heating demand	SIA 380/1 heat model
(Mastrucci et al., 2017)	Esch-sur-Alzette, LX - R	>6000	Hourly, one-zone	- (use available data for BSM)	Heating and domestic hot water	Global Sensitivity Analysis
(Torabi Moghadam, Toniolo, Mutani, &	Settimo Torinese, IT - R	300	-	Cartography, Google earth, ISTAT national census, DH Company	GIS Database	- (Regression analysis)

Lombardi, 2018)*						
(Johansson et al., 2017)*	SE - MFB	152 470	250 x 250 m2 zone	EPC, Property Register, GIS Data, Demographic statistics data, Real estate business data	GIS Database	- (Regression analysis)
(Mangold, Österbring, Wallbaum, Thuvander, & Femenias, 2016)*	Gothenburg, SE - MFB	5 098	250 x 250 m2 zone	EPC, Property Register, GIS Data, Demographic statistics data, Real estate business data	Renovation cost, Renovation year	- (Regression analysis)
(Loga, 2009)**	-	-	-	BETSI	Archetype	-

Area: SE – Sweden, US – United States, UK – United Kingdom, SP – Spain, GR – Germany, FR – France, SW – Switzerland, LX – Luxemburg, IT - Italy
Type: R- Residentials, SFB – Single-family building, MFB – Multi-family building
*) The paper did not use a bottom-up modelling building stock modelling, but instead used regression analysis. However, the database building, GIS utilization, and validation are relatable for this thesis.
**) Archetype database study, not a building stock model research

2.2 Building stock modelling

Kavgic et al. (2010) summarize the building stock model (BSM), which is a powerful tool to model the building stock and have the capabilities to:

a) Evaluate housing energy demand in a disaggregated level
b) Able to quantify with different emission reduction policy on the socio-technical impact, including the application of new technologies such as renewable energy and smart metering
c) Measures the energy reduction strategies linked with the indoor environmental quality issue.

In addition, BSM could be used to assess the socio-technical and environmental impact on the building stock level (Booth et al., 2012). Based on the model approach, Kavgic et al. (2010) also mentioned that fundamentally, BSM could be approached between two methods: "top-down model" and "bottom-up model". Top-down model works on aggregated data as the main input that could fit historical series of empiric data on the energy demand or emission data, usually on the regional or national level (Johansson et al., 2017; Kavgic et al., 2010). According to Swan & Ugursal (2009), top-down model has a long-term perspective including such as macroeconomic and socioeconomic effect for the energy demand projection by assessing the empirical data. Top-down model generally uses a statistical method based on function derived from the data sample usually without obvious heat transfer calculation (Mastrucci et al., 2017). However top-down model is less suitable when assessing the dynamic performance and the actual systems within individual buildings as the result did not represent the end-uses (Booth et al., 2012; Swan & Ugursal, 2009).

Bottom-up model works upon disaggregated data based on individual building components which then aggregated and weighted the result to an aggregate level, commonly in an archetypes, to represent the influence of applied policy (Kavgic et al., 2010). Generally, bottom-up approach could overcome inflexibility of top-down approach by simulating using actual building physics model (Booth et al., 2012). Since it uses disaggregated data as input, this type of model need an extensive database consists of empirical data for each module on individual building level for the model to work (Kavgic et al., 2010). Hence, a major limitation of the bottom-up model is a heavy dependence on the availability and validity of the dataset. Since it models an extensive data, generally it will not be suitable with large and detailed simulation, for example, the use of energy modelling software (i.e. EnergyPlus, IESVE, etc.) (Cerezo Davila et al., 2016) (Buffat et al., 2017).

Mastrucci et al. (2017) summarize bottom-up model could be done in steady-state or dynamic fashion, depends on the time step used in the model. Steady-state uses a relatively long-time step to show a seasonal change. Dynamic model uses a shorter time step, often in an hourly basis, to assess the impact on the model thoroughly. Bottom-up model could also be approached in statistical model which did not necessitate exhaustive data as a dynamic model approach. However, it cannot present much flexibility on the result and have limited access to the impact of the measure taken on the model (Kavgic et al., 2010).

2.3 Implementation of bottom-up modelling

2.3.1 Application of bottom-up building physics models

In this thesis, a bottom-up model relies on building physics approach is used. Hagentoft (2001) defined building physics as *"the study of the transport of heat, moisture, and air through a building's envelope in relation to both the indoor and outdoor climate"*. Furthermore, Burke (2009) emphasise that building physics in Sweden focused mostly on heat, moisture, and air transfer. Thus, for example, lighting or acoustics of the building are not included in the definition.

A bottom-up approach based on building physics is used to represent the physical behaviour and building geometry acquired from the dataset such as U-value, building appliances, and indoor temperature environment (Österbring et al., 2016). Kavgic et al. (2010) describe that the approach based on building physics requires aggregation of empirical data from housing surveys and another type of datasets along with some assumptions on building operation. The main advantage of this model is that it comprehensively uses physically measurable data (Kavgic et al., 2010). Thus, it gives an effective result on the targeted consumption based on the applied measure. On the other hand, in addition to the need for extensive datasets, it also could not define building occupant behaviour within the model without assumptions. Reliability issue for the dataset and uncertainty on the building archetypes could also be an issue for this model (Österbring et al., 2016).

It should be noted that there are plenty of BSM based on building physics already developed. Heat model based on SIA 380/1 is one of the examples, which is used by Buffat et al., (2017) to model space heating demand of building stock in St. Gallen and Zernez, Switzerland. The BSM itself divided the data properties into four categories: building dimensions, physical properties, user behaviour, and climate. Buffat (2017) mentioned that from the modelling result compared to the measured data, he got an R^2 of 0,6, indicate a relatively good result with some uncertainties that can be improved.

Another example of BSM based on building physics is Energy, Carbon and Cost Assessment for Building Stocks (ECCABS) model developed by Mata (2009). ECCABS is a bottom-up model assessing energy-saving measures (ESM) and emission reduction policy with building physics approaches, investigating hourly heat balances in one-zone building spatial resolution. This model presents net energy and delivery energy along with annual cost and carbon emission on the results. Since it focuses on building physics as the input, a variation of the implementation ESM such as U-values in overall thermal transfer area in building envelope, appliances power reduction, indoor temperature set-point reduction to 20 °C and hot water demand reduction could be conducted. Additionally, Mata et al. (2014) used ECCABS to model aggregated data for UK, Spain, France, and Germany. The modelling method uses a building archetype retrieved from several sampling data gathered.

2.3.2 Data processing in building stock models

Kavgic et al. (2010) mentioned that among the criteria of building stock model, it should be able to assess policies implemented on the building stock. Hence, data processing is an important part of building stock model application. Previous work by Johansson et al., (2017) succeed to develop an energy atlas for multifamily building in Sweden regarding renovation strategy using bottom-up statistical approach. The energy atlas is developed in automated fashion aggregating all the data information that is handled via Extract Transform and Load technology (ETL) in FME. The data exported on the model is joined in attributional and spatial way in the staging process and aggregated based on the category, time, and level of detail. With the same approach on the socio-economic factor, Mangold (2016) investigated renovation and retrofitting needed in Gothenburg, especially buildings that will reach 50 years of life before 2026. However, as Mangold (2016) focusing on socio-economic impact when the renovation strategy being applied, a top-down approach is used instead. Although the dataset covers the country level, multi-family buildings in Gothenburg (5098 n-data) are used for the case study, along with the average income data within the area. The main parameter assessed in this statistical approach is concentrating on the renovation year to determine the renovation cost. In addition on the data process, Österbring et al. (2016) managed to build a method to create a group classification based on the building age with joining the dataset from Energy Performance Certificate (EPC) and 2.5D GIS map of Gothenburg. The previous work by Johansson, Österbring, and Mangold shows that linking the dataset to create a dataset that consists of a property register, energy data and property map is possible in the case of Sweden. The works also show that to have a robust model, all dataset that builds to the model must be able to be linked and validated with a verified dataset, in this case, EPC data.

2.3.3 Implementation of GIS in building stock models

Johansson et al., (2017)**,** as discussed before, created an energy atlas which took the spatial layer of Sweden in 250x250 m2 resolution scales referring to the smallest scale given by SCB. With the incorporation of EPC and socio-economic data in the statistic, the atlas could provide an overview of how the condition of existing building stock and renovation cost with the energy potential reductions on the national level. Torabi Moghadam et al., (2018) developed a geospatial bottom-up statistical model assessing the heating demand of the building stock with 2D/3D GIS and Multiple Linear Regression (MLR) to specify spatial information based with energy demand for each building.

Since building stock model relies on geospatial data, GIS implementation could be used not only to visualize the model results but as a tool to aggregate the information taken on the model (Buffat et al., 2017). Buffat et al., (2017) developed a new approach of building stock model using a big GIS data not only to present the visual results of the model but also use it to model building heat demand in a high temporal resolution, including the integration of renewable energy in the system. With the extensive GIS data and integration with climate data and solar radiation data, it allowed the model to have concrete information about the building location, topography, climate condition, and even shadowing effect. Cerezo Davila et al., (2016) developed building stock model based on GIS dataset for Boston and custom-building archetypes within EnergyPlus simulation. While modelling the data, Davila aggregated the spatial structure was on GIS and assigned with data from 76 archetype defined. Davila then created a massing of building stock manually from the GIS data to have a representation of building adjacency and shading model before modelled to the EnergyPlus.

2.3.4 Characterization of building archetype for building stock models

BSM is an engineering model for building stock, and the scale could be a city level, or more extensive. As the main dataset is not always giving much information that is required by the model. Hence, a tool is needed to classify the individual building information required. With the limitation on the time and data availability, normally a building archetype is used to characterize the individual data properties (Österbring et al., 2016). Building archetype referred in BSM is a typology approach for building stock assessment (Loga, 2009). Cerezo et al., (2017) also mentioned that building archetypes are *"a simplification tool to assigning non-geometric parameters to individual building models [...] to model large national building stocks where the analysis of individual structures is not practical".*

Tabula Project (2009) is one of the comprehensive projects to define the building typology around Europe that is built in 2009. For the Sweden case, Tabula Project uses BETSI[1] as the reference. According to the Tabula Project study, building stock in Sweden characteristics can be observed by the typical properties of the thermal insulation based on the building age, explained by the progression of the building regulation over the years. Based on the archetype developed by the Tabula Project, five different periods of age are classified for three different climate zones according to the National Board of Housing, Building and Planning, compiled on a building display webtool[2]. From the webtool, one could see how the possibility to improve the condition and compare to the base case, in this case, for example, it could be useful when renovating the building. However, since the referenced sample by BETSI for this typology is limited, it was not necessarily comprehensive to capture the entire building typology condition in Sweden.

Österbring et al. (2016) give the example of archetype construction from a local building portfolio in Gothenburg multi-family building to investigate the Energy Efficiency Measure impact. Österbring et al. (2016) built a method to create a group classification based on the building age with joining the dataset from Energy Performance Certificate (EPC) and 2.5D GIS map of Gothenburg. To define the building stock description, Österbring built an archetype from regulation and historical data referring to the building-age type. As for the non-specific input such as heat gains and indoor temperature, an assumption is applied. Furthermore, the dataset is validated in ECCABS for the space heating and domestic hot water energy demand calculation. The method

[1] See chapter 3.2.4 for more detail description about BETSI

[2] Can be accessed in http://webtool.building-typology.eu/#bm

developed by Österbring to define the building typologies will be used in this thesis as the case study is the same for both of the work.

2.4 Summary of literature review

Based on the literature reviewed, building stock model is a tool to perform and assess the building datasets regarding the energy demand in disaggregated level, quantify different building regulations, and measure the energy reduction strategies aiming for the energy efficiency and renewable energy introduction. The availability of the primary dataset is an essential factor for the model to work and valid especially when the model is tackling an extensive range of area, such a city level or more. The data building on the BSM should be able to link all the dataset used and validate the result to the applied policy and verified with the already measured data to have a reliable model result.

Since BSM is heavily related to geospatial data, GIS data could provide plenty of information to support the building stock modelling, not only to visualize the data but also to build more accurate datasets. Moreover, the result could give an analysis and communication method with the spatial results. With the extensive information that could be taken from GIS data, the model could take a better and high-resolution regarding building location and geometry properties.

BSM rely on the simplified building characterization since the data used is limited (Booth et al., 2012), yet it should be managed to create a robust and valid model. Therefore, a solid building archetypes library is needed to represent the building stock modelled. Reinhart & Cerezo Davila (2016) found that a major uncertainty related to building stock model is archetypes classification to represent the building stock. To overcome this issue, the model should be incorporated and validated with accurate measured energy data from the audited building. Booth et al., (2012) also mentioned that uncertainty of inaccurate assumptions could lead to misleading datasets.

3 Methodology

The chapter explains all the preparation and workflow for the input building and modelling the datasets into ECCABS. The collected datasets are merged and aggregated into one big data that is ready to build and modelled. Two archetypes approaches are built and observed to understand how the importance of archetypes in the BSM.

3.1 Research approach

The thesis work is mainly divided into two steps which are to build a data integration model based on the available datasets collected within a structured framework to be used in the building stock model ECCABS.

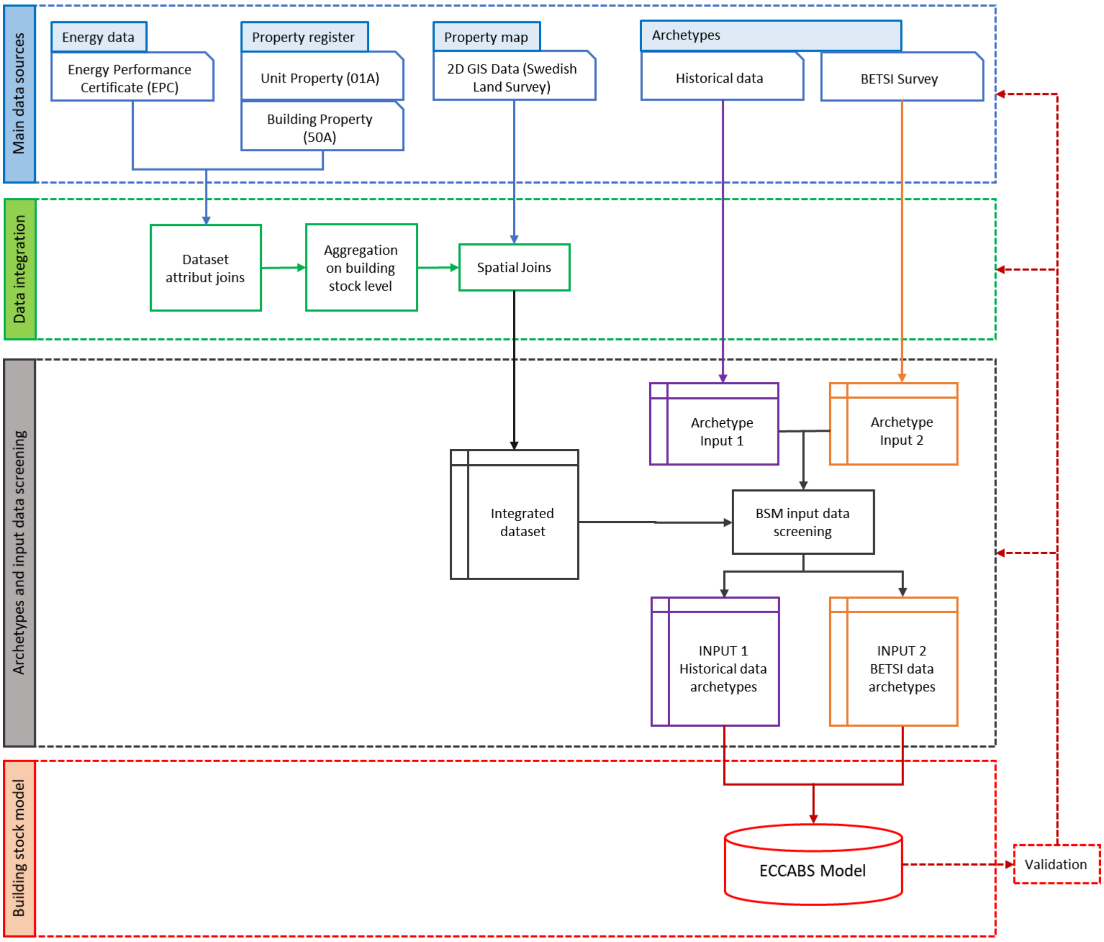

Figure 3.1 Methodology scheme approach

Figure 3.1 presents the general overview of the methodology used in this thesis. The first step to build the BSM input data was to extract the information from the available dataset and analyse the potential information that could be taken into the model. All the major datasets need to be integrated into one integrated database. Since the aggregation level of each data is different, the database needs to be aggregated in the same level of depth. With the aggregated data ready, a spatial join then conducted to extract the information regarding the building geometry. The last stage is to screen and process the database into a BSM input data framework. In this stage, an archetype needs to be built to represent the building properties. Two inputs were built in regard to the archetype used as described in table 3.1. This input name will be used throughout the rest of this thesis. Each definition of the archetype and the input is presented in chapter 3.4. With the data source already joined and assigned with the archetype, it is sufficient to build the dataset in ECCABS format and model it afterwards. The resulting output from ECCABS then used to validate the input dataset. If there is an error from the results, it could be observed within each step.

Table 3.1 Input description

Name	Description
Input 1	Based on archetype 1: Historical architecture data
Input 2	Based on archetype 2: BETSI survey

3.1.1 Data Processing Tools

Four types of datasets are used as the main sources in this work and two main supporting data for archetype building, summarized in Table 3.2. Most of the data is formatted in comma separated value (.csv). The real estate map vector, however, is formatted in shapefile (.shp) while the historical data is a literature-based data from a book (Björk, Kallstenius, & Reppen, 2013). On the table, the number of data (n-data) was also shown to show the difference on how big the database is.

Most of this work to connect and build the input data for the building stock is based on MATLAB, except for the spatial join of GIS data is done by ArcGIS. Since the data cover on the urban scale, the process could take a long time thus MATLAB is chosen since it could process a relatively large data in a quick manner.

Table 3.2 Format and sizes of the data source

	01A	50A	EPC	GIS[3]	Bjork	BETSI
Format	.csv	.csv	.csv	.shp	- (physical)	.csv
Size (Mb)	24.1	89.2	30.9	519	-	1.4
n-data[4]	70638	156937	65043	251466	-	1753

3.1.2 ECCABS Model

In this project, the building stock model used is ECCABS (Energy, Carbon and Cost Assessment for Building Stocks). ECCABS is a model based on Simulink and MATLAB, developed at the Division of Building Technology and Division of Energy Technology, Chalmers. ECCABS is a bottom-up building physics model that calculates energy use based on the physical properties of the buildings. The energy use calculation including heat

[3] Based on layer "buildings" on *fastighetkartan* vector, containing all building polygon in Gothenburg

[4] The amount of data is valid for Gothenburg municipality, based on the county code and municipality code of 1480

balances, building service system as well as the domestic energy appliances, with the output of the model present the delivered energy as well as the carbon emitted (Érika Mata & Kalagasidis, 2009).

On ECCABS, the heat transfer through the building envelope is calculated based on the surface area of the wall above and below ground, roof, floor, and windows. ECCABS calculate the energy demand from the heat balances over the building. While calculating the heat balances, ECCABS modelled a building as one thermal zone. The heat demand mainly consists of transmission losses, ventilation heat losses, solar heat gains and internal heat gains. The internal temperature of the building is derived from the heat demand and building thermal mass in each time step. Since the model aims to calculate various measures applied in the entire building stock on an individual level, the complexity of the building modelled needs to be limited. One way to represent the whole building stock is to classify the buildings based on sample buildings or archetypes (Érika Mata & Kalagasidis, 2009).

Aligned with the thesis objective, the simulation part of this thesis is a validation of the input model built along with the applied archetype. For the model input and output, as well as the algorithm of the model has explained in detail by Érika Mata & Kalagasidis (2009) in their report and briefly mentioned in the following method.

Heat demand calculation in ECCABS

ECCABS basically calculate the energy and heat demand based on the heat balances over the time. The model takes one building as one thermal zone and then it calculates the heat balances in an hourly based time step. The energy balance for the heating (or cooling) demand is calculated as shown in equation (3.1).

$$q(t) = TC \cdot \frac{dT_{int}(T)}{dt} - [q_t(t) + q_v(t) + q_r(t) + q_{int}(t)] \qquad (3.1)$$

From the equation, it can be observed that the heat gains calculated are consisted of the sum of transmission heat losses (q_t), ventilation heat losses (q_v), solar radiation (q_r) and internal heat gains (q_{int}). The heat demand (q) therefore is the thermal inertia of the building (TC) over the internal indoor air temperature (T_{int}) subtracted by the heat gains in each time step (Érika Mata & Kalagasidis, 2009).

3.2 Main data sources

As the main research question of this thesis is exploring the data flows on building stock modelling, building-specific datasets for Gothenburg has been collected and reviewed. Table 3.3 is summarizing the primary datasets used in this thesis.

