

Performance Gap

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Contents

1	Abstract	4
2	Introduction	5
2.1	Background	5
2.2	Purpose and scope of this thesis	5
2.3	Description of this thesis	5
2.4	Office Building Introduction	5
2.5	Residential Building Introduction	7
3	Literature Review	10
3.1	Root Causes of Performance Gap	10
3.1.1	Design and simulation problem	10
3.1.2	Contractors	10
3.1.3	User behaviors	10
3.2	Strategies For Closing Performance Gap	11
3.2.1	Design Concept	11
3.2.2	Technology and methods (T&M)	11
3.2.3	”Soft” Measures	14
3.3	Selection of Simulation Tools	14
3.4	SIA Documentations	15
3.5	Previous Research	16
4	Methodology	17
4.1	Building Model Construction	17
4.1.1	Building Geometry	17
4.1.2	Building Envelope Material	20
4.1.3	Assumptions	22
4.2	Weather Data Selection	24
4.2.1	Weather Data For Static Calculation	24
4.2.2	Weather Data For Dynamic Calculation	25
4.3	Static Calculation	28
4.3.1	Heat Losses	28
4.3.2	Heat Gains	29
4.3.3	Measurements expected to close the performance gap	30
4.4	Dynamic Analysis	30
4.4.1	Schedule and Occupancy Assumptions	30
4.5	jEPlus Dynamic Simulation	31
4.5.1	Basic description of je-Plus	31
4.5.2	Dynamic Parameter Assumptions	31
4.6	Calibration	31
4.6.1	Outdoor Environment Calibration	31
4.6.2	Building Envelope Calibration	31
4.7	Data Processing	31
4.7.1	Dynamic Analysis Range	32
4.7.2	Correlation Matrix	32

5	Results	33
5.1	Initial Annual Energy Analysis	33
5.1.1	SIA Calculation	33
5.1.2	EnergyPlus Simulation Result	33
5.1.3	Calibration	34
5.1.4	jE-Plus Simulation Results	34
6	Discussion	35
7	Conclusion	36

1 Abstract

This thesis aims to reduce the deviation between calculated and measured heating demands. A residential building and an office building are accurately modeled and calculated using EnergyPlus and SIA 180 standard. Both buildings are firstly calibrated based on historical annual heating demand and hourly indoor temperature, then several key building parameters are changed into different values. Based on the a large number of simulations, the result indicated that the most influential parameters in simulation are key area temperature heating set points, external wall solar absorptance, infiltration and lighting schedule. In order to reduce the performance gap, it is recommended to create an accurate building envelope and apply accurate outdoor environment. Therefore, an update to SIA standard weather data is also recommended. [1]

2 Introduction

2.1 Background

Building simulation are widely used for different purposes such as to benchmark buildings or to evaluate energy demands and indoor thermal comforts. However, due to a number of factors, there are always deviations between calculated value and measurement value, which is also called **performance gap**. Previous studies which used standardized method **SIA 180/1** to calculate the heating demand of several buildings observed considerably large performance gap in uninsulated buildings.

2.2 Purpose and scope of this thesis

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 in building simulation. In addition, this thesis also aim to investigate how the resulting energy demand variations affect the performance gap.

2.3 Description of this thesis

Two uninsulated buildings, one residential and one office buildings, are carefully modeled and analyzed using different approaches including SIA 180/1 calculation and EnergyPlus simulation. The buildings is firstly calibrated to match the historical measurement, then building parameters are modified and the most influential factors can be discovered.

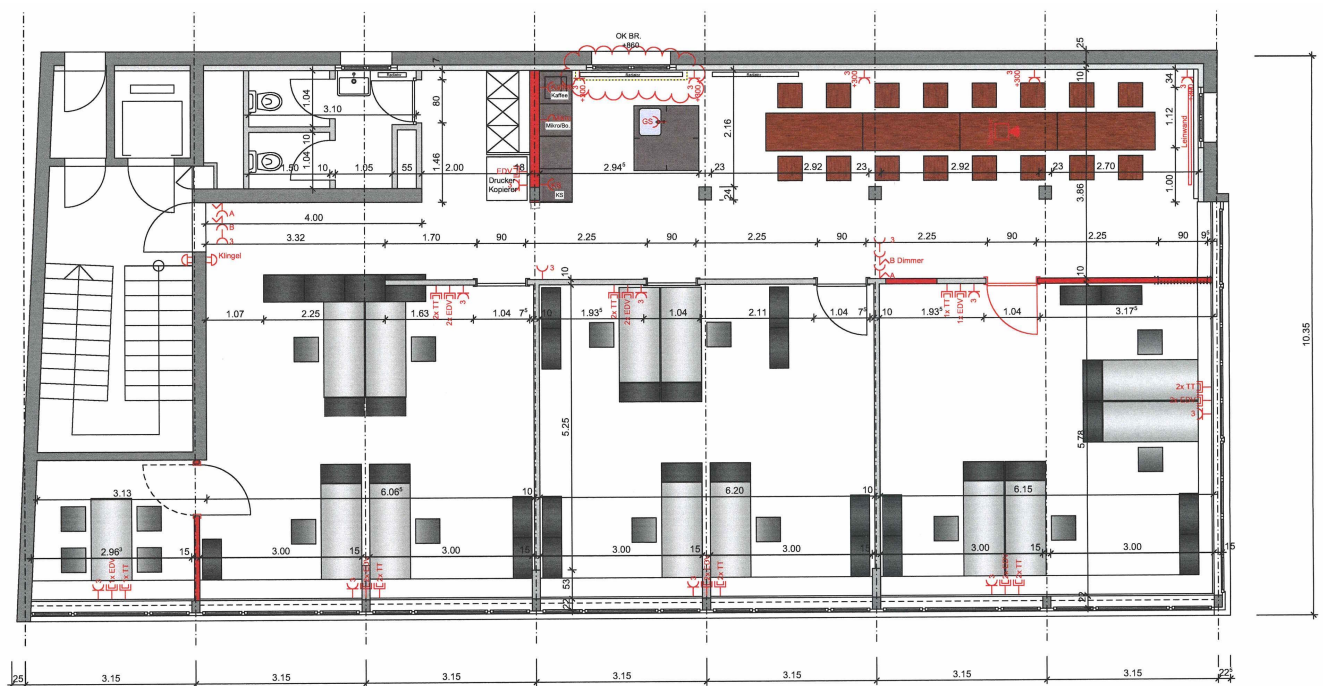
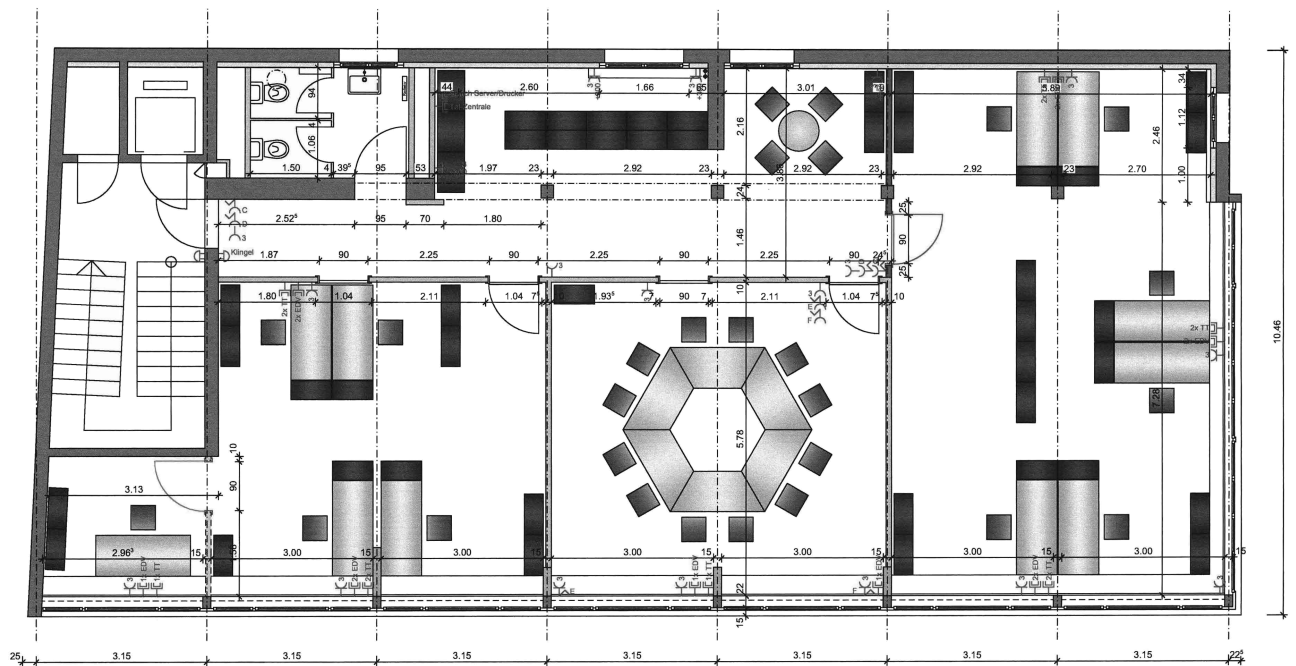
2.4 Office Building Introduction



