Performance Gap

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Contents

1 Abstract

Around 30% of the world energy are consumed by building sector. Therefore, it is of importance to develop an accurate and efficient approach to estimate the building energy consumption and help improving the current building energy systems. This thesis aims to reduce the deviation between calculated and measured heating demands and find the short-comings in SIA 380/1 calculation method. In addition, this thesis also aims to validate a number of factors which are thought to have great impacts on building energy consumption, and to find out some important factors which are neglected in SIA 380/1 standards. A residential building and an office building are firstly accurately modeled and calculated using EnergyPlus and SIA 380/1 standard. Then, both buildings are calibrated based on historical annual heating demand and hourly indoor temperature, then several key building parameters are modified within a certain range given by both SIA 2024 Norm and experience values. Based on a large number of simulations, the result indicated that the most influential parameters in simulation are outdoor environments, key area temperature heating setpoints, external wall solar absorptance, infiltration and installed lighting capacity and schedule. In order to reduce the performance gap, it is recommended to create an accurate building envelope with accurate construction material properties and air-tightness, as well as a close-to-reality assumption on user behaviors and indoor environment, and apply a representative outdoor environment.

2 Introduction

Building simulation are widely used for different purposes such as to benchmark buildings or to evaluate energy demands and indoor thermal comfort. However, due to a number of factors, there are often deviations between calculated and measurement values, a phenomenon which is called **performance gap**. Previous studies which used a standardized method **SIA 180/1** to calculate the heating demand of several buildings observed considerably large performance gaps in uninsulated buildings as shown in Figure 1 [1]. It is believed that part of the problem come from a non-accurate calculation method and non-realistic assumptions on some building parameters and outdoor environment [1].

Therefore, the purpose of this thesis is to find out the main causes of the performance gap in uninsulated buildings, as well as the most influential factors and input assumptions in building simulation. In addition, this thesis also aims to investigate how the resulting energy demand variations affect the performance gap.

Two uninsulated buildings, one residential and one office buildings, are carefully modeled and analyzed using different approaches including static calculation (SIA 180/1) which based on monthly average inputs, and dynamic simulation (EnergyPlus) which based on hourly timestep inputs initiative calculation method [**crawley2000energy**, 2, 1]. The buildings are firstly calibrated to match the historical measurement, then model input parameters are modified and the most influential factors can be identified.

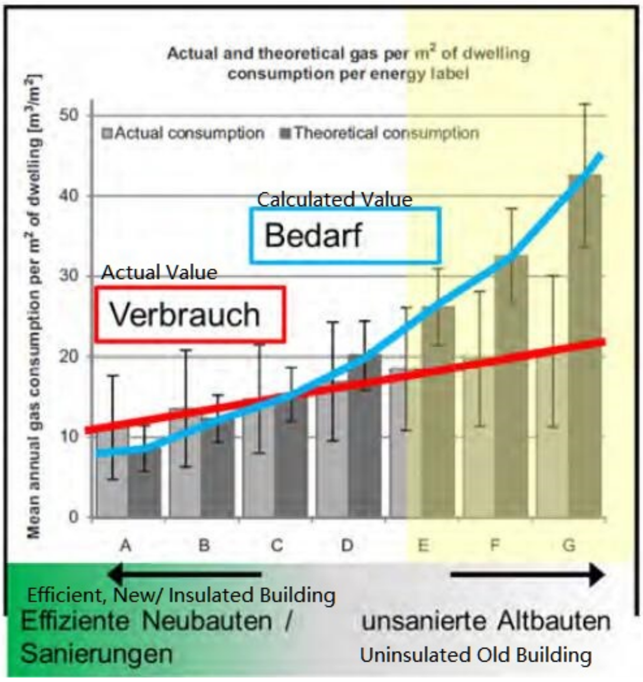

Figure 1: SIA380/1 Calculation Performance Gap Indicator [1]

3 Literature Review

Over the past years, there is a large number of research paper about the building energy performance gap (BEPG). Performance gap can cause problems in energy management system as they provide inaccurate information to upstream energy suppliers or waste investments in buying over-capacity or under-capacity equipment. However, the root cause of this gap is not clearly identified, and the gap can't be effectively managed and eliminated [3].

According to a recent review about the building energy performance gap by Zou et al.[4], most of these research papers on the topic of performance gap would contain one or more of the following 5 elements: (1) building type, which can be classified into different groups such as residential, office, commercial, or even more specific types such as single-family house, multi-family house, shopping mall, hospital, prison, etc; (2) strategies for closing performance gap, which focus about design concept, technology dependent method, and "soft" measures such as policies and regulations; (3) building life cycle, which analyses the cause of performance gap in different stages of a building; (4) energy-related stakeholders, whose behavior would affect the performance gap; (5) the influence factors or building parameters that would cause or affect the performance gap [3, 4].

Formation of Performance Gap
Most causes of performance gap can be grouped into 3 categories base on the stages in the building life-cycle. They are design and simulation problems, construction problems by contractors and unexpected behaviors of building users [5, 6].These three categories are analysed below:

(1) Design and simulation problems
Firstly, in most cases, building designers are account for the wrong aspects in design and simulation processes. These include wrong assumptions and predictions about their design such as inaccurate building unheated area's temperature, wrong representation of user behavior, and wrong forecast of outdoor environment [7, 6]. Also, it is difficult to predict the future environment such as climate, weather, and solar activities, which factors can lead to huge performance gaps [8, 9]. For example, rainfall would greatly increase the heat convection coefficient of building facade surface, and therefore increase heat exchange rate through the building envelope [8]. In addition, due to a difference between labotary environment and site environment, the performance of building materials or technologies in actual use is usually not the same as the lab test value. For example, a 5% efficiency PV panel would be less than 5% efficiency if covered with dusts or snow. Therefore, designers usually overestimate the actual performance of technology and apply inappropriate assumptions about user behaviors [10].

(2) Contractors
Secondly, construction practicers are also a cause for performance gaps. Low quality constructions lead to diviations between the actual building quality and the designed building quality. Poor building quality and poor workmanship will usually reduce the thermal performance and therefore change the building envelope from its designed state. For example, a room with less air-tightness than its design value would require more energy to maintain indoor comfort, and therefore consumes more energy than its designed and simulated results. Additionally, performance gap can be caused by contractors when they use improper construction techniques and when they are unable to discover hidden problems such as thermal bridge or small cracks due to time and budget constraints [10]. In some cases, these problems would lead to huge building parameter deviations and alter the building energy consumptions from the design value and create performance gaps [3, 10].

(3) User Behaviors
Lastly, as the last and main stage of building's life-cycle, different behaviors of building users are also important sources of performance gap [4]. These behaviors, either deliberate or unconscious, are usually not the optimum ways to operate a building. Building owners or occupants have specific behaviors due to their social and personal characteristics, attitude, experience, and thermal comfort standard [5, 11]. For example, users may leave unnecessary appliance on without notice or open the windows when heatings or cooling system is operating [3].

3.1 Strategies For Closing Performance Gap

When the causes of performance gap are found out, strategies for closing the gap can also need to be developed. These strategies are grouped into 3 categories, which is, namely, design concept, technology and methods, and ”soft” measures [4].

3.1.1 Design Concept

Passive design is thought to be able to eliminate or decrease the impact of user behavior on energy consumption. Its philosophy is that if a building is designed in a way that no active equipment is needed, user behaviors would not influence the passive mechanism [12, 13]. However, this approach has high construction quality requirements and can only have positive effects when both building designers and the occupants fully understand the building energy system. If building designers have inaccurate information about occupants, or building constructors do not have the capability to construct the building according to the specifications, or if the occupants do not fully understand the building system, passive design approach can only have adverse impacts [4].

Active design, on the other hand, use building automation system to improve occupants' thermal comfort and hopefully reduce the chance of wrong operations by occupants. Same as passive design, this design approach also require high quality equipment and construction team, and a comprehensive understanding of buildings and occupant behaviors to function well [10].

Human-in-the-loop is another approach that requires human interaction [14]. As information is a critical factor in building energy, the more comprehensive and accurate the obtained data, the more precise the result would become [6]. Therefore, in order to improve the accuracy of ”human-in-the-loop design”, is of importance to collect accurate data. There have been research which used advanced technology such as genetic algorithm, machine learning, virtual reality technology and augment reality technology to collect building data for simulations and calculations [14]. The limitations of this approach would be the difficulty to collect comprehensive human information, and there is an uncertainty of occupant behaviors and different occupants may influence each other [15].

3.1.2 Technology and methods (T&M)

It is believed that using more advanced and innovative technologies and calculation methods would help closing the performance gap [4]. Previous research has grouped most technologies and methods into 4 categories, namely T&M for calculating energy consumption, T&M for energy related data collection and analysis, T&M for occupant behavior modeling and simulation and T&M for energy system controlling [4].

(1) T&M for calculating energy consumption can be further divided into *Black box* methods, *Grey box* methods, and *White box* methods. A black box method, such as genetic algorithm and artificial neural networks, calculates energy consumption without physical knowledge. The white box method, such as *EnergyPlus, DOE-2, Ecotect* calculation engines, calculates energy consumption based on the thermodynamic behavior of the building and its occupants [16, 17]. The grey box method is a combination of the black and white box method, in hope of eliminating the limitations of both methods [4].

(2) T&M for data collection and analysis focuses on obtaining and utilizing the occupant behavior and building operation information [4]. Similarly, T&M for data collection and analysis can be divided into two approaches, namely *post occupancy* data collection and *pre-occupancy* data collection [4]. *Post-occupancy data collection* is the traditional and most commonly used data collecting approach which use different sensors and monitors to record occupants' activities as shown in Figure 2 below. However, since all buildings are more or less different from each other, post-occupancy data collection would not provide a customized and future-oriented prediction of a newly designed building, neither would it explain the reasons behind certain occupant behaviors [6].

To overcome this limitation, *pre-occupancy data collection* is developed to collect virtual occupancy behavior data based on VR or BIM building models. By this approach, customized occupancy data can be collected and designers can also improve the building design based on the collected virtual occupancy data. However, this method is not flawless, as the virtual occupancy behavior would likely be different from the actual behaviors in the real buildings.

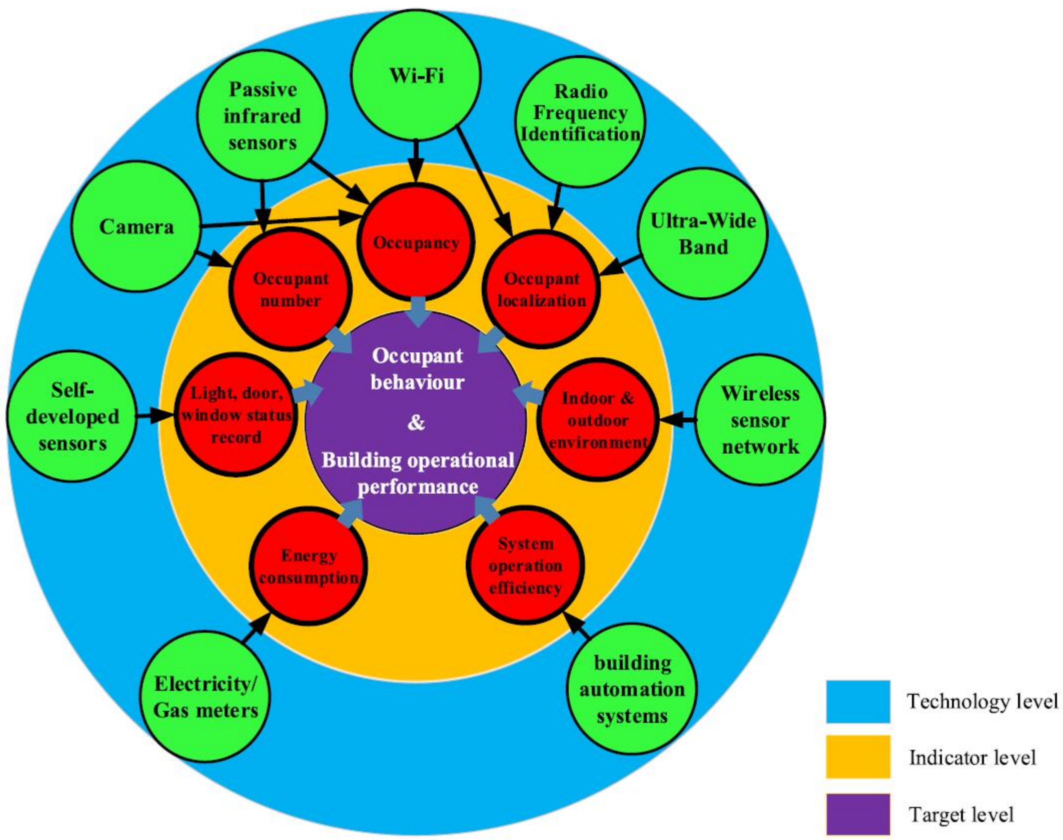

Figure 2: Technology and method for energy-related data collection [18]

Statistical analysis is mostly used to develop a numerical relationship among energy consumption, outdoor environment, indoor environment and comfort, occupant behavior and other information using statistical tests, regression analysis and curve fitting [4]. Previous research also show that the above mentioned data collection approaches would be slow and expensive, and the collected data volume is massive and unstructured [19].

In order to process this massive amount of data, *Data mining* would be a good technology to structure the collected data and find out the unknown correlations between different data sets. Currently, data mining is used to analyze building energy consumption data and occupancy/occupant behavior data [20].

As building occupants are capable to greatly alter the building indoor environment, it is of importance to know how exactly did they operate the building when a building is subjected to energy analysis or building simulations. However, obtaining an exact set of occupant activity record through the simulation period is hardly possible for most cases. Therefore, some technologies and methods are developed to generate a reasonable set of occupant behavior. *T&M for occupant behavior modeling and simulation* are mainly two groups, namely *agent-based modeling (ABM)* and *stochastic process modeling* [4].

Agent-based modeling (ABM) simulates the actions and interaction of agents, such as individual, group or equipment, and investigate how they interact with the whole system [18]. Some previous studies have used ABM to address the interrelation between different occupants, or to simulate user-defined social constraints from other occupants on an agent's certain behavior. The advantage of ABM is its potential capability to integrate with energy simulation program and its capability to deal with interactions and uncertainties [4]. However, the limitation of ABM is not negligible. Currently, ABM are more dependent on assumptions rather than actual data, and it is difficult to verify a model based on ABM [4, 18].

As the occupant behavior is more or less random, *stochastic modeling* can be widely used in many researches involing estimating probability distributions of occupant behavior. In most cases, stochastic process modeling approach focus on relatively long-term occupancy prediction or classification instead of a certain behavior at a certain time [4]. In this thesis, stochastic process modeling approach based on SIA standards is used in the dynamic energy analysis part, the detailed parameters can be found in chapter methodology.

T&M for energy system controlling aims at reducing building energy consumption without sacrificing the occupants' thermal comfort, and can be devided by three groups: *intelligent HVAC system, artificial lighting* and *occupancy-based control system* [4, 21]. The limitation for T&M for building automatic control would be it relies heavily on controlling algorithms and the accuracy of sensoring equipments. Therefore, a mal-functioning sensor group would paralise the control system.

3.2 Previous Research

One similar research has been done in 2015 aiming to investigate the reason behind the huge performance gaps in uninsulated old buildings when using SIA 380/1 and SIA 382 calculation method. The research concluded that three main reasons are the most important: too poor U-values, too low indoor air temperature for unheated ares (based on a research on basement actual temperature), and the discrepancies between standard climate data and actual outdoor air temperature [1]. However, there are still some unsolved problems in the previous research. Firstly, the actual temperature of the building site is not fully recorded and used in SIA 380/2 calculation. Secondly, the relations and rankings between the key parameters are not clear. Therefore, in this thesis, more accurate weather information is implemented in both static and dynamic calculations, and a more accurate correlation relationship between the heating demand and each key parameter are also investigated.

4 Methodology

In order to achieve the thesis aim to reduce the deviation between calculated and measured heating demands and find the short-comings in SIA 380/1 calculation method, the whole thesis research is divided into three stages. In the first stage, a 3D model with exact geometry and orientation for each building is built using *DesignBuilder (version4.7)*, the building material and the thermal performance of the building envelopes are given by measurements in the previous research. In the second stage, the two buildings are subject to building energy analyses using both SIA 380/1 standard tool and EnergyPlus. The models are then verified and calibrated by comparing the measured historical indoor temperature with the calculated indoor temperature . In the final stage, a set of key building parameters are varied and stochastic building environment is subject to analyses using jE-Plus. Further analyses would find out the correlation between parameters as well as the influence about climate data. Figure 3 below shows the key approaches to achieve the thesis aim.

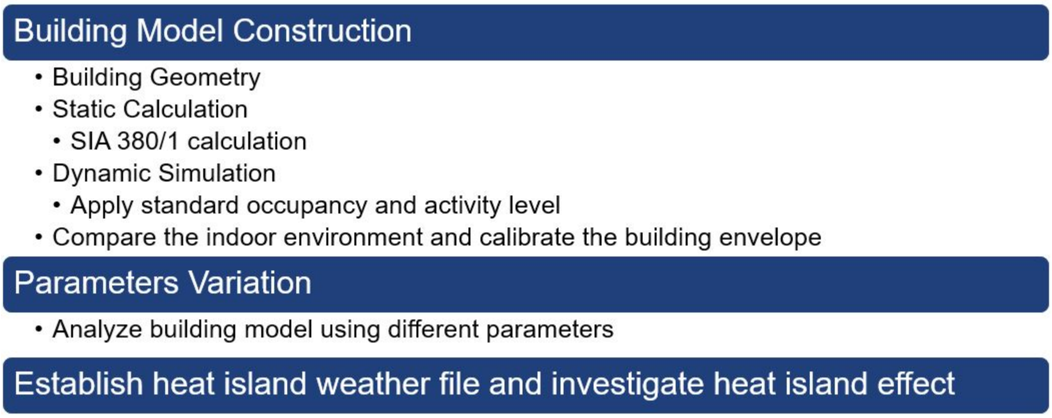

Figure 3: An overview of the methodology

4.1 Office Building Introduction

According to the given information, the office building is constructed in 1951 and is located at Sumatrastrasse 10, 8006 Zurich, Switzerland. The building has 4 floors and a basement. The building is facing west, and the window-to-wall ratio is 59% on its west and south facade. The east facade of its ground floor and first floor is submerged into ground and there are heavy cover of plants on the upper floors with only a few necessary windows. There is also an underground floor used as warehouse and it's not included in any building model in this thesis.