Table 3.3 Summary of building specific-dataset used

Main data source group	Dataset	Source	Aggregation level	Relevant information	Identifier
Energy data	Energy Performance Certificate (EPC)	National Board of Housing, Building, and Planning (Boverket)	Dwelling	Energy use, heated floor area, building properties, HVAC systems	Cadastral, house number
Property register	01A Registerenhet	Swedish Land Survey (Lantmäteriet)	Cadastral[5]	Link to 50A	FNR, cadastral
	50A Registerbyggnad	Swedish Land Survey (Lantmäteriet)	Building number	Link to GIS, Renovation year	FNR, house number, coordinates
Property map	Real estate map vector	Swedish Land Survey (Lantmäteriet) retrieved from SLU	Building number on each building polygon	2D Polygon data	Coordinates
Archetype input 1	Historical data	Så byggdes husen 1880–2000: arkitektur, konstruktion och material i våra flerbostadshus under 120 år[6] (Björk, 2009)	-	Typical building types material and construction ages	-
Archetype input 2	BESTI Database	BETSI	Building	Typical building types material and construction ages	-

EPC and Land Survey datasets is an open-access database from National Board of Housing, Building, and Planning (Boverket) and Swedish Land Survey (Lantmäteriet) respectively while the 2D GIS dataset is taken from SLU Geodata database. A supporting data which mainly to build the archetypes are described in table 3.3. For Input 1, the historical data is a physical book whereas BETSI data is a survey data from National Board of Housing, Building, and Planning.

[5] In Swedish: Fastighetbeteckning

[6] Free translation in English as "The houses built on 1880-2000: Architecture, construction, and material in multi-family buildings for 120 years"

3.2.1 Energy Performance Certificate

EPC stands for Energy Performance Certificate[7] which first declared in September 2007 in Sweden to promote building energy efficiency and ensuring a pleasant indoor environment performance (Boverket, 2010). The Swedish EPC contains information on measured energy demand for the HVAC systems as well as the domestic hot water system, non-domestic electric appliance use, and other information regarding the system related to energy efficiency installed on the building (Boverket, 2017). Atemp, which stands for the heated floor area for at least 10°C, is used as the area measured for the space heating calculation. The energy measured in EPC are either directly measured or distributed, which means that it is calculated by an energy expert while partially still based on measured data (Mangold et al., 2016). This energy information is measured in annual value. EPC contains energy information on the heating energy (E_{uppv}), comfort cooling (E_{kyl}), hot domestic water (E_{tvv}) and building's property energy (E_f). All of this energy information summed into the total delivered energy (E_{bea}) and then divided by the Atemp to get the specific energy performance results in kWh/m^2 (Boverket, 2017).

Since EPC provided the detailed information on an individual building level, information related to the energy performance is mostly extracted from here. On the model, data taken from the EPC consists of all information related to the building energy demand as well as the Atemp. Other information taken is related to the building address and geometry of the building such as the number of floors and staircases. Other relevant information taken from the EPC is building address information used for linking process. EPC has the information related to the address, house number, and the cadastral information. This information is useful for the EPC in the data merging process as the EPC did not contain any unique identifier that is linked to other datasets.

3.2.2 Swedish Land Survey

Swedish land survey data is a property register data that consist of more than 95 different datasets. However, in this thesis, the data used from the Swedish land survey is limited only to 01A unit registry and 50A building registry as it contains the necessary information regarding the building property information. There is a key property (FNR) to link the data between Land Survey data.

01A Unit Registry

The 01A dataset is the basic information about the property address which mainly consists of county code, commune code, municipality, and also more importantly cadastral information. In Sweden, all of the lands are specified into properties, and each of them has a property name and number within the municipality, termed as cadastral[8] (Lantmäteriet, 2011). This information is found on 01A which is a concatenation of unique identifier of "region – block – tkn – unit". For example "Kallebäck – 7 – : – 9", read as Kallebäck 7:9, assigned for Mejerigatan 2A and Mejerigatan 2B [9] in Gothenburg municipality. The cadastral code is useful in this work to create a link within each dataset.

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[7] In Swedish: Energideklarationen

[8] In Swedish: Fastighetbeteckning

[9] In Sweden, the address generally consist of street name and number. In this case, Mejerigatan 2A and Mejerigatan 2B is referring to the Mejerigatan street number 2A or 2B.

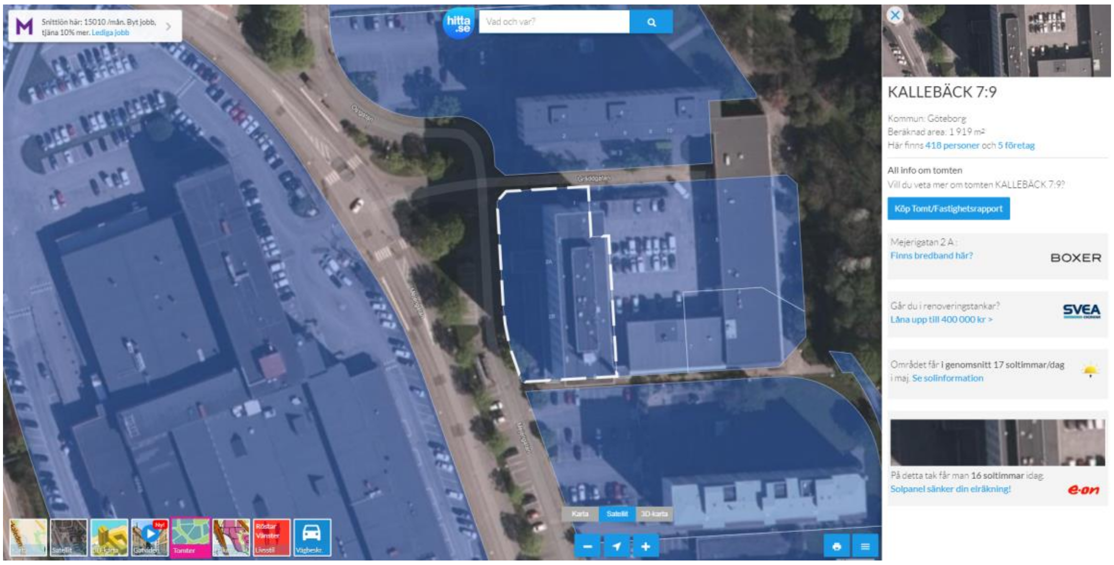


Figure 3.2 Cadastral of Kallebäck 7:9, indicating the property in Mejerigatan 2A and 2B, Gothenburg (Lantmäteriet/Metria, 2018)[10]

50A Building Registry

50A dataset contains detailed information about building property, which the relevant information that could be taken from the dataset such as house number, county code, municipality, and mid-coordinate of the building. House number in here explained as a unique serial number on each individual building, while the coordinate is pinpointed the building on each house number. The coordinate is using SWEREF 99 TM which correspond to the application at the national level, consist of x-axis as 7 digits of North coordinate and y-axis as 6 digits of East coordinate (Lantmäteriet, 2018).

Other information in 50A considered is building types, construction year, renovation year, and value year. There are two types of building type data in 50 A which are observed for the construction purposes and detailed building objectives.

3.2.3 2D GIS Data

The GIS map used in this thesis is a 2D map. The map is retrieved from SLU[11] limiting a square area of coordinate as shown on figure 3.3 which basically enough to cover the whole city of Gothenburg. Two vectors of GIS maps are used for this thesis which is a property map building vector[12] and real estate map vector[13]. Both are produced by Swedish Land Survey. Therefore, the coordinate system used is also using SWEREF 99 TM and could be spatially linked with another dataset using the same coordinate system.

---

[10] The interactive map to find the address as well as the cadastral information could be accessed from hitta.se

[11] The map is retrieved from an open access portal at https://maps.slu.se/

[12] In Swedish: Fastighetskartan bebyggelsevektor

[13] In Swedish: Fastighetskartan fastighetsindelning vektor

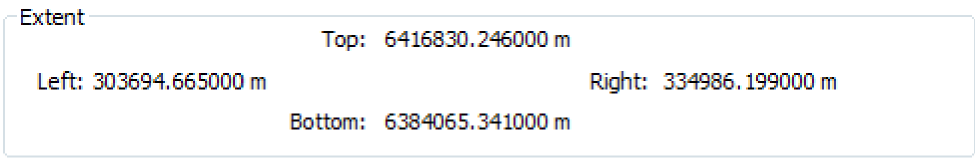
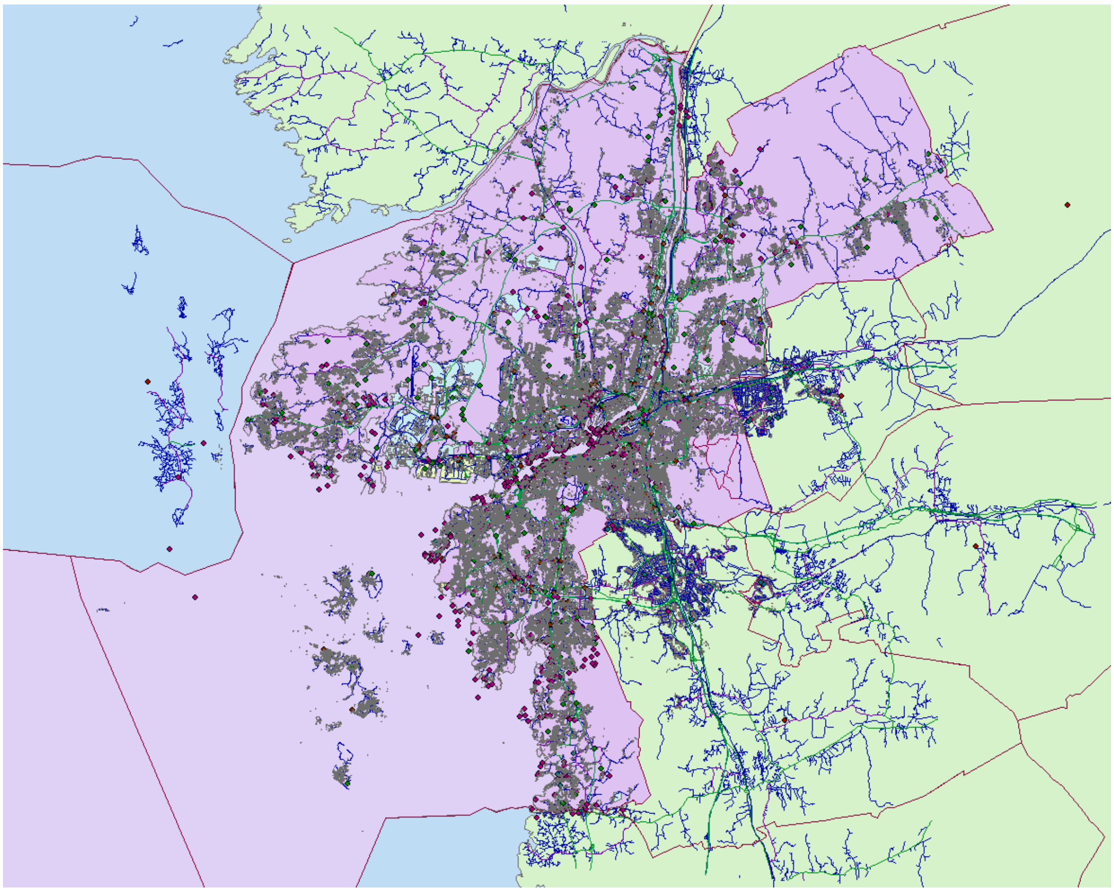


Figure 3.3 *Coordinate extent retrieved from SLU*

Although there are many layers extracted from both vectors, the layers used for this thesis only consist of building polygon layer and cadastral polygon layer. Building polygon layer as depicted in figure 3.4 (see code colour: blue) is a 2D map of the individual building. The polygon is translated as one zone with the roof and floor having the same area as the footprint area. Hence, from the building polygon, footprint area and perimeter of the building can be extracted. Another layer used is cadastral polygon to indicate where the cadastral address of the individual building stands. This layer is mainly used for a validation purpose. In addition, each of the individual polygon data from both layers has the information embedded such as building type, address, and cadastral code.



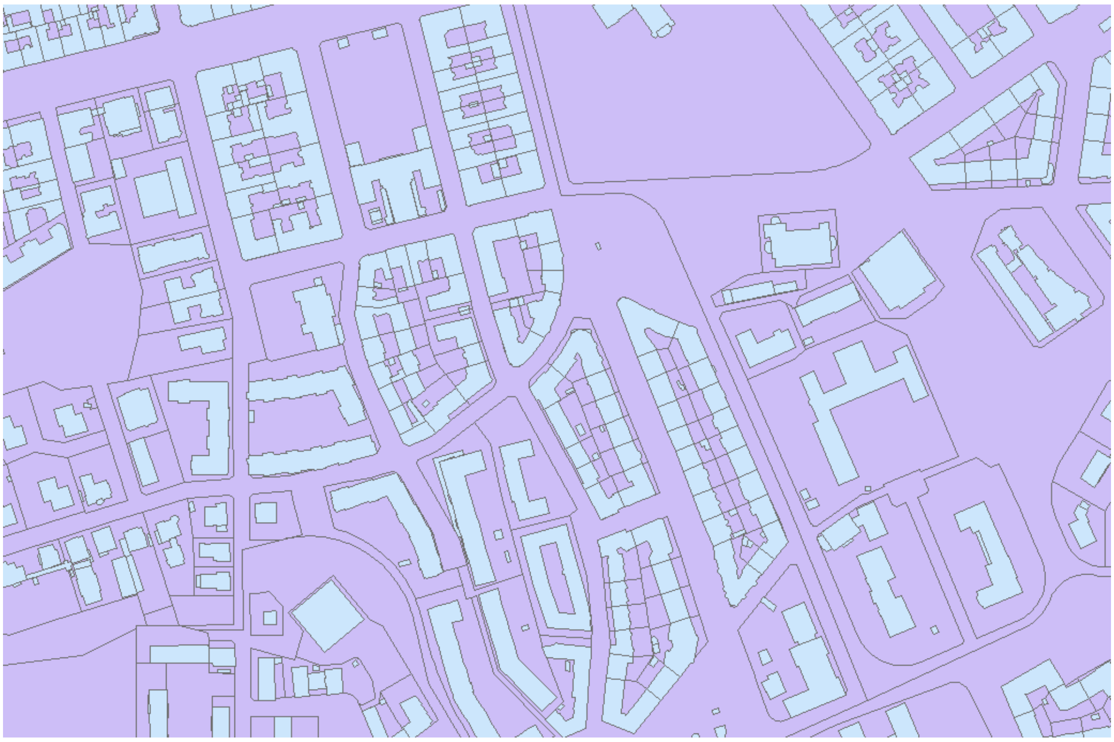


Figure 3.4 *a) General overview of the 2D GIS map of Gothenburg retrieved from SLU, b) Interface of building polygons found in property map building vector*

3.2.4 Supporting data sources for archetypes

While the data described above served as the primary data for the model, there are other supporting data that is used, mainly to be a reference for creating building archetypes.

Historical data

A historical data on Swedish residential dwellings development is observed to get a better understanding of Swedish residential dwellings, mainly sourced by Björk, Kallstenius, & Reppen, (2013). The book is reflecting the 120 years of development on the Swedish multi-family buildings from 1880 till 2000. Included in the book is the information of the architectural design, layout and constructive between houses from different construction years and different building types.

BETSI Survey

BETSI (*bebyggelsens energianvändning, tekniska status och innemiljö*)[14] is a survey data result conducted by the National Board of Housing, Building and Planning on the summer period of 2007 – 2008 about building technical specification in regard to the energy use (Boverket, 2015). BETSI surveyed 1752 buildings and categorized the building surveyed into 3 types, which is a single house building (S), multifamily building (F), and mixed-use building (L). The survey result is published as an open-access database. While there are several datasets available in BETSI, the most interesting dataset for this thesis is the climate data which consist of information on building envelope performance such as measured area and U-value for each building component. To calculate the U-value, the correspondent indicated the total area of the building component and the materials used from the list option provided by BETSI. BETSI then imposed the material configuration and calculated the U-value based on the external and internal thermal resistance directly on the protocol. Hence, the U-value may be a bit too high for some cases (BETSI, 2007).

3.3 Data Integration

3.3.1 Data Integration Process

The process of merging the dataset starts with linking both EPC and Land Survey data. The interesting dataset taken from Land Survey used in this thesis is 01A and 50A. Those two data somehow need to be linked with EPC to gather complete information about building property information such as building type, construction year, and mid-coordinate along with the energy performances. To link the dataset, it needs some identifier that is applicable to all the data merged. While EPC has a unique identifier for each building (Formular-ID), it did not have a valid ID that could be used and linked to the other dataset. The same condition also happened with Land Survey data. It has an identifier (FNR) to link between Land Survey data, but it is not valid to link with another dataset. Therefore, an attempt to join the data process is made using concatenation of address information (Johansson et al., 2017).

In order to link both of the Land Survey data and EPC, at least two steps should be made. On the initial dataset, both of 01A and EPC data has the cadastral and municipality code, while both of 50A and EPC has the house number. 01A and 50A dataset could be joined with FNR ID. Table 3.5 below describes the relationship between each dataset.

[14] Free translation in English as Building energy use, technical status and indoor environment

Furthermore, on the integration process, this thesis takes inspiration from the work by Österbring et al., (2016) and Johansson et al., (2017), where the identifier is taken is from the address information.

Table 3.4 Information from each dataset that could be set into an identifier

Identifier	EPC	01A	50A	GIS
Municipality code	✓	✓	✓	✓
Cadastral	✓	✓	-	✓
House number	✓	-	✓	-
FNR	-	✓	✓	-
Formula ID	✓	-	-	-
Coordinate	-	-	✓	✓

3.3.2 Attribute joins between 01A and EPC

The first step of the merging process is to join 01A with EPC dataset. EPC data is aggregated on various level, mostly on one street address, while 01A aggregated within one cadastral. Both datasets are possible to be joined using concatenation of cadastral and municipality code. Figure 3.5 depicts the flowchart of the merging process.

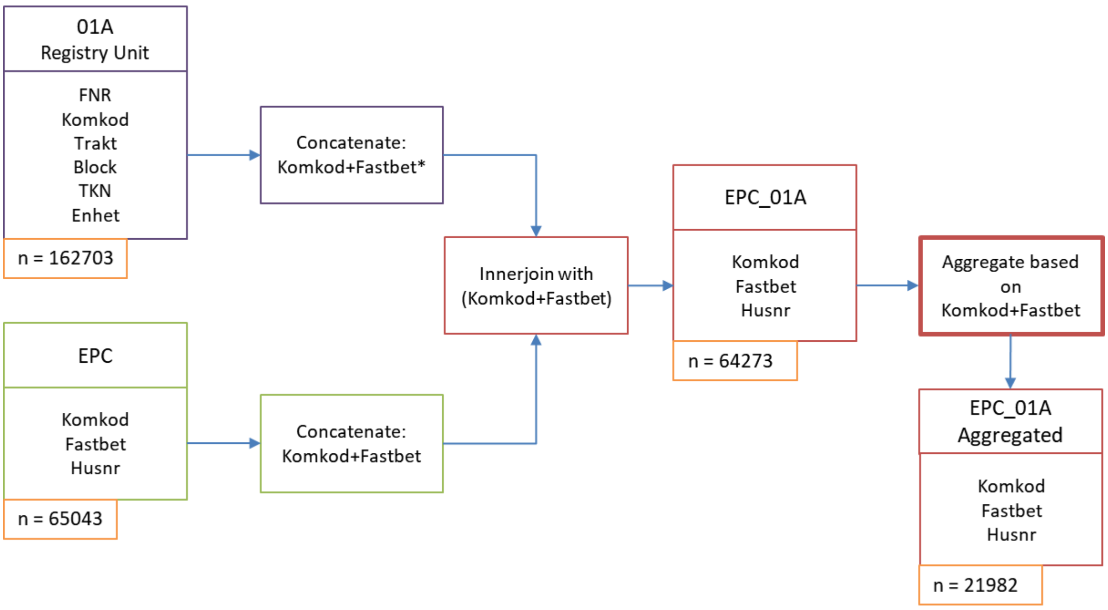


Figure 3.5 Flowchart on how to link the 01A and EPC data. Orange box shows n-data of each dataset.

3.3.3 Aggregation on building stock level

Since every dataset comes with different aggregation, all of the data that is used needs to be aggregated into the same level before progressing to the next step of data integration. From the main data source, 3 level of aggregation is observed, first is property information, or cadastral (light blue), building number (dark blue), and dwellings (yellow) as depicted in figure 3.6. In this case, the entire data is aggregated into the level of building number (in the figure, it is depicted in the colour code of dark blue) referenced by the house number variable and FNR code from Land survey data to create a link with 50A dataset which already have the level of aggregation based on building number. The result of the aggregation is 21982 n data. The aggregated data in here also be used for validation point for the model simulation result.