Figure 1: Sumatrastrasse 10 Office Building

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 2 and 3 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*.



2.5 Residential Building Introduction

Figure 4 and 5 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 6 and Figure 7 below are the floor plans of the residential building. The ground floor is connected with the first floor internally via a small staircase behind the kitchen. The black and red lines in Figure 6 show the ground floor layout and the yellow line indicates the layout of the upper floor. Similarly, Figure 7 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*.



Figure 4: Honggerstrasse 23, NE Side

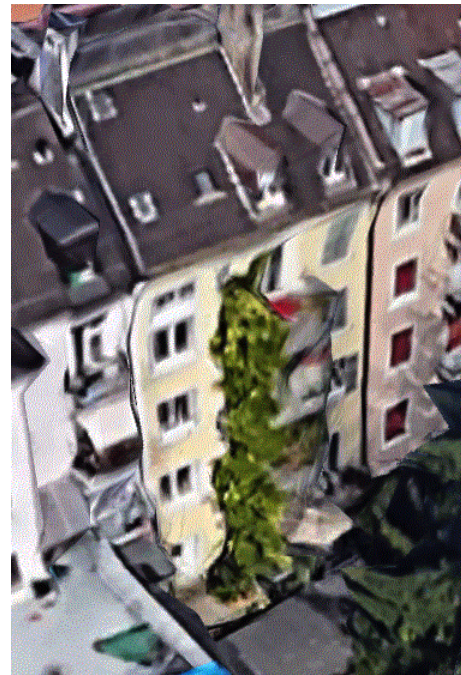


Figure 5: Honggerstrasse 23, SW side

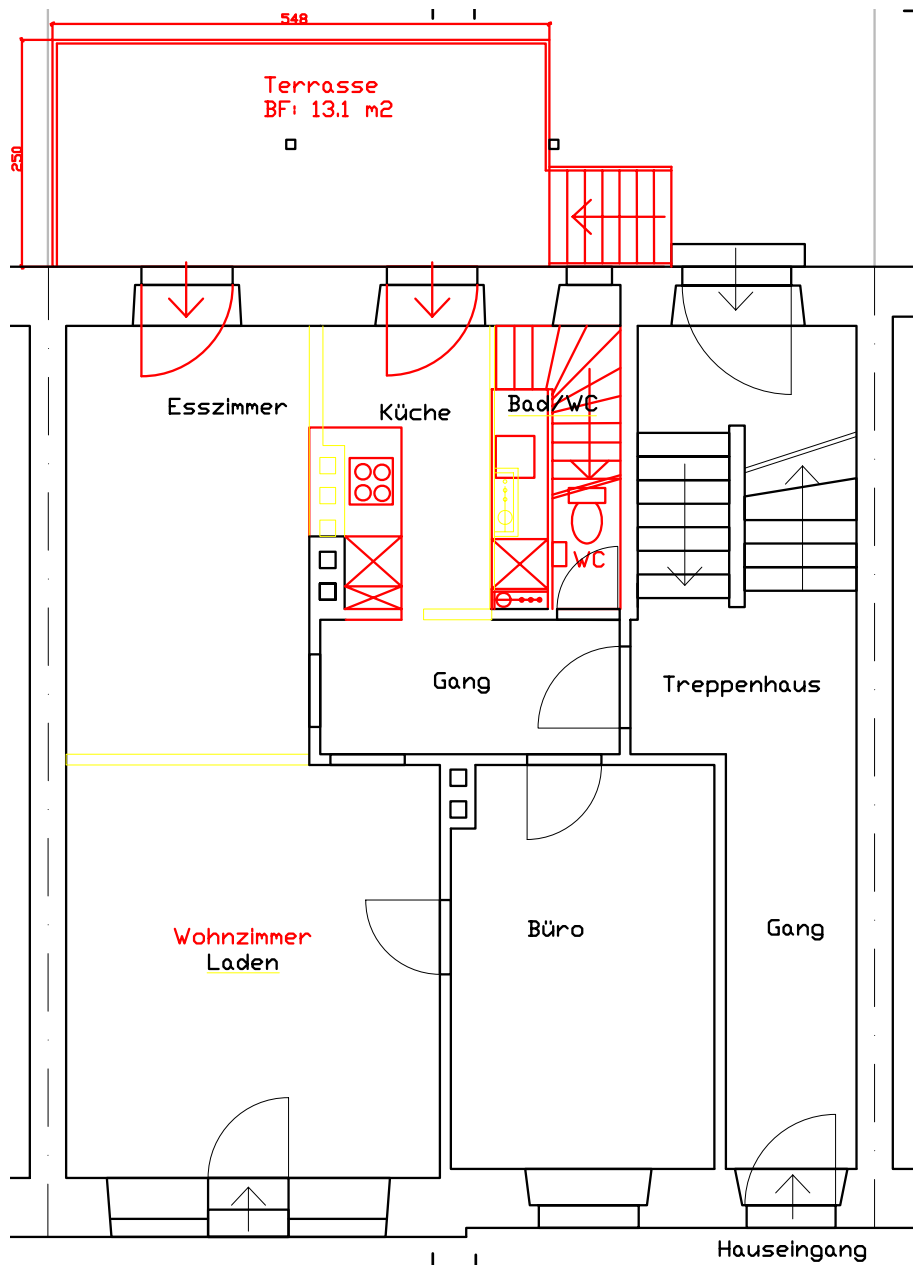


Figure 6: Floor plan of residential building (Hongger) ground - 1st floor

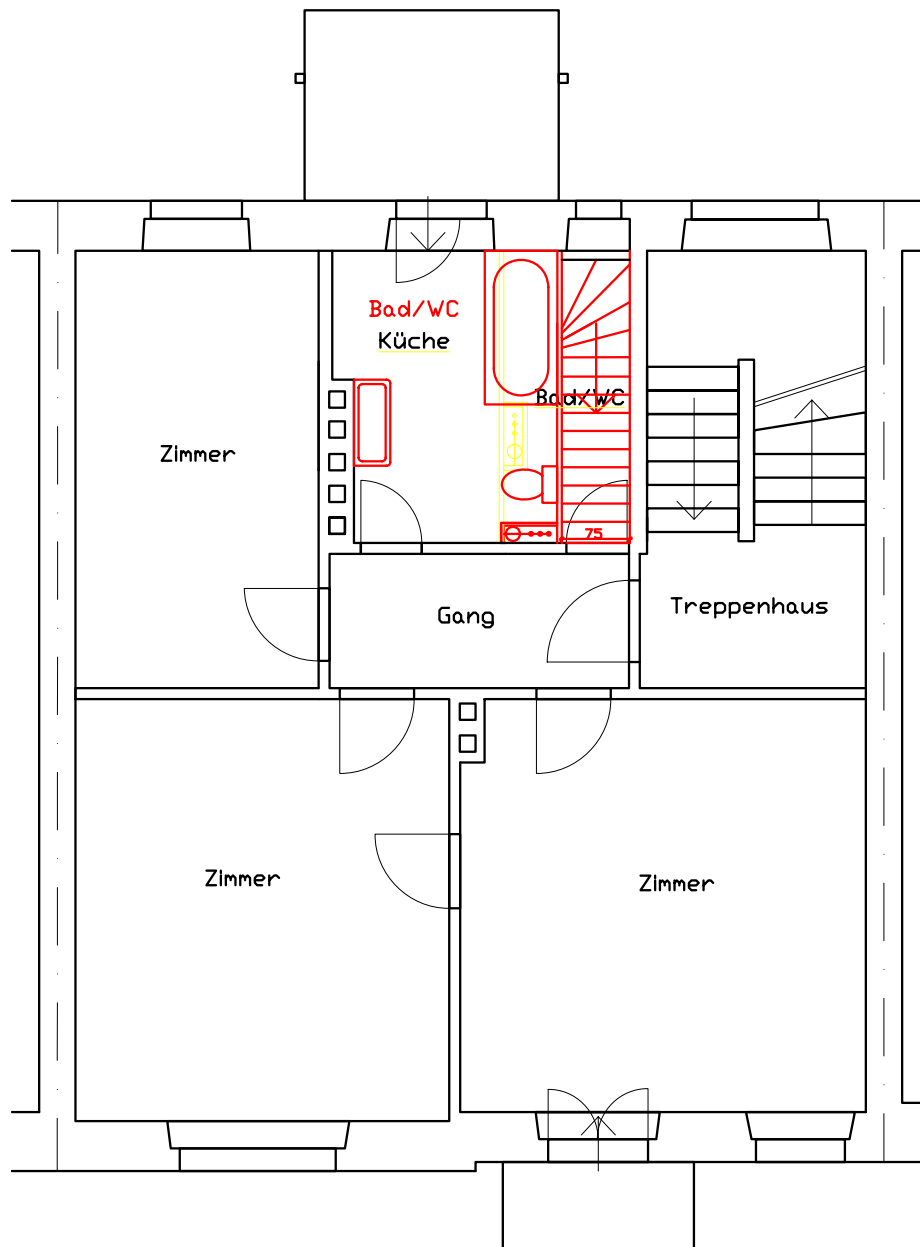


Figure 7: Floor plan of residential building (Hongger) 1st – 4th floor

3 Literature Review

Over the past years, there are a large number of research about building energy performance gap (BEPG). Performance gap can cause problems in energy management system. However, the root cause of this gap is not clearly identified, and the gap can't be effectively managed and eliminated [1]. According to a recent review of building energy performance gap by Zou and Xu et.al, most of them would contain one or more of the following 5 elements: (1) building type, which can be classified as residential and non-residential, or even more specific types such as single-family house, multi-family house, office building, commercial building, hospital, prison, etc; (2) strategies for closing performance gap, which focus about design concept, technology and method, and "soft" measures; (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 [1, 2]. Consider the objective of this thesis, the focus is on these following topics.

3.1 Root Causes 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, misbehavior of contractors and misbehavior of building users [3, 4].

3.1.1 Design and simulation problem

Firstly, in most cases, building designers are account for the wrong doings 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 [5, 4]. Also, it is difficult to predict the future environment such as climate, weather, and solar activities, which factors can lead to huge performance gaps [6, 7]. For example, rainfall would greatly increase the heat convection coefficient of building facade surface, and therefore increase heat exchange rate through the building envelope [6]. In addition, the actual thermal performance of building materials subject from different factors and are usually perform worse than how they should in lab environments. Therefore, designers usually overestimate the actual performance of technology and apply inappropriate assumptions about user behaviors [8].