Figure 5 and 6 below are the floor plans of the building. The floor layout of ground floor, first floor and second floor are thought to be identical, and the third would have some small differences. For each floor, there is a toilet, a small office and 2 middle offices and a staircase. There is also a big office in each floor at the south side at ground floor, first floor and second floor. At the third floor, part of the big office and the corridor become a meeting room and a small pastry area as shown in the figures below. The detail building envelope material and modelling parameters are at chapter *Methodology*.

Figure 4: Sumatrastrasse 10 Office Building

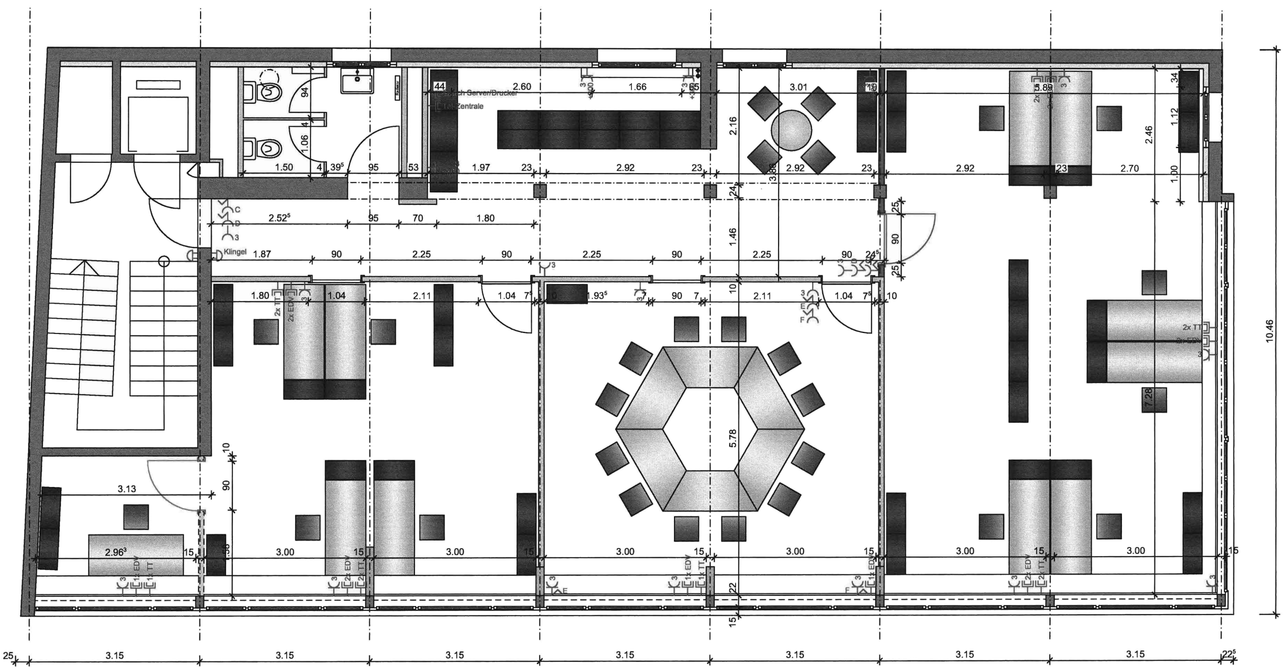

Figure 5: Floor plan of office building (Sumatra) ground floor to 2^{nd} floor

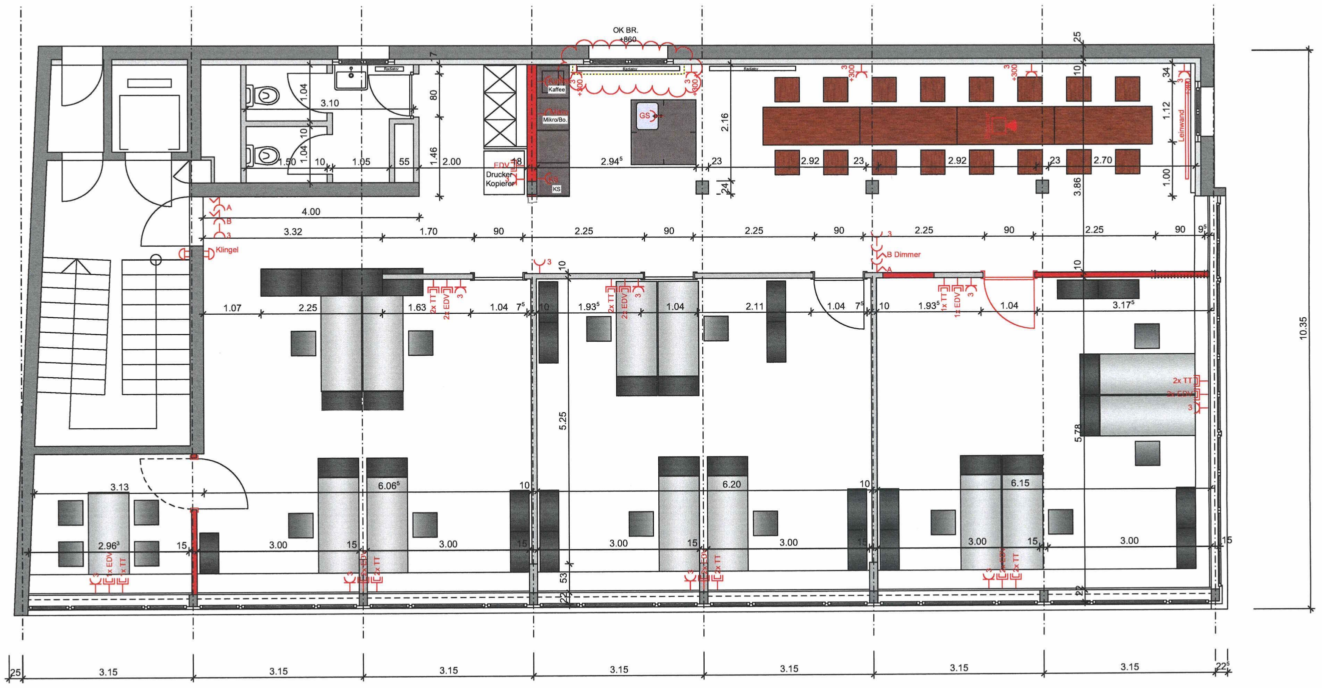

Figure 6: Floor plan of office building (Sumatra) 3^{rd} floor

4.2 Residential Building Introduction

Figure 7 and 8 below show the photo of the residential building. The residential building is a part of a multi-family town house constructed in 1894. It is located at Honggerstrasse 23, 8037 Zurich, Switzerland. The building has 5 floors, the top floor is a loft and there is also an extra basement. There are 4 apartments in the building. The first apartment occupies the ground floor and the first floor, and the other 3 apartments each occupy one floor. Figure 9 and Figure 10 below are the floor plans of the residential building. The ground floor is connected with the first floor internally via a small staircase behide the kitchen. The black and red lines in Figure 9 show the ground floor layout and the yellow line indicates the layout of the upper floor. Similarily, Figure 10 shows the floor plans from first floor upward. The red line indicates the layout of first floor and the yellow line shows the layout from second floor up. The detail building envelope material and modelling parameters are at chapter *Methodology*.

4.3 Building Model Construction

DesignBuilder is used to model the building envelopes of both buildings. It is compatible with EnergyPlus and provides advanced tools to model building geometry and building system.
A brief introduction of DesignBuilder, also describe the scope of work (Building envelope, create a formated file for EnergyPlus engine, also provide accurate geometry data for SIA calculation)

4.3.1 Building Geometry

The actual geometry of the building is not specifically given in the previous report. However, a detailed floor plan and some geometries are given in pdf format as shown above in Figure 5, and 6, 9, 10. Therefore, in order to obtain an accurate building geometry, the pdf floor plan is firstly scaled to fit its nominated geometry, then a drawing file with correct scales are made according to the given pdf floor

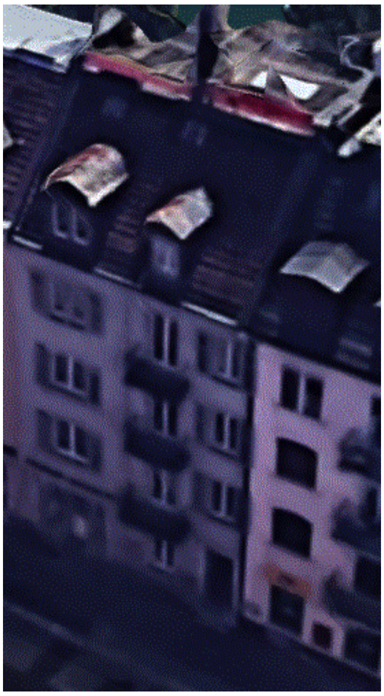

Figure 7: Honggerstrasse 23, NE Side

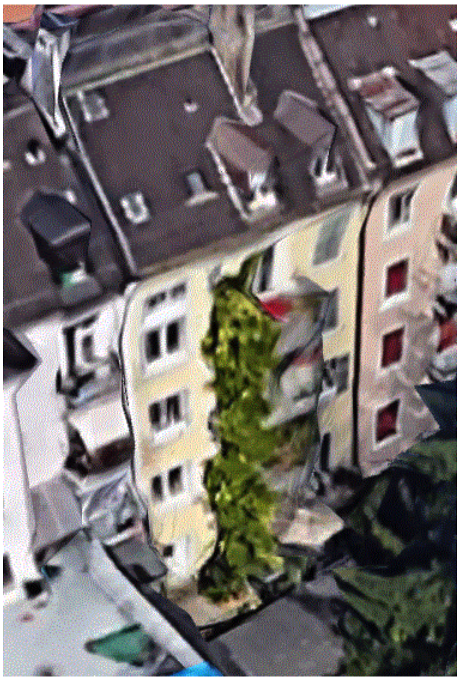

Figure 8: Honggerstrasse 23, SW side

plans. After the drawing files are completed, they can be imported to DesignBuilder as a construction basis as shown in Figure 11 and 12 below.