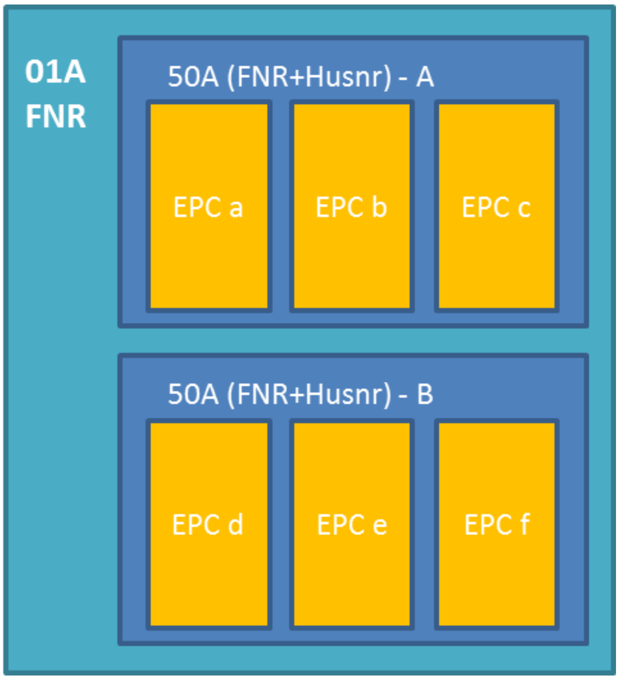


Figure 3.6 *Description of aggregation level within each dataset. The dataset in this thesis is aggregated to building number level, depicted as dark blue in the figure.*

3.3.4 Attribute joins with 50A

The final step is to create a link with 50A that contain information about building properties and the coordinates. The link is created via concatenation of FNR and house number, which in this case also be used as the building ID to be input on the model. Figure 3.7 depicts the merging process. On the final merged data, 18586 n data are linked. The

3396 building unlinked data is due to unavailable data of house number, mainly in EPC data.

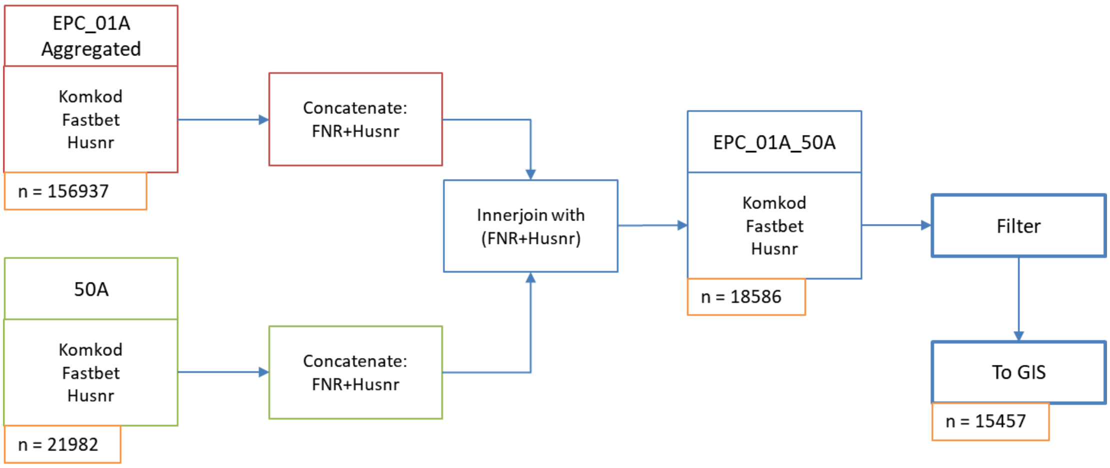


Figure 3.7 Flowchart on how to link the 50A and EPC+01A merged data. Orange box shows n-data of each dataset.

3.3.5 Filtering the dataset to residential building

The integrated database of EPC and Land Survey contains all information for both residential and non-residential building. As this thesis focuses on residential buildings, the dataset needs to be limited only to residential buildings. In this case, both EPC and Land Survey have their own definition of a building type that sometimes overlaps with each other. In order to make sure that the resulting data is valid for residential building, a filter needs to be made. In this work, data is true for the residential building if both of the building types match with the filter presented in table 3.5 which only taken from EPC dataset to restrict the definition of a residential building. The data will be eliminated if one condition present from each dataset present, or no condition match at all. In this last step, the resulting output from the filtering process is 15457 n data.

Table 3.5 Residential building set of filters

Residential building types	**Set filter**
Single house building	220 = Small house unit, full-year residence for 1-2 families
Multi-family building	320 = Rent house unit, mainly residential
	321A = Rent house unit, housing >= 50%
	321B = Rental housing unit, housing, and premises> 50%

3.3.6 Spatial join with GIS

One of the aggregated data results is mid-coordinate. Since the coordinate uses the same system with the 2D map vector of Gothenburg, it could be used as a reference for the merged data to do a spatial join within GIS environment. By adding the mid-coordinate as a xy-data on GIS, it would point to a specific vector based on the building layer. While there is a lot of information could be taken from the map, the interesting point is how the actual shape of the building, indicated on their footprint area and perimeter. Combined with the archetype information on the building weight and the window and wall ratio, one could get a representation of the building shape in the most straightforward manner, i.e. when calculating the building envelope area. Figure 3.8 depicts the flowchart of how the spatial join from both datasets.

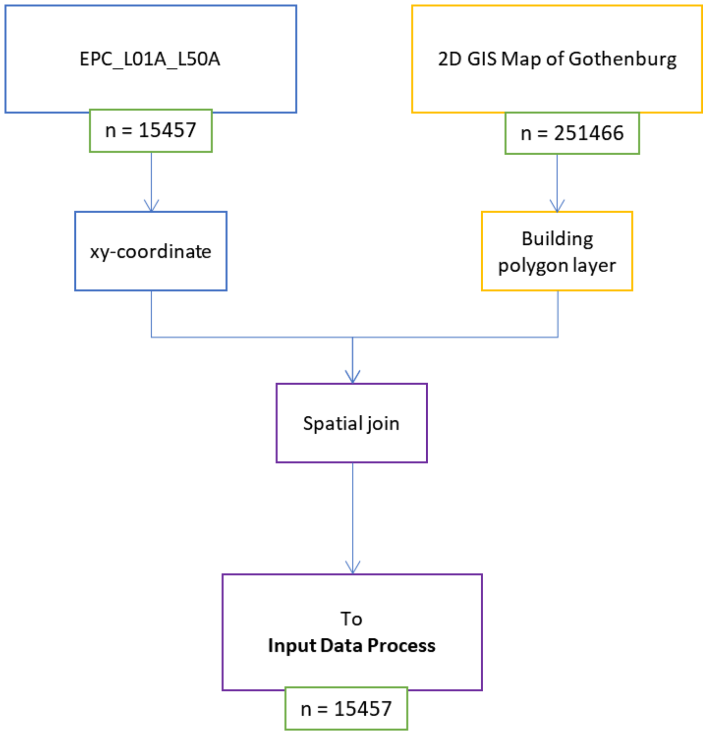


Figure 3.8 Flowchart on how to spatially join the data

As for the steps to do a spatial join in ArcGIS environment, the information needed is the mid-coordinate of each individual building data which could be found in the already merged data. The integrated data from EPC, 01A and 50A then imported to the ArcGIS as a table with a coordinate point as the indicator of where the individual data is placed in the map. The selection method is done by intersecting the point to the building polygon and spatially joined all together. With all data already joined, all the information needed can be imported as one table. Figure 3.9a depict the building selected from the intersection process while figure 3.9b show the detail interface pointing the information from the already spatially joined building polygon.

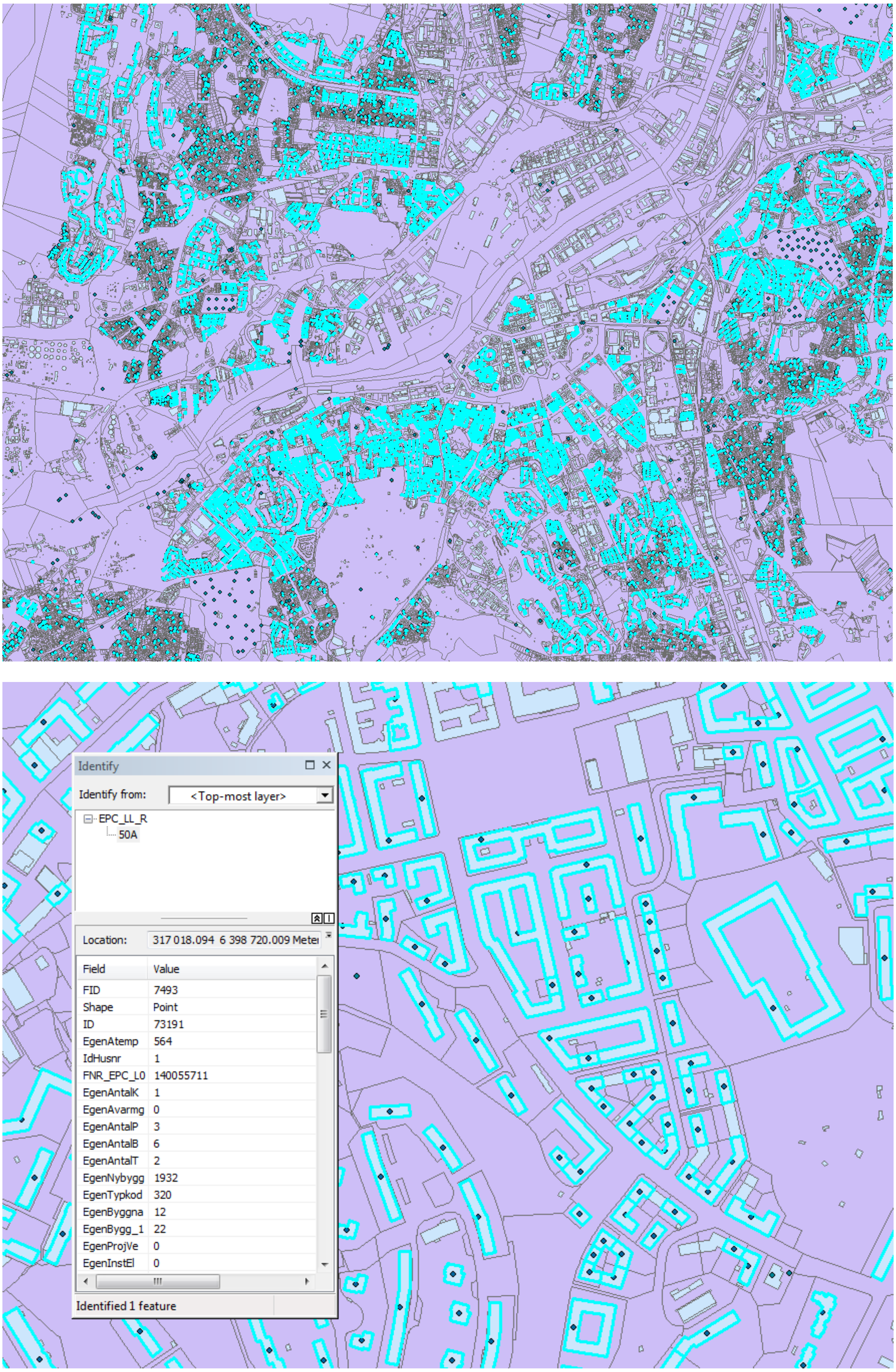


Figure 3.9 *a) GIS map showing the selected building from the spatial join, b) Interface of spatial join in GIS*

3.4 Archetypes

As explained in chapter 2.3, the archetype is used as a simplification tool to classify the building properties defined for the building stock. This is due to the lack of information found on main data sources mainly regarding the building type and material. Two kinds of archetypes are built for this thesis purpose sourced from two different main references which are the historical book (Björk et al., 2013) and BETSI as explained in chapter 3.1. Table 3.6 below describes the main variable for each layer component, which is applied the same for both archetypes.

Table 3.6 Variable in the archetype building material configuration

Variable	Description	Unit
WWR	Windows and wall ratio	-
T	Layer thickness	m
K	Thermal conductivity	W/mK
D	Density	kg/m^3
Cp	Specific heat capacity	J/kg.K
R	Thermal resistance factor	$m^2.K/W$
U	Heat transfer factor	$W/m^2.K$

The layer component taken in the calculation are wall above and below the ground, roof, floor, and window as depicted in figure 3.10. In this case, the building simplified as one zone, with a "cold bridge" on the attic[15], means that no insulation in the roof part so the temperature in the attic is the same as outside.

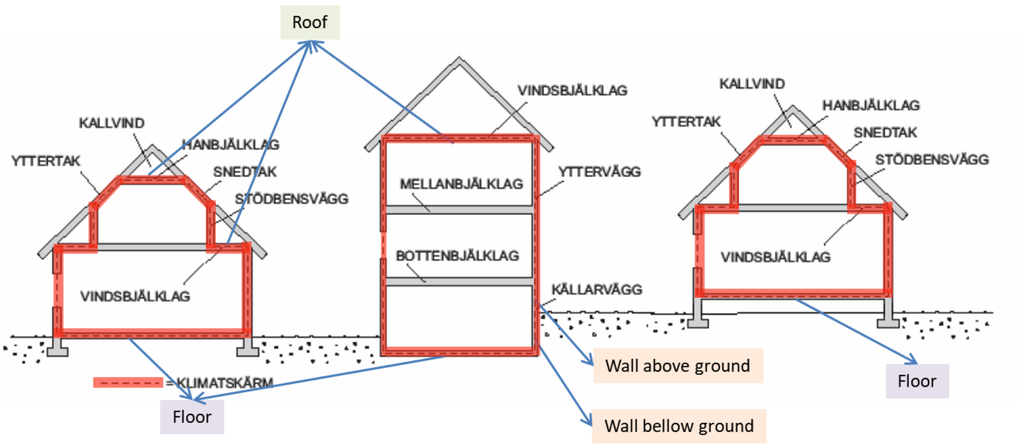


Figure 3.10 Building component layer considered in the model. A building is simplified as one zone. (BETSI, 2007)

[15] Swedish: Vindsbjålklag

3.4.1 Building type classification

Before assigning the archetypes, the building type should be classified since there is no information about the building type or category in the main dataset. Based on the historical architecture, there are seven common multi-family dwelling types in Sweden based on the historical architecture as depicted on figure 3.11 (Björk et al., 2013; Österbring et al., 2016).

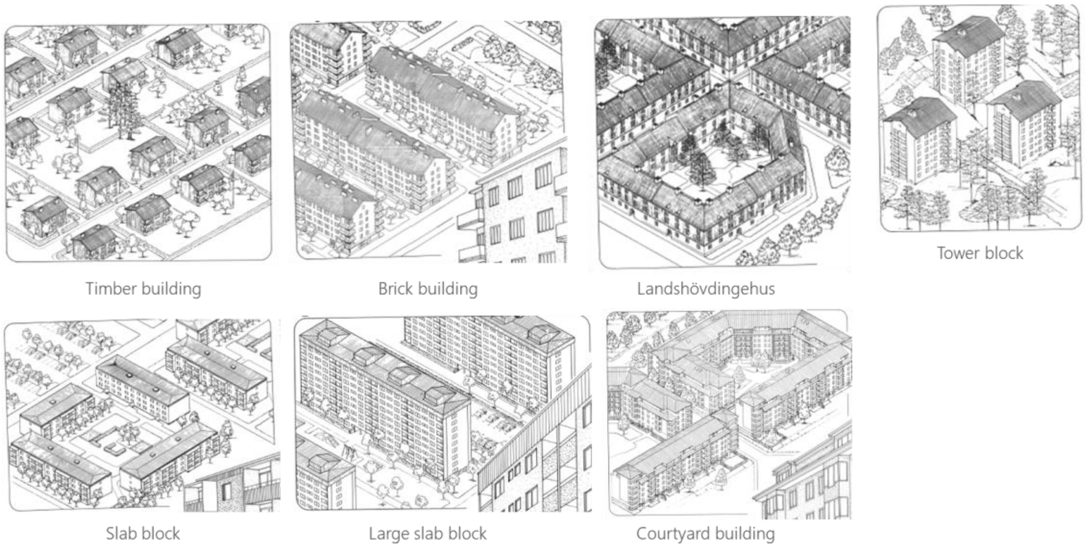


Figure 3.11 Building types used as archetypes categorization (Björk et al., 2013)

To classify the building type can be deducted using the number of stories, construction year, number of staircases[16], and the attachment to other building as the identifier to match with the building types shown on figure 3.11 (Österbring et al., 2016). Table 3.7 describes the matching properties of building type for an individual building. For single house building, since there is no further information regarding the building type, it assumed that all the building observed is a timber building. However, the U-value calculated in the archetype will follow the regulation when the building constructed.

Table 3.7 Assigned condition to categorize multi-family building (Österbring et al., 2016)

Building type	Attachment	Stories	Staircases	Construction period
Timber building	Detached	2	0-1	-1950
Brick building	Multiple	>3	Multiple	-1940
Landshövdingehus	Attached/semi detached	3	1+	1880 - 1940
Slab block	Detached/semi detached	2 to 4	1+	1930 - 2015
Tower block	Detached	>2	1	1935 - 2015
Large slab block	Detached/semi detached	>4	Multiple	1950 - 2015
Courtyard building	Attached	>3	Multiple	1975 - 2015

[16] Swedish: Traphus

Österbring, (2016) described the demands on U-value for Swedish building component according to the building code ranging from 1946 to 2014. The building code regulations have existed since 1946. However, the regulation is constantly changing. Regulation for average U-value from 1946 to 1988 is applied on construction based, differentiating the heavy and light construction while the regulation from 1989 to 2006 is based on the ratio of window area to building envelope area. From 2007 till present, a constant average U-value has been set as the standard. Table 3.8 summarized the U-value demand in Swedish building code.

Table 3.8 Demand for U-value in Swedish building (Österbring, 2016)[17]

Building code (unit)	Valid	Heavy brick construction	Light brick construction	Other stone material	Wood	Heavy roof construction	Wooden roof construction	Floor	Window
BABS 46	1946-1950	1	0.9	0.8	0.6	0.6	0.5	0.4	2-pane
BABS 50	1951-1960	1.05	0.95	0.85	0.65	0.55	0.45	0.45	2-pane
BABS 60	1961-1967	1	1	0.8	0.5	0.5	0.4	0.4	2-pane
SBN 67	1968-1975	1.1	1.1	0.8	0.5	0.5	0.4	0.4	3.1
SBN 75	1976-1981	0.3	0.3	0.3	0.3	0.2	0.2	0.2	2
SBN 80	1982-1988	0.3	0.3	0.3	0.3	0.2	0.2	0.2	2
NR	1989-1994	0.18+0.95*Aw/Aenv							
BBR 1-8	1995-2002	0.18+0.95* Aw/Aenv							
BBR 9-11	2003-2006	0.18+0.95* Aw/Aenv							
BBR 12-15	2007-2008	0.5							
BBR 16-18	2009-2011	0.5							
BBR 19-21	2012-2014	0.4							

The U-value for BABS and SBN is in kcal/m²ch, for NR and BBR the U-value in W/m²K. Aw means window area and Aenv means envelope area.

3.4.2 Archetype 1: Based on historical architecture data

The first archetype is referenced from the historical architecture data (Björk et al., 2013) to find the building material configuration and adjust it within the Sweden building regulation standard. The information taken from historical data are including the material component for each layer and the thickness (T,i) of a building type in accordance with the building age. Density (D,i), thermal conductivity (K,i), and specific heat capacity (CP,i) could be derived from the material used on each layer. Windows and wall ratio also calculated from the building layout found on the book. From this information, R-value and U-value for each component can be calculated using equation (3.2) below.

$$R_l = \frac{1}{\lambda_l} = \frac{T_l}{k_l} \qquad (3.2)$$

[17] Below is the denotation of the building code and English translation in bracket:

1) BABS Byygnadsstadgan (Building code)
2) SBN Swedish Building Code
3) NR Nybyggnadsregler (New construction rules)
4) BBR Boverket byggregler (National board of building, housing and planning's construction rules)

$$U_i = \frac{1}{R_i} = \frac{1}{R_{l1} + R_{l2} + R_{l3} + \cdots + R_{ln}}$$

Where U is the heat transfer factor of the material often called U-value (W/m^2.K), R is the material thermal resistance factor (m^2.K/W), k is the thermal conductivity (W/mK), and T is the thickness of the layer (m). The R-value is calculated from each layer of the building component, and this is including the air film resistance on the inside and outside layer. Figure 3.12 shows the U-value and window to wall ratio (WWR) for each building component assigned for each building type from the year 1900 till 2015. For the building built before 1900, the U-value assigned is following the value for 1900 and the same treatment also for the building built after 2015 the assigned value following the value on 2015. Appendix 8.1 describes the detail of archetype for each building components on each building-age type.