3.1.2 Contractors

Secondly, contractors are mainly account for performance gaps caused by low quality constructions. Poor building quality and poor workmanship will usually reduce the thermal performance and therefore require more energy to maintain indoor comfort. Additionally, performance gap can be caused by contractors when they use improper construction techniques and when they are unable to discover hidden problems due to time and budget constraints [8]. In some cases, these problems would lead to huge building parameter deviations and therefore higher energy consumption than the design value [1, 8].

3.1.3 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 [2]. 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 [3, 9]. For example, users may leave unnecessary appliance on without notice or open the windows when heatings or cooling system is operating [1].

3.2 Strategies For Closing Performance Gap

When the causes of performance gap are found out, strategies for closing the gap can also be developed. These strategies are grouped into 3 categories, which is, namely, design concept, technology and methods, and "soft" measures [2].

3.2.1 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 [10, 11]. 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 don't 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 [2].

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 [8].

Human-in-the-loop is another approach that requires human interaction [12]. As information is a critical factor in building energy, the more comprehensive and accurate the obtained data, the more precise the result would become [4]. 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, VR and AR to collect building data for simulations and calculations [12]. The limitations of this approach would be the difficulty to collect comprehensive human information, and there is an uncertainty of occupants behaviors and different occupants may influence each other [13].

3.2.2 Technology and methods (T&M)

It is believed that using more advanced and innovative technologies and calculation methods would help closing the performance gap [2]. 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 [2].

T&M for calculating energy consumption

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 base on thermodynamic behavior of the building and its occupants [14, 15]. The grey box method is a combination of the black and white box method, in hope of eliminating the limitations of both methods [2].

T&M for data collection and analysis

T&M for data collection and analysis focuses on obtaining and utilizing the occupant behavior and building operation information [2]. Similarly, T&M for data collection and analysis can be divided into two approaches, namely *post occupancy* data collection and *pre-occupancy* data collection [2]. *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 8 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 [4].

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 base 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.

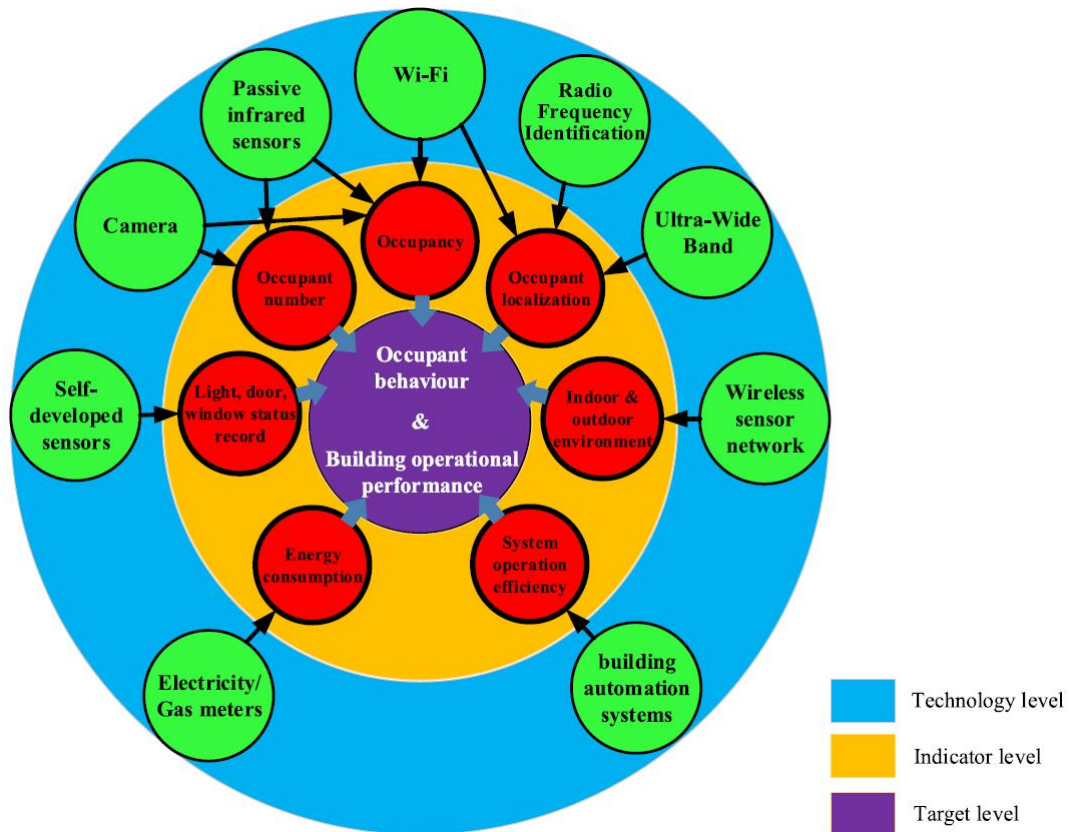


Figure 8: Technology and method for energy-related data collection [16]

Statistical analysis is mostly used to develop a numerical relationship among energy consumption,

	Pre-occupancy data collection	Post-occupancy data collection
Method or technology	Prototyping with sensor, virtual reality	Questionnaire, interview, sensor, meter, camera, Wi-Fi and building automation system
Project stage	Information is collected in the design stage	Information is collected in the operation stage
Customization for design	Knowledge obtained from the collected information is applied to the same building	Knowledge obtained from the collected information is applied to subsequent projects
Customization for operation	Knowledge obtained from the collected information is applied to the same building	Knowledge obtained from the collected information is applied to the same building
Type of information	Dynamic: both the processes and the results of occupant behavior in the building can be observed and recorded	Dynamic (sensor, meter, camera, Wi-Fi camera, Wi-Fi and building automation system) or static (questionnaire & interview: only the results of occupant behavior in the building can be observed and recorded)
Source of information	Direct	Direct (sensor, meter, camera and Wi-Fi camera, Wi-Fi and building automation system) or indirect (questionnaire & interview)
Strength	Low cost; provide useful suggestions and a powerful design review; enhance the information interaction between designers and users	Highlight inefficient operations and optimize them
Shortcoming	Limited in minimizing uncertainty in smart buildings	Limited in guiding new projects; high cost; challenged by authenticity

Figure 9: Comparison of pre-occupancy data collection and post-occupancy data collection [2]

outdoor environment, indoor environment and comfort, occupant behavior and other information using statistical tests, regression analysis and curve fitting [2]. 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 [17].