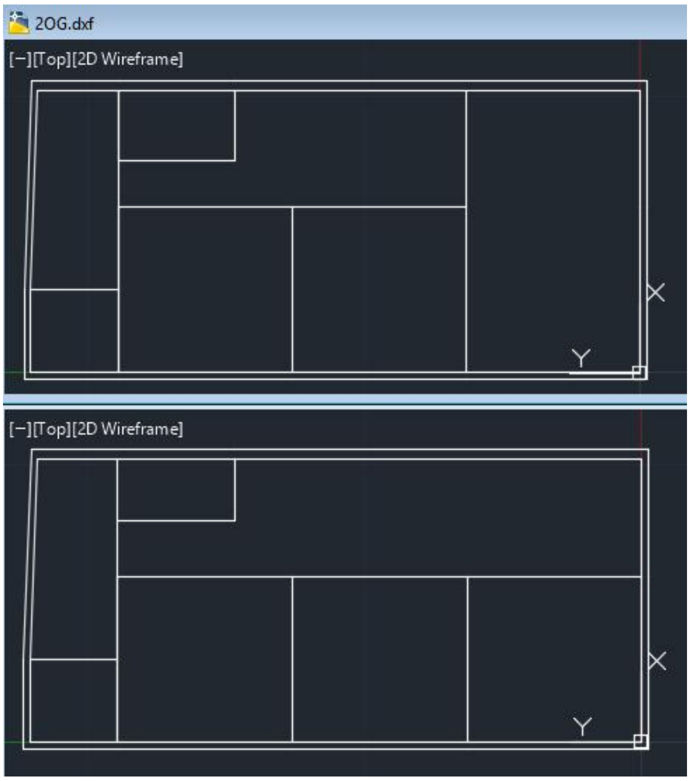

Figure 11: dxf drawing files for office building

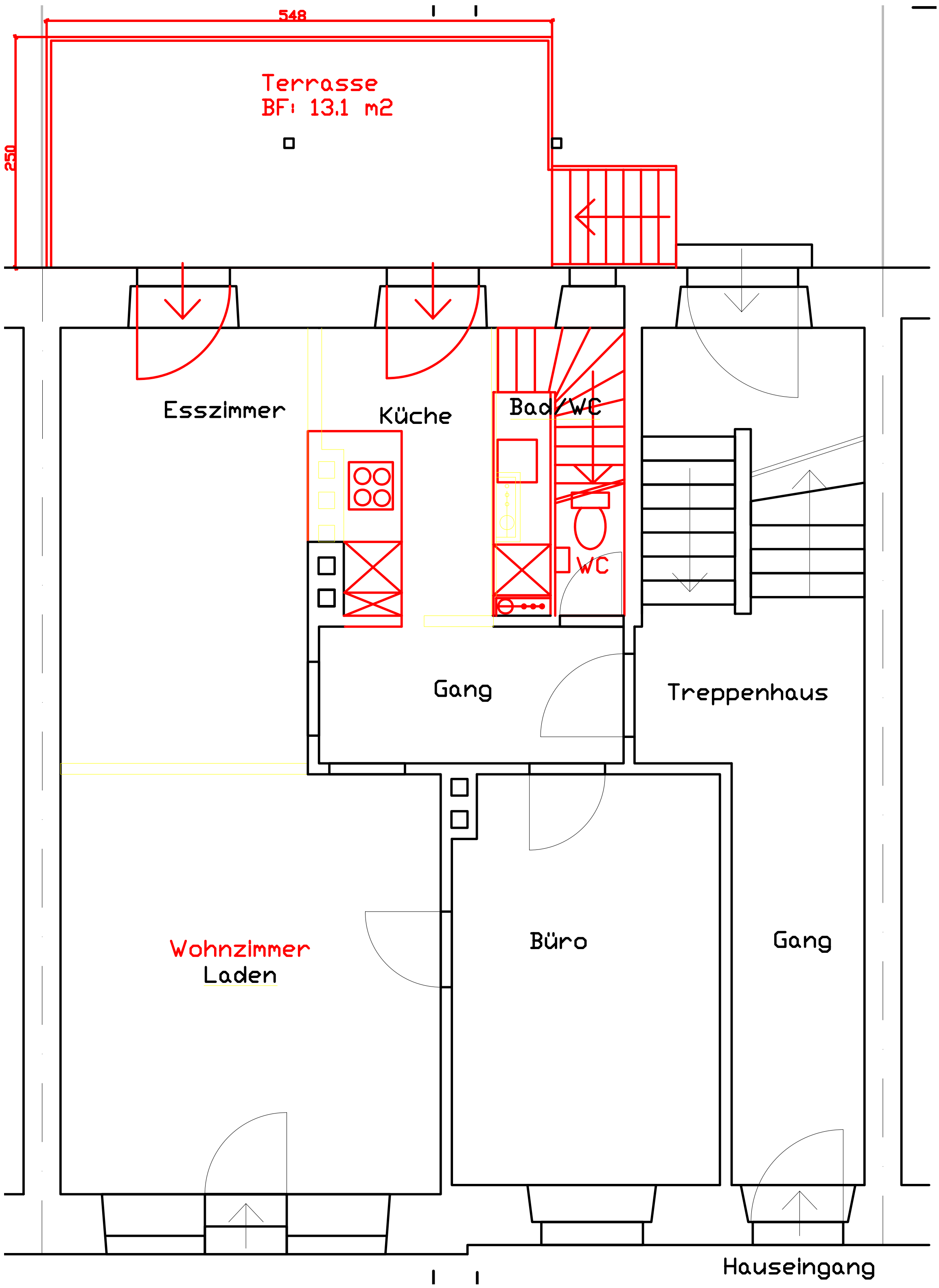

Figure 9: Floor plan of residential building (Hongger) ground - 1^{st} floor

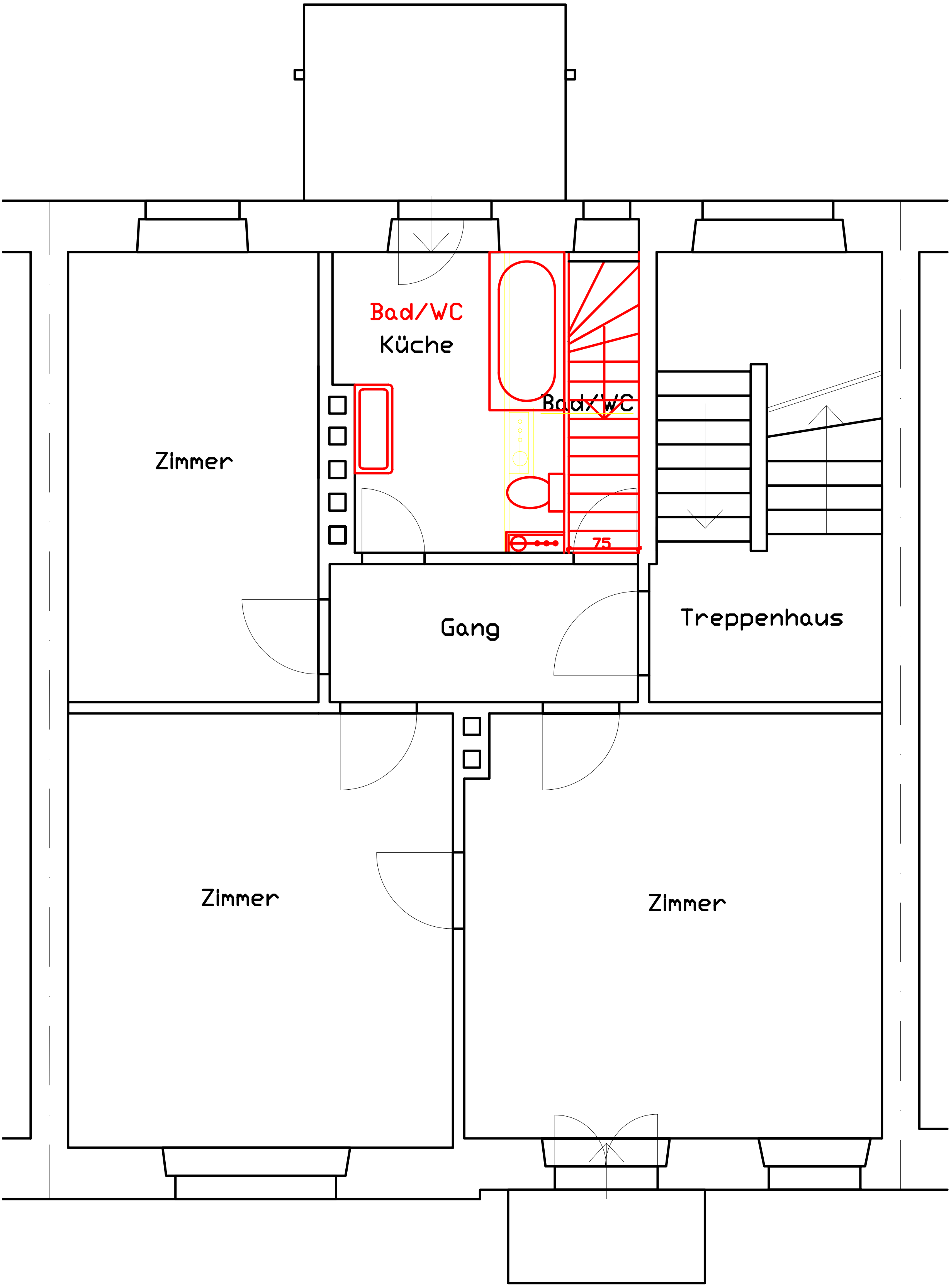

Figure 10: Floor plan of residential building (Hongger) $1^{st} - 4^{th}$ floor

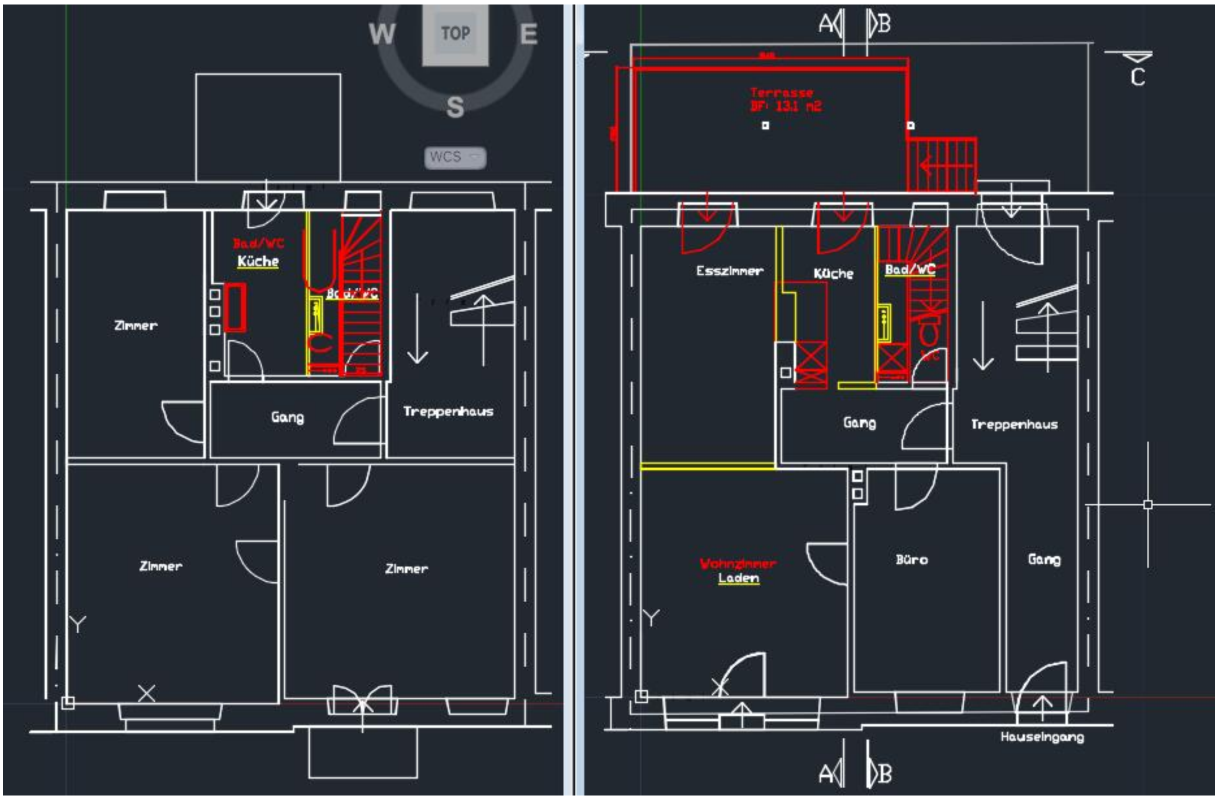

Figure 12: dxf drawing files for residential building

After the outline of buildings are constructed, windows and doors are defined. The window and door geometries of the office building and the residential building are shown at the table 1 and table 2 below. The detailed window code information can be found in Table 3.

Table 1: Window Layout of Residential Building

Ground Floor			
Orientation	Location	Code	Number of window
SW	Terrasse	2a	2
	WC	3a	1
	Staircase	1a	1
	Front Door	TH	1
NE	Laden	1a	1
	Office	4a	1
	Door	TH 1a	1
1st Floor to 4th Floor			
SW	Terrasse	2a	1
	WC	3a	1
	Office	4a	1
	Corridor	TH 1a	1
NE	Office	4a	2
	Terrasse	2a	1

Table 2: Window Layout of Office Building

Ground Floor			
Orientation	Location	Code	Number
W	Right Office	FE1	2
	Conference room	FE1	2
	Large office	FE1	2
	Corridor	FE6	2
S	Large office	FE6	2
1st Floor and 2nd Floor			
W	Right Office	FE1	2
	Conference room	FE1	2
	Large office	FE1	2
	small office	FE1	1
S	Large office	FE1	1
3rd Floor			
W	Right Office	FE1	2
	Middle office	FE1	2
	Corner office	FE1	2
	small office	FE1	1
S	Corner office	FE1	2
	Kitchen and Corridor	FE4	1
	Kitchen and Corridor	FE5	1
E	Kitchen and Corridor	FE7	1
	Staircase	FE3	1

Table 3: Office building window specification

Code	U-Value W/m^2K	Number of window	Unit area m^2	Total area m^2
FE1	2.001	33	6	198
FE2	2.500	1	8.125	8.13
FE3	2.500	1	2.7	2.7
FE4	2.048	3	3.5	10.5
FE5	2.072	3	2.598	7.79
FE6	2.028	2	2.25	4.5
FE7	2.042	2	2.88	5.76
FE8	1.907	3	0.975	2.93

Table 4: Residential building window specification

Code	U-Value W/m^2K	number of window	unit area (m^2)	Total Area (m^2)
FE-EG-1a	2.379	1	6.9	9.9
FE-EG-2a	2.388	10	2.6	26
FE-EG-3a	2.19	5	0.6	3
FE-EG-4a	2.285	13	1.6	20.8
FE-TH-1a	2.33	1	2.88	3.7
Tur-TH	3.5	1	2.5	2.5

4.3.2 Building Envelope Material

After the building geometry is construct, the building wall and window elements are then assigned a set of thermal properties based on measurememt. Both buildings are uninsulated reinforced concrete structure buildings with thin outer and inner plaster layers. The detailed building wall material of both buildings as well as their thermodynamic properties are measured from the actural building and are shown in Table 5 and Table 6. The window properties and geometries of both buildings can be found in 3 and 4. Also note that the office building has PV panels on the roof but they are not included in either building geometry or building envelop. After the building material are assigned to all part of the buildings, static calculation and dynamic calculation can be performed.
Figure 13 and 14 shows a completed office and residential building DesignBuilder model with geometry and material information.

Table 5: Wall material list of office building

	Thickness m	Density kg/m^3	Lambda W/MK	Heat Capacity KJ/Kg.K	R Value m^{2}K/W	U Value W/m^{2}K
EG East Wall						
Outside convection coefficient						
Outer Layer	0.36	2400	2.5	1	0.144	
Inner Layer	0.01	1400	0.7	1	0.014	
Inside convection coefficientr					0.13	7.7
					0.288	3.4703
West and Other Wall						
Outside convection Coefficient					0.04	25
Outside Layer	0.02	1400	0.7	1	0.029	35
Layer2	0.05	1100	0.44	0.94	0.114	8.8
Middle Layer	0.02	120	0.056	1.56	0.357	2.8
Inside Layer	0.15	2400	2.5	1	0.06	16.667
Inside Convection Coefficient					0.13	7.7
					0.729	1.3713
East Wall (Thick)						
Outside convection Coefficient					0.04	25
Outside Layer	0.02	1800	0.87	1	0.023	43.5
Middle Layer	0.36	1100	0.44	0.94	0.818	1.2222
Inside Layer	0.02	1400	0.7	1	0.029	35
Inside Convection Coefficient					0.13	7.7
					1.04	0.9619
Ceiling						
Outside convection coefficient					0.04	25
Layer 1	0.04	120	0.056	1.56	0.714	
Layer 2	0.0042	1100	0.23	1	0.15	
Layer 3	0.0035	1100	0.23	1	0.015	
Layer 4	0.001	980	0.5	1.8	0.002	
Layer 5	0.22	2400	2.5	1	0.088	
Inside convection coefficientr					0.13	7.7
					1.139	0.8777
Ground						
Outside convection coefficient					0.13	7.7
Layer 1	0.01	120	0.056	1.56	0.179	
Layer 2	0.22	2400	2.5	1	0.088	
Inside convection coefficientr					0.13	7.7
					0.526	1.9

Table 6: Residential building wall material

	Thickness m	Density kg/m^3	Lambda W/MK	Heat Capacity KJ/Kg.K	R Value m^2K/W	U Value W/m^2K
			External Wall			
Outside convection Coefficient					0.04	25
Outside Layer	0.04	1800	0.87	1	0.046	21.75
Middle Layer	0.6	1800	0.8	0.94	0.75	1.3333
Inside Layer	0.02	1400	0.7	1	0.0286	35
Inside Convection Coefficient					0.1299	7.7
					0.9944	1.0056
			Ground			
Outside convection coefficient					0.1299	7.7
Layer 1	0.02	900	0.25	1	0.08	
Layer 2	0.1				0.15	
Layer 3	0.03	1500	1.5	2.1	0.02	
Layer 4	0.03	500	0.13	1.6	0.2308	
Inside convection coefficientr					0.1299	7.7
					0.7405	1.3504
			Ceiling			
Outside convection coefficient					0.1299	7.7
Layer 1	0.02	1400	0.7	1	0.0286	
Layer 2	0.2	2300	2.3	1	0.087	
Layer 3	0.02	1500	1.5	2.1	0.0133	
Layer 4	0.03	500	0.13	1.6	0.2308	
Inside convection coefficientr					0.1299	7.7
					0.6194	1.6145

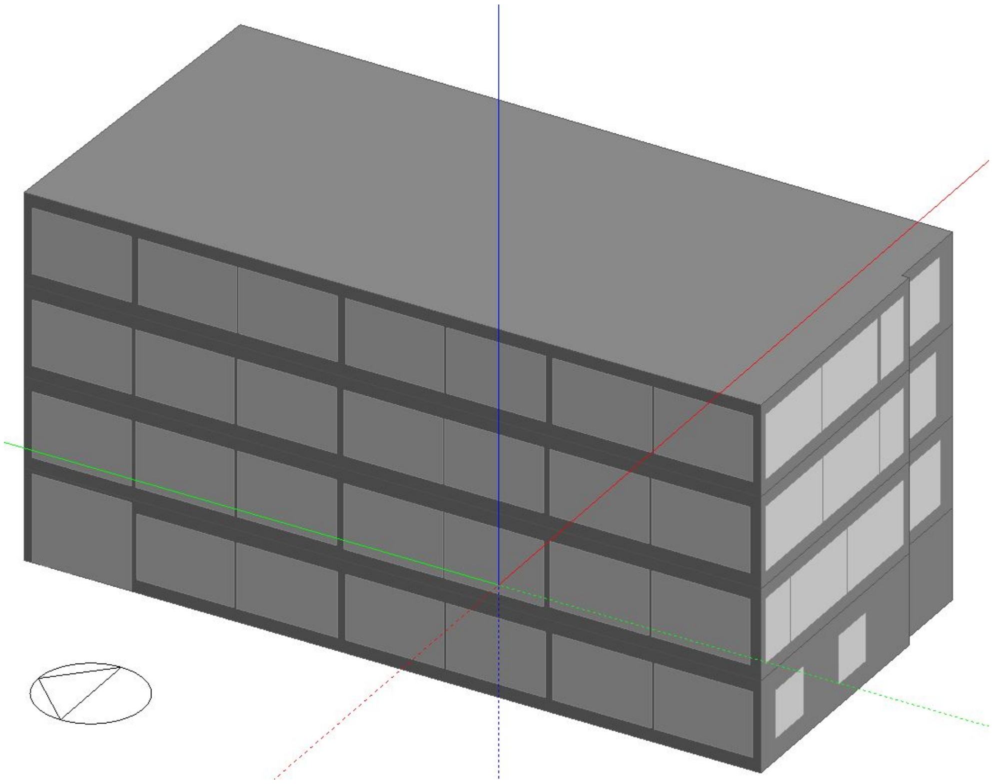

Figure 13: Office building DesignBuilder model

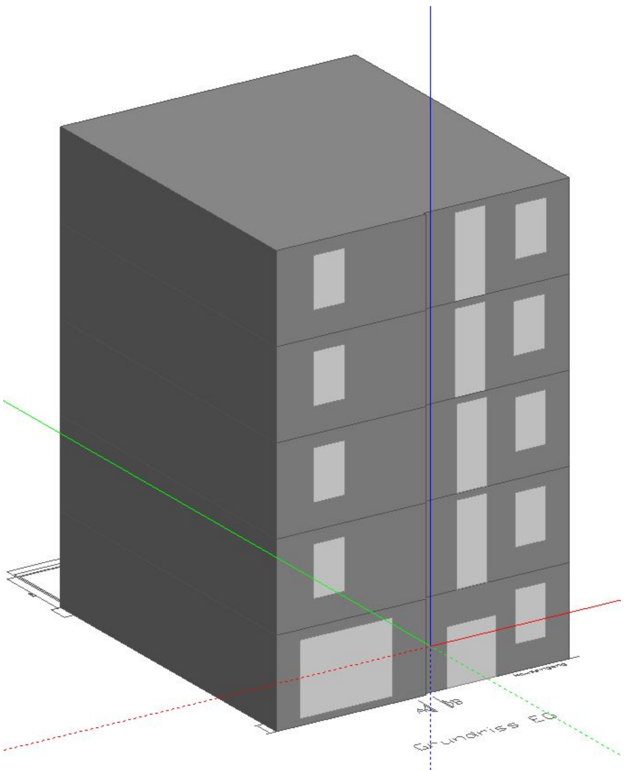

Figure 14: Residential building DesignBuilder model

4.4 Selection of Simulation Tools

Crawley and Hand et.al provided a comprehensive review on currently in-use building energy simulation tools back in 2008, and it include a brief review of EnergyPlus 1.2.2 and its basis building simulation tools [23]. As EnergyPlus is compatible with building modeling software *DesignBuilder*, it is more convenient to use it in this thesis comparing to other simulation tools. Additionally, as EnergyPlus is based on the features and capabilities of BLAST and DOE-2, these two tools are also briefly reviewed [23]. However, the reviewed EnergyPlus version is more than 10 years old, it is believed that most of the functions have been updated and improved since then.

Building BLAST

The BLAST system predicts building energy consumption, building energy system performance and building costs [23]. It contains three major subprograms: Space Loads Prediction, Air System Simulation, and Central Plant. *Space Loads Prediction* computes hourly space loads based on the given hourly weather data, building construction properties and operation details. It uses a radiant, convective, and conductive heat balance for all surfaces and a heat balance of indoor air [23]. The energy balance equations include heat transmission, solar loads, internal heat gains, air infiltration loads, and temperature control strategy used to manipulate the indoor temperature. BLAST can be used on new or existing buildings of almost any type and shape [23].

DOE-2.1E

DOE-2 predicts hourly energy consumption and energy cost for a building based on the given weather information, building geometry, HVAC description, and utility cost. DOE-2 has one subprogram to translate input (BDL Processor), and four simulation subprograms namely *Loads, Systems, Plant, and ECON (Economics).*

Loads, Systems and Plant are executed in sequence, with the output of the predecessor become the input of the next program in sequence. The output then becomes the input to *Economics* [23]. Each of the simulation subprograms can also generate printable reports of the results of its calculations.

DOE-2 has been used extensively for more than 35 years for both building design studeis, retrofit analysis, and for developing and testing building energy standards [23].

EnergyPlus

EnergyPlus is a modular and structured code based calculation engine. As mentioned above, it is based on the most popular features and functions of BLAST and DOE-2 and it is a more advanced tool compared to the previous two simulation engines. It is a simulation engine with input and output as text files. Loads are firstly calculated at a user-defined time step, then passed on to the building systems simulation module at the same time step [23]. The EnergyPlus building system simulation module calculates heating and cooling system and plant and electrical system response. The integrated simulation also capable to evaluate realistic system controls, moisture adsorption and deorption in building elements, radiant heating and cooling system and interzone air flow [23].

4.5 SIA Documentations

Most of the building occupancy and activity assumption are from the standard values published by the Swiss society of engineers and architects (hereinafter: SIA Standard). The SIA standards range from energy consumption calculation formulars to the supporting informations about a perticular building type or a room type. It also include a reference standard weather data set for most of the cities in

Switzerland. Here are the main SIA standards that are used or taken into account in this thesis.

SIA 380/1: Thermal energy in buildings

This SIA standard is published in 2009 replacing its predecessor SIA 380/1 (2007). It is often used with other standardized calculation parameters when assessing the energy efficiency of existing buildings [1]. It also serves as a forecasting tool to evaluate the refurbishment plans. However, the building usually consume less energy than what the calculation suggest, and this issue become more severe as the building envelope gets worse as shown in figure 1. When using SIA 380/1 to calculate the entitlements for governmental energy certificates, standardized data is used, when using SIA 380/1 for energy consulting, design and optimizations, the best known data is used [1].

SIA 2028: SIA Weather Data

SIA also published a set of standard weather information for most cities in Switzerland. It separates Switzerland into several climate zones and each zone would have their specific climate patten and typical weather data for energy calculation. As SIA 380/1 use monthly average temperature and monthly heating degree days to calculate annual heating demand, this SIA standard weather data is used in this thesis as a reference guide.

The weather data set include monthly and annual average temperature, monthly and annual heating degree days, monthly and annual solar radiation in north, south, east, west and horizontal surfaces. In addition, SIA also published another set of standard hourly data on its partner website *www.energytool.ch* for purchase.

SIA 2024: SIA Occupancy and schedule

Apart from the standard calculation of SIA 380/1 which use monthly and annual unit area standard values for a specific building type, SIA also developed a dynamic building energy analysis approach which use hourly unit area data for a specific room or zone type. SIA 2024 is the unification of assumptions about occupancy and equipment or appliance usage level for specific zone types such as corridor, bedroom, living room and toilet.

The assumptions listed in SIA 2024 include room heating and/or cooling setpoint, maximum supply wind speed, typical room area, window-to-wall ratio, window g-values, room occupancy level and activity level, internal gain level, electricity usage level and activities, minimum and typical amount of outdoor air and ventilation level, lighting and domestic hot water demand etc.