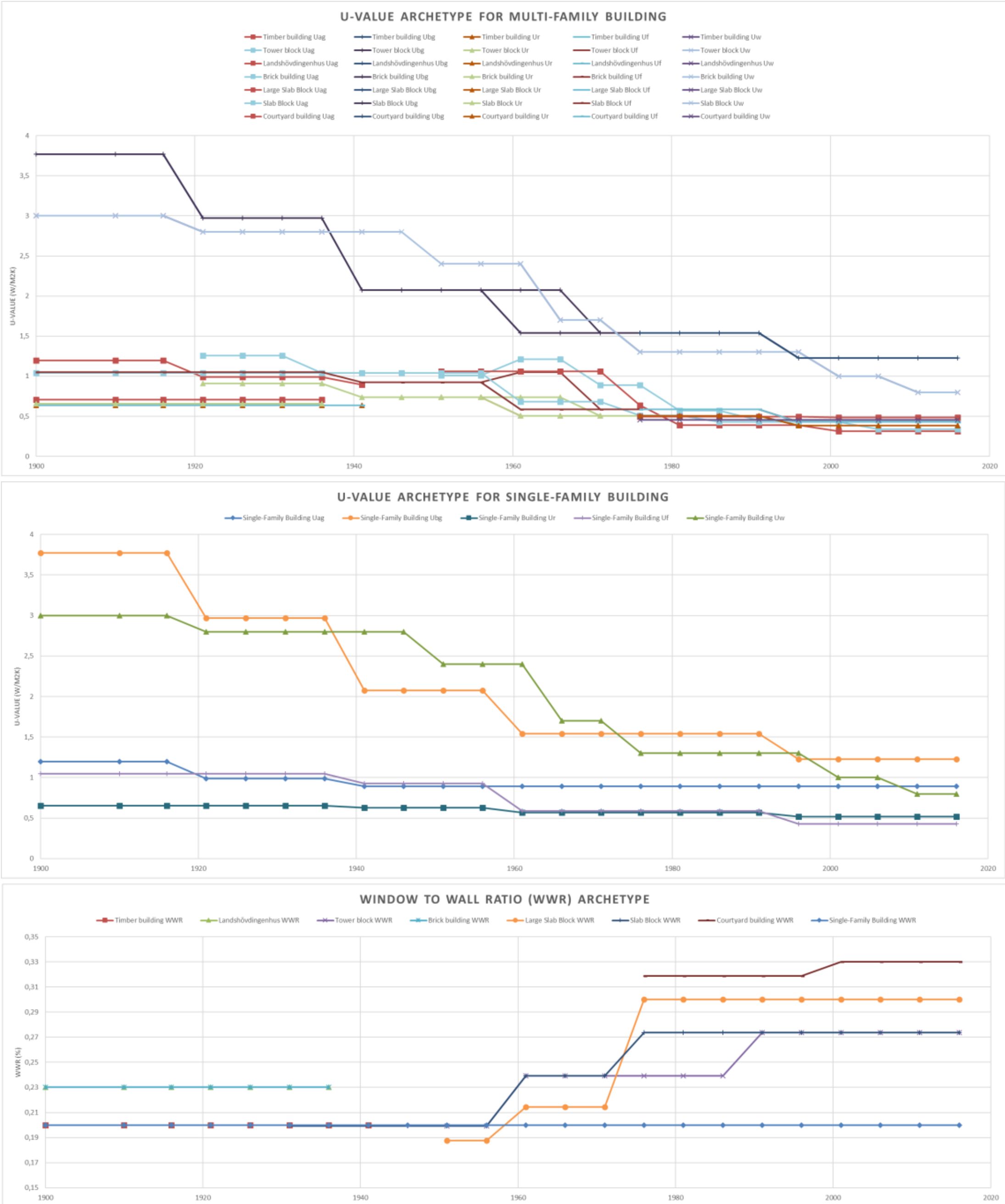


Figure 3.12 U-value (W/m2K) and WWR assignment for Archetype 1: Based on historical data

3.4.3 Archetype 2: Based on BETSI

The second archetype is referenced from BETSI. The database has the detail information about building envelope and material configuration, as well as the U-value from the buildings surveyed. Due to no information available regarding neither the weighting nor the address of the building surveyed, the U-value per component calculated as the average value. Figure 3.13 shows the U-value for each building component and the WWR for single-house dwelling and multi-family dwelling. As the BETSI did not state the building type, the archetypes are aggregated into single-family buildings and multi-family buildings.

Figure 3.13 U-value (W/m2K) and WWR assignment for Archetype 2: BETSI

3.5 Data Input Screening

3.5.1 Building information

The building information is input data regarding the ID for the model, building type, and construction year. Building number is taken from the formular ID on the EPC, while the building type is using the already classified building type as discussed in the chapter 3.4.1 Building type classification. For the construction year, although both 50A and EPC have the information about it, the data from 50A is incomplete, yet it may not be reliable to be taken on this model.

Table 3.9 Building information variables

Variable	Description	Unit	Input method	Source
Building number	ID used in the model	-	Formular ID from EPC	EPC
Location_no	Assigned location for the model	-	Concatenate of kommun kode and lankod	50A
Byggnads_typ	Building type according to the assigned archetype (code)	-	Based on archetypes	Archetypes
Byggnads_typM	Building type according to assigned archetype (description)	-	Based on archetypes	Archetypes
Nybyggnadsår	Construction year	-	Construction year in EPC	EPC

3.5.2 Building properties

Building properties are input model in one zone regarding the total number of floors above and below the ground, the total number of apartments, total number of staircases, and total number of occupants. All the information is directly taken from EPC, except number of occupants is based on SCB. According to the SCB, number of occupants in a single house building is 2 people/unit while on the multi-family building is 2,4 people/unit (Statistics Sweden, 2017).

Table 3.10 Building properties variables

Variable	Description	Unit	Input method	Source
N_{ag}	Number of floors above ground	-	Based on number of floors from EPC	EPC
N_{bg}	Number of floors below ground	-	Based on number of floors from EPC	EPC
N_{app}	Number of apartments	-	Based on number of apartments from EPC	EPC
N_{oc}	Number of occupants on the buildings	-	Based on number of apartments, SHB = 2 people/unit, MFB = 2,4 people/unit	EPC, SCB
$N_{traphus}$	Number of staircases	-	Based on number of staircases from EPC	EPC

3.5.3 Building geometry

Building geometry is considered as an important factor in the model input due to many inputs defined is based on the building shape, particularly from the heated floor and surface area.

Table 3.11 Building geometry variables

Variable	Description	Unit	Input method	Source
A	Heated floor area	m^2	Based on Atemp from EPC, corrected with a correction factor (Mangold, Österbring, & Wallbaum, 2015)	EPC
A_{bg}	Heated basement floor area	m^2	Based on heated basement floor area from EPC	EPC
A_{fp}	Building footprint area	m^2	Based on the GIS polygon data	GIS
P	Perimeter	m	Based on the GIS polygon data	GIS
S_{ag}	Total wall area above ground	m^2	Eq. 3.3	GIS
S_{bg}	Total wall area below ground	m^2	Eq. 3.4	GIS
S_f	Total floor area	m^2	Equal to footprint area	GIS
S_r	Total roof area	m^2	Equal to footprint area	GIS
S_w	Total window area (area of opening)	m^2	Eq. 3.6	GIS
S	Total exterior area of building envelope	m^2	Eq. 3.5	GIS
Ts	Window solar transmission	0-1	Based on the historical data	Table 3.13
Wc	Window frame area	0-1	Based on the historical data	Table 3.13
Wf	Shading coefficient	0-1	Based on the historical data	Table 3.13
H_{floor}	Storey height	m	Based on the historical data	Table 3.13
WWR	Window to wall ratio	0-1	Based on the archetypes	Archetype

The heated floor area (Atemp) is referenced from the EPC. There are some uncertainties in calculating the Atemp as Mangold et al., (2015) have discussed in their paper. Therefore an adjustment factor is used to improve the accuracy of the Atemp. Table 3.12 below is the Atemp adjustment factor on different building age.

Table 3.12 Atemp adjustment factor based on different building age (Mangold et al., 2015)

Building age group	α for buildings without basement	α for buildings with basement
-1900	1.178	1.084
1900-1910	1.178	1.084
1911-1920	1.138	1.047
1921-1930	1.195	1.1
1931-1940	1.2	1.104
1941-1950	1.261	1.16
1951-1960	1.188	1.093
1961-1975	1.208	1.112
1976-1985	1.095	1.007
1986-1995	1.144	1.052
1996-2005	1.181	1.087
2016-	1.154	1.062

As for the windows geometry properties, the value is derived from the historical data, and it is valid for both inputs as described in the table 3.13.

Table 3.13 Windows geometry input based on different building age (Björk et al., 2013; Österbring et al., 2016)

Building age group	H_{floor}	Ts	Wf	Wc
-1900	3,2	0,7	0,7	0,5
1900-1910	3,2	0,7	0,7	0,5
1911-1920	3,2	0,7	0,7	0,5
1921-1930	3,2	0,7	0,7	0,5
1931-1940	3,2	0,7	0,7	0,5
1941-1950	2,7	0,7	0,7	0,5
1951-1960	2,7	0,6	0,7	0,5
1961-1975	2,7	0,6	0,8	0,5
1976-1985	2,7	0,6	0,8	0,5
1986-1995	2,6	0,6	0,8	0,5
1996-2005	2,6	0,6	0,9	0,5
2016-	2,6	0,6	0,9	0,5

For the building envelope geometry, an individual building data is considered as a one zone building, as discussed in chapter 3.4.2. The information about building envelope area mainly taken from GIS polygon, with the height of the building is referenced from Österbring et al., (2016). Equation bellow is used to define the building envelope area.

$$S_{ag,i} = N_{ag,i} \cdot A_{fp,i} \cdot H_{floor} \qquad (3.3)$$

$$S_{bg,i} = N_{bg,i} \cdot A_{fp,i} \cdot H_{floor} \tag{3.4}$$

$$S_i = S_{ag,i} + S_{bg,i} + S_{f,i} + S_{r,i} \tag{3.5}$$

$$S_{w,i} = S_{ag,i} \cdot WWR \tag{3.6}$$

While calculating the building shape, an attachment of the building could become an issue, for example, walls that touch other buildings. This method could result in some error when calculating the building envelope area which is discussed in chapter 5.1.

3.5.4 Heat transfer and heat capacity

The variables in this category are taken from the archetypes and create the major differences between the two inputs. The average U-value is calculated in equation 3.8, to understand the impact of the inputs. The model though did not assign the average U-value but instead the U-value of each layer.

$$Um = \frac{(Uw \times Sw) + (Uag \times (Sag - Sw)) + (Ubg \times Sbg) + (Uf \times Sf) + (Ur \times Sr)}{S} \tag{3.7}$$

For the internal heat capacity, equation 3.9 is used. Internal heat capacity is the thermal inertia also calculated from the entire heated structural components that have direct contact with the internal air.

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i \tag{3.8}$$

Table 3.14 Heat transfer and heat capacity variables

Variable	Description	Unit	Input method	Source
U_i	U-value of the building component (i)	W/m^2K	Based on archetypes	Archetypes
Cp_i	Thermal mass of the building component (i)	J/K	Based on archetypes	Archetypes
D_i	Density of the building component (i)	Kg/m^3	Based on archetypes	Archetypes
T_i	Thickness of the building component (i)	m	Based on archetypes	Archetypes
U_m	Average U-value of the building	W/m^2K	Eq 3.x	-
TC	Effective internal heat capacity of the building	J/K	Eq 3.x	-
Thermal bridge	Percentage of thermal bridge	(%)	0,1	Assumption

3.5.5 Temperature set point

The indoor air temperature (T_0) is calculated the same with all building components. On the model, the indoor air temperature is calculated at each time step from the energy balance below.

$$TC \cdot \frac{dT_{int}(T)}{dt} = q_t(t) + q_v(t) + q_r(t) + q_{int}(t) \tag{3.9}$$

Based on the equation above, indoor air temperature for the next time step calculated from the current time step t.

$$T_{int}(t + \Delta t) = T_{int}(t) + \frac{q_t(t) + q_v(t) + q_r(t) + q_{int}(t)}{TC} \tag{3.10}$$

The control system in the model is a simple on and off model (Érika Mata & Kalagasidis, 2009) meaning that to cover the heat demand the heating is ON if the indoor air temperature is less than set point temperature (Tr_{min}) otherwise the heating is OFF. In the model, the set point for indoor air temperature is according to Boverket, where for single-family building is 21,2°C and multi-family building is 22,3°C (Boverket, 2009). For the maximum set point for indoor air temperature is 25°C and the indoor air temperature set point when the window is opened is 24°C.

Table 3.15 Temperature set point variables

Variable	Description	Unit	Input method	Source
T_0	Indoor air temperature	°C	21,2°C for SHB and 22,3°C for MFB	Boverket
Tr_{min}	Minimum indoor air temperature	°C	21,2°C for SHB and 22,3°C for MFB	Boverket
Tr_{max}	Maximum indoor air temperature	°C	25°C	Assumption
Tv	Indoor air temperature set point for natural ventilation	°C	24°C	Assumption

3.5.6 Heating and cooling power

To deliver the heat, an input of maximum for heating power (Sh) and cooling power (Sc) as well as maximum heat capacity (Ph) and cooling capacity (Pc) is defined. In ECCABS, the heating power delivered from the heating system calculated as

$$q_{heat}(t) = P_h \cdot TC \cdot [Tr_{min} - T_{int}(t + \Delta t) \tag{3.11}$$

$$q_{heat}(t) \leq S_h$$

As well for the cooling power delivered

$$q_{cool}(t) = P_c \cdot TC \cdot [Tr_{min} - T_{int}(t + \Delta t) \tag{3.12}$$

$$q_{cool}(t) < S_c$$

Hence for the input assigned, the input given for heating and cooling power capacity is a maximum value (in this case 5000000W for Sh, Ph, and Pc and -2000000W for Sc) just to make sure that the heating system can fulfil the heat demand.

Table 3.16 Heating and cooling power variables

Variable	Description	Unit	Input method	Source
Sh	Maximum heating power	W	5000000 W	Assumption
Sc	Maximum cooling power	W	-2000000 W	Assumption
Ph	Response capacity of heating power	W	5000000 W	Assumption
Pc	Response capacity of cooling power	W	5000000 W	Assumption
Hw	Hot water demand	W/m^2	Derived from hot water demand in EPC	EPC

3.5.7 Airflow and ventilation system

In the model calculation, the ventilation flow composed of sanitary ventilation and natural ventilation. Natural ventilation is when there is opening in the building, for example opening the windows, while sanitary ventilation is the mechanical ventilation to exhaust the supply air. The sanitary ventilation rate is adjusted according to the supply air needed, which is 0,35 l/s/m^2 (Boverket, 2009). For the specific fan power (SFP) and the heat recovery efficiency, the input is according to the supply fan power deduction based on the HVAC system used as shown in the table 3.17.

Table 3.17 Supply fan power assignment condition

SFP	Ventilation system	Assumed condition	SFP (W/l/s)	Hrec-eff	Pfh
Extract and supply air with heat recovery 2 kW/(m3/s)	FTX ventilation	Hpa (frånluft)	2	0.8	0.8
Extract and supply air without heat recovery 1.5 kW/(m3/s)	FT ventilation	HPb (luftluft, elluft)	1.5	0	0
Extract air with recovery 1 kW/(m3/s)	FX ventilation	HPc (luftvatten), HPd (mark)	1	0	0.8
Extract air 0.6 kW/(m3/s)	F-valve	EB (elvatten), ED (eldirekt), DH, other systems	0.6	0	0

Table 3.18 Airflow and ventilation system variables

Variable	Description	Unit	Input method	Source
Vc	Sanitary ventilation rate	l/s/m^2	0,35 l/s/m^2	Boverket
Vcn	Natural ventilation rate	l/s/m^2	2 l/s/m^2	Assumption

SFP	Specific fan power	W/m^2	Based on archetypes referenced from BBR23 BFS 2011:6	BBR 23, Archetypes
HRec_eff	Heat recovery efficiency	0-1	Based on archetypes referenced from BBR23 BFS 2011:6	BBR 23, Archetypes

3.5.8 Internal heat gain and electricity use

The internal heat gain calculated in the model consists of lighting, appliances, occupancy, and ventilation heat gains, formulated on the equation (x.x).

$$q_{int} = q_{lig} + q_{app} + q_{oc} + q_{Buis} \quad (3.13)$$

where q_{int} is internal heat gain (W), q_{app} is appliances heat gain (W), q_{occ} is occupancy heat gain, and q_{Buis} is ventilation heat gains. Since there is no information about the loads, general assumptions are taken in this model as described in the table 3.19. The load (W/m2) is the same for internal heat gain generation and electricity output demand. In addition, on the electricity demand is hydro pump demand.

Table 3.19 Internal heat gain and electricity use variables

Variable	Description	Unit	Input method	Source
Ac	Appliances load	W/m^2	3.4 W/m2	Assumption
Lc	Lighting load	W/m^2	0,85 W/m2	Assumption
Oc	Occupancy load	W/m^2	76W/person	Boverket
Pfh	Fan heat gains	W/m^2	Pfh is 0.8 if there is heat recovery. Otherwise, Pfh is 0	Assumption
HyP	Hydro pump load	W/m^2	0,34 W/m2	Assumption

3.5.9 Heating demand utilization

This section described the input to define the system along with the fuel used to provide the heating needed both for the space heating and hot water demand. The information is mainly taken from EPC dataset with factorize the measured output of each system used compared to the total measured heat demand. Since there is no information on what system used to provide hot water demand, the percentage is the same as space heating demand.

Table 3.20 HVAC system variables

Variable	Description	Unit	Input method	Source
PerHPinH	Heating by heat pump	0–1	HP demand (kWh) / Heating demand (kWh)	EPC

P_Sh_HPa	Ground HP (%)	0–100	Ehxaust air HP (kWh) / Heating demand (kWh)	EPC
P_Sh_HPb	Air/Water HP (%)	0–100	Air to air HP (kWh) / Heating demand (kWh)	EPC
P_Sh_HPc	Air/Air HP and Airborne vent. system (%)	0–100	Air to water HP (kWh) / Heating demand (kWh)	EPC
P_Sh_HPd	Ground HP(%)	0–100	Ground HP (kWh) / Heating demand (kWh)	EPC
P_Sh_HP	Total HP usage (%)	0–100	Sum P_Sh_HP(a-d)	EPC
P_Sh_O	Oil (%)	0–100	Oil (kWh) / Heating demand (kWh)	EPC
P_Sh_G	Gas (%)	0–100	Gas (kWh) / Heating demand (kWh)	EPC
P_Sh_P	Pellets (%)	0–100	Pellets (kWh) / Heating demand (kWh)	EPC
P_Sh_W	Woods (%)	0–100	Wood (kWh) / Heating demand (kWh)	EPC
P_Sh_EB	Waterborne vent. system (%)	0–100	-	EPC
P_Sh_ED	Direct electric heating (%)	0–100	-	EPC
P_Sh_OF	Open fire (%)	0–100	-	EPC
P_Sh_DH	District heating (%)	0–100	District Heating (kWh) / Heating demand (kWh)	EPC
P_Sh_E	Electric heating (%)	0–100	HPtotal+Waterbourne+Airbourne+Electric heating (kWh) / Heating demand (kWh)	EPC
P_Sh_BW	Biomass and Waste (%)	0–100	Other biomass fuel (kWh) / Heating demand (kWh)	EPC
P_Sh_C	Coal (%)	0–100	-	EPC
P_Sh_A	Other (%)	0-100	-	EPC
P_Sh_S	Solar (%)	0-100	-	EPC
P_Sh_Tot	Total fuel usage for heating (%)	0-100	Sum P_Sh, should always 100	EPC
P_Hw_HPa	Heating by heatpump	0-100	Ehxaust air HP (kWh) / Heating demand (kWh)	EPC
P_Hw_HPb	Ground HP (%)	0-100	Air to air HP (kWh) / Heating demand (kWh)	EPC
P_Hw_HPc	Air/Water HP (%)	0-100	Air to water HP (kWh) / Heating demand (kWh)	EPC

P_Hw_HPd	Air/Air HP and Airborne vent. system (%)	0-100	Ground HP (kWh) / Heating demand (kWh)	EPC
P_Hw_HP	Ground HP(%)	0-100	Sum P_Hw_HP(a-d)	EPC
P_Hw_O	Total HP usage (%)	0-100	Oil (kWh) / Heating demand (kWh)	EPC
P_Hw_G	Oil (%)	0–100	Gas (kWh) / Heating demand (kWh)	EPC
P_Hw_P	Gas (%)	0–100	Pellets (kWh) / Heating demand (kWh)	EPC
P_Hw_W	Pellets (%)	0–100	Wood (kWh) / Heating demand (kWh)	EPC
P_Hw_EB	Woods (%)	0–100	-	EPC
P_Hw_ED	Waterborne vent. system (%)	0–100	-	EPC
P_Hw_OF	Direct electric heating (%)	0–100	-	EPC
P_Hw_DH	Open fire (%)	0–100	District Heating (kWh) / Heating demand (kWh)	EPC
P_Hw_E	District heating (%)	0–100	(HPtotal+Waterbourne+ Airbourne+Electric heating (kWh)) / Heating demand (kWh)	EPC
P_Hw_BW	Electric heating (%)	0–100	Other biomass fuel (kWh) / Heating demand (kWh)	EPC
P_Hw_C	Biomass and Waste (%)	0–100	-	EPC
P_Hw_A	Coal (%)	0–100	-	EPC
P_Hw_S	Other (%)	0–100	-	EPC
P_Hw_Tot	Solar (%)	0–100	Sum P_Hw, should always 100	EPC
P_W_Hw	Total fuel usage for hot water (%)	0–100	Wood (kWh) + Pellets (kWh) / Heating demand (kWh)	EPC

3.5.10 Input factorization

While linking the dataset especially via GIS, sometimes there is an error regarding the unmatched coordinate or error in building polygon, which is discussed in detail in chapter 4.1.2. Obviously, this problem creates an error regarding the building envelope area. To minimize this issue, the input data is reduced by creating a factorization from the total heated floor area to the total surface area and total footprint area as shown in the table 3.21. By eliminating the data, the risk of getting the wrong building geometry is reduced.