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 [18].

T&M for occupant behavior modeling and simulation

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* [2].

Agent-based modeling (ABM)

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 [16]. 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 [2]. 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 [2, 16].

Stochastic process modeling

As the occupant behavior is more or less random, *stochastic modeling* can be widely used in many researches involving 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 [2]. 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 building mechanical system controlling

T&M for energy system controlling aims at reducing building energy consumption without sacrificing the occupants' thermal comfort, and can be divided by three groups: *intelligent HVAC system*, *artificial lighting* and *occupancy-based control system* [2, 19]. The limitation for T&M for building automatic control would be it relies heavily on controlling algorithms and the accuracy of sensing equipments. Therefore, a mal-functioning sensor group would paralise the control system.

3.2.3 "Soft" Measures

Apart from several policy measures, one of the "*soft measures*" would be to develop a more comprehensive and reliable benchmarking and standard tools to improve building energy performance. Some of these guidelines or benchmark standards are National Australia Building Environment Rating Standard (NABERS), Australia's Green Star, European Union Passive House, UK's Building Research Establishment Environment Assessment Method (BREEAM), Swiss Minergie, US's Leadership in Energy and Environmental Design (LEED) and Energy Star [2]. However, these benchmark standards rely heavily on predicted building comfort and energy consumption, while the actual energy consumption is usually far from the calculated values [20]. As there are many designers use standard benchmark calculation tool as their design basis, developing a more reliable calculation method would be a good approach to improve the problem.

3.3 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 [21]. 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 [21]. Although the reviewed EnergyPlus version is more than 10 years old, it is believed that the bone structure of the tool remains the same till today.

Building BLAST

The BLAST system predicts building energy consumption, building energy system performance and building costs [21]. 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 [21]. 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 [21].

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* [21]. 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 studies, retrofit analysis, and for developing and testing building energy standards [21].

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 [21]. 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 desorption in building elements, radiant heating and cooling system and interzone air flow [21].

3.4 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 formulas to the supporting informations about a particular 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 [22]. 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 10 below. 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 [22].

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 pattern 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

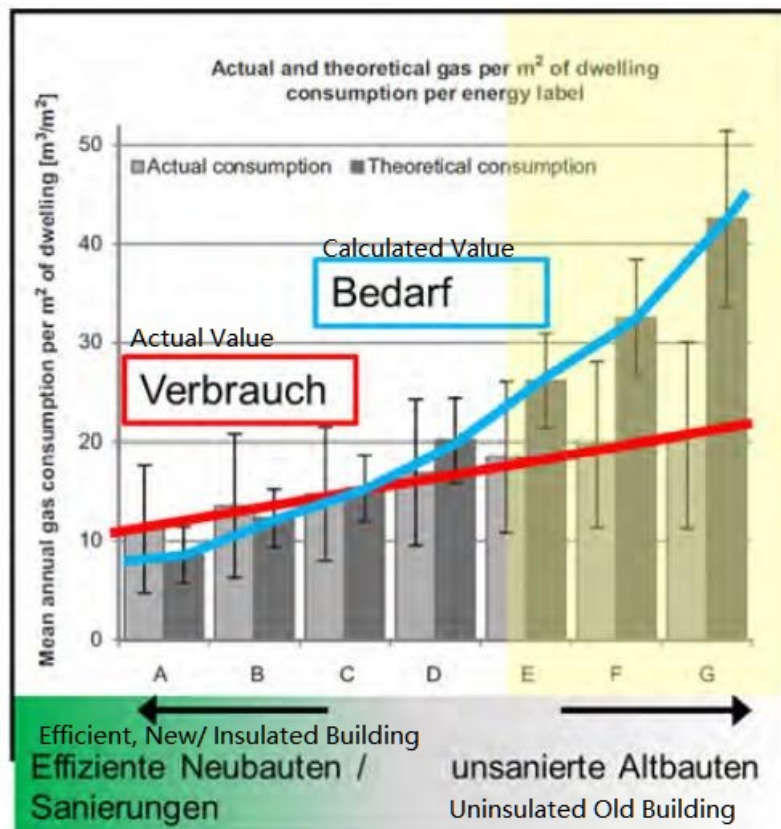


Figure 10: SIA380/1 Calculation Performance Gap Indicator [22]

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 reasonable 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 [23].

3.5 Previous Research

One similar research has been done in 2015 aiming to investigate the reason behind the huge performance gap 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, and discrepancies between standard climate data and actual outdoor air temperature [22].

4 Methodology

The whole thesis research was 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.

4.1 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 formatted file for EnergyPlus engine, also provide accurate geometry data for SIA calculation)

4.1.1 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 2, and 3, 6, 7. 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 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.