These assumptions are used in calculations and verifications according to energy and building service standard. For occupancy and appliance level assumptions, it gives not only a specific value but also a resonable range which enable a stochastic building energy consumption analysis. SIA 2024 has provide assumptions for 46 different zone types, which cover a majority of building types [2].

4.6 Weather Data Selection

A number of data files or weather data are used during this research. These weather files and data include a typical SIA standard monthly weather and hourly weather; a typical hourly weather file which contains an average or typical weather information from the recent 10 to 15 years; a created data file based on weather station measurement in 2015, and a created heat island weather file. These weather data can be grouped into two categories according to their functions.

4.6.1 Weather Data For Static Calculation

SIA 381/2 Weather Data

SIA has published a standard weather data *SIA 381/2 Klimadaten zi Emfehlung SIA 380/1* (Recommended climate data for SOA 380/1) in 1988. It separate Switzerland into a number of climate zones. It also contain monthly weather data set for most main cities in Switzerland. The useful information from this weather dataset are monthly air temperature, monthly heating days, monthly heating degree days and monthly solar radiation on different orientation surfaces.

Table 7: SIA 381/2 Weather Data

SIA 381/2 Weather Data													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Average Temperature	0.1	2.1	4.8	9	14	18	19	18	16	11	5.4	0.6	3260
HDD	615	501	467	255	110	23	7	6	35	207	433	601	1091
Solar Energy at N (MJ/m^2)	33	48	78	108	158	172	168	116	89	61	32	28	2248
Solar Energy at E (MJ/m^2)	57	96	170	243	299	320	330	284	212	127	61	49	3133
Solar Energy at S (MJ/m^2)	149	217	281	315	299	290	318	337	347	272	166	142	2303
Solar Energy at W (MJ/m^2)	67	110	170	248	294	308	330	284	227	138	70	57	4156
Horizontal Solar Energy	94	166	299	450	565	616	648	526	385	227	104	76	1564
Solar Energy at NE	43	68	115	162	217	235	235	182	137	88	44	37	2653
Solar Energy at SW	100	154	219	279	296	299	324	309	281	194	108	90	2653

2015 Weather Data

The 2015 Zurich weather data for static calculation is based on the information from the given 2015 *.epw* weather file. The hourly data is firstly extracted from the weather file then calculate the monthly average. *Rhino6* and *Grasshopper* are also used to extract the hourly data as well as calculating the average monthly solar radiation on the nominal orientations (N, E, S, W, NE, SW, and Horizontal). The resultant monthly weather data is shown at Table 8. Table 9 below indicate a comparison of two different weather data.

Table 8: 2015 Zurich Monthly Data

2015 Weather Data													
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Average Temperature	3.7	1.5	8.2	12	16	20	25	23	15	11	9	5.1	
Heating Degree Days	498	519	344	149	31	0	0	0	18	225	268	462	2513.1
Solar Energy at N (MJ/m^2)	25	42	62	86	116	158	150	107	74	46	30	23	919.15
Solar Energy at E (MJ/m^2)	55	103	176	238	289	301	332	278	185	113	65	41	2176.1
Solar Energy at S (MJ/m^2)	183	213	304	298	244	237	245	284	279	238	146	116	2786.3
Solar Energy at W (MJ/m^2)	67	97	186	233	261	294	299	258	206	127	61	52	2140.7
Horizontal Solar Energy	104	174	316	446	549	596	605	512	353	208	108	78	4049.9
Solar Energy at NE	26	51	92	140	202	231	244	179	108	58	33	24	1388.6
Solar Energy at SW	146	167	269	287	273	282	288	290	268	204	112	97	2683.8

Table 9: Weather Data Comparison

	SIA Standard Weather	2015 Weather	Typical Zurich Weather
Heating Day	208	175	213
Heating Degree Day	3260	2513	3283
Annual Average Temperature	8.5	12.3	9.75

4.6.2 Weather Data For Dynamic Calculation

An *.epw* weather file is needed for dynamic calculation using *EnergyPlus*. The weather file is either from a meteological organization or from modifying an existing weather file. It contains a large number of weather information such as dry-bulb temperature, wet-bulb temperature, relative humidity, wind speed, wind direction, hourly solar radiation, cloudiness etc.

Typical Year Weather File

A typical year Zurich weather file is given by EMPA research unit. It also become the basis for other custom-made weather files that are used in this thesis. The basic statistic information of the typical year weather file is shown at the 3^{rd} column of Table 9.

2015 Weather File

The 2015 weather file is created from the typical Zurich weather file by replacing the dry bulb temperature, wet bulb temperature, relative humidity, wind speed, and wind direction by the actual hourly measured data in Zurich in 2015. The source of weather data is from *Federal Office of Meteology and Climatology MeteoSwiss*. Considering the location of the two existing building, the weather station is chosen to be *NABZUE*, which located at Zurich city as shown in Figure 15.

Figure 15: Weather Station Location

Table 10: Weather Data Information

2015 Weather Data Information	
Source	MeteoSwiss: IDAWEB
Weather Station Code	NABZUE
Station Coordinate	E 8^{o}31'49" , N 47^{o}22'39"
Altitude	409 m
Year	2015

SIA382 Weather File
The full weather data is not fully accessible, and only the hourly temperature is obtained. However, the SIA 382 Weather File is only used to investigate the global warming effect in Zurich. The hourly stand weather temperature is used to replace the typical year weather temperature in the typical year weather file, while all other information remain the same as the 2015 weather data. The comparison between SIA 382 temperature and 2015 actual temperature

Heat Island Weather File
Similarly, heat island weather is created based on measured data in year 2015 and aimed to investigate the heat island effect of Zurich city. Firstly, the temperature difference between building site temperature and the weather station data is recorded and average temperature difference is taken hour by hour as shown in Figure 16 below. Then, a simple rule is apply on the 2015 weather temperature for each hour and create a new heat island weather temperature as shown in Figure 17. Lastly, the new heat island temperature is imported to the *.epw* weather file and become the *heat island weather file*.

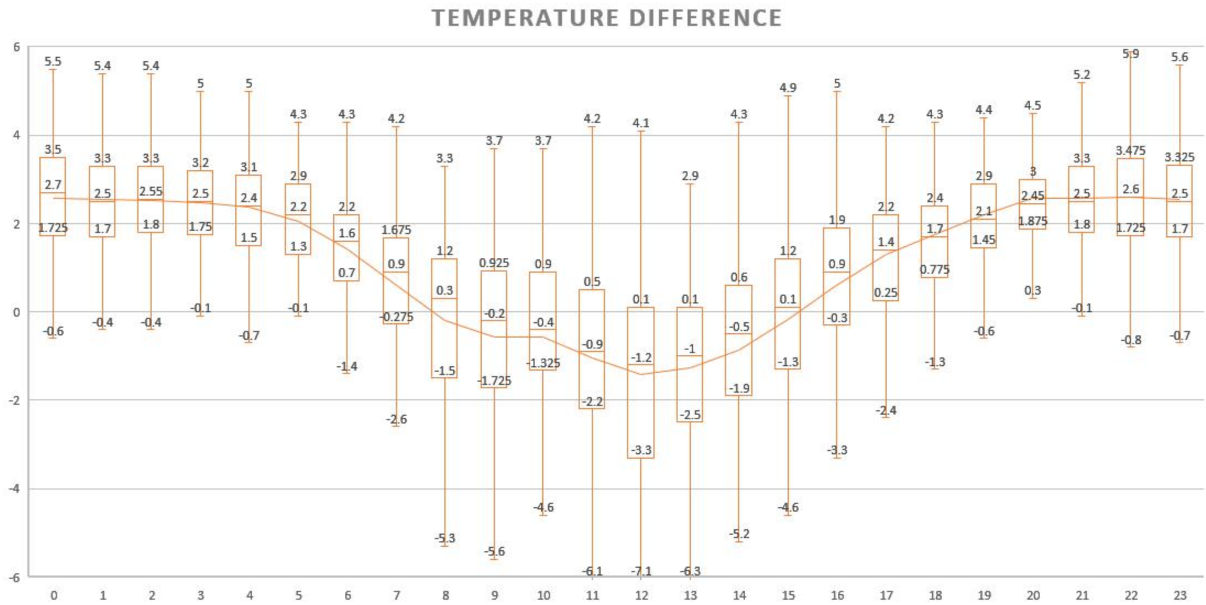

Figure 16: Temperature Difference

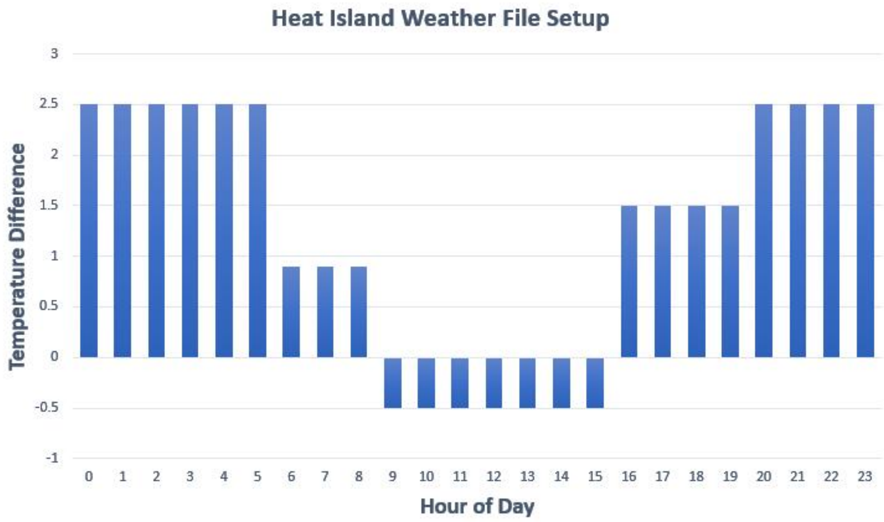

Figure 17: Heat Island Temperature Modification Rule

4.7 Static Calculation

To investigate the cause of huge deviation between previous static calculation and measurement heating demand, a new static calculation is conducted with more accurate geometry and weather information. As static calculation follows the standard method proposed by SIA 180/1. The SIA calculation is divided into several parts. Each part calculates a type of energy loss or energy gain.

4.7.1 Losses

SIA takes a number of losses into account, mainly *transmission loss* and *ventilation loss*. The *transmission loss* includes heat loss through conduction, heat loss through convection, and heat loss through thermal bridge. The losses are calculated based on the building location's heating degree days, building material thermal properties, and the dimension of building elements. The formula for the losses are given below.

Transmission Heat Loss

$$\dot{Q}_{transmission} = \frac{A_{surface} \cdot U \cdot HDD \cdot 24 \cdot 3600}{A_{floor} \cdot 10^6}$$

where:
$\dot{Q}_{transmission}$: Heat transmission in MJ/m^2
$A_{surface}$: Surface area of building element in m^2
U: U-Value of building element in W/m^2K
HDD: Heating degree days
A_{floor}: Total conditioned area of entire building

The ground floor use a different formula to calculate the heat transmission heat loss.

$$\dot{Q}_{\text{ground}} = \frac{A_c \cdot U \cdot HT \cdot \Delta T \cdot 24 \cdot 3.6}{1000 \cdot A_{floor}}$$

where:
A_c: ground area (in m^2)

HT: Heating days
U: U-value of the element
ΔT: Temperature different between heating setpoint temperature and the unheated zone temperature

The U-value of the building elements can be calculated by the formula below:

$$U = \frac{1}{R_{Ex} + R_{Layer} + R_{In}} = \frac{1}{\frac{1}{h_{ex}} + \sum_i \frac{d_i}{\lambda_i} + \frac{1}{h_{in}}}$$

where:
h_{ex}: External heat convection coefficient in W/m^K
h_{in}: Internal heat convection coefficient
R_{Layer}: Total heat resistance of building element in m^K/W
d: thickness of building element in m
λ: Thermal conductivity of building element in W/mK

Thermal Bridge Heat Loss
The loss through thermal bridges can be calculated in the following formula.

$$\dot{Q}_{TB} = \frac{\Psi \cdot L \cdot HDD \cdot 24 \cdot 3600}{A_{floor} \cdot 10^6}$$

where:
$\dot{Q}_{TB}$: Thermal bridge heat loss in MJ/m^2
L: Length of thermal bridge
Ψ: Thermal bridge loss factor
HDD: Heating degree days
A_{floor}: Total conditioned area of entire building

Ventilation Loss The ventilation heat loss is given below:

$$Q_{\text{vent}} = \frac{\dot{V} \cdot c_{p,air} \cdot HDD}{24 \cdot 1000}$$

where:
$\dot{Q}_{\text{vent}}$: Ventilation heat loss in MJ/m^2
$\dot{V} = 0.7$: Ventilation rate in $m^3/m^2 \cdot h$
$c_{p,air} = 1.16$: Heat capacity of air $kJ/m^3 \cdot K$
HDD: heating degree days

4.7.2 Gains

In SIA 380/1 calculation, heat gain can be obtained from solar radiations, internal gains by electronics, and internal gains by occupant activities.

Solar Gains
The heat gain from solar energy is given below:

$$Q_{\text{solar}} = \frac{G \cdot A_{\text{glazing}} \cdot f_1 \cdot f_2 \cdot f_3 \cdot f_g \cdot g}{A_{floor}}$$

where:
f_1, f_2, f_3, f_g: Reduction factors for shading, frames, overhangs, and impurities on the window, the values are given in previous calculations
g: g-value of the window, transmittance
G: Unit solar radiation onto the surface in MJ/m^2
A_{glazing}: Window area in m^2

Internal Gains by electronics
The heat gain from electronics comes from a factor of electricity demand.

$$\dot{Q}_{\text{elec}} = \frac{E_{unit} \cdot f_{ele} \cdot HT \cdot 3.6}{365}$$

$\dot{Q}_{\text{elec}}$: Heat gain by electronics in MJ/m^2
E_{unit}: Unit area electricity demand in kWh/m^2
$f_{ele} = 0.7$: electricity gain factor
HT: Heating day
A_{floor}: Total floor area

Internal Gains by person
The internal gain from occupant activities is given below:

$$Q_{\text{occ}} = \frac{\dot{q}_{pl} \cdot h_{\text{present}} \cdot 365 \cdot 3.6}{\text{Occ} \cdot 1000}$$

where:
$\dot{Q}_{\text{occ}}$: Internal gains by person in MJ/m^2
Occ: Unit area occupancy, Occ = $40m^2/pl$ for residential, $20m^2/pl$ for office building
$\dot{q}_{pl} = 70W/pl$: internal gain produce by a single person
h_{present}: present hour per day, 12 for residential building, 6 for office building

Total Heat Gain

$$Q_{\text{gain}} = (Q_{\text{solar}} + Q_{\text{elec}} + Q_{\text{occ}}) \cdot x$$

where x is heat gain factor given by:

$$x = \frac{\sum \text{Heat Gain}}{\sum \text{Heat Loss}}$$

4.7.3 Measurements expected to close the performance gap

The building model is firstly subject to static calculation with all standard values and assumptions. After the reference static calculation has been made, another calculation with 2015 weather information is conducted. Depend on the obtained result, further parameters are modified and try to match the calculation results with the measured annual results.

4.8 Dynamic Calculation

The dynamic analysis include a time-step calculation considering the step change of building thermal information. Therefore, EnergyPlus is used to provide an hourly analysis of the two buildings. A detailed setup of parameters are given below.

The occupancy schedule and activity level of all zones of the two buildings are from the SIA 2024 standard. The SIA 2024 standard provides a guideline assumptions for different building areas such as bedroom, bathroom, kitchen, office, and corridor.

The detailed information of is stored in separate *.csv* files which contains 8760 entries of hourly data. Below is a list of information obtained from SIA 2024.

- Heating/Cooling Setpoint temperature
- Occupancy schedule
- Activity level
- Lighting Schedule
- Lighting Level
- Domestic hot water schedule
- Domestic hot weater level
- Electricity appliance schedule and level

Figure 18 below shows the heating setpoints of all zones. Most schedules and activities have a certain weekday/weekend pattern and have different patterns in different months. Figure 19 below shows the bathroom lighting schedule in January.

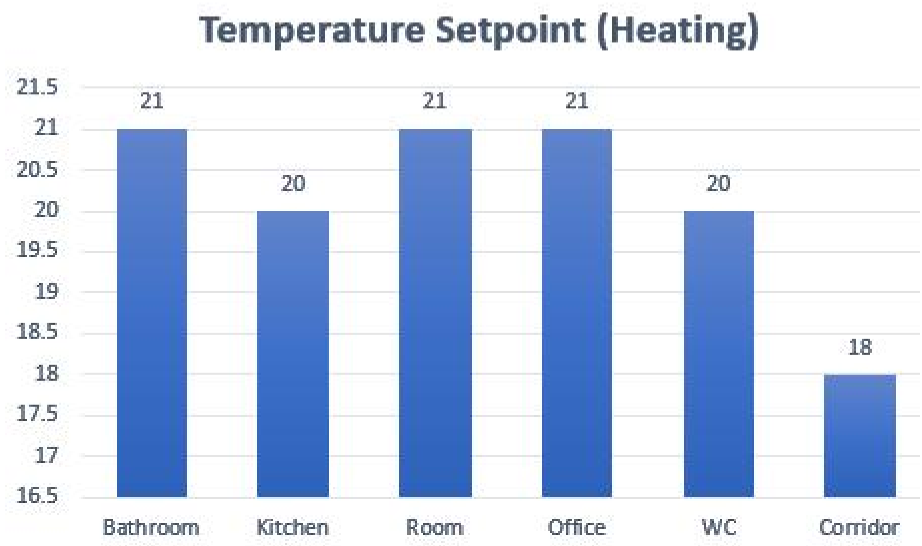

Figure 18: Heating Temperature Set point

4.9 Calibration

In order to ensure the simulated buildings have similar thermal behaviors as the real buildings, a calibration to the building envelope is needed. The calibration process needs to be in a summer period where no heating and cooling is performed. The calibration process vary the building air tightness, internal loads, and user behaviors until the calculated indoor temperature behaves similar enough to the historical measurement. Lastly, the calibrated building is again subject to annual analysis and aim to match the calculated annual energy consumption with the actual measured value.