Table 3.21 Elimination factor to reduce the error in building geometry

	Equation	Condition for data to be eliminated
A_{ratio}	$A_{temp}/A_{footprint}$	$A_{ratio} > 4$
SA_{ratio}	A_{env}/A_{temp}	$SA_{ratio} > 4$

Atemp = total heated floor area; Afootprint = total footprint area; Aenv = total surface area

3.6 Building stock modelling

This section is explaining the output generated from ECCABS model and the compared variable from EPC. For this thesis, space heating and electricity output will be compared, along with the total energy delivered. All of the output calculated as annual delivered energy in kWh.

1. **Space heating**
   Delivered energy for space heating is divided by the system each building used. In the model, space heating consists of the utilization of district heating, electric heating (heat pumps, airborne, waterborne, and direct), and other technologies. Since the ECCABS output and measured data from EPC use the same definition on the delivered space heating, the comparison can be made directly for each technology.

2. **Electricity**
   The delivered electricity is the electricity consumption for the building appliances including the lighting, fan, and hydronic pump use. Nevertheless, not much information can be taken for this variable and mostly the input is based on assumption as discussed in the chapter 3.5.8.

3. **Total energy**
   Total energy use is simply the total delivered energy for electricity and heating, including the hot water demand. The total energy in the model, however, is also subtracting the heat recovered from the heat exchanger.

3.6.1 Validate the output

To validate the output from the model, the output from ECCABS and the EPC is compared as the results. The output generated from the ECCABS that is used as the validation is the total delivered energy (DelEn), space heating demand (DelSh) and delivered energy from each system especially with district heating demand (DelDH) and electric heating demand (DelElH).

An initial validation also performed to see how the heating demand is covering the mean indoor air temperature (Tint) annually. The validation is performed using a linear regression which is to find the coefficient of determination (R^2) to see the fitting from the measured data from EPC and modelled data from ECCABS (Booth et al., 2012). Equation is performed to find the R^2 from the model and measured data.

For the following equation, x is the modelled value (ECCABS) while y is the measured value (EPC).

Mean observed data

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

Total sum of squares proportional to the variance of data

$$SS_{tot} = \sum_{i}(y_i - \overline{y})^2$$

The regression sum of squares

$$SS_{reg} = \sum_{i}(x_i - \overline{y})^2$$

The sum of squares of residuals

$$SS_{res} = \sum_{i}(y_i - x_i)^2$$

Coefficient of determination (R^2)

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

4 Results

This chapter presents the result of the thesis work followed by analysis and discussion by applying the methodology. Result from this work discussed mainly focused on two topics: the input data building result from dataset linking and the ECCABS model result regarding the energy output.

4.1 Data integration result

In this chapter, the result of the input data building is presented. Chapter 3.2 already present the purpose of each dataset into the model. Since there is no identifier found from each dataset, another method to join the dataset is taken. Due to both EPC and Land survey data has the information regarding the address code and the cadastral, it could be taken as an identifier to link both data. Obviously, this method has a limitation for example if the information is missing from the data source. Figure 4.1 depicts the amount of data on each merging process. From the first merging process, EPC and 01A data have a high consistency as the data lost is just 0.49%. On the next phase, the data is aggregated on the individual building number level to be consistent when linking to 50A. The merging phase for EPC, 01A, and 50A resulting loss of 15.5%. This is mainly due to missing information of building number from EPC data, showing that to establish a better connection between dataset, valid and complete information from all dataset. The next reduction comes from filtering the dataset to be residential building only, which the definition is taken from EPC. The final reduction is coming from the eliminating the unnatural ration found from building envelope area to heated floor area. If the ratio is higher than 4, the data is eliminated. This error is explained in detail in chapter 5.2. Finally, 14947 building data from the integrated dataset is modelled on ECCABS.

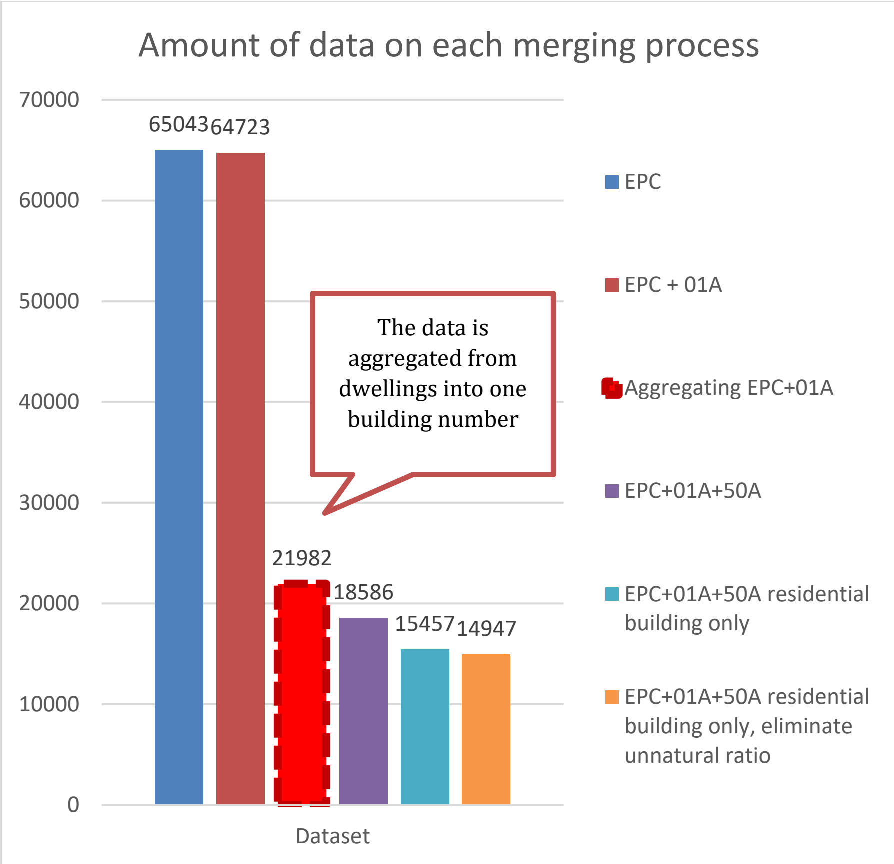


Figure 4.1 Amount of aggregated data on each data integration process

4.1.1 Building assignment result

The data building type needs to be categorized to give each of the individual data their own properties with the archetypes. From the EPC and Land survey data, there is information regarding the building category which are single-family building or multi-family building. However, there is no further information about the building type regarding the shape or material used. Nevertheless, each individual building data have information regarding the building age and properties which then used to deduct the building type. Using the method developed by Österbring et al., (2016), the multi-family building is assigned to seven different building types. Meanwhile, due to there is no further reference to categorize the single-family building, the building type is not categorized, and the archetype uses the value referenced from the timber building properties and the standard over the years. Figure 4.2 depicts the distribution of building type assignment. From the initial data source, the number of single-family building is slightly higher than multi-family building. However, the heated floor area of the single-family building is particularly small just 8% of total heat area observed compared to multi-family building as depicted in figure 4.3.

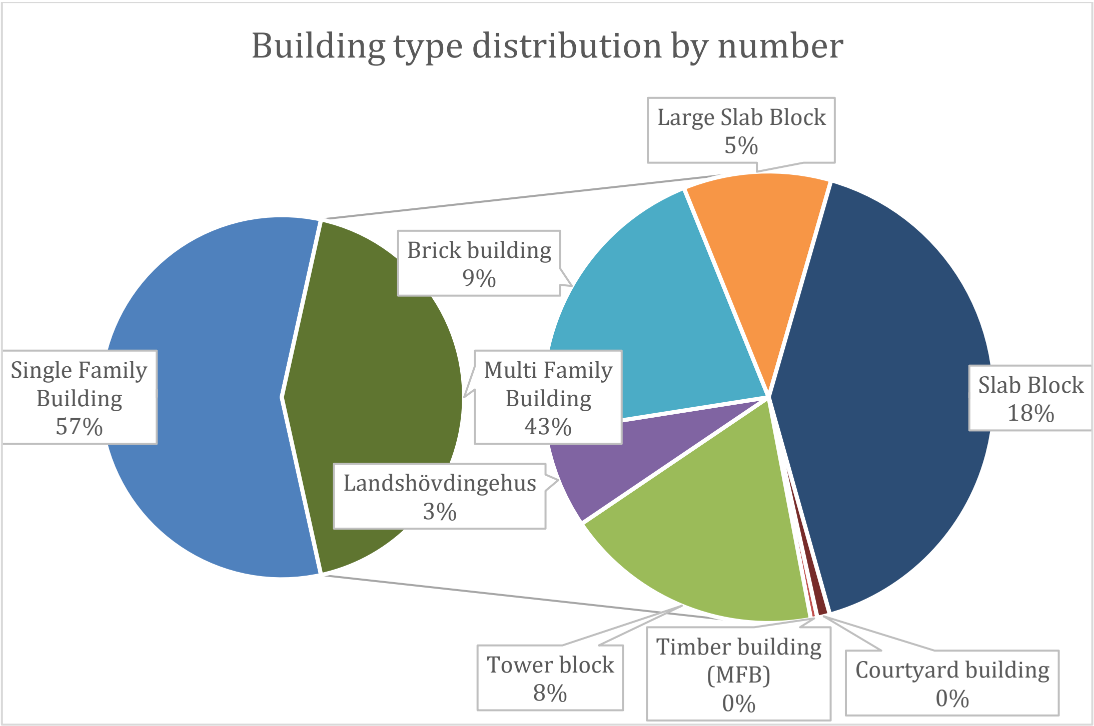


Figure 4.2 Building type assignment distribution

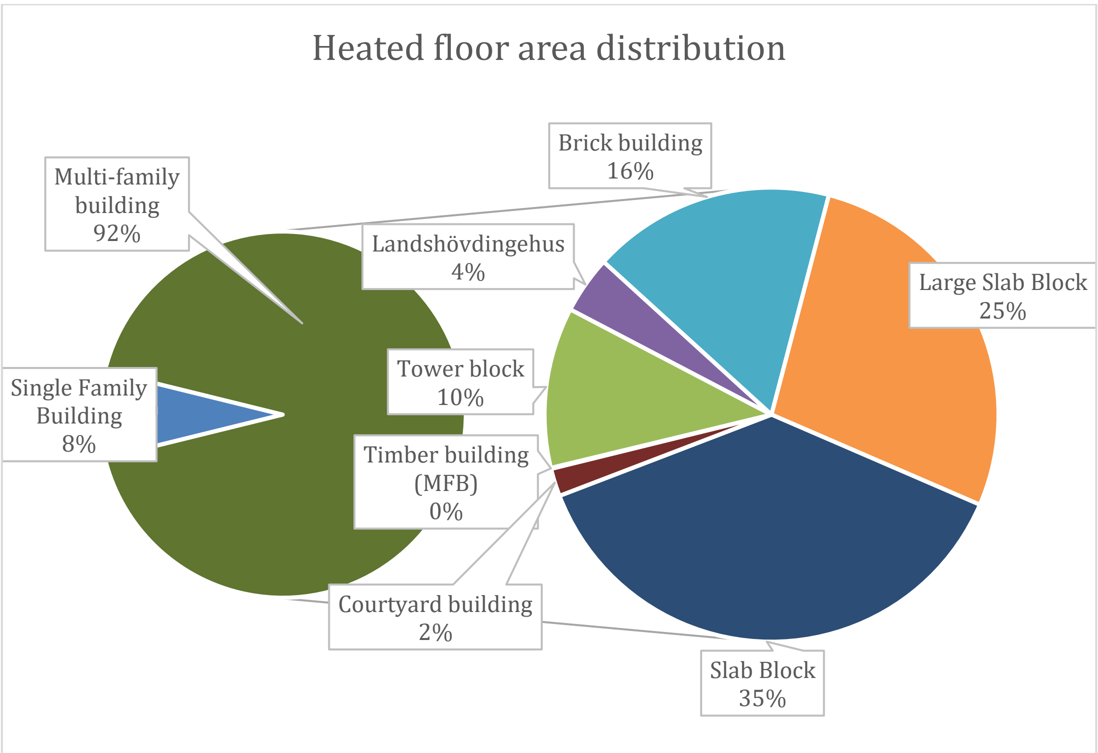


Figure 4.3 Heated floor area distribution

In the model, slab block has the highest heated floor area share compared to all building types followed by large slab block, which together makes up a total of 60% of the heated floor area. Based on the condition assigned to the dataset, slab block and large slab blocks have the range of building construction from 1930 till present with high area utilization.

On the distributed number of building based on construction years showed on figure 4.4, 3208 buildings with heated floor area share of 4477000 m² constructed before 1940 are still in use. A high number of buildings also constructed on the 60s with the heated floor area of 5768000 m2 which share the highest heated floor area over the building age groups. These buildings were built during the million homes project which happened in Sweden around this era (Hall & Vidén, 2005). A lower building number was constructed in the later years along with low heated floor area.

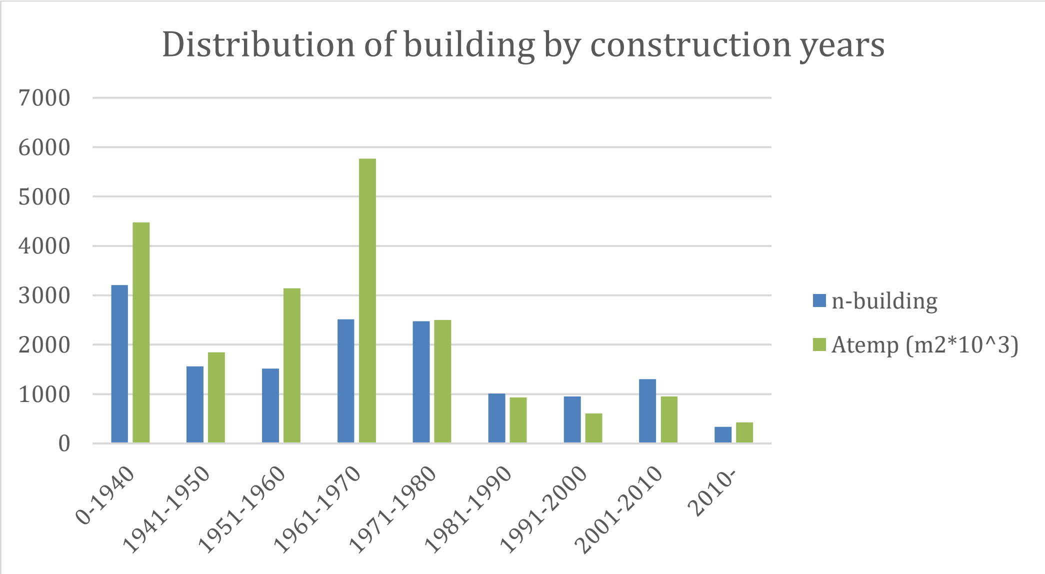


*Figure 4.4 Distribution of building number and heated floor area construction (m2*10³) over the years*

4.2 Archetype impact on the input

As described in chapter 3.5, two inputs are used in this thesis. The main difference of the input is the archetype used, mainly in the building transfer thermal performance. Due to the U-value assigned for each building component, the result on the average U-value is varied since it depends on the surface area on each building envelope component and the windows to wall ratio. Figure 4.5 depicts the comparison of the average U-value between both inputs to understand the impact of the archetype assigned to each input model. As depicted in the figure, the average U-value on the input 1 is generally higher than the input 2. This can be explained by the variables assigned to the archetypes, in which the information extracted from historical data is generally higher than the result on the BETSI database as depicted in the chapter 3.4. Moreover, as can be seen from the figure, the average U-value in this input 2 based on BETSI is rather random compared to the input 1 which has a consistent decrease over the years. For example, between 1920 to 1940 in single-family building, there is a fluctuation in the average U-value. However, this fluctuation is in line with what happened to the input assigned as seen in the figure 3.13. This depicts that based on the sample building surveyed by BETSI, the average U-value is lower than the standard reduced from the old building age to the new building age although it is not constant.

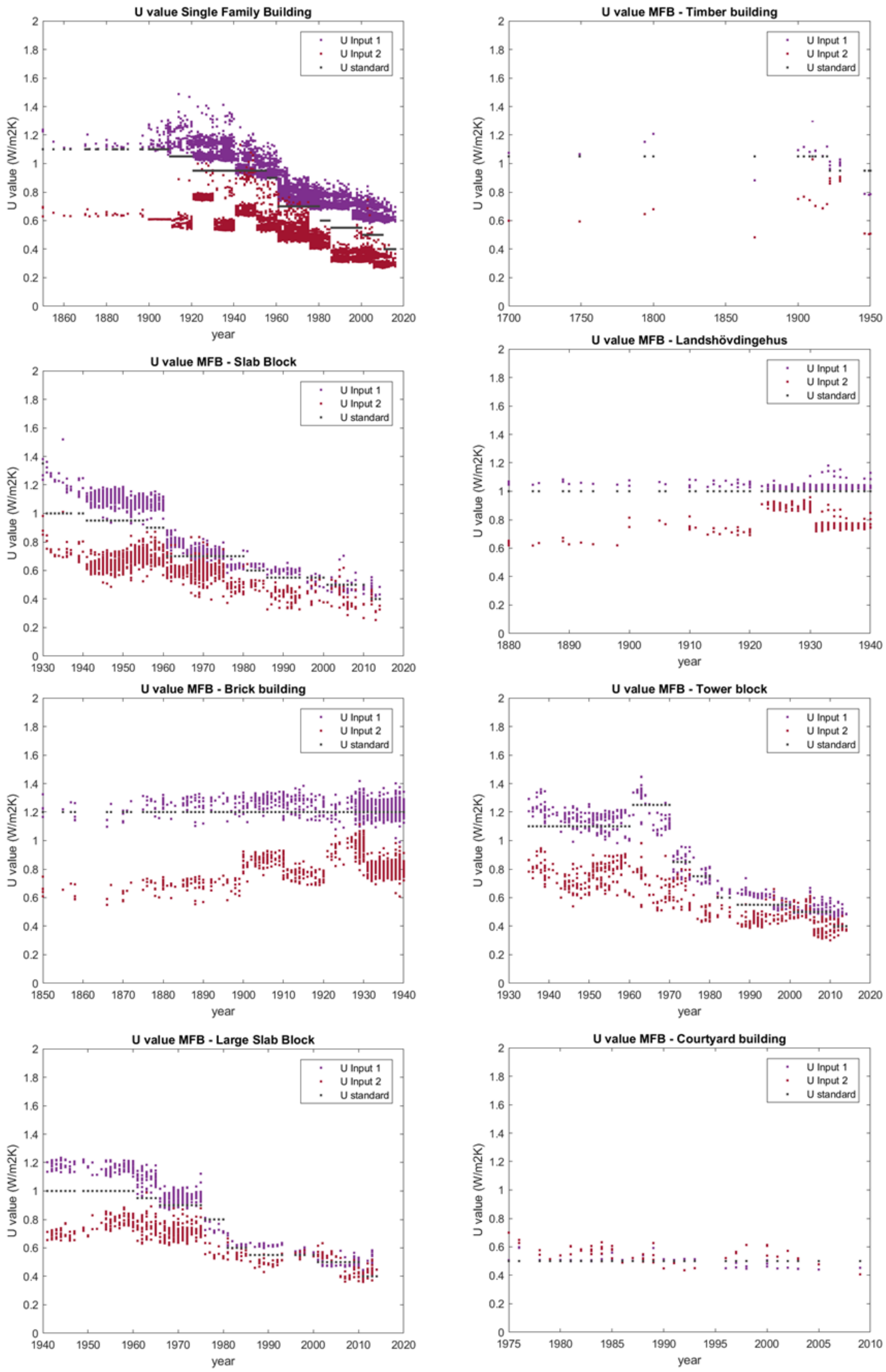


Figure 4.5 Average U-value for input 1. Black dots mean the calculated average U-value on the input model, red dots mean the standard U-value

4.3 ECCABS Result

In this section, the result from the ECCABS model is presented. ECCABS produce the result from two categories, which are the calculated heat demand of the building and the delivered energy. Corresponding with the objective of this thesis, the result discussed is focused on the delivered energy. The validation method itself is to compare the results from the ECCABS model and measured data from EPC *vis-à-vis.* The coefficient of determination is calculated based on the modelled results and measured data to find the goodness of the fit of data. The error margin is also discussed as part of the evidence from the data validation. The results discussed consist of the space heating, electric appliances, and the total energy. Energy delivered result will be presented at the annual energy delivered, calculated in kWh for each individual building.

Mean indoor air temperature is observed as the preliminary result in order to see how the heat demand performance could be satisfied. Figure 4.6 depicts the mean indoor air temperature calculated in ECCABS. Based on the value assigned for both input (as seen on table 3.15), the heat power capacity assigned could cover the heat demand from all of the building as the average indoor air temperature is between Trmin (21.2 C for single-family building and 22.3 C for multi-family building) and Trmax (25 C).