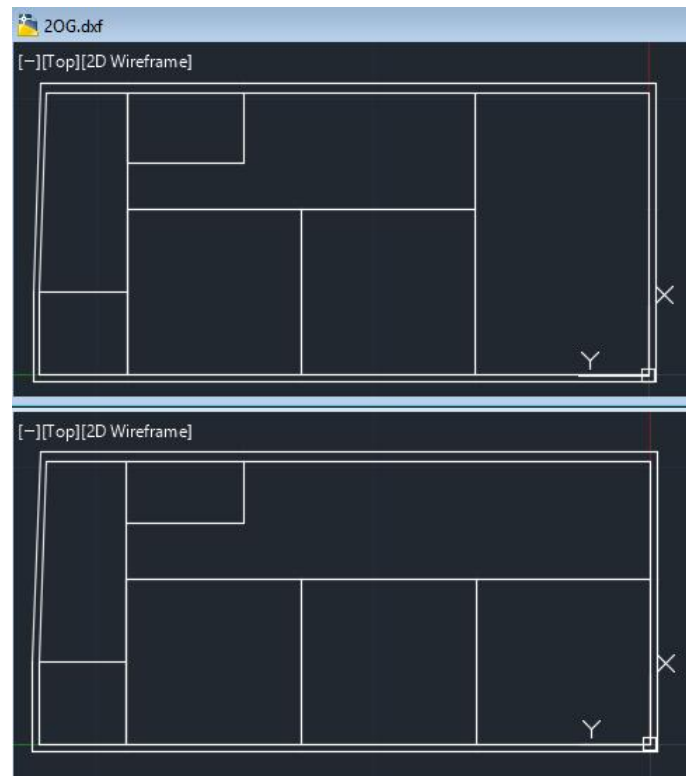


Figure 11: dxf drawing files for office building

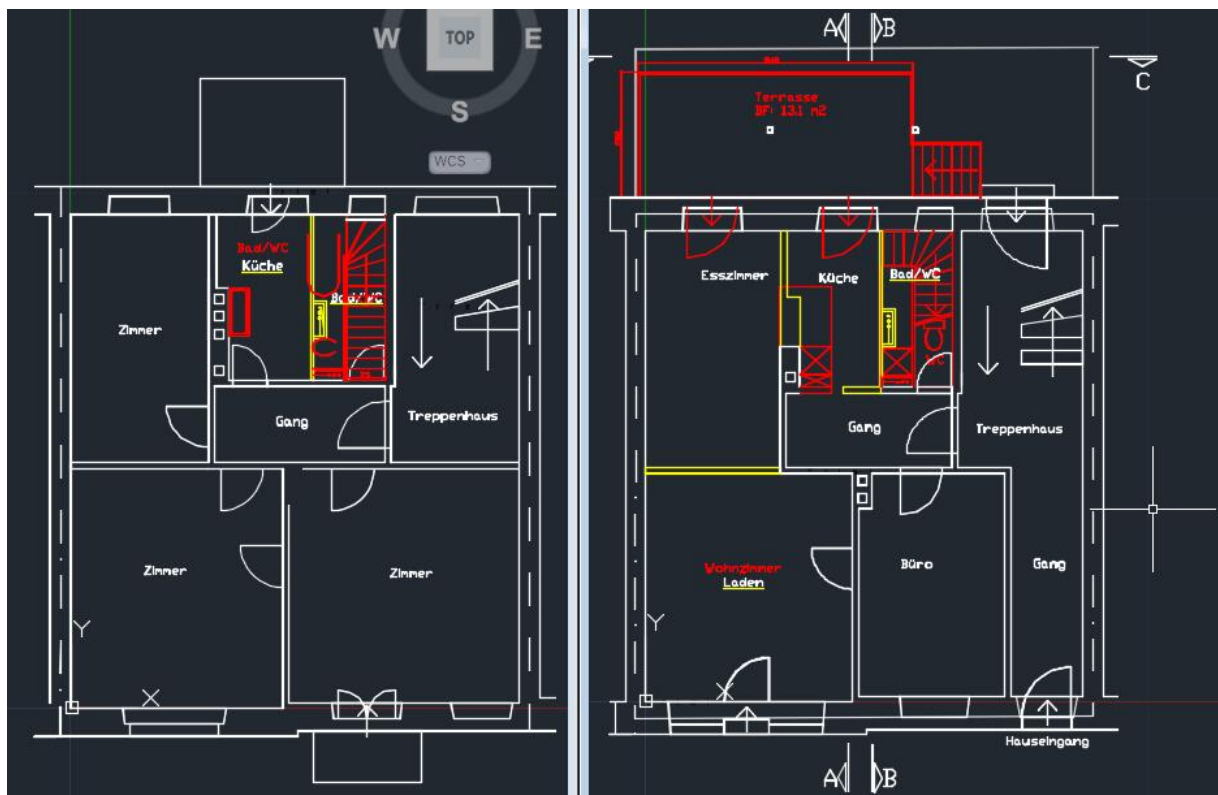


Figure 12: dxf drawing files for residential building

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	Window Code	# 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 ² K	#	unit area	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 ² K	number of windows	unit area	Total Area
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

4.1.2 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 measurement. 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 actual building and 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.

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 coefficient					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 coefficient					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 coefficient					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 ² K/W	U Value W/m ² K
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

4.1.3 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. Similarly, 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 vegetation covering

The majority part of the northern and the eastern facade of the office building as well as both external walls of the residential building are covered with plants. However, as the effect of vegetation covering is unknown, the vegetation layer of these facade is ignored in the modeling and analysis process.

Figure 13 and 14 below shows a complete office building geometry.

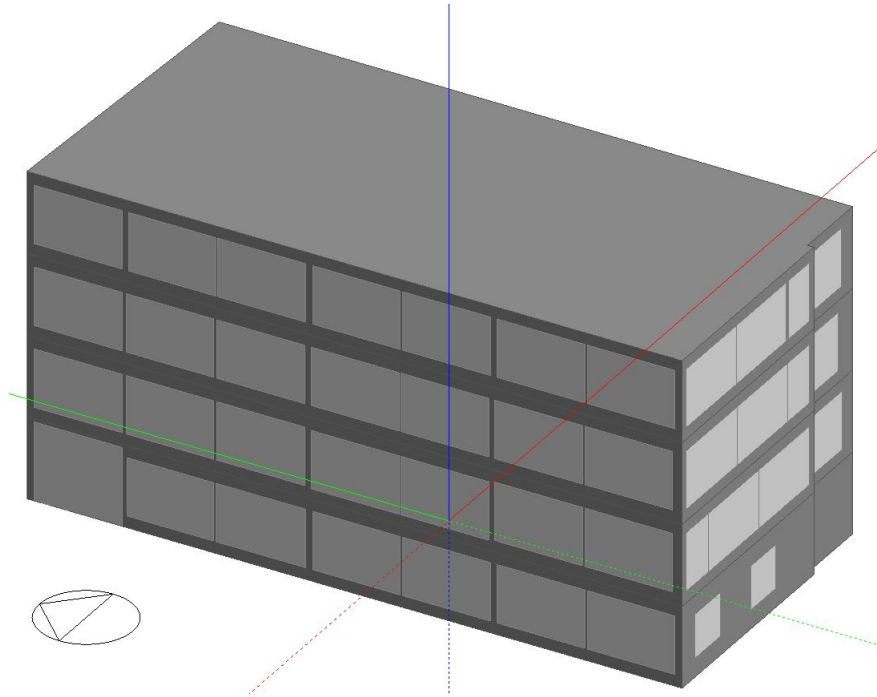


Figure 13: Office building DesignBuilder model

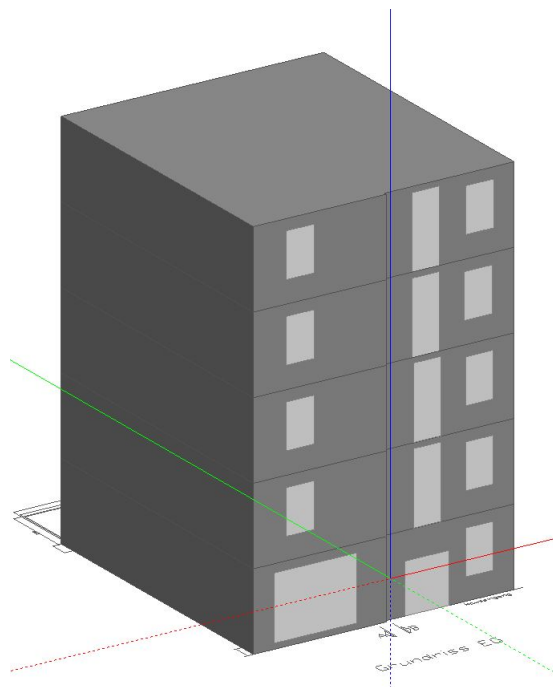


Figure 14: Residential building DesignBuilder model

4.2 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.