Building Envelope Calibration

The air tightness is thought to be an important factor in building simulation. Therefore, the calibration

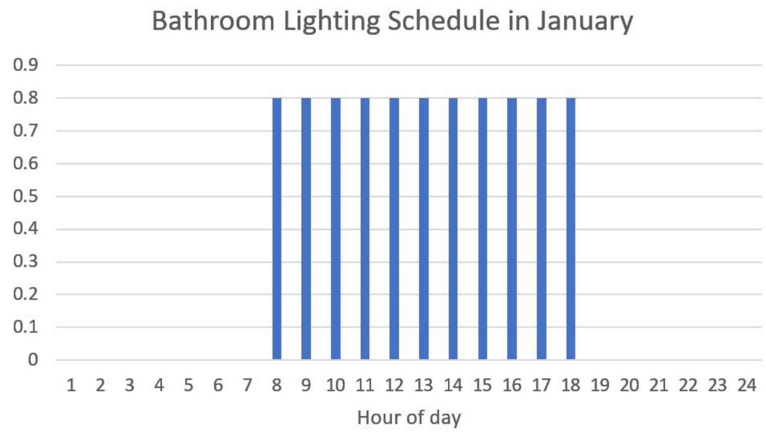

Figure 19: Bathroom Lighting Schedule in January

process would vary the air tightness between 0.1 to 0.5 ach and try to match both the hourly indoor temperature as well as the annual heating demand.

Internal Loads
Internal load such as Lighting and appliance schedule can change the indoor temperature patten. Therefore, in the calibration process, lighting schedule and electricity schedule are modified to observe the indoor temperature of the focused un-heating period. The newly constructed schedules should be separated into weekday and weekend schedule.

User behavior
The user behavior is also thought to be an influential factor to indoor comfort. The calibration also investigate the control strategies for users to operate the window shading. A number of shading control is used and the strategy with most similar indoor temperature patten is used in the calibrated model. The newly constructed shading schedule should vary between summer and winter schedule.

4.10 Parameters Variation

After the building model has been constructed and calibrated, a further analysis with varied parameters can be performed. Here are the parameters that are focused and subject to variation:

- Heating temperature setpoint for all zones
- Occupancy schedule for kay zones (except toilet, wc and corridor)
- appliance schedule for all zones (Lighting, Electricity, Domestic hot water)
- Ventilation level for all zones
- Air infiltration
- Internal convection coefficient
- External convection coefficient
- Facade solar absorptance

jE-Plus
jE-Plus is used as a tool to process the parameter variation analysis. It allows a number of preset

parameters to replace certain values in the EnergyPlus file, and allow parallel There are one thousand building samples with random combination of parameters.

Heating Temperature Setpoint

All zones' heating setpoint temperature are part of the parameter variation. The heating setpoint temperature for the same category at the same floor are thought to be identical. For example, the heating setpoint temperature of *Room2* and *Room3* at the second floor would be the same, but might be different to the heating setpoint temperatues for *Room2* and *Room3* at third floor.

The range of temperature setpoints for each zones is shown in Figure 20 below. The temperature setpoint is randomly created in a normal distribution between a pre-set range.

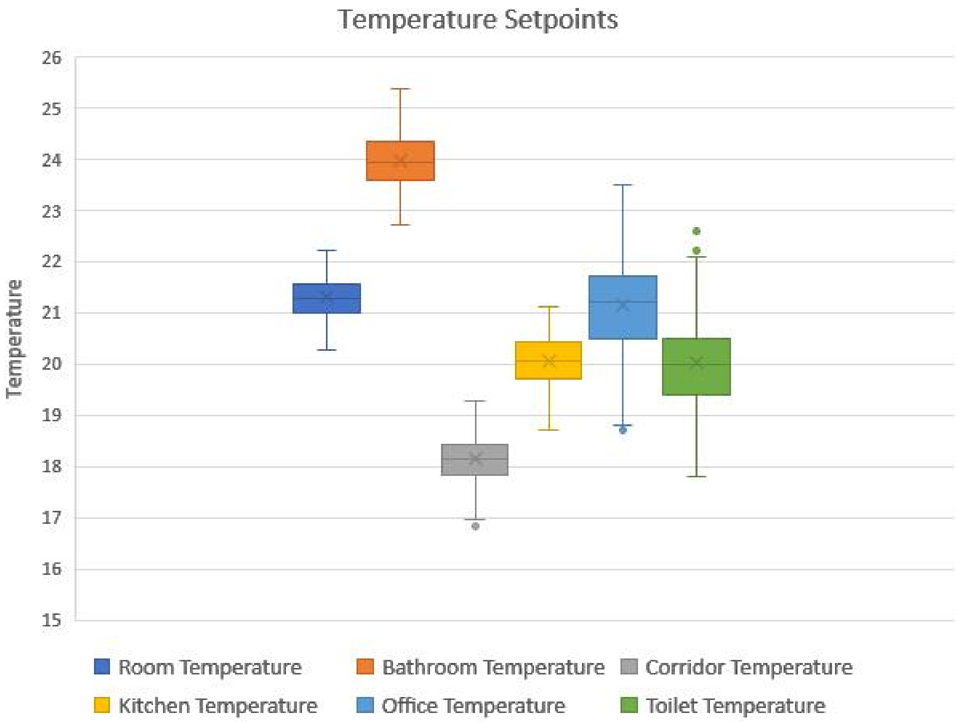

Figure 20: Heating Temperature Setpoint Distribution

Ventilation Level

Similarly, the ventilation level for each zone is given in Figure 21 below. The ventilation level for the same zone category at the same floor are thought to be identical. The ventilation level vary according to a normal distribution rule as shown in Figure 22 below.

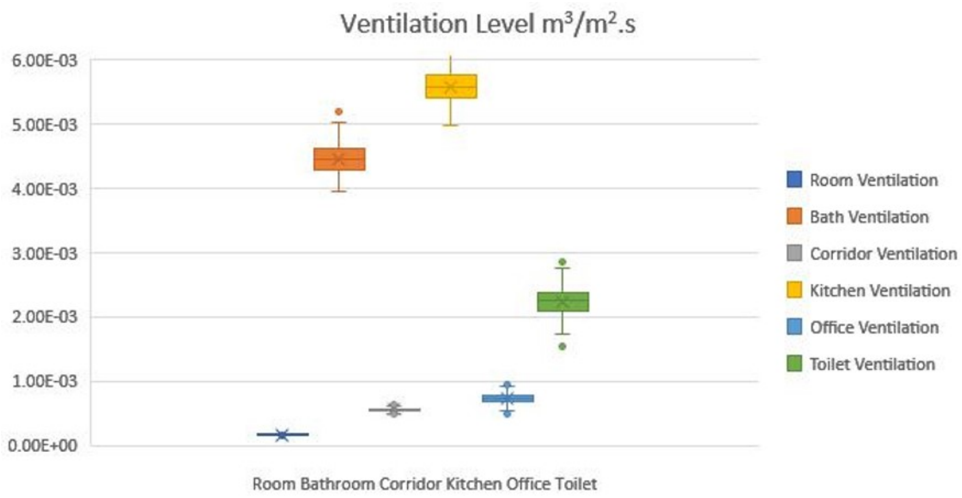

Figure 21: Ventilation Level Distribution

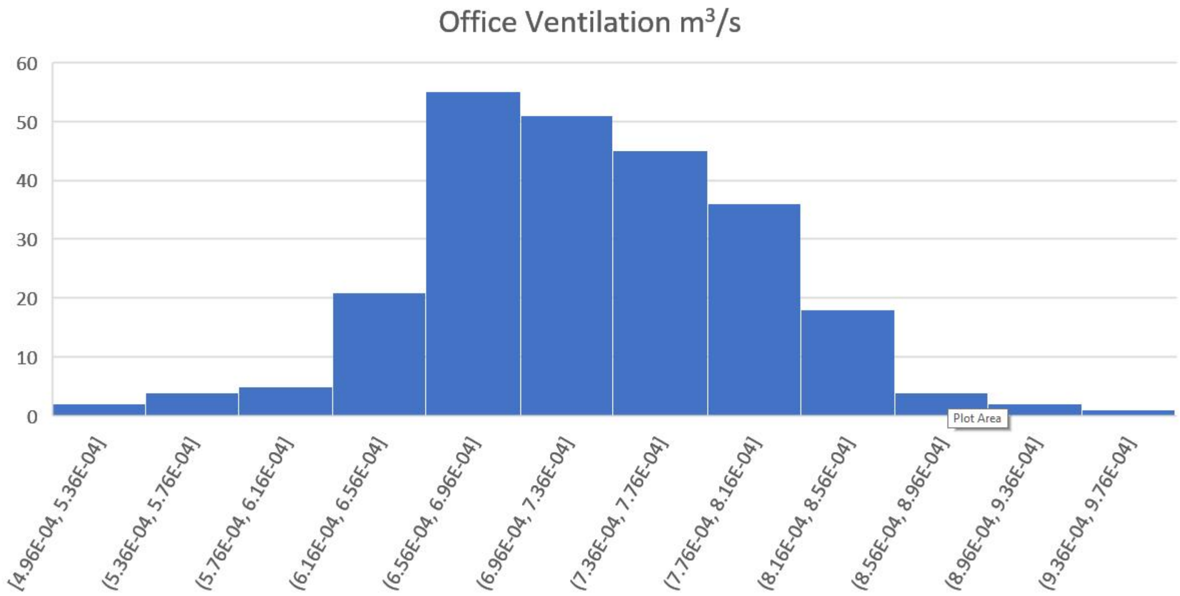

Figure 22: Air Ventilation Distribution

Infiltration
The infiltration level is roughly a normal distribution which takes $\pm$ 10% of the calibrated value as its standard deviation. Figure 23 below shows an example air infiltration distribution.

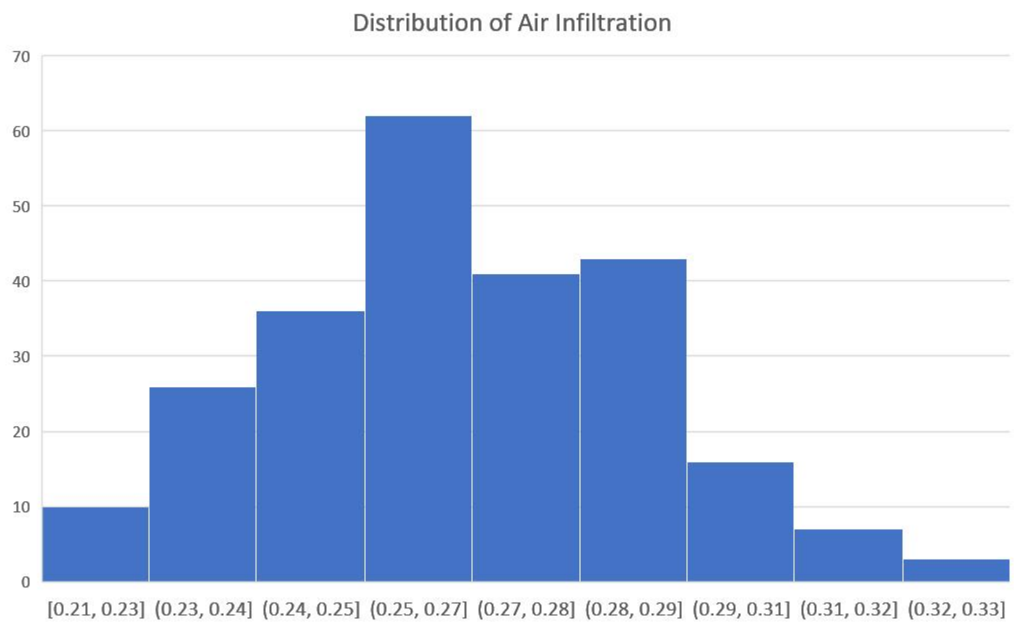

Figure 23: Example Air Infiltration Distribution

Internal and External convection coefficient
The internal and external convection coefficient range between $\pm 10\%$ of the nominal value. A discrete distribution is applied, means the probability of the convection coefficient being any number between $\pm 10\%$ of the nominal value is the same. Figure xx and Figure below shows a distribution histogram of the internal and external heat convection coefficient.

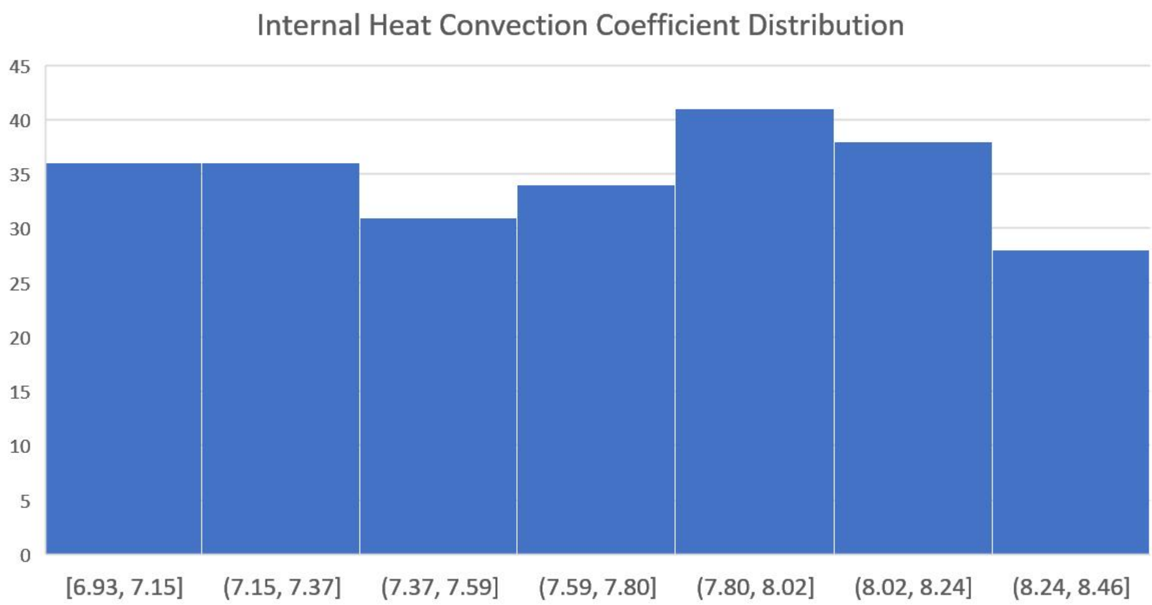

Figure 24: Internal Heat Convection Coefficient Distribution

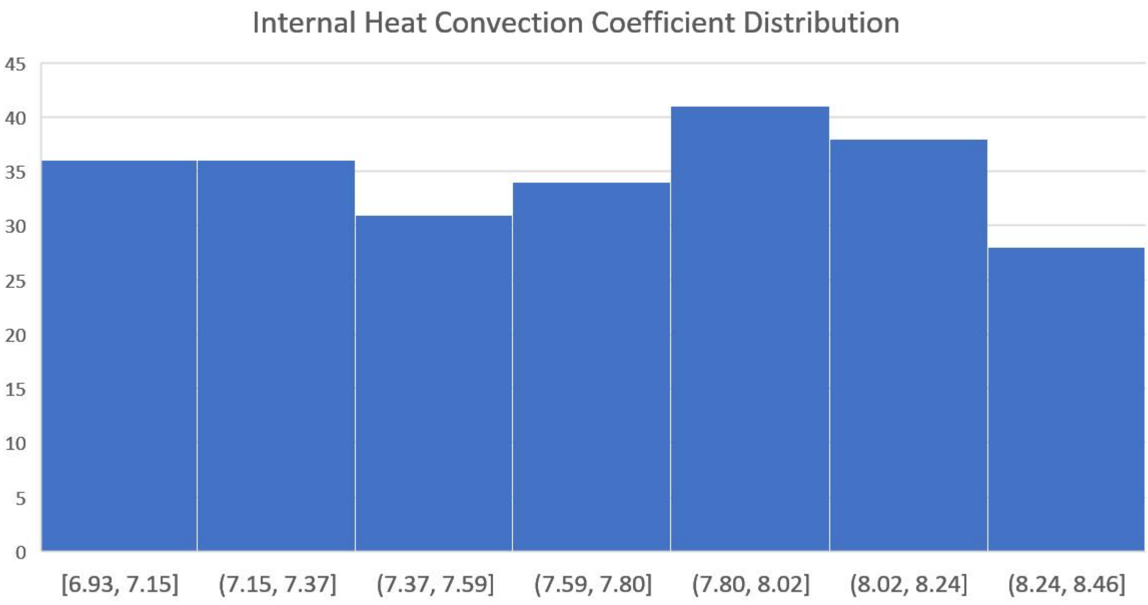

Figure 25: External Heat Convection Coefficient Distribution

Facade solar absorptance
The facade paint and facade color determine the facade solar absorptance. It range from 0 to 1 where a 0 absorptance means the surface reflex all the energy onto the surface, and a 1 absorptance means the facade absorb all the solar energy onto the surface. In this analysis the solar absorptance vary between 0.2 to 0.9 at a discrete distribution.

4.11 Data Processing

Python and Excel are used process the results, where excel is used to generate histograms and other regular charts, while Python (with Matplotlib package) is used to merge data sets, process a series of data files, generate other irregular charts such as correlation matrix, and some boxplots.

4.12 Dynamic Analysis Range

Histogram and boxplots are used to show the distribution and the range to the dynamic analysis results after the parameter variation. A box is focus on the effect of different simulation environments or parameters while a histogram focus more on the range and the distribution of a single variable.

4.13 Correlation Matrix

In order to display the relations between parameters and the relations between parameters and heating demands and DHW demands, a correlation matrix is needed to show their influence on each other.
Essentially, the correlation matrix is a heat map matrix where a deeper color represent a higher absolute value. Correlation range between -1 to 1, where -1 and 1 represent a perfect linear relationship and 0 indicates that there is no association between two variables.

5 Results

5.1 Static Calculation

The results of static calculation are shown in the following sections. Firstly the results of office building then the residential building results at each steps are shown below according the methodology. A summary is also given after each energy loss and energy gain section is presented.