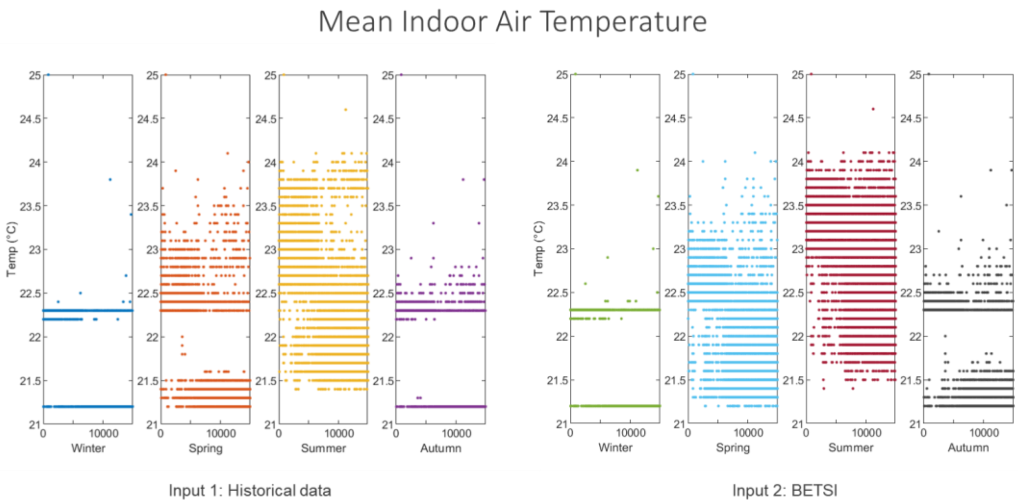


Figure 4.6 Mean indoor air temperature for input 1 (left) and input 2 (right)

4.3.1 Total delivered energy

Figure 4.7 shows the total delivered energy result from two inputs modelled in ECCABS model. On the figure also showed the total energy delivered from EPC as the measured data for each building. From the modelling results, it can be observed that both inputs modelled have a higher energy demand compared to EPC. Input 1 has the highest energy demand with 4153 GWh followed with input 2 with 3202 GWh while according to EPC the total energy demand was 2816 GWh. Since the difference from both inputs were the variables in transmission losses, input 1 which have the higher U-values gives a higher result on the total delivered energy compared to the input 2.

The high energy yielded from the model compared to the EPC data were possibly due to high assumption is taken on the input model such as a high set point on the indoor temperature, airflow, and internal heat gain variables. In addition, the assumption on the electricity and appliances was also considered as a high value with no additional input regarding the load profile. The error on the building geometry, mainly from wall attachment issue, also contribute to the thermal loss overestimation. The power rating system on the model was disregarded, means that the system could provide the heating power at any demand.

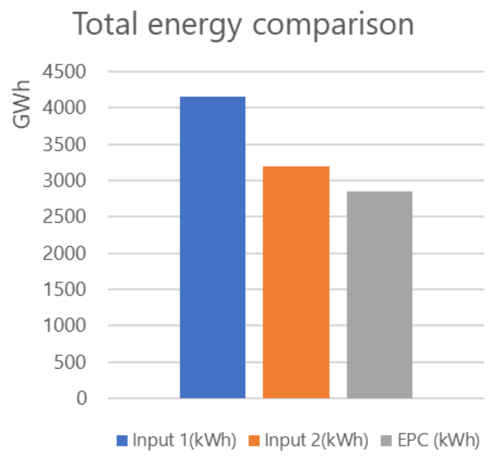


Figure 4.7 Total energy delivered from the ECCABS results for three parameters: input 1 based on the historical data archetype, input 2 based on BETSI archetype, and EPC as the measured data for the validation

Further on the total energy delivered, figure 4.8 depicted the total delivered energy distributed based on the building types and construction years. Based on the building type distribution, slab blocks and large slab blocks share the highest energy demand. This is aligned with the high heated floor area showed on figure 4.3 in chapter 4.1. Single-family building on the other hand while having the highest number of building data turns out consumed relatively lower energy demand compared to other building types. In addition, based on the construction years, buildings constructed before the 1940s have the highest energy demand compared to other periods. However, there is a peaking on the share of energy demand in building constructed on the 1960s. Both of this era share the highest heated floor area, thus explains the high energy consumption needed. Starting from the 1970s, the energy demand is gradually becoming lower as the heating floor area shares also lowered.

While observing all inputs modelled and EPC as a comparison dataset on both distribution figure, the trend seems to be in line for all the datasets. This indicates that although the value of energy demand modelled differs from the measured data, all of the inputs and the model proved that it is able to capture the real condition measured on EPC.

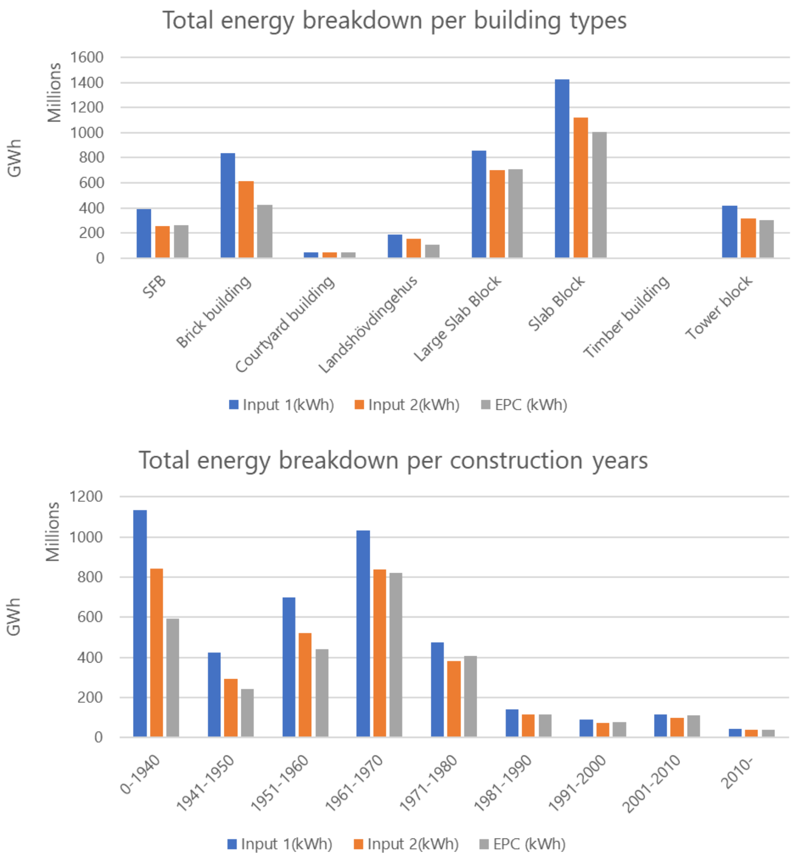


Figure 4.8 *The total delivered energy distributed based on the building types (above) and construction years (below)*

More on the results of total energy, figure 4.9 and figure 4.10 showed the total energy delivered distribution measured as energy per heated floor area (kWh/m2) based on the building types and construction years respectively depicted as a boxplot. From the building types distribution, single-family buildings have the highest uncertainties, depicted with the highest range of data outliers compared to all building types. Timber buildings, on the other hand, consumed the highest average of energy demand albeit the low number of buildings modelled.

Based on the construction years, the energy demand result on the model consistently decreased from the older to the newer constructed building, in contrast with the EPC data that shows a fluctuation of the energy demand overall building ages. Buildings before the 1940s consume the highest energy in average with 267 kWh/m2 for input 1 and 192 kWh/m2 for input 2 while on the EPC the average energy is 137 kWh/m2. However, building constructed in this era also have the highest error depicted with the highest outliers on both modelled and measured data. For the 1960s buildings, input 1 consume 220 kWh/m2 on average while input 2 consume 164 kWh/m2 which is close to the EPC data on 150 kWh/m2. Fewer outliers also found on the model for the building constructed in this era. For the 2000s buildings and later, input 1 with 149 kWh/m2 have the closer result to EPC which is 139 kWh/m2. On the other hand, the result of average energy demand in input 2 is significantly lower than EPC with 98 kWh/m2. Based on this result, it could be analysed that input based on BETSI have a better representation on the older building constructed while the historically based input captures the energy consumption better for a newer building constructed.

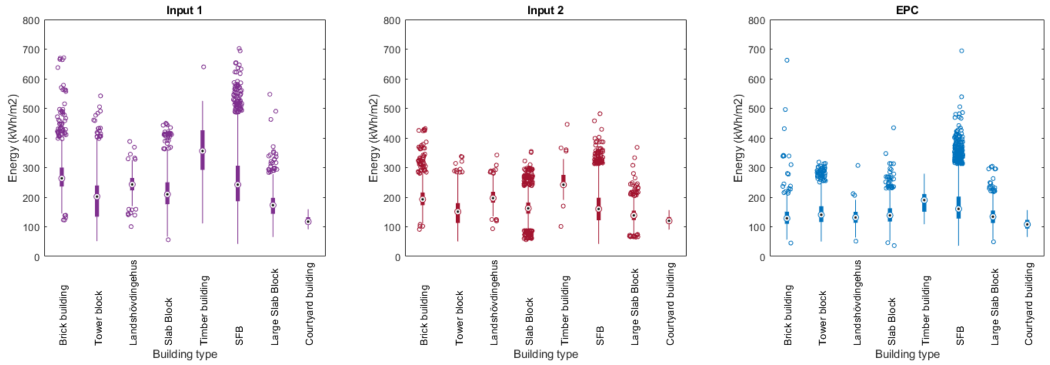


Figure 4.9 *Total energy delivered distribution measured as energy per heated floor area (kWh/m2) based on the building types*

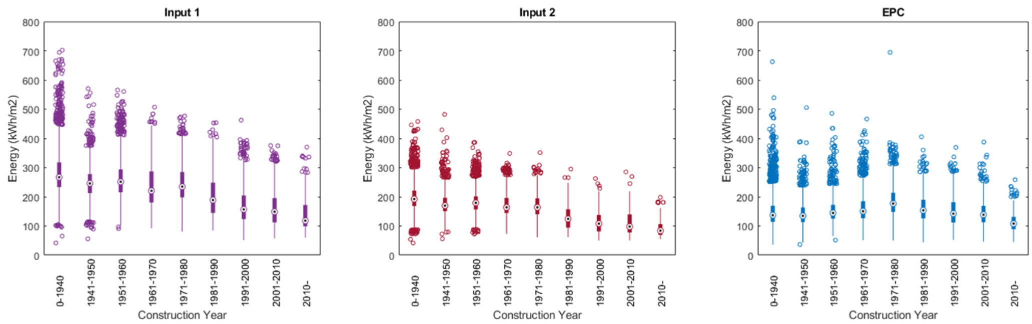


Figure 4.10 *Total energy delivered distribution measured as energy per heated floor area (kWh/m2) based on the construction ages*

A direct comparison of the modelled results and measured data depicted in figure 4.11. From left to right, the figure presented the total energy delivered sorted on the lower to higher energy demand from the model result, the direct comparison for both model and measured data in linear regression, and the error margins of the data modelled. As observed on the figure, input 1 has R^2 of 0,71 while input 2 have the R^2 of 0,92. In addition on the error margins, 54% of the building modelled on input 1 have at least 50% error margin distribution whereas 52% of the building modelled on input 2 have an error margin of 30%. Aligned with the previous observation on the total energy delivered, this result explained that input based on BETSI have a higher coefficient of determination and could capture the results better when comparing to EPC data.

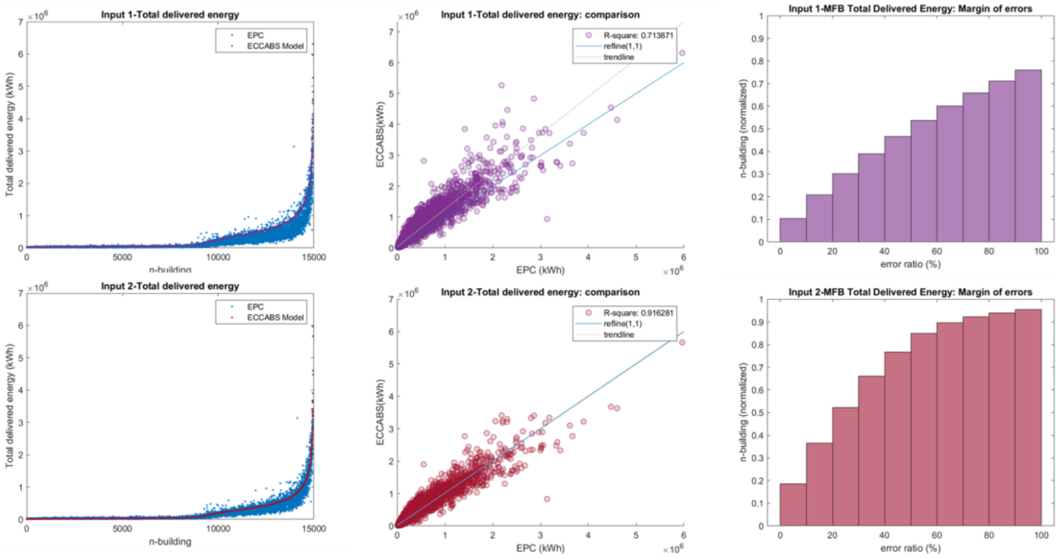


Figure 4.11 From left to right: the total energy delivered sorted on the lower to higher energy demand from the model result, the direct comparison for both model and measured data in linear regression, and the error margins of the data modelled.

In detail comparison of the modelling of single-family building to multi-family building, the figure 4.12 shows the direct comparison on modelled and measured data for each building category. Single-family building generally has a higher error result on the model while multi-family building result is somewhat fit with the EPC data. This explains that a lower heated floor area generally has a higher degree of error on the modelling compared to a large heated floor area. Moreover, the result also explains that uncompleted information on the building typologies, such as no information leading to the building types and materials on single-family building, leads to uncertainties on the results. Another factor of the unfit relation on single-family building was also caused by the majority of the heating system used that is discussed in the chapter 4.3.2.

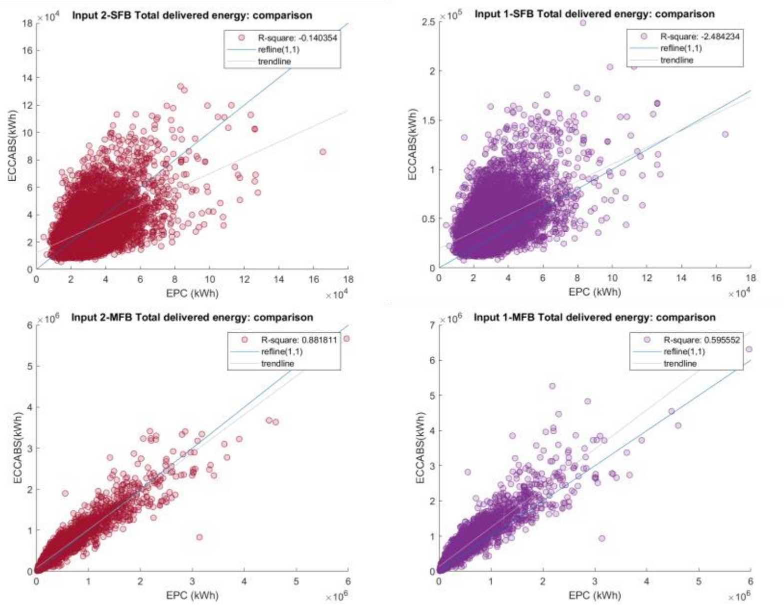


Figure 4.12 Total delivered energy linear regression analysis from ECCABS and EPC

4.3.2 Space heating

The cumulative of delivered energy for space heating is shown in figure 4.13, distributed by the increase of heat demand from the ECCABS model. Based on the heating systems information taken from EPC, at least five types of heating systems are used on the building stock modelled, which is district heating, electric heating, oil, gas, and biomass. Electric heating itself was a group of system consist of heat pumps (exhaust HP, air/air HP, air/water HP, ground HP) and direct electric heating with considering the supply from either waterborne or airborne ventilation system. From the figure 4.13, it could be observed that a centralized system, e.g. district heating has a better coefficient of determination compared to electric heating as a more individual system. This possibly due to more uncertainties found on the electric heating system. An individual system required more detailed information for example regarding the efficiency of the system on each building or the load profile of the system, while on a centralized system such in district heating, a direct calculation from a common district heating information could be utilized. Since the information regarding the energy measures regarding the individual system could not be found from the main data sources, the modelling of electric heating was conducted with a default efficiency as defined by the model. In the end, the overall coefficient of determination showed on the figure explain the same results found in total energy plot that BETSI typology input have a better relation to EPC with the R^2 of 0,80 compared to the historical data typology input with R^2 of 0,70.

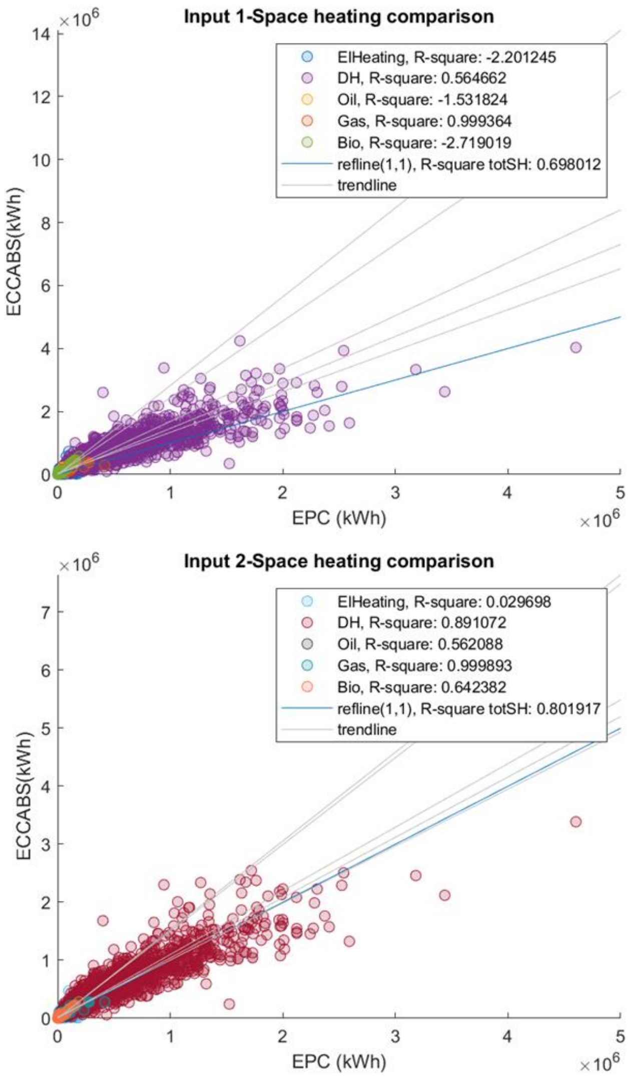
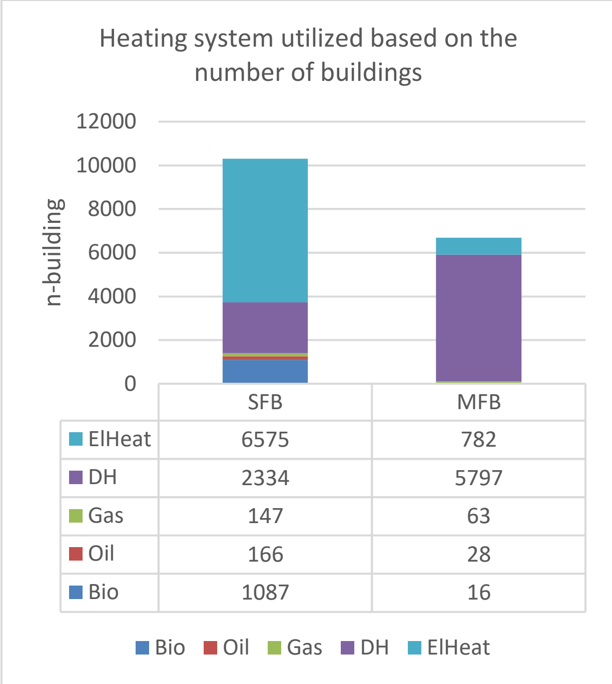


Figure 4.13 Space heating direct comparison between ECCABS results and EPC data distributed by the heating system utilized on the buildings.

As depicted in the figure 4.12 in the previous chapter, single-family building has a higher uncertainty result on the model compared to the multi-family building. This is also explained by the high number of the electric heating utilized on the single-family building depicted in the figure 4.14 while a high number of multi-family buildings is mostly utilizing district heating.



	SFB	MFB
ElHeat	6575	782
DH	2334	5797
Gas	147	63
Oil	166	28
Bio	1087	16

Figure 4.14 Heating system utilized based on the number of building

4.3.3 Electricity delivered

As seen in figure 4.15, the distribution of electricity use is far from fit. This is due to the lack of information regarding the electricity use that could be derived into the model. The high electricity uses in the model is caused due to the large heated floor area, which is the parameter deducting how large the electricity use as the input is taken as W/m2. Not much can be further discussed in this case regarding the electricity use as it is not comparable between the model and the measured data.

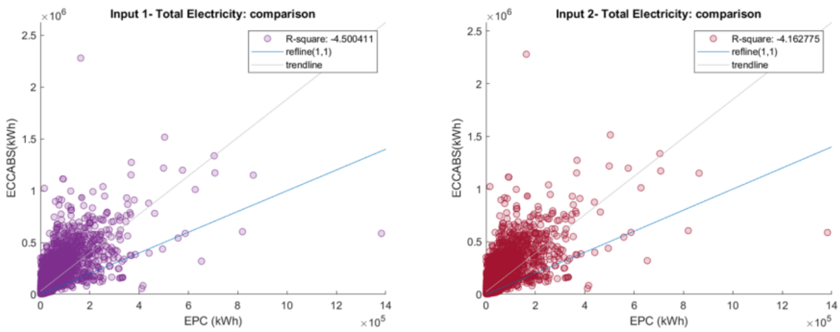


Figure 4.15 Delivered electricity linear regression analysis from ECCABS and EPC

5 Discussion

This chapter presents the discussion regarding the error and troubleshoots the data integration process and reflection on the building stock modelling results

5.1 Error and troubleshoot the data integration process

While doing the merging process, some errors that are worth mentioning are found. The error mainly originated from the dataset used in this work. The next section is explaining the error and possibly troubleshoot within each dataset.