4.2.1 Weather Data For Static Calculation

SIA 381/2 Weather Data

SIA has published a standard weather data *SIA 381/2 Klimadaten zi Empfehlung 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/m2)	33	48	78	108	158	172	168	116	89	61	32	28	2248
Solar Energy at E (MJ/m2)	57	96	170	243	299	320	330	284	212	127	61	49	3133
Solar Energy at S (MJ/m2)	149	217	281	315	299	290	318	337	347	272	166	142	2303
Solar Energy at W (MJ/m2)	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/m2)	25	42	62	86	116	158	150	107	74	46	30	23	919.15
Solar Energy at E (MJ/m2)	55	103	176	238	289	301	332	278	185	113	65	41	2176.1
Solar Energy at S (MJ/m2)	183	213	304	298	244	237	245	284	279	238	146	116	2786.3
Solar Energy at W (MJ/m2)	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
Heating Day	208	175
Heating Degree Day	3260	2513
Annual Average Temperature	8.5	12.3

4.2.2 Weather Data For Dynamic Calculation

An .epw weather file is needed for dynamic calculation using *EnergyPlus*. The weather file is either from a meteorological organization or from modifying an existing weather file.

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.

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 Meteorology 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.

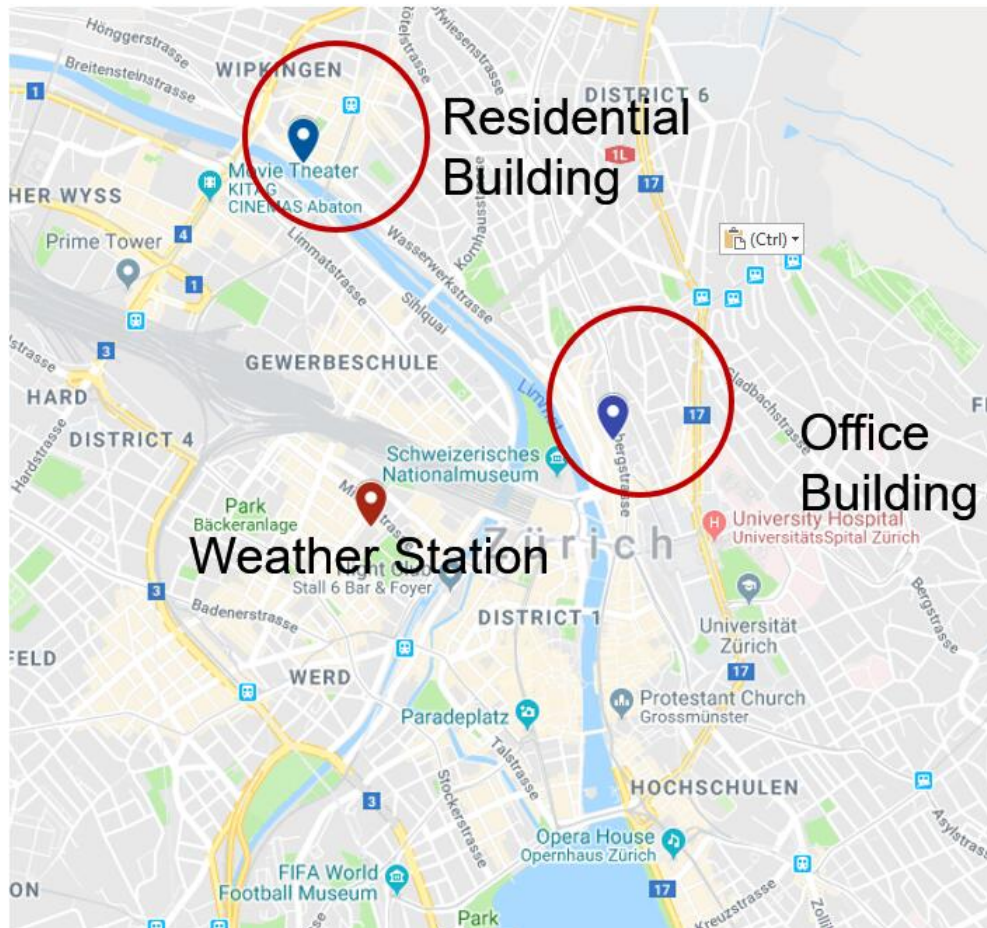


Figure 15: Weather Station Location

Table 10: Weather Data Information

2015 Weather Data Information	
Source	MeteoSwiss: IDAWEB
Weather Station Code	NABZUE
Station Coordinate	E 8o31'49" , N 47o22'39"
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*.