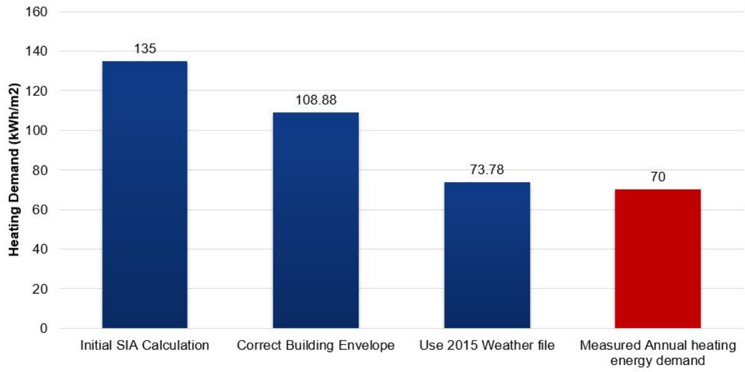

Figure 26: SIA Calculation Improvement for Office Building

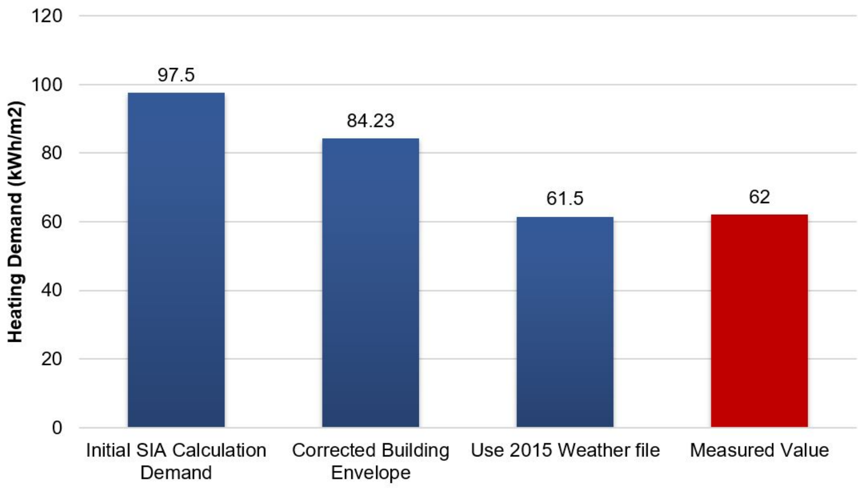

Figure 27: SIA Calculation Improvement for Residential Building

5.2 Dynamic Simulation

The dynamic simulation results are shown below in Figure 28 and Figure 29 below. Firstly, the simulation is run in 2015 weather conditions and with standard building envelope. Secondly, the air change ratio is changed to a more realistic value of 0.3 ACH. Then, the SIA standard heat convection coefficient values are applied on the model and the result shows a close match between the calculated heating demand and the measured heating demand. It appears that both buildings can obtain a very close estimation when using these approaches. However, in order to further verify the building simulation methods and parameters, a building calibration is needed for both buildings.

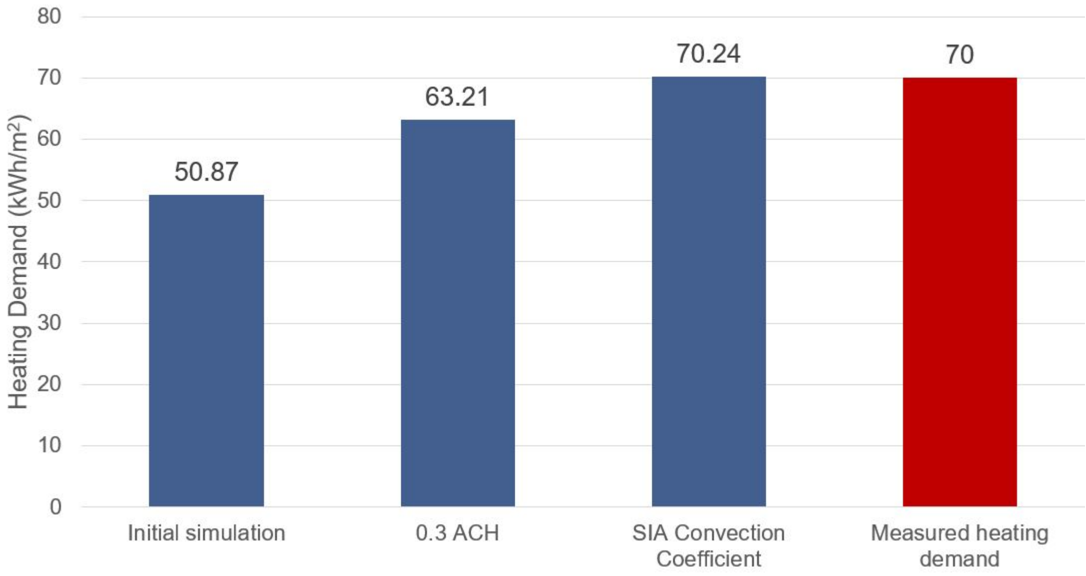

Figure 28: Office Building Dynamic Calculation Correction

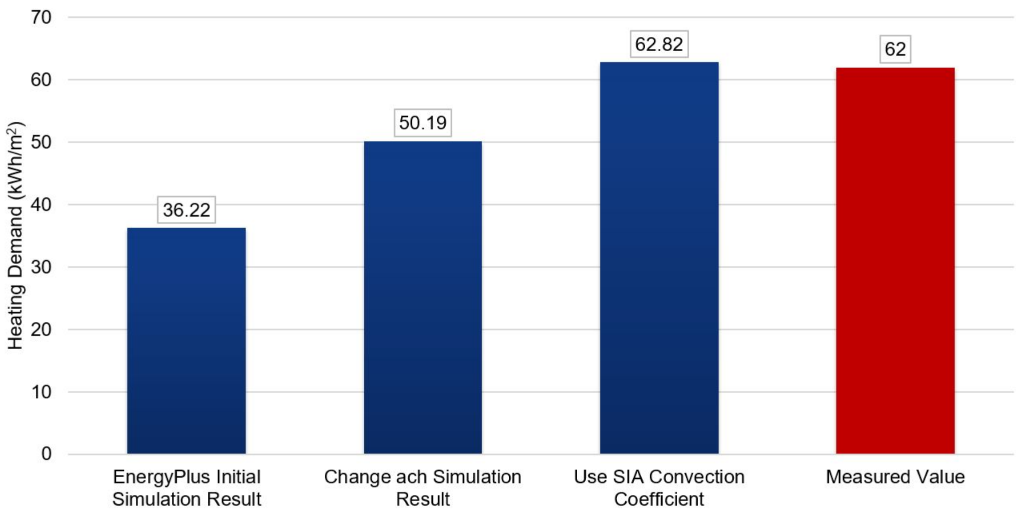

Figure 29: Residential Building Dynamic Calculation Correction

5.3 Calibration Results

Figure 30 below shows a comparison of calculated indoor temperature from 1^{st} June to 10^{th} June in 2015 in the residential building under different air tightness (0.1/0.3/0.5 air change per hour infiltration level).

The blue line with huge fluctuation represents the outdoor temperature from the weather station, the red line represents the measured indoor temperature, and the gray, orange, and dark blue line represent the calculated indoor temperature of the three rooms at the same apartment. The result indicates that the air infiltration dose not have a strong impact on indoor temperature profile. Therefore, the air infiltration is used to calibrate the annual heating demand to the measured value after the temperature profile is matched.

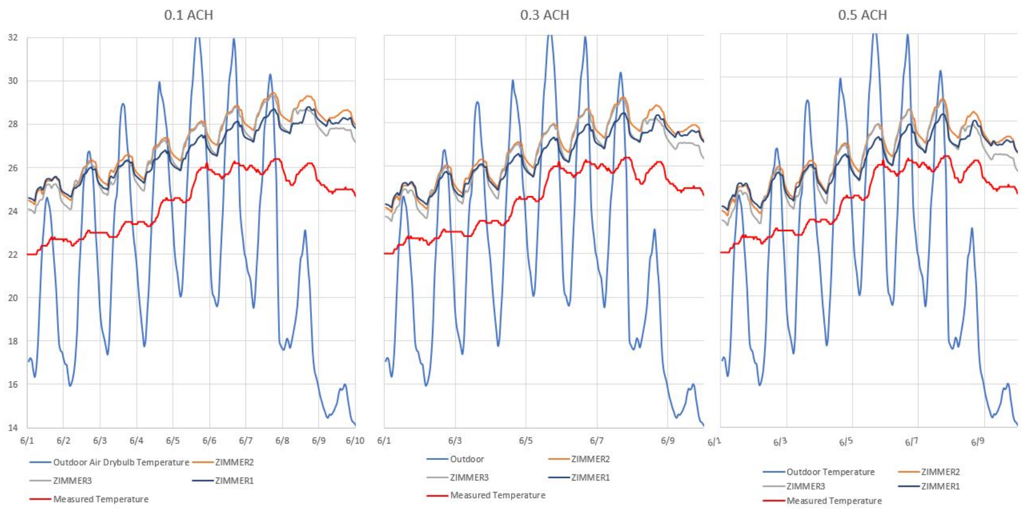

Figure 30: Origin Temperature Profile of Residential Building

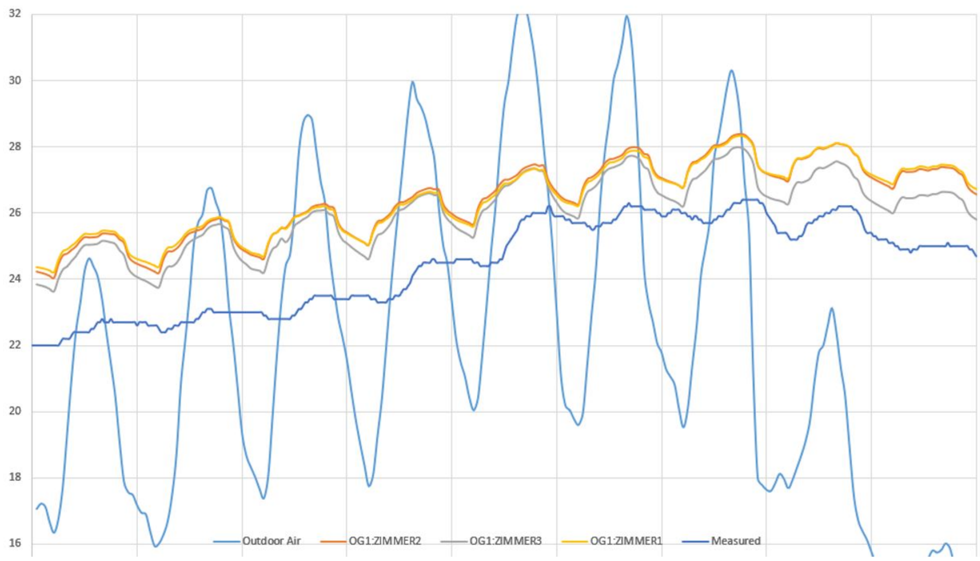

Figure 31: Origin Temperature Profile of Residential Building

Figure 31 above shows a temperature profile of the first floor apartment with 0.3 ACH infiltration. The light blue line with huge fluctuation is the outdoor temperature measured by the weather station. The The less fluctuated dark blue line represents the measured indoor temperature. The rest lines in grey, yellow and red represent the calculated indoor temperature of three bedrooms within the apartment. This origin temperature profile indicates an over-estimation on heat gains. Therefore, the calibration process aimed on reducing the internal gains by varying the building appliance schedules.

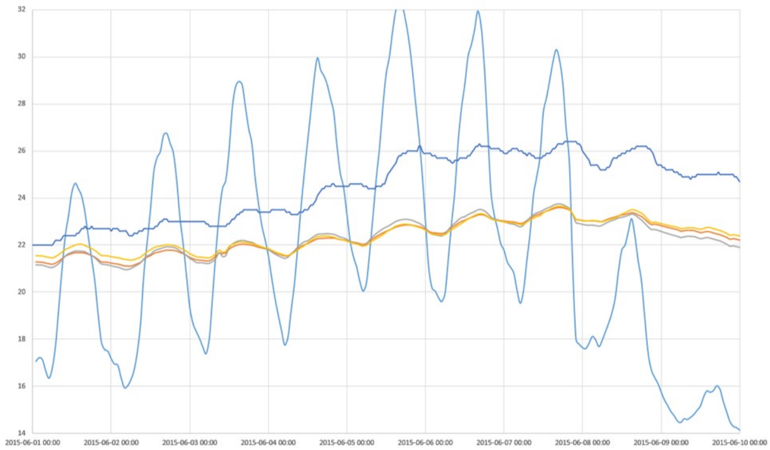

Figure 32: Temperature Profile of Residential Building Without Internal Gains

In order to verify the above conclusion, another simulation is taken with no active appliance. The result in Figure 32 proved that the wrong appliance assumption schedule is the cause of this over-heating problem. The room temperature dropped around 4 degrees when all the appliances are turned off. From the SIA 2024 schedule, the lighting schedule and lighting level for residential buildings are modified as it shows an over-estimation during daytime.

Figure 33: Temperature Profile of Residential Building with No Lighting

Figure 33 above shows the temperature profile without lighting. The highly fluctuated blue line represents the outdoor temperature, the red line represents the actual measured data, and the orange, yellow, and light green lines represent the calculated indoor temperature of three rooms. The result again indicated that the lighting schedule is the main cause of over-heating. Therefore, a new lighting schedule is created and rerun the simulation under a new lighting schedule. The new lighting schedule can be found in Table 11 below.

Table 11: New Lighting Schedule

Lighting Schedule	Weekday	Weekend
Until 02:00	0.05	0.05
Until 06:00	0.03	0.03
Until 09:00	0.5	0.3
Until 17:00	0.2	0.2
Until 22:00	0.7	0.7
Until 22:00	0.7	0.7
Until 24:00	0.2	0.5

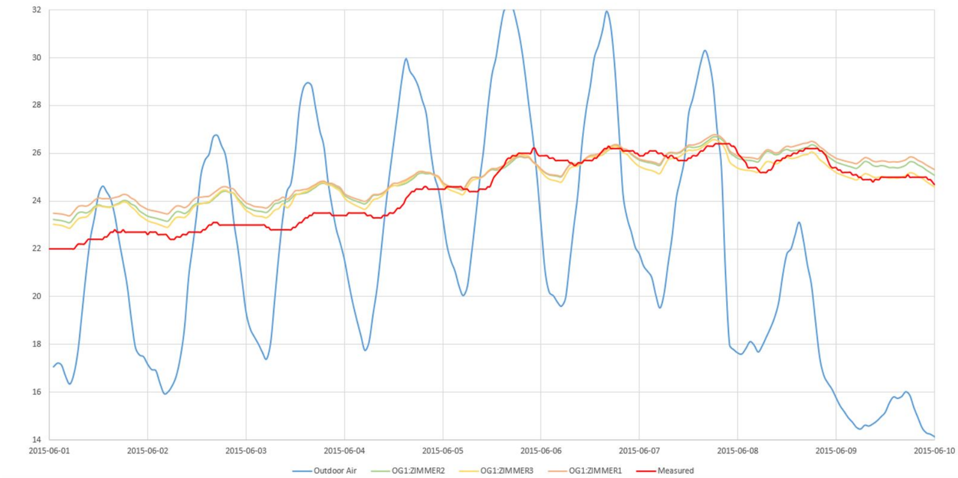

Figure 34: Temperature Profile of Residential Building with New Lighting Schedule

From Figure 34 above it is known that The origin air infiltration level is 0.3 ACH. However, the annual heating demand indicates that this setting has higher demand than the measured value. Therefore, the air infiltration is slightly decreased to 0.25 ACH in order to fit the annual heating demand.

Office Building Calibration

Similarly, the office building went through a calibration process with the same approach. Firstly, the simulation is taken without any modification. An overheating is observed from the temperature profile. As the building is mostly covered with window on the west and south side, applying shading control would probably solve the problem. To test the effect of window shadings, another simulation is done under 24/7 on shading schedule. The results in Figure 36 indicates that the shading of the actual building is mainly on, as the calculated temperature profile behaved very similar with the measured temperature profile. Therefore, it can assume that the blinds at the office building is mainly on at non-heating period. While in winter period, a modest blind control is applied and the annual heating demand is observed.

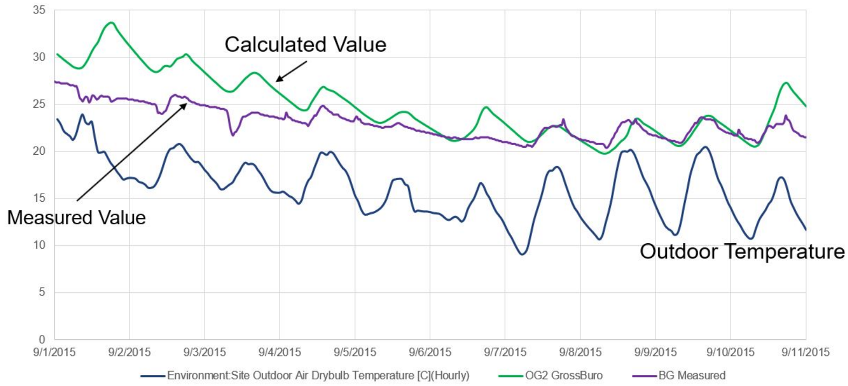

Figure 35: Origin Temperature Profile of Office Building

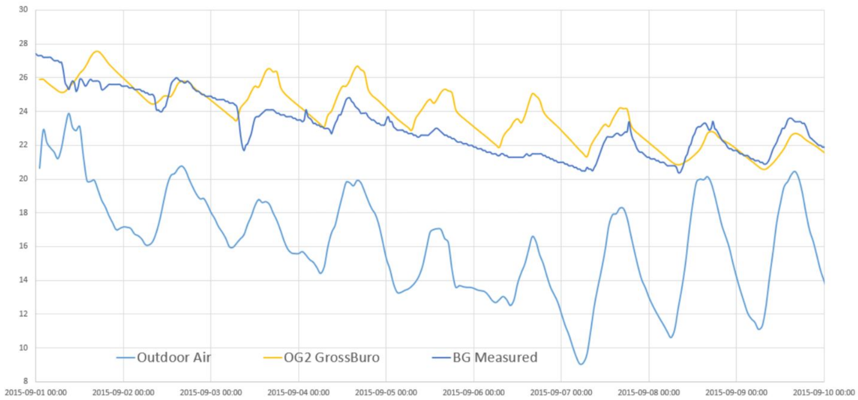

Figure 36: Temperature Profile of Office Building with 24/7 shading

Table 12 below shows a new shading control schedule in both summer and winter. Another simulation is taken after the new shading schedule is applied on the model. The result in Figure 37 below shows an identical pattern as Figure 36 in summer period. The annual heating demand for office building with different air infiltration and total ventilation level is shown below at Table 13. As the measured total heating consumption was around 70 kWh/m^2, the air infiltration is then calibrated to 0.1 ACH.