5.1.1 EPC

EPC data use aggregation level based on the dwellings. While it may serve the purpose of the documentation for each building to have a detailed data for each of the dwellings, the value mentioned on the dataset is already aggregated on building level. This creates a problem when the data is used and linked with another dataset since the aggregation level is inconsistent. For example, when merging the EPC to Land survey data, both aggregation level is often contradicting each other as EPC aggregated on dwellings level while Land survey aggregated on building number level. This is also correlated with the mid-coordinate as Land survey data take the mid-coordinate based on the building number. Figure 5.1 depicts the perfect example of this problem. In this building, the aggregated value for the BSM input is different for each building number (see the mid-coordinate), but EPC takes the aggregation value for both buildings. Obviously, this will create an error in some input with the same issue as depicted in the figure. Fortunately, the issue is rare although it is worth noting.

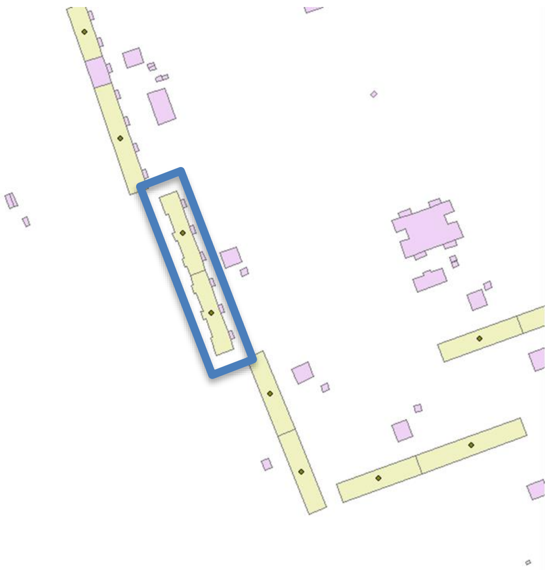


Figure 5.1 Example of error in EPC aggregation: two adjacent building number aggregated to one building in EPC

Another observed problem is uncompleted data. On the EPC dataset used, 3398 n-data was unlinked due to the empty value on the building number variable. This loss will not likely happen if the main dataset is completed.

5.1.2 Land Survey Data

The most noticed problem from the land survey data is the mid-coordinate error found in 50A. The mid-coordinate variable formed as a xy-coordinate, however, the axis is inversed and applies to all data on the 50A dataset. This creates a problem when the coordinate is imported to the GIS as it will not match to the building polygon. This problem is solved merely by inverting the x-axis and y-axis in the GIS.

Another problem related to the coordinate is the displacement of the coordinate. Figure 5.2 shows the example found from this problem. The data that should be taken into the model was supposedly the building as shown with the blue highlight. However, the mid-coordinate is placed into the wrong place (in the case shown in figure 5.2 it is a garbage dump).

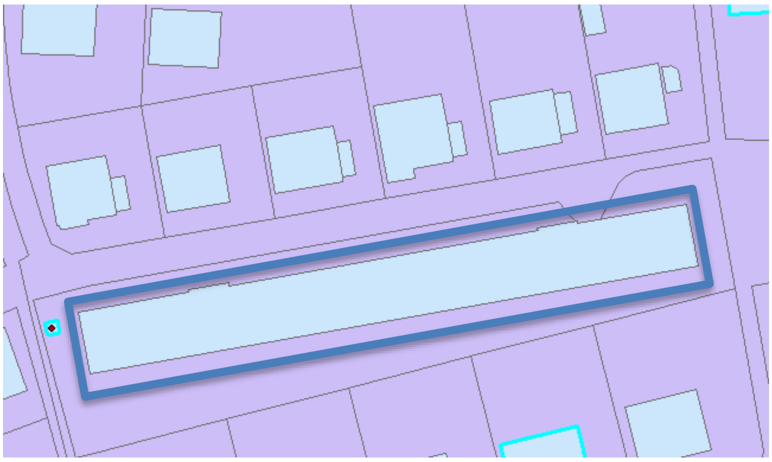


Figure 5.2 *Error in the mid-coordinate example. Red dot is shown on the figure point the mid-coordinate from land survey data while it is supposed to point the building highlighted in dark blue line.*

Another typical error on the dataset is the uncompleted database. On the Land survey data, there is a lot of information regarding building properties such as building types, BOA, LOA, and information about construction year, renovation year, and even value year. However, since the data is not comprehensive enough to cover the input demand and often mismatch with EPC data, this data is not used in this thesis. To keep the consistency of the data, the building properties reference data is taken mainly from EPC.

5.1.3 GIS

Information taken from map data on GIS is mainly regarding the building geometry, such as the building perimeter and footprint area. Due to the aggregation method by the building number, there is an error on the building envelope area related to the building attachment. For example, building having an attached wall to another building will keep counted as a single building with four sides of the wall. Obviously, this will create an impact to the thermal transfer loss. Through this error, the building thermal transfer loss will have a higher value than it should have, resulting in higher energy demand. Although there is information related to the building attachment, unfortunately, no accurate method found from the author to reduce the error besides manually select and filter the building and considered as a limitation of this thesis. Figure 5.3 shows the error in this category which yields an unnecessary thermal loss from the attached building. However, GIS also has the potential to reduce and verified the dataset. In case of error found, one could quickly check and verified the building through google maps or hitta[18] based on the address and cadastral information from the EPC data.

Figure 5.3 *Attached building should have discounted the thermal losses on the attached wall*

5.2 Reflection on building stock modelling process and results

In this thesis work, two different inputs are assigned which differentiated based on the building typologies. This input has a direct impact mainly on the thermal transfer of the building. While conducting the data integration process, it is reflected in the results that the building stock model extremely depends on the robustness of the main data source. For example, the uncompleted data of building number in EPC caused a loss on data integration for 15,5%. Error in the mid-coordinate of map data also contributes to the losses of the building input data. From the building envelope area calculation on GIS, there is also an issue regarding the wall attachment of the building. The attached wall that still calculated as a thermal loss possibly give a contribution on the high energy demand mirrored on the model result.

Based on the data integration process, the multi-family building has the highest share of heated floor area. From the model results, there is a direct impact regarding the heated

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[18] See footnote 8 on Chapter 3.2.2

floor area, as the heated floor area share total energy demand also yielded higher. But on the other hand, a higher energy demand did not mean that the specific energy demand per heated floor area (kWh/m2) is also high. It can be observed timber building, albeit the low heated floor, share the highest specific energy demand. Single-family building, although the average specific energy demand was comparable to other building types, share the highest rate of error reflected in the high number of outliers from the boxplot distribution on figure 4.9. It implicitly tells that the specific energy demand on single-family building is more uncertain compared to other building types.

When observing the distribution of energy demand over the construction years, it could be analysed that the energy use from the model results is constantly decreasing over the years. However, this condition does not happen in the EPC data which have a fluctuation over, mainly with buildings constructed in 1960s era. Comparing both inputs, the BETSI based typology have a closer result with EPC data on the building constructed in the 1960s while the historical data typology on input 1 tends to have similar results with EPC data on the latest building constructed, mainly for buildings after 2000s.

A closer look for a comparison between the two inputs with a direct validation to EPC data showed that historical data typology on input 1 generally yields a higher energy demand compared to BETSI based typology on input 2 and EPC data. Although lots of factors impacting the high energy demand, the obvious reason was due to the high thermal transfer input variable in the input 1, e.g. higher U-value taken on the archetype as this is the main difference between these two inputs. As the input 1 is based on the typical building materials and architecture layout from the historical data, it is not proven to have a better relationship when used to model the building stock, although from the coefficient of determination it tells that the relationship is not that weak.

Looking at the results based on the building category, the model has more consistent results on the multi-family building rather than in single-family building. Aside from the more assumptions taken on the single-family building, it also correlates with the heating system used. On the detailed look of the space heating systems, the result from the model clarified that a centralized system such as district heating, which is mostly utilized in multi-family building, is easier and more reliable to model compared to individual system as in electric heating that is mostly used in single-family building. The reason mainly comes from the lack of data of on the individual systems. While it is understandable that thorough and complete information on the individual system such as the efficiency and load profile is hard to access, it will certainly help for a better result as a reliable data lead to reliable model.

6 Conclusion and possibilities

This chapter presents the conclusion of this thesis work answering the aim and research question and provide some possibilities for future work in this topic

6.1 Conclusion

This thesis work has focused on exploring the data flows in building stock modelling at the city level. The case study for this thesis is residential buildings in Gothenburg, both single-family building and multi-family building. Based on this study, the data flow for building stock modelling in Gothenburg residential building could be developed by integrating the dataset from EPC, Land survey and property map. The building data on the integrated data is aggregated on the level of building number address, which means that in one building it may have more than one dwelling. This case is common in multi-family buildings, as generally one multi-family building includes data from many dwellings in that building, and will be calculated together as one building, translated in the model as one thermal zone. Two kinds of archetypes are built to classify the individual building information. The archetypes are constructed from historical architecture data and BETSI database. The integrated dataset along with assigned archetypes screened and modelled on ECCABS. In regard to this archetypes, two integrated datasets, which are typology based on historical data called input 1 and BETSI typology based called input 2.

The modelling result was performed better in typology based on BETSI with the R2 of 0,92 while typology based on the historical archetype has the R2 of 0,71. In addition with the error margins, 54% of the building modelled on input 1 have at least 50% error margin distribution whereas 52% of the building modelled on input 2 have an error margin of 30%. Aligned with all the observation conducted on this thesis, this result explained that input based on BETSI have a higher coefficient of determination and could capture the results better when comparing to EPC data. A final remark for this work is that the model, like any, extremely depends on the robustness of the main dataset. A linking process is proven that it is possible to be conducted, but a more completed and thorough dataset may result in a better output as a more reliable data sources will reduce the uncertainties and leads to a better modelling result. A calibration based on this result could be conducted to feedback the original data and minimize the gaps of error based on the findings.

6.2 Possibilities

The GIS application on the building stock model was a significant help to define the building geometry. In the GIS data of Gothenburg used in this thesis, the building polygon is already complete and up to date, covering all area modelled. Although there are some errors found as discussed in the previous chapter, the benefit of GIS utilization assisted on building an accurate representation of building shape. However, since the GIS data used is a 2D data, there are assumptions that need to be made especially with the building height and basement area. This issue probably could be fixed with the utilization of 3D GIS data. If a 3D GIS data on each building is available and could be captured in the model, a better representation of the building shape and geometry may represent the actual thermal transfer in the building, for example as shown by google maps on figure 6.1 (Johansson et al., 2017; Torabi Moghadam et al., 2018).

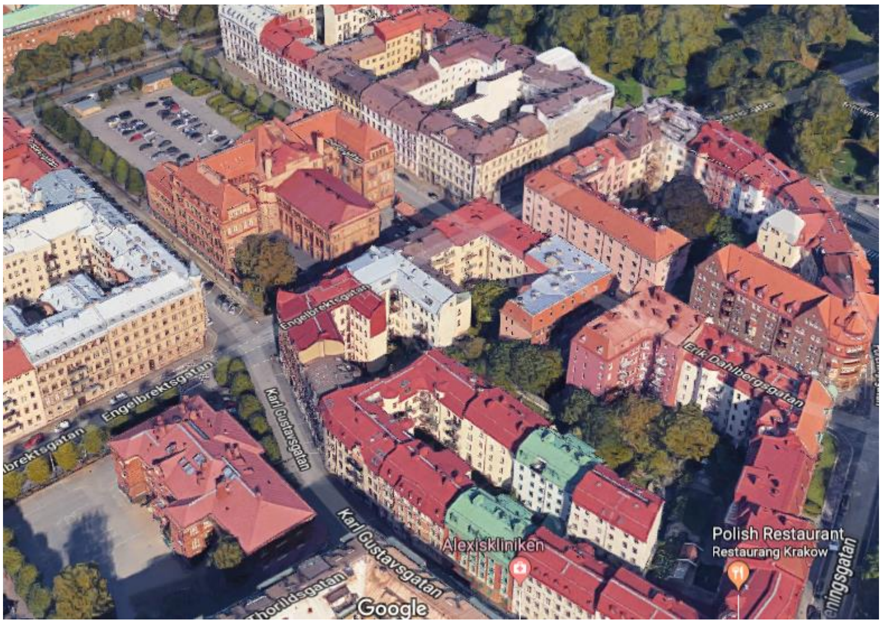

Figure 6.1 3D Maps of Gothenburg depicted on Google Maps. If the 3D polygon data could be acquired, a better representation of building envelope area could be implemented in the model

Building stock model with the incorporation of GIS data also offer some possibilities for building stock model analysis. In this thesis, a GIS data related to socio-economic is found and ready to be incorporated, but due to the time constraints, the data did not utilize in this work. With the implementation of socio-economic data on the model, one could easily observe the area related to the socio-economic condition, such as education level, employment rate, or rent of the apartments. The use of GIS also may be able to give a better visualization of the energy demand, for example by creating a map of energy demand resulting from the model. This further possibility may provide a better understanding of the building stock energy performance on a specific area, along with a proper decision making related to the energy efficiency of the building sector.

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8 Appendix

8.1 Archetype table

This following table is the input values on the assigned archetypes on the input model.

8.1.1 Archetype 1: Historical architecture data

Timber building

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1909	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	3	0.05	2400	840
1910	1915	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	3	0.05	2400	840
1916	1920	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	3	0.05	2400	840
1921	1925	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840
1926	1930	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840
1931	1935	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840
1936	1940	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840
1941	1945	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840
1946	1950	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.64	0.2	650	1400	0.64	0.2	650	1400	2.8	0.05	2400	840

Tower block

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
1936	1940	0.2	1.01	0.2	1500	880	1.99	0.4	2400	750	0.4	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1941	1945	0.2	1.01	0.2	1500	880	1.54	0.4	2200	880	0.4	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1946	1950	0.2	1.01	0.2	1500	880	1.54	0.4	2200	880	0.4	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1951	1955	0.2	1.01	0.2	1500	880	1.54	0.4	2200	880	0.45	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1956	1960	0.2	1.01	0.2	1500	880	1.54	0.4	2200	880	0.45	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1961	1965	0.24	0.89	0.13	1500	880	1.23	0.4	2200	880	0.4	0.4	1500	880	0.4	0.25	1500	880	2.4	0.05	2400	840
1966	1970	0.24	0.89	0.13	1500	880	1.23	0.4	2200	880	0.4	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1971	1975	0.24	0.57	0.13	1500	880	1.23	0.4	2200	880	0.4	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1976	1980	0.24	0.57	0.13	1500	880	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1981	1985	0.24	0.42	0.13	1500	880	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1986	1990	0.24	0.42	0.13	1500	880	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1991	1995	0.27	0.37	0.12	2200	880	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1996	2000	0.27	0.37	0.12	2200	880	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
2001	2005	0.27	0.37	0.12	2200	880	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2006	2010	0.27	0.37	0.12	2200	880	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2011	2015	0.27	0.37	0.12	2200	880	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840
2016	-	0.27	0.37	0.12	2200	880	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840

Landshövdingenhus

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1909	0.23	0.81	0.3	1800	840	2.32	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	3	0.05	2400	840
1910	1915	0.23	0.81	0.3	1800	840	2.32	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	3	0.05	2400	840
1916	1920	0.23	0.81	0.3	1800	840	2.32	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	3	0.05	2400	840
1921	1925	0.23	0.81	0.3	1800	840	1.99	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	2.8	0.05	2400	840
1926	1930	0.23	0.81	0.3	1800	840	1.99	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	2.8	0.05	2400	840
1931	1935	0.23	0.81	0.3	1800	840	1.99	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	2.8	0.05	2400	840
1936	1940	0.23	0.81	0.3	1800	840	1.99	0.4	2400	750	0.51	0.25	650	1400	0.51	0.25	650	1400	2.8	0.05	2400	840

Brick building

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1909	0.23	1.04	0.25	1800	840	2.32	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	3	0.05	2400	840
1910	1915	0.23	1.04	0.25	1800	840	2.32	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	3	0.05	2400	840
1916	1920	0.23	1.04	0.25	1800	840	2.32	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	3	0.05	2400	840
1921	1925	0.23	1.04	0.25	1800	840	1.99	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	2.8	0.05	2400	840
1926	1930	0.23	1.04	0.25	1800	840	1.99	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	2.8	0.05	2400	840
1931	1935	0.23	1.04	0.25	1800	840	1.99	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	2.8	0.05	2400	840
1936	1940	0.23	1.04	0.25	1800	840	1.99	0.4	2400	750	0.44	0.2	650	1400	0.63	0.2	650	1400	2.8	0.05	2400	840

Large slab block

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
1951	1955	0.19	1.06	0.15	1500	880	1.54	0.4	2200	880	0.55	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1956	1960	0.19	1.06	0.15	1500	880	1.54	0.4	2200	880	0.55	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1961	1965	0.21	1.06	0.15	1500	880	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	2.4	0.05	2400	840
1966	1970	0.21	1.06	0.15	1500	880	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1971	1975	0.21	1.06	0.15	1500	880	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1976	1980	0.3	0.64	0.15	1500	880	1.23	0.4	2200	880	0.5	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1981	1985	0.3	0.39	0.15	1500	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1986	1990	0.3	0.39	0.15	1500	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1991	1995	0.3	0.39	0.15	1500	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1996	2000	0.3	0.39	0.15	1500	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
2001	2005	0.3	0.31	0.15	1500	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2006	2010	0.3	0.31	0.15	1500	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2011	2015	0.3	0.31	0.15	1500	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840
2016	-	0.3	0.31	0.15	1500	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840

Slab block

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
1931	1935	0.2	1.26	0.25	1800	840	1.99	0.4	2400	750	0.6	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1936	1940	0.2	1.04	0.15	1800	840	1.99	0.4	2400	750	0.6	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1941	1945	0.2	1.04	0.15	1800	840	1.54	0.4	2200	880	0.6	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1946	1950	0.2	1.04	0.15	1800	840	1.54	0.4	2200	880	0.6	0.4	1500	880	0.4	0.25	1500	880	2.8	0.05	2400	840
1951	1955	0.2	1.04	0.15	1800	840	1.54	0.4	2200	880	0.55	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1956	1960	0.2	1.04	0.15	1800	840	1.54	0.4	2200	880	0.55	0.4	1500	880	0.45	0.25	1500	880	2.4	0.05	2400	840
1961	1965	0.24	0.68	0.15	1800	840	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	2.4	0.05	2400	840
1966	1970	0.24	0.68	0.15	1800	840	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1971	1975	0.24	0.68	0.15	1800	840	1.23	0.4	2200	880	0.5	0.4	1500	880	0.4	0.25	1500	880	1.7	0.08	2400	840
1976	1980	0.27	0.51	0.15	1800	840	1.23	0.4	2200	880	0.5	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1981	1985	0.27	0.51	0.15	1800	840	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1986	1990	0.27	0.43	0.15	1800	840	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1991	1995	0.27	0.43	0.15	1800	840	1.23	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1996	2000	0.27	0.43	0.15	1800	840	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
2001	2005	0.27	0.43	0.15	1800	840	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2006	2010	0.27	0.34	0.15	1800	840	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2011	2015	0.27	0.34	0.15	1800	840	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840
2016	-	0.27	0.34	0.15	1800	840	1.02	0.4	2200	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840

Courtyard building

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
1976	1980	0.32	0.29	0.35	725	880	0.8	0.4	1500	880	0.5	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1981	1985	0.32	0.29	0.35	725	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1986	1990	0.32	0.26	0.35	725	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1991	1995	0.32	0.26	0.35	725	880	0.8	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
1996	2000	0.32	0.26	0.35	725	880	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1.3	0.08	2400	840
2001	2005	0.33	0.29	0.17	650	1400	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2006	2010	0.33	0.25	0.17	650	1400	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	1	0.08	2400	840
2011	2015	0.33	0.25	0.17	650	1400	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840
2016	-	0.33	0.25	0.17	650	1400	0.7	0.4	1500	880	0.2	0.4	1500	880	0.2	0.25	1500	880	0.8	0.08	2400	840