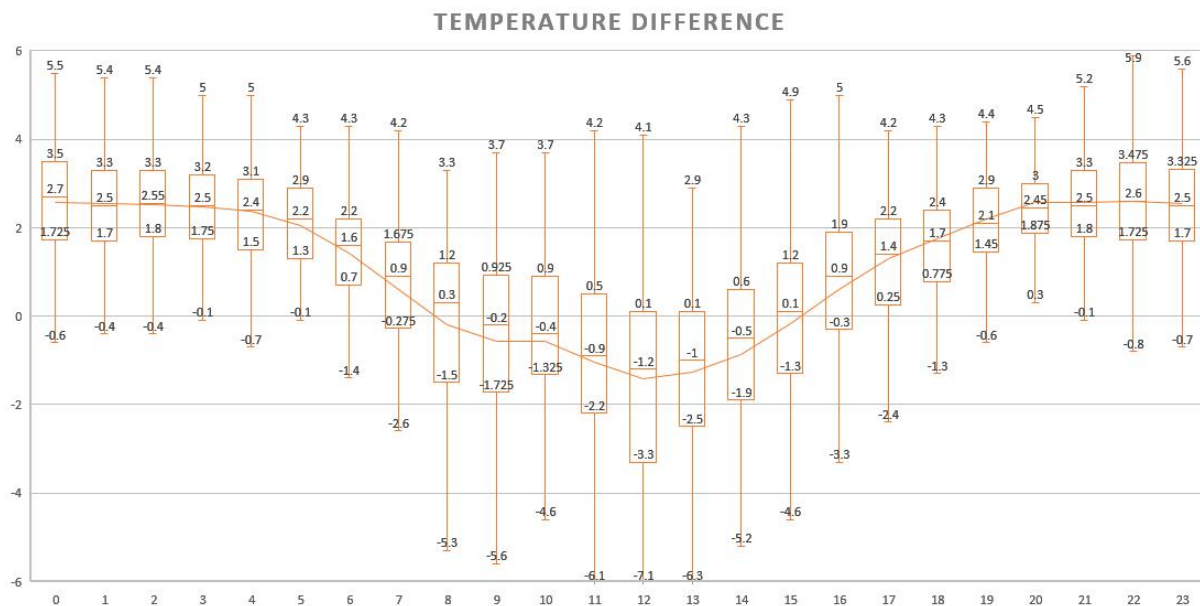


Figure 16: Temperature Difference

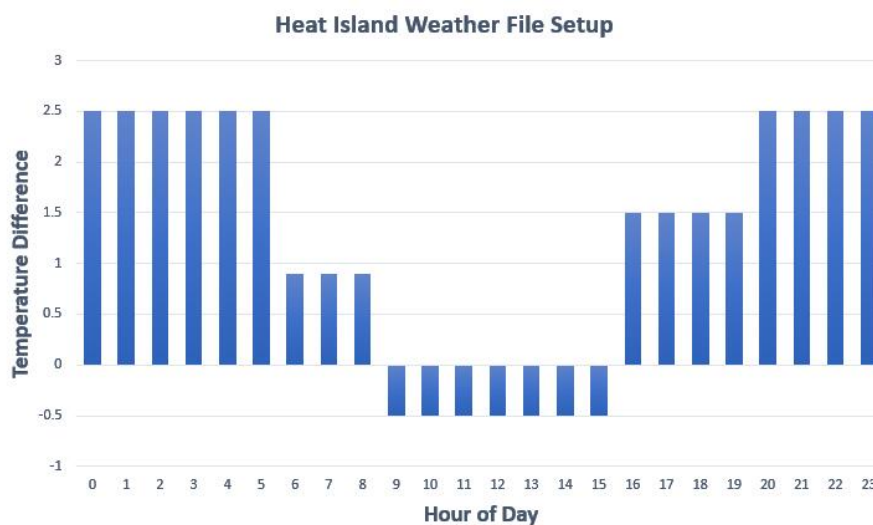


Figure 17: Heat Island Temperature Modification Rule

4.3 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.

4.3.1 Heat 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 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^2K

h_{in} : Internal heat convection coefficient

R_{Layer} : Total heat resistance of building element in m^2K/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:

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

where:

\dot{Q}_{vent} : Ventilation heat loss in MJ/m^2

$\dot{V} = 0.7$: Ventilation rate in $m^3/m^2 \cdot h$

$c_{p,\text{air}} = 1.16$: Heat capacity of air $kJ/m^3 \cdot K$

HDD : heating degree days

4.3.2 Heat 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:

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

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.

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

\dot{Q}_{elec} : Heat gain by electronics in MJ/m^2

E_{unit} : Unit area electricity demand in kWh/m^2

$f_{\text{ele}} = 0.7$: electricity gain factor

HT : Heating day

A_{floor} : Total floor area

Internal Gains by person

The internal gain from occupant activities is given below:

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

where:

\dot{Q}_{occ} : Internal gains by person in MJ/m^2

Occ : Unit area occupancy, $\text{Occ} = 40m^2/pl$ for residential, $20m^2/pl$ for office building

$\dot{q}_{\text{pl}} = 70W$: 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:

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

4.3.3 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.

4.4 Dynamic Analysis

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.

4.4.1 Schedule and Occupancy Assumptions

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.

- Heating/Cooling Setpoint temperature
- Occupancy
- Schedule
- Activity level
- Lighting / new-lighting schedule
- DHW
- Electricity

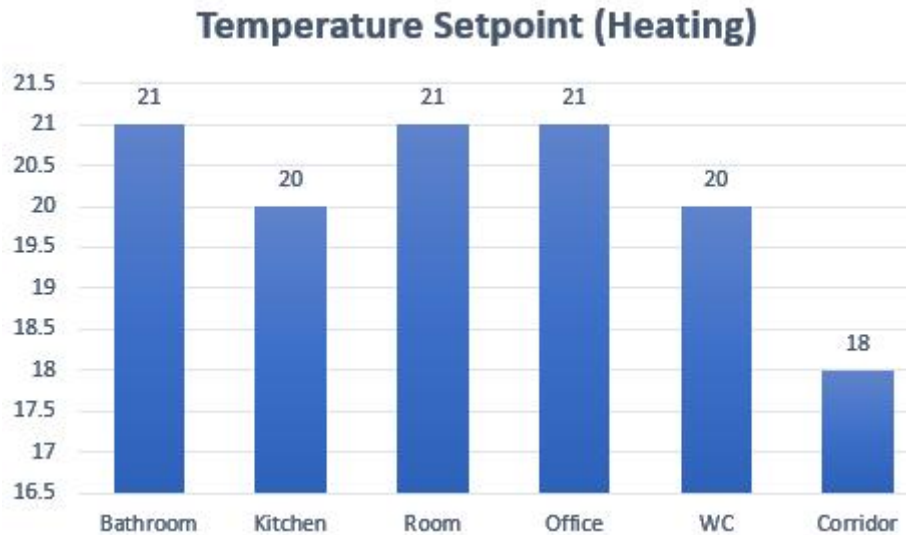


Figure 18: Heating Temperature Setpoint

4.5 jEPlus Dynamic Simulation

Why using je-Plus and how to use

4.5.1 Basic description of je-Plus

- Main functions
- Advantages
- How to use

4.5.2 Dynamic Parameter Assumptions

List of parameters, range of parameters and distribution of parameters

4.6 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 should vary the building tightness and basic appliance schedules until the calculated indoor environment (temperature in this case) behaves similar enough to the historical measurement.

4.6.1 Outdoor Environment Calibration

4.6.2 Building Envelope Calibration

- EnergyPlus Hourly Analysis

4.7 Data Processing

Briefly describe the resulting data structure from je-Plus and introduce 2 different graphs.

4.7.1 Dynamic Analysis Range

4.7.2 Correlation Matrix

An introduction about Correlation matrix

5 Results

5.1 Initial Annual Energy