Table 12: New Shading Control Schedule

Blind Schedule	Summer	Winter
Weekday	Always on	10:00 - 16:00
Weekend	Always on	Always off

Table 13: Annual Heating Demand of Office Building in Different Ventilation Level

Infiltration Level (ACH)	Total Outdoor Air (ACH)	Heating Demand (kWh/m^2)
0.1	$\approx$ 0.87	71.87
0.2	$\approx$ 0.97	77.97
0.3	$\approx$ 1.07	84.18

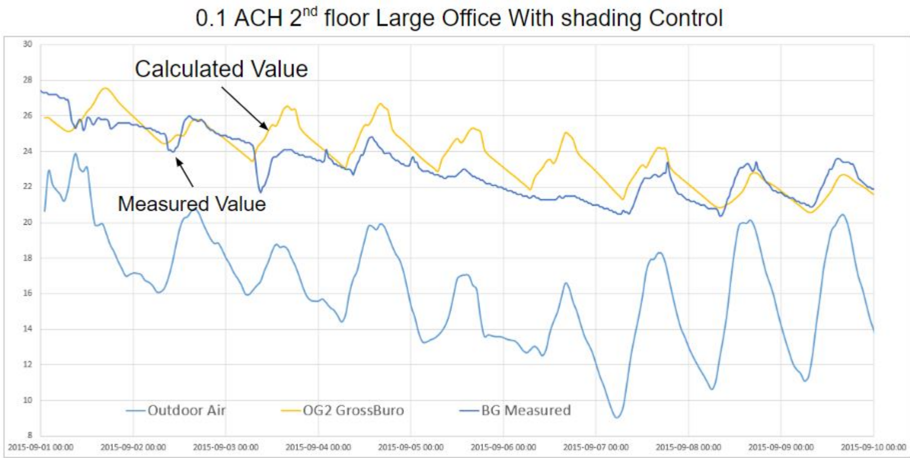

Figure 37: Temperature Profile of Office Building with new shading schedule

5.4 Parameters Variation Results

The parameters variation processes can be done after the buildings are calibrated. The results are presented in a form of histograms and correlation matrices. The histogram helps understand the range of the varied samples and the total influence to parameter variation, while the correlation matrix can better understand the correlations between parameters and parameters, or parameters and heating demand. In addition, the relationship between all parameters and the domestic hot water consumption is also observed from the correlation matrices

Figure 38 and Figure 39 below showed the heating demand histograms of the office building and the residential building. The office building has a heating demand range between 55 and 86 kWh/m^2 and the residential has a heating demand range between 48 to 68 kWh/m^2.

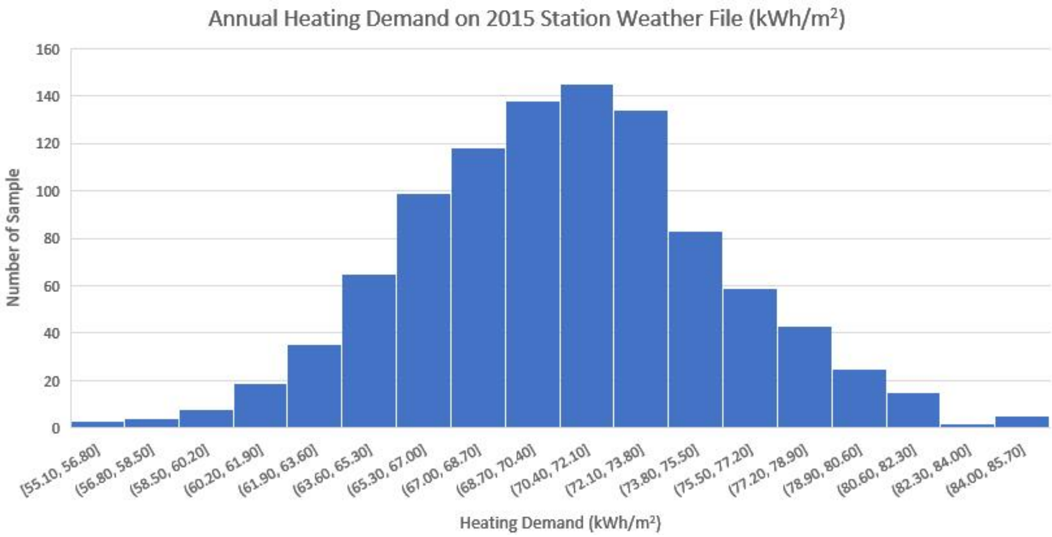

Figure 38: Office Building Heating Demand Histogram

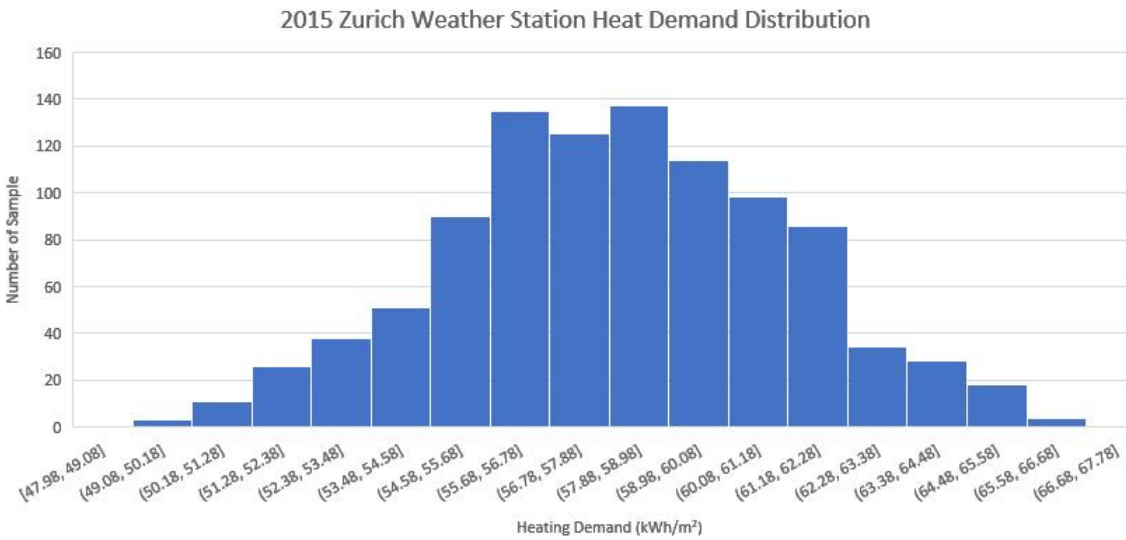

Figure 39: Residential Building Heating Demand Histogram

Figure 40 and Figure 41 below shows the correlation matrices of the office building and the residential building. Correlation matrix is a heat map with many pixels, where each pixel represent a correlation between two intersec parameters. A pixel with deep color indicates the correlation between two parameters is strong, while a pixel with light color indicates the correlation between two parameters is weak.

In this thesis, the main focus is the correlation between heating demand, domestic hot water consumption and others. Therefore, the second last row represents the correlation between domestic hot waters and other parameters, and the last row represents the correlation between heating demand and other parameters.

The correlation matrix of office building indicates that a strong correlation exists between office temperature setpoint (0.67)/solar absorptance (-0.34) and heating demand. Also, corridor temperature setpoint (0.28) and office appliance (-0.17) are the influential facters among all others. The residential building's correlation matrix also indicated that the key area setpoint temperature (0.58) and the solar absorptance (-0.45) are the influential facters to heating demand. In addition, air infiltration in residential building also showed a very strong correlation of 0.53, making it the second most strongest correlated factor among all. As for domestic hot water, both correlation matrices showed that the domestic hot water demand is strongly depended on the domestic hot water demand of the key area.

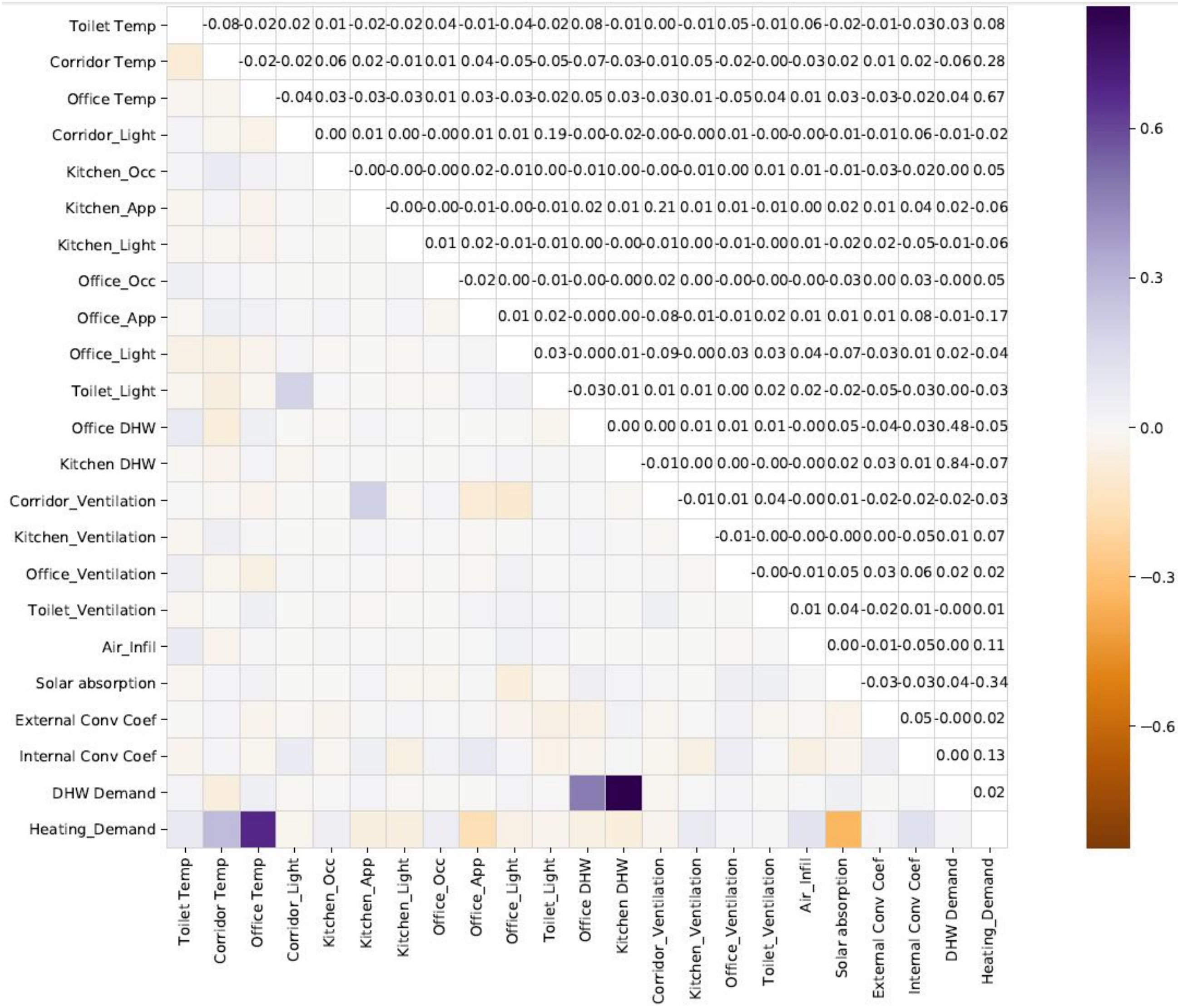

Figure 40: Office Building Correlation Matrix

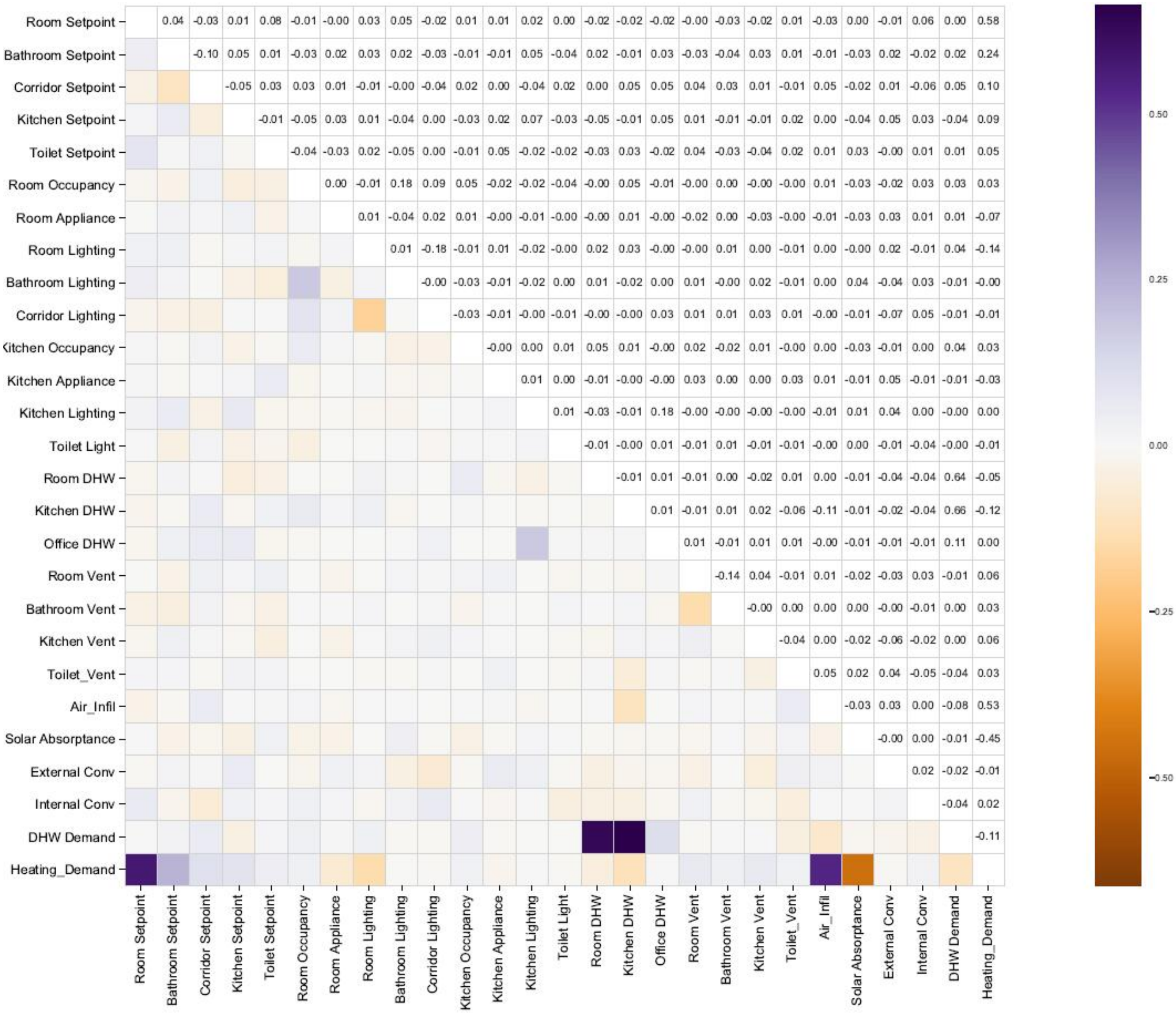

Figure 41: Residential Building Correlation Matrix

5.5 Effect of Solar Absorptance on Heating Demand

In order to prove the influence of solar absorptance on heating demand, an extra set of 150 samples with different solar absorptance in the residential building are processed in jE-Plus and the results are displayed at Figure **??** below.

The results above show that solar absorptance has proven its ability to influence the heating demand. By solely changing the solar absorptance, the heating demand can achieve a $\pm4\%$ variation on the residential building. As 50% of the 1000 parameter variation samples fall within the range of $\pm3.4\%$ of average energy consumption (the residential building), it can conclude that solar absorptance in external facade is worth to be taken into account in energy calculations.

5.6 Effect of Convection Coefficient on Heating Demand

As the correlation matrix above indicates a weak correlation between heating demand and heat convection coefficients, which is contradicted to the hypothesis that heat convection coefficient is an important factor in heating demand calculation, another set of simulation with 150 extra samples are processed.

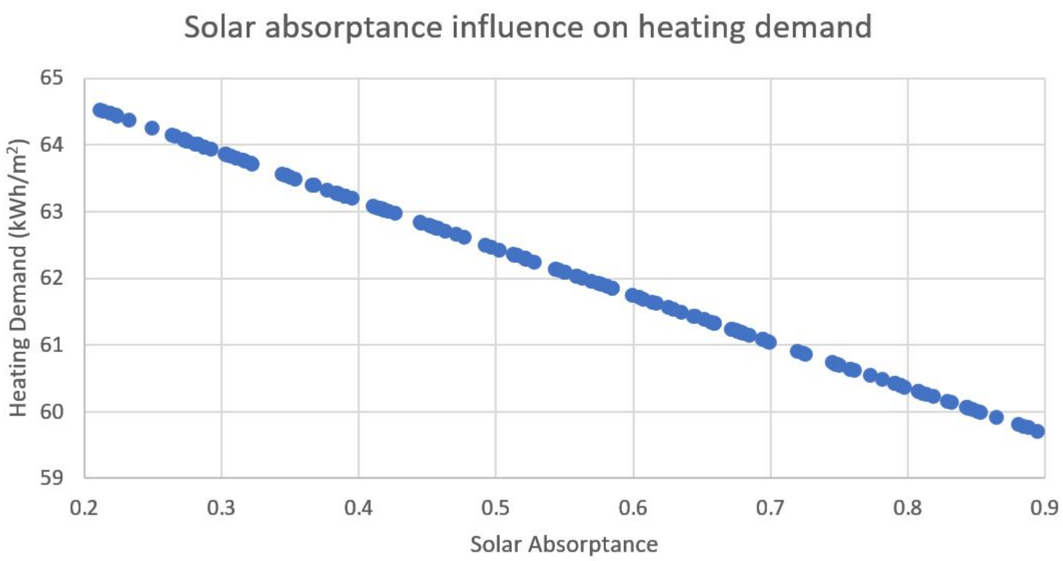

Figure 42: Influence of Solar Absorptance on Heating Demand (Residential Building)

These samples are modified from the calibrated building model, with the only difference in convection coefficient (ranging from 90% to 110% of the calibrated values).The results shown in the Figure below indicate a $\pm 2\%$ variation on heating demand. Therefore, it is clear that $\pm 10\%$ of the heat convection coefficient would have less effects on heating demand than altering the solar absorptance from 0.2 to 0.9.