Single-family building

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1909	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	3	0.05	2400	840
1910	1915	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	3	0.05	2400	840
1916	1920	0.2	1.2	0.1	650	1400	2.32	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	3	0.05	2400	840
1921	1925	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1926	1930	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1931	1935	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1936	1940	0.2	0.99	0.1	650	1400	1.99	0.4	2400	750	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1941	1945	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1946	1950	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.5	0.2	650	1400	0.4	0.25	650	1400	2.8	0.05	2400	840
1951	1955	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.45	0.2	650	1400	0.45	0.25	650	1400	2.4	0.05	2400	840
1956	1960	0.2	0.89	0.1	650	1400	1.54	0.4	2200	880	0.45	0.2	650	1400	0.45	0.25	650	1400	2.4	0.05	2400	840
1961	1965	0.2	0.62	0.1	650	1400	1.23	0.4	2200	880	0.4	0.2	650	1400	0.4	0.25	650	1400	2.4	0.05	2400	840
1966	1970	0.2	0.62	0.1	650	1400	1.23	0.4	2200	880	0.4	0.2	650	1400	0.4	0.25	650	1400	1.7	0.08	2400	840
1971	1975	0.2	0.47	0.1	650	1400	1.23	0.4	2200	880	0.4	0.2	650	1400	0.4	0.25	650	1400	1.7	0.08	2400	840
1976	1980	0.2	0.47	0.1	650	1400	1.23	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1.3	0.08	2400	840
1981	1985	0.2	0.46	0.1	650	1400	1.23	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1.3	0.08	2400	840
1986	1990	0.2	0.46	0.1	650	1400	1.23	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1.3	0.08	2400	840
1991	1995	0.2	0.41	0.1	650	1400	1.23	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1.3	0.08	2400	840
1996	2000	0.2	0.41	0.1	650	1400	1.02	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1.3	0.08	2400	840
2001	2005	0.2	0.41	0.1	650	1400	1.02	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1	0.08	2400	840
2006	2010	0.2	0.34	0.1	650	1400	1.02	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	1	0.08	2400	840
2011	2015	0.2	0.34	0.1	650	1400	1.02	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	0.8	0.08	2400	840
2016	-	0.2	0.34	0.1	650	1400	1.02	0.4	2200	880	0.2	0.2	650	1400	0.2	0.25	650	1400	0.8	0.08	2400	840

8.1.2 Archetype 2: BETSI Database

Single-family buildings

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1899	0.19	0.5	0.1	650	1400	2.8	0.4	1500	880	0.65	0.2	650	1400	0.37	0.2	650	1400	2.3	0.05	2400	840
1900	1910	0.12	0.37	0.1	650	1400	3.88	0.4	1500	880	0.89	0.2	650	1400	0.33	0.2	650	1400	2.3	0.05	2400	840
1911	1920	0.19	0.38	0.1	650	1400	3.53	0.4	1500	880	0.53	0.2	650	1400	0.37	0.2	650	1400	2.26	0.05	2400	840
1921	1930	0.16	0.55	0.1	650	1400	2.4	0.4	1500	880	0.96	0.2	650	1400	0.44	0.2	650	1400	2.34	0.05	2400	840
1931	1940	0.14	0.41	0.1	650	1400	2.93	0.4	1500	880	0.58	0.2	650	1400	0.34	0.2	650	1400	2.25	0.05	2400	840
1941	1950	0.16	0.53	0.1	650	1400	2.92	0.4	1500	880	0.77	0.2	650	1400	0.37	0.2	650	1400	2.28	0.05	2400	840
1951	1960	0.18	0.45	0.1	650	1400	2.7	0.4	1500	880	0.48	0.2	650	1400	0.37	0.2	650	1400	2.33	0.05	2400	840
1961	1975	0.21	0.33	0.1	650	1400	2.16	0.4	1500	880	0.33	0.2	650	1400	0.37	0.2	650	1400	2.34	0.05	2400	840
1976	1985	0.23	0.21	0.1	650	1400	1.03	0.4	1500	880	0.37	0.2	650	1400	0.28	0.2	650	1400	2.05	0.05	2400	840
1986	1995	0.2	0.18	0.1	650	1400	0.87	0.4	1500	880	0.24	0.2	650	1400	0.23	0.2	650	1400	1.95	0.05	2400	840
1996	2005	0.2	0.2	0.1	650	1400	1.57	0.4	1500	880	0.27	0.2	650	1400	0.18	0.2	650	1400	1.89	0.05	2400	840
2006	-	0.2	0.2	0.1	650	1400	1.5	0.4	1500	880	0.2	0.2	650	1400	0.15	0.2	650	1400	1.83	0.05	2400	840

Multi-family buildings

Year		WWR	Uag	Tag	Dag	Cpag	Ubg	Tbg	Dbg	Cpbg	Ur	Tr	Dr	Cpr	Uf	Tf	Df	Cpf	Uw	Tw	Dw	Cpw
-	1899	0.19	0.5	0.1	650	1400	2.8	0.4	1500	880	0.65	0.2	650	1400	0.37	0.2	650	1400	2.3	0.05	2400	840
1900	1910	0.12	0.37	0.1	650	1400	3.88	0.4	1500	880	0.89	0.2	650	1400	0.33	0.2	650	1400	2.3	0.05	2400	840
1911	1920	0.19	0.38	0.1	650	1400	3.53	0.4	1500	880	0.53	0.2	650	1400	0.37	0.2	650	1400	2.26	0.05	2400	840
1921	1930	0.16	0.55	0.1	650	1400	2.4	0.4	1500	880	0.96	0.2	650	1400	0.44	0.2	650	1400	2.34	0.05	2400	840
1931	1940	0.14	0.41	0.1	650	1400	2.93	0.4	1500	880	0.58	0.2	650	1400	0.34	0.2	650	1400	2.25	0.05	2400	840
1941	1950	0.16	0.53	0.1	650	1400	2.92	0.4	1500	880	0.77	0.2	650	1400	0.37	0.2	650	1400	2.28	0.05	2400	840
1951	1960	0.18	0.45	0.1	650	1400	2.7	0.4	1500	880	0.48	0.2	650	1400	0.37	0.2	650	1400	2.33	0.05	2400	840
1961	1975	0.21	0.33	0.1	650	1400	2.16	0.4	1500	880	0.33	0.2	650	1400	0.37	0.2	650	1400	2.34	0.05	2400	840
1976	1985	0.23	0.21	0.1	650	1400	1.03	0.4	1500	880	0.37	0.2	650	1400	0.28	0.2	650	1400	2.05	0.05	2400	840
1986	1995	0.2	0.18	0.1	650	1400	0.87	0.4	1500	880	0.24	0.2	650	1400	0.23	0.2	650	1400	1.95	0.05	2400	840
1996	2005	0.2	0.2	0.1	650	1400	1.57	0.4	1500	880	0.27	0.2	650	1400	0.18	0.2	650	1400	1.89	0.05	2400	840
2006	-	0.2	0.2	0.1	650	1400	1.5	0.4	1500	880	0.2	0.2	650	1400	0.15	0.2	650	1400	1.83	0.05	2400	840

8.2 Input data table

This following table is the example of the input model. The detailed variables taken is as described on the chapter 3.5.

Building number	Location_no	Byggnads-typ	Byggnads-typM	BuildingKat	A	Nybyggnadsår	Uag	Ubg	Uf	Ur	Uw	Ts	Wc	Wf	WWR	N_ag	N_app	N_oc	N_trphs	A_bg_heated	StoreyHeight	A_footprint	Perimeter	Sag	Sbg	Sf	Sr	S	Sw	Tag	Tbg	Tf	Tr	Tw
2482051	1480	SubtyR6	Slab Block	12	2555	1973	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	4	30	60	4	0	2.7	786	162	1750	0	786	786	3323	418	0.15	0.4	0.25	0.4	0.08
721972	1480	SubtyR6	Slab Block	12	2970	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	36	72	6	0	2.7	396	93.4	757	0	396	396	1548	181	0.15	0.4	0.25	0.4	0.08
2481943	1480	SubtyR2	Tower block	12	1673	1973	0.89	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	2	21	42	1	0	2.7	898	172	926	0	898	898	2722	221	0.13	0.4	0.25	0.4	0.08
715124	1480	SubtyR6	Slab Block	12	2720	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	24	48	4	0	2.7	777	153	1242	0	777	777	2796	297	0.15	0.4	0.25	0.4	0.08
715185	1480	SubtyR6	Slab Block	12	4325	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	36	72	6	0	2.7	1226	229	1858	0	1226	1226	4310	444	0.15	0.4	0.25	0.4	0.08
2482126	1480	SubtyR6	Slab Block	12	2555	1973	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	4	30	60	4	0	2.7	783	161	1740	0	783	783	3307	416	0.15	0.4	0.25	0.4	0.08
2482327	1480	SubtyR6	Slab Block	12	688	1973	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	2	9	18	2	0	2.7	445	106	571	0	445	445	1461	136	0.15	0.4	0.25	0.4	0.08
715138	1480	SubtyR6	Slab Block	12	2621	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	24	48	4	0	2.7	772	153	1240	0	772	772	2784	296	0.15	0.4	0.25	0.4	0.08
2482029	1480	SubtyR2	Tower block	12	1593	1973	0.89	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	18	36	1	0	2.7	646	130	1054	0	646	646	2346	252	0.13	0.4	0.25	0.4	0.08
2482160	1480	SubtyR6	Slab Block	12	688	1973	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	2	9	18	2	0	2.7	451	106	574	0	451	451	1477	137	0.15	0.4	0.25	0.4	0.08
721181	1480	SubtyR6	Slab Block	12	2305	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	18	36	3	0	2.7	650	133	1080	0	650	650	2381	258	0.15	0.4	0.25	0.4	0.08
7143102	1480	SubtyR1	Timber building	11	127	1979	0.89	1.54	0.59	0.57	1.3	0.6	0.5	0.8	0.2	2	1	2.4	0	0	2.7	96.8	40.5	219	0	96.8	96.8	412	43.7	0.1	0.4	0.25	0.2	0.08
510233	1480	SubtyR6	Slab Block	12	716	1979	0.51	1.54	0.59	0.51	1.3	0.6	0.5	0.8	0.27	2	8	16	4	0	2.7	459	114	614	0	459	459	1531	168	0.15	0.4	0.25	0.4	0.08
721234	1480	SubtyR6	Slab Block	12	1791	1970	0.68	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	21	42	3	0	2.7	596	129	1043	0	596	596	2236	249	0.15	0.4	0.25	0.4	0.08
279625	1480	SubtyR5	Large Slab Block	12	8758	1970	1.06	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.21	8	124	248	4	0	2.7	816	152	3284	0	816	816	4916	704	0.15	0.4	0.25	0.4	0.08
4588016	1480	SubtyR1	Timber building	11	184	1946	0.89	2.07	0.93	0.63	2.8	0.7	0.5	0.7	0.2	1	1	2.4	0	0	2.7	176	55.6	150	0	176	176	503	30	0.1	0.4	0.25	0.2	0.05
6326327	1480	SubtyR1	Timber building	11	176	1929	0.99	2.97	1.05	0.65	2.8	0.7	0.5	0.7	0.2	1	1	2.4	0	0	3.2	86.1	40	128	0	86.1	86.1	300	25.6	0.1	0.4	0.25	0.2	0.05
215418	1480	SubtyR2	Tower block	12	1591	1970	1.21	2.07	1.05	0.74	1.7	0.6	0.5	0.8	0.24	3	16	32	1	0	2.7	455	88.5	717	0	455	455	1628	171	0.2	0.4	0.25	0.4	0.08
5215009	1480	SubtyR1	Timber building	11	191	1980	0.89	1.54	0.59	0.57	1.3	0.6	0.5	0.8	0.2	1	1	2.4	0	0	2.7	140	47.6	129	0	140	140	409	25.7	0.1	0.4	0.25	0.2	0.08
199920	1480	SubtyR2	Tower block	12	1591	1970	1.21	2.07	1.05	0.74	1.7	0.6	0.5	0.8	0.24	3	16	32	1	0	2.7	455	88	713	0	455	455	1623	170	0.2	0.4	0.25	0.4	0.08
200101	1480	SubtyR2	Tower block	12	1441	1971	0.89	1.54	0.59	0.51	1.7	0.6	0.5	0.8	0.24	3	16	32	1	0	2.7	454	87.6	709	0	454	454	1617	170	0.13	0.4	0.25	0.4	0.08
7254482	1480	SubtyR1	Timber building	11	214	1926	0.99	2.97	1.05	0.65	2.8	0.7	0.5	0.7	0.2	2	1	2.4	0	0	3.2	87.9	37.5	240	0	87.9	87.9	416	48	0.1	0.4	0.25	0.2	0.05

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Building number	Dag	Dbg	Df	Dr	Dw	Cpag	Cpbg	Cpf	Cpr	Cpw	Um	U	Thermal bridge [%]	Cag	Cbg	Cf	Cr	Cw	TC	T0	Trmin	Trmax	Sc	Sh	Pc	Ph	Tv	Vcn	Vc	Weight
2482051	1800	2200	1500	1500	2400	840	880	880	880	840	0.75	0.75	0.1	3E+08	0	3E+08	4E+08	6E+07	1E+09	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
721972	1800	2200	1500	1500	2400	840	880	880	880	840	0.73	0.73	0.1	1E+08	0	1E+08	2E+08	3E+07	5E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
2481943	1500	2200	1500	1500	2400	880	880	880	880	840	0.73	0.73	0.1	1E+08	0	3E+08	5E+08	3E+07	9E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
715124	1800	2200	1500	1500	2400	840	880	880	880	840	0.72	0.72	0.1	2E+08	0	3E+08	4E+08	4E+07	9E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
715185	1800	2200	1500	1500	2400	840	880	880	880	840	0.71	0.71	0.1	3E+08	0	4E+08	6E+08	7E+07	1E+09	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
2482126	1800	2200	1500	1500	2400	840	880	880	880	840	0.75	0.75	0.1	3E+08	0	3E+08	4E+08	6E+07	1E+09	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
2482327	1800	2200	1500	1500	2400	840	880	880	880	840	0.69	0.69	0.1	1E+08	0	1E+08	2E+08	2E+07	5E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
715138	1800	2200	1500	1500	2400	840	880	880	880	840	0.72	0.72	0.1	2E+08	0	3E+08	4E+08	4E+07	9E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
2482029	1500	2200	1500	1500	2400	880	880	880	880	840	0.79	0.79	0.1	1E+08	0	2E+08	3E+08	4E+07	7E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
2482160	1800	2200	1500	1500	2400	840	880	880	880	840	0.69	0.69	0.1	1E+08	0	1E+08	2E+08	2E+07	5E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
721181	1800	2200	1500	1500	2400	840	880	880	880	840	0.72	0.72	0.1	2E+08	0	2E+08	3E+08	4E+07	8E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
7143102	650	2200	1500	650	2400	1400	880	880	1400	840	0.79	0.79	0.1	2E+07	0	3E+07	2E+07	7E+06	7E+07	21.2	21.2	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
510233	1800	2200	1500	1500	2400	840	880	880	880	840	0.62	0.62	0.1	1E+08	0	2E+08	2E+08	3E+07	5E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
721234	1800	2200	1500	1500	2400	840	880	880	880	840	0.72	0.72	0.1	2E+08	0	2E+08	3E+08	4E+07	7E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
279625	1500	2200	1500	1500	2400	880	880	880	880	840	0.98	0.98	0.1	5E+08	0	3E+08	4E+08	1E+08	1E+09	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
4588016	650	2200	1500	650	2400	1400	880	880	1400	840	0.93	0.93	0.1	1E+07	0	6E+07	3E+07	3E+06	1E+08	21.2	21.2	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
6326327	650	2400	1500	650	2400	1400	750	880	1400	840	1.06	1.06	0.1	9E+06	0	3E+07	2E+07	3E+06	6E+07	21.2	21.2	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
215418	1500	2200	1500	1500	2400	880	880	880	880	840	1.08	1.08	0.1	1E+08	0	2E+08	2E+08	3E+07	6E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
5215009	650	2200	1500	650	2400	1400	880	880	1400	840	0.7	0.7	0.1	9E+06	0	5E+07	3E+07	4E+06	8E+07	21.2	21.2	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
199920	1500	2200	1500	1500	2400	880	880	880	880	840	1.08	1.08	0.1	1E+08	0	2E+08	2E+08	3E+07	6E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
200101	1500	2200	1500	1500	2400	880	880	880	880	840	0.78	0.78	0.1	9E+07	0	1E+08	2E+08	3E+07	5E+08	22.3	22.3	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1
7254482	650	2400	1500	650	2400	1400	750	880	1400	840	1.14	1.14	0.1	2E+07	0	3E+07	2E+07	5E+06	7E+07	21.2	21.2	25	-2E+06	5E+06	5E+06	5E+06	24	2	0.35	1

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Building number	PerHPinH	P_Sh_HPa	P_Sh_HPb	P_Sh_HPc	P_Sh_HPd	P_Sh_HP	P_Sh_O	P_Sh_G	P_Sh_P	P_Sh_W	P_Sh_EB	P_Sh_ED	P_Sh_OF	P_Sh_DH	P_Sh_E	P_Sh_BW	P_Sh_C	P_Sh_A	P_Sh_S	P_Sh_Tot	P_Hw_HPa	P_Hw_HPb	P_Hw_HPc	P_Hw_HPd	P_Hw_HP	P_Hw_O	P_Hw_G	P_Hw_P	P_Hw_W	P_Hw_EB	P_Hw_ED	P_Hw_OF	P_Hw_DH	P_Hw_E	P_Hw_BW	P_Hw_C	P_Hw_A	P_Hw_S	P_Hw_Tot	P_W_Hw
2482051	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
721972	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
2481943	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
715124	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
715185	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
2482126	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
2482327	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
715138	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
2482029	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
2482160	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
721181	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
7143102	1	100	0	0	0	100	0	0	0	0	0	0	0	0	100	0	0	0	0	100	100	0	0	0	100	0	0	0	0	0	0	0	0	100	0	0	0	0	100	0
510233	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
721234	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
279625	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
4588016	0	0	0	0	0	0	0	0	0	0	0	11.6	0	88.4	11.6	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	11.6	0	88.4	11.6	0	0	0	0	100	0
6326327	0.84	0	0	83.5	0	83.5	0	0	0	0	0	16.5	0	0	100	0	0	0	0	100	0	0	83.5	0	83.5	0	0	0	0	0	16.5	0	0	100	0	0	0	0	100	0
215418	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
5215009	0.57	0	57.2	0	0	57.2	0	0	0	0	0	42.8	0	0	100	0	0	0	0	100	0	57.2	0	0	57.2	0	0	0	0	0	42.8	0	0	100	0	0	0	0	100	0
199920	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
200101	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	100	0
7254482	0	0	0	0	0	0	0	0	0	0	0	7.78	0	92.2	7.78	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	7.78	0	92.2	7.78	0	0	0	0	100	0

Cont.

Building number	Ac	Lc	HyP	Oc	Hw	VcA	SFP	HRec_eff	Pfh	prodPV_kWh	PV_kWp	PV_C_Eur	M_tot_PV	M_EAC_PV	M_0	Aratio	SAratio
2482051	3.4	0.85	0.34	1.78	3.34	894	0.6	0	0	0	0	0	0	0	0	0.81	1.3
721972	3.4	0.85	0.34	1.84	2.57	1040	0.6	0	0	0	0	0	0	0	0	2.5	0.52
2481943	3.4	0.85	0.34	1.91	3.34	585	0.6	0	0	0	0	0	0	0	0	0.93	1.63
715124	3.4	0.85	0.34	1.34	2.42	952	0.6	0	0	0	0	0	0	0	0	1.17	1.03
715185	3.4	0.85	0.34	1.27	2.42	1514	0.6	0	0	0	0	0	0	0	0	1.18	1
2482126	3.4	0.85	0.34	1.78	3.34	894	0.6	0	0	0	0	0	0	0	0	0.82	1.29
2482327	3.4	0.85	0.34	1.99	3.34	241	0.6	0	0	0	0	0	0	0	0	0.77	2.12
715138	3.4	0.85	0.34	1.39	2.42	917	0.6	0	0	0	0	0	0	0	0	1.13	1.06
2482029	3.4	0.85	0.34	1.72	3.08	558	0.6	0	0	0	0	0	0	0	0	0.82	1.47
2482160	3.4	0.85	0.34	1.99	3.34	241	0.6	0	0	0	0	0	0	0	0	0.76	2.15
721181	3.4	0.85	0.34	1.19	2.42	807	0.6	0	0	0	0	0	0	0	0	1.18	1.03
7143102	3.4	0.85	0.34	1.44	1.17	44.4	2	0.5	0.8	0	0	0	0	0	0	0.66	3.25
510233	3.4	0.85	0.34	1.7	3.61	251	0.6	0	0	0	0	0	0	0	0	0.78	2.14
721234	3.4	0.85	0.34	1.78	2.63	627	0.6	0	0	0	0	0	0	0	0	1	1.25
279625	3.4	0.85	0.34	2.15	5.44	3065	0.6	0	0	0	0	0	0	0	0	1.34	0.56
4588016	3.4	0.85	0.34	0.99	0.96	64.4	0.6	0	0	0	0	0	0	0	0	1.04	2.73
6326327	3.4	0.85	0.34	1.04	1.3	61.6	1	0	0	0	0	0	0	0	0	2.04	1.7
215418	3.4	0.85	0.34	1.53	7.36	557	0.6	0	0	0	0	0	0	0	0	1.16	1.02
5215009	3.4	0.85	0.34	0.95	1.79	67	1.5	0	0	0	0	0	0	0	0	1.37	2.14
199920	3.4	0.85	0.34	1.53	5.49	557	0.6	0	0	0	0	0	0	0	0	1.16	1.02
200101	3.4	0.85	0.34	1.69	5.74	504	0.6	0	0	0	0	0	0	0	0	1.06	1.12
7254482	3.4	0.85	0.34	0.85	1.71	74.9	0.6	0	0	0	0	0	0	0	0	1.22	1.94