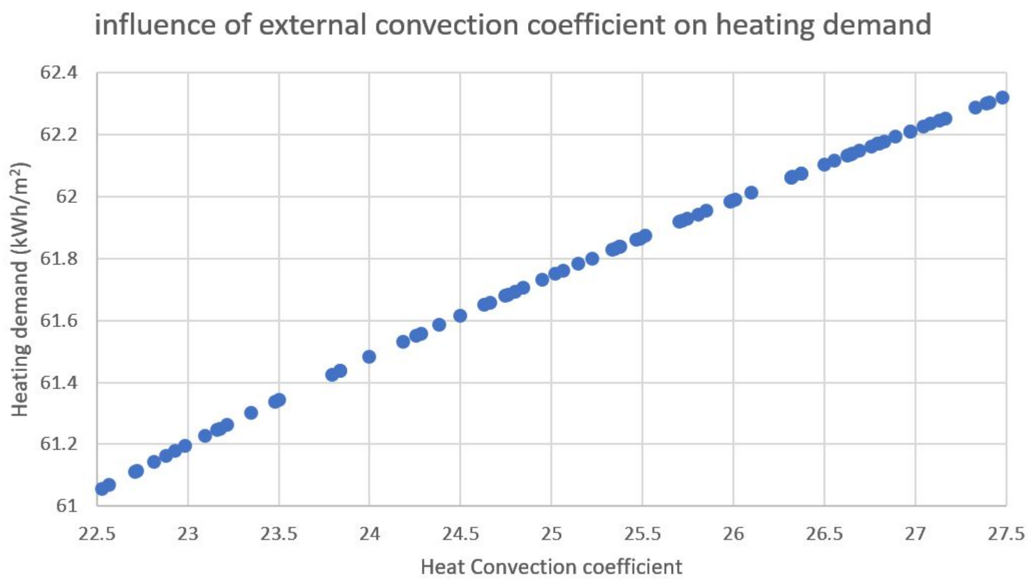

Figure 43: Influence of Heat Convection Coefficient on Heating Demand (Residential Building)

5.6.1 Global Warming and Heat Island Effect

Figure 44 and 45 shows the heating demand range after the parameter variation in three different outdoor environments, namely, the SIA standard hourly data, the 2015 station weather, and the generated heat island weather based on the 2015 station weather. The annual heating demand range shows a clear decline as the outdoor environment gets warmer.

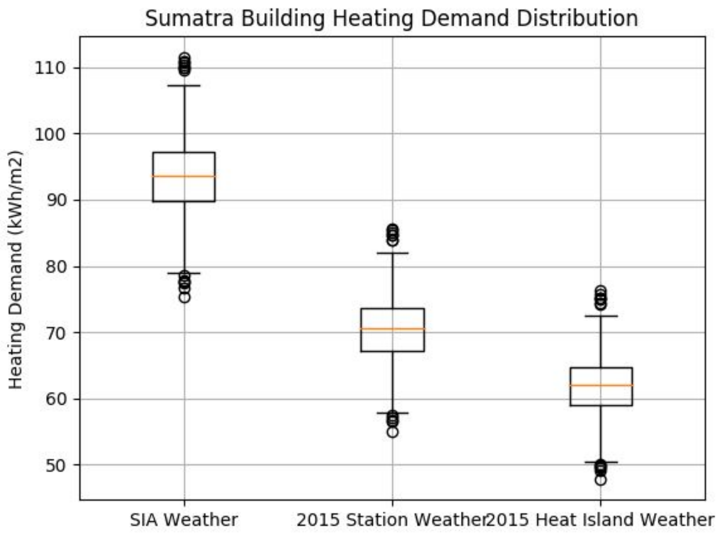

Figure 44: Office Building Heating Demand Comparison

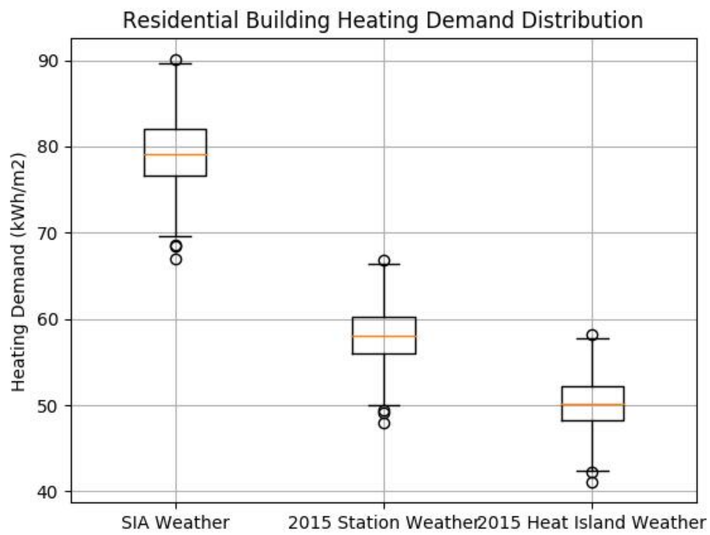

Figure 45: Residential Building Heating Demand Comparison

6 Discussion

From the calculation and simulation results above, there are a few points that worth mentioning. For static calculation, the SIA 380/1 standard calculatiom method can achieve a reasonably accurate result when an updated weather information is implemented. The standard can probably consider using internal (net) area instead of external (gross) area for energy calculation, as it provides a more accurate results when net area (excluding walls) is used in calculation.

For dynamic simulation, weather information is also critical as global warming effect and heat island effect makes the outdoor temperature greatly differ from its assumed values. Also, a more accurate algorithm to simulate heat island effect is needed, as the temperature in city area can differ largely from the weather station's temperature even they are very close to each other. In addition, calibration process is important for analyzing the hourly building performance and gives more confident in annual energy analyses.

At the current stage, it is known that the performance gap come from a number of wrong assumptions of building parameters and schedules. However, these wrong assumptions managed to achieve an internal balance and the combination of these current standard assumptions can indeed provide a reasonably accurate results in macroscopic scale (annual per square meter demand for example). For example, an over estimated heat convection coefficient may lead to a higher energy demand, but an over estimated internal loads would lead to a lower energy demand, and the effect of both over estimation cancel each other. To obtain true accuracy, review or modification are needed for not only a single parameters but also all the others. Improving a single assumption without considering others would even lead to more diverse and inaccurate results.

7 Conclusion

In conclusion, this thesis aims to reduce the deviation between calculated and measured heating demands and find the limitations and short-comings in SIA 380/1 calculation method. A residential building and an office building are accurately modeled and calculated using EnergyPlus and SIA 180 standard calculation method. Both buildings are calibrated then subjected to a large number of simulations with different parameters. The results indicate that the most influential parameters in simulation are key area temperature heating set points, external wall solar absorptance, infiltration and key area lighting schedules. The results also show that the current SIA 380/1 and SIA 2024 schedule would provide a reasonably accurate result if correct weather information is obtained. This is, however, due to a mutuel cancelation effect of a few coupling unappropriated assumptions. In order to obtain true simulation accuracy and reduce the performance gap, it is recommended to create an accurate building envelope and apply accurate outdoor environment, as well as using a set of more comprehensive and accurate occupancy and schedule assumptions.

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8 Appendix

8.1 Assumptions

Adiabatic Walls
As the residential building is attached to other buildings on both sides, the two walls that attach other buildings are seen as adiabatic. Similarily, as the north facade of the office building is attached to another building, it is also seen as adiabatic wall.

No underground warehouses
The cellar of the residential building is not considered in this thesis and assume a constant temperature of 18 degree environment attach the ground floor.

Ignore the tilted roof and loft
Due to lack of information about the internal layout of the top floor, the tilted roof and the loft of the residential building is represented as a regular size floor with exactly the same layout as the first floor.

Ignore the vegitation covering
The majority part of the northen and the easten facade of the office building as well as both external walls of the residential building are covered with plants. However, as the effect of vegitation covering is unknow, the vegitation layer of these facade is ignored in the modeling and analysis process.

8.2 TARP Algorithm for convection coefficient

$$h_c = h_f + h_n$$

$$h_f = 2.537 W_f R_f \left(\frac{P V_z}{A} \right)^{\frac{1}{2}}$$

$$W_f = 1 \text{ Windward surface}$$

$$W_f = 0.5 \text{ Leeward surface}$$

$$R_f = 1.67\text{: Brick}$$

$$R_f = 1.52\text{: Concrete}$$

$$R_f = 1.13\text{: Clear pine}$$

$$R_f = 1\text{: glass}$$

$$h_n = 1.31 |\Delta T|^{1/3}$$

for vertical surface

Table 14: Heat Transmission Heat Loss of Residential Building

Heat Transmission Loss				
	Area m2	U-Value W/m2.K	Loss (SIA) MJ/m2	Loss(2015) MJ/m2
Outside Wall	208.6088	1.006	152.60	117.63
Window FE-EG-1a	9.9	2.379	17.13	13.21
Window FE-EG-2a	26	2.388	45.16	34.82
Window FE-EG-3a	3	2.19	4.78	3.68
Window FE-EG-4a	20.8	2.285	34.57	26.65
Window FE-TH-1a	3.7	2.33	6.27	4.83
Door Tur-TH	2.5	3.5	6.36	4.91
Ceiling	101.2115	1.6145418	37.92	31.90
Ground floor	101.2115	1.3504216	31.72	26.69
Total			336.52	264.32

8.3 Detailed SIA Calculation

8.3.1 Residential Building Heating Demand

Transmission Heat Loss

Table 14 below show a the transmission heat loss for each building element under both SIA 381/2 weather data and the 2015 weather station data. The unit of heat loss is in MJ/m^2.

Ventilation Heat Loss

Table 15 below shows the monthly and the annual ventilation heat loss per m^2 of floor area under monthly SIA 382/1 weather data and 2015 Zurich weather station data. Similarly, the energy loss is in MJ/m^2.

Table 15: Residential Building Ventilation Heat Loss

Ventilation Heat Loss MJ/m2													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Heating Degree Days (2015)	498	519	344	149	30.6	0	0	0	17.8	225	268	462	2513
Heating Degree Days (SIA)	615	501	467	255	110	23	7	6	35	207	433	601	3260
Ventilation Loss SIA	12	9.76	9.1	4.97	2.14	0.45	0.14	0.12	0.68	4.03	8.44	11.7	63.53
Ventilation Heat loss 2015	9.71	10.1	6.7	2.9	0.6	0	0	0	0.35	4.38	5.23	9	48.98

Heat Loss Through Thermal Bridge

The heat loss through thermal bridge of all building elements are shown below in Table 16 below.

Table 16: Thermal Bridge Calculation For Residential Building

Nr.	Component		Lost Coefficient W/mK	Length m	H(U*A*b) W/K	SIA 381/2 MJ/m2	2015 Zurich MJ/m2
1	Tür-TH	(Sturz)	0.1	1	0.1	0.07323747	0.056459083
2	Tür-TH	(Brüstung)	0.1	1	0.1	0.07323747	0.056459083
3	Tür-TH	(Leibung)	0.1	5	0.5	0.36618737	0.282295415
4	FE-EG-1a	(Sturz)	0.1	3.6	0.36	0.26365491	0.203252699
5	FE-EG-1a	(Brüstung)	0.1	3.6	0.36	0.26365491	0.203252699
6	FE-EG-1a	(Leibung)	0.1	5.8	0.58	0.42477735	0.327462681
7	FE-EG-2a	(Sturz)	0.1	10	1	0.73237474	0.56459083
8	FE-EG-2a	(Brüstung)	0.1	10	1	0.73237474	0.56459083
9	FE-EG-2a	(Leibung)	0.1	52	5.2	3.80834863	2.935872315
10	FE-EG-3a	(Sturz)	0.1	2.5	0.25	0.18309368	0.141147707
11	FE-EG-3a	(Brüstung)	0.1	2.5	0.25	0.18309368	0.141147707
12	FE-EG-3a	(Leibung)	0.1	12	1.2	0.87884968	0.677508996
13	FE-EG-4a	(Sturz)	0.1	13	1.3	0.95208716	0.733968079
14	FE-EG-4a	(Brüstung)	0.1	13	1.3	0.95208716	0.733968079
15	FE-EG-4a	(Leibung)	0.1	41.6	4.16	3.0466789	2.348697852
16	FE-TH-1a	(Sturz)	0.1	3.68	0.37	0.27097865	0.208898607
17	FE-TH-1a	(Brüstung)	0.1	3.68	0.37	0.27097865	0.208898607
18	FE-TH-1a	(Leibung)	0.1	7.8	0.78	0.57125229	0.440380847
	Total			191.8		14.05	10.83

Internal Gains by Occupants

Table 17: Internal Gains by Occupants in Residential Building

Internal Gains by person			
Occupancy m2/P	Unit Gain W/P	Present hour	Gain (MJ/m2)
40	70	12	27.594

Internal Gains by Electronics

Table 18: Heat Gain by Electronics in Residential Building

Internal Gains by electronics				
Weather data	Unit demand (kWh/m2)	Factor	Heating Day	Heat Gain (MJ/m2)
2015	28	0.7	175	33.83
SIA	28	0.7	208	40.21

Internal Gains by Solar Radiation

Table 19: Solar Gains in Residential Building

Solar Gains (MJ/m^2)											
Window Names	Orient	Area	f1	f2	f3	fg	g	Radiation SIA	Radiation 2015	Solar Gain (SIA)	Solar Gain (2015)
FE-EG-1a	NE	6.9	0.89	0.97	0.99	0.64	0.5	1563.92	1388.59	7.62	6.77
FE-EG-2a	NE	10.4	0.89	0.97	0.99	0.53	0.5	1563.92	1388.59	9.51	8.45
FE-EG-2a	SW	15.6	0.82	0.97	0.98	0.53	0.5	2653.31	2683.81	22.08	22.34
FE-EG-3a	SW	3	0.82	0.97	0.98	0.3	0.5	2653.31	2683.81	2.40	2.43
FE-EG-4a	NE	14.4	0.89	0.97	0.99	0.5	0.5	1563.92	1388.59	12.43	11.03
FE-EG-4a	SW	6.4	0.82	0.97	0.98	0.5	0.5	2653.31	2683.81	8.55	8.64
FE-TH-1a	NE	2.88	0.89	0.97	0.99	0.54	0.5	1563.92	1388.59	2.68	2.38
FE-TH-1a	SW	2.8	0.82	0.97	0.98	0.54	0.5	2653.31	2683.81	4.04	4.08
Total										69.32	66.13

8.3.2 Office Building Calculation Results

Transmission Heat Loss

Table 20: Transmission Heat Loss of Office Building

Heat Transmission Loss MJ/m^2				
	Area	U-Value	Loss (SIA)	Loss (2015)
Earth Wall East	121.73	3.47	143.92	110.94
External Wall East	110.34	0.96	36.16	27.88
Outside Wall Other	159.35	1.37	74.43	57.38
Window FE1	198.00	2.00	134.98	104.05
Window FE2	8.13	2.50	6.92	5.33
Window FE3	2.70	2.50	2.30	1.77
Window FE4	10.50	2.05	7.32	5.65
Window FE5	7.79	2.07	5.50	4.24
Window FE6	4.50	2.03	3.11	2.40
Window FE7	5.76	2.04	4.01	3.09
Window FE8	2.93	1.91	1.90	1.47
Ceiling	231.96	0.88	69.39	53.49
Ground floor	231.96	1.90	38.32	32.24
Total			528.26	409.92

Ventilation Heat Loss

Table 21: Ventilation Heat Loss of Office Building

Ventilation Heat Loss (MJ/m2)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
HDD 2015	498.3	518.9	343.8	148.6	30.6	0.0	0.0	0.0	17.8	224.9	268.3	461.9	2513.15
HDD SIA	615.0	501.0	467.0	255.0	110.0	23.0	7.0	6.0	35.0	207.0	433.0	601.0	3260.00
Ventilation Loss 2015	9.71	10.11	6.70	2.90	0.60	0.00	0.00	0.00	0.35	4.38	5.23	9.00	48.98
Ventilation Loss SIA	11.99	9.76	9.10	4.97	2.14	0.45	0.14	0.12	0.68	4.03	8.44	11.71	63.53

Heat Loss Through Thermal Bridge

Table 22: Thermal Bridge Heat Loss in Office Building

Thermal Bridge Loss in Office Building (MJ/m^2)						
Code			Ψ	Length m	Loss (SIA)	Loss (2015)
FE	1	(Sturz)	0.5	99	16.864	11.772
FE	1	(Brüstung)	0.5	99	16.864	11.772
FE	1	(Leibung)	0.5	132	22.486	15.696
FE	2	(Sturz)	0.5	3	0.511	0.357
FE	2	(Brüstung)	0.5	3	0.511	0.357
FE	2	(Leibung)	0.5	5.4	0.920	0.642
FE	3	(Sturz)	0.5	1.35	0.230	0.161
FE	3	(Brüstung)	0.5	1.35	0.230	0.161
FE	3	(Leibung)	0.5	4	0.681	0.476
FE	4	(Sturz)	0.5	5.1	0.869	0.606
FE	4	(Brüstung)	0.5	5.1	0.869	0.606
FE	4	(Leibung)	0.5	12	2.044	1.427
FE	5	(Sturz)	0.5	3.9	0.664	0.464
FE	5	(Brüstung)	0.5	3.9	0.664	0.464
FE	5	(Leibung)	0.5	12	2.044	1.427
FE	6	(Sturz)	0.5	3	0.511	0.357
FE	6	(Brüstung)	0.5	3	0.511	0.357
FE	6	(Leibung)	0.5	6	1.022	0.713
FE	7	(Sturz)	0.5	3.2	0.545	0.381
FE	7	(Brüstung)	0.5	3.2	0.545	0.381
FE	7	(Leibung)	0.5	7.2	1.226	0.856
FE	8	(Sturz)	0.5	3.9	0.664	0.464
FE	8	(Brüstung)	0.5	3.9	0.664	0.464
FE	8	(Leibung)	0.5	4.5	0.767	0.535
Total				428	72.908	50.894

Internal Gains by Occupants

Table 23: Internal Gains by Occupants in Office Building

Internal Gains by person			
Occupancy m2/P	Unit Gain W/P	Present hour (per day)	Gain (MJ/m2)
20	80	6	31.536

Internal Gains by Electronics

Table 24: Internal Gains by Electronics

Internal Gains by electronics				
Weather Data	Unit Demand (MJ/m2)	Factor	HT (heating day)	Heat Gain (MJ/m2)
SIA	8	0.9	175	3.45
2015	8	0.9	208	4.10

Internal Gains by Solar Radiation

Table 25: Solar Gains in Office Building

Heat Gains through windows											
Window Names	Orient	Area m2	f1	f2	f3	fg	g	Radiation SIA	Radiation 2015	Solar Gain SIA	Solar Gain 2015
FE1	S	36	0.96	0.98	0.97	0.64	0.7	3133	2786.25	55.78	49.60
FE1	W	162	0.94	0.98	0.97	0.64	0.7	2303	2140.71	180.65	167.92
FE2	W	8.125	0.82	0.98	0.97	1	0.7	2303	2140.71	12.35	11.48
FE3	E	2.7	0.82	0.98	0.97	1	0.7	2248	2176.09	4.01	3.88
FE4	S	10.5	0.96	0.98	0.98	0.48	0.7	3133	2786.25	12.33	10.96
FE5	S	7.794	0.96	0.98	0.98	0.39	0.7	3133	2786.25	7.43	6.61
FE6	S	4.5	0.89	0.98	0.97	0.4	0.7	3133	2786.25	4.04	3.59
FE7	E	5.76	0.82	0.98	0.97	0.44	0.7	2248	2176.09	3.76	3.64
FE8	E	2.925	0.81	0.98	0.97	0.2	0.7	2248	2176.09	0.86	0.83
Total										281.20	258.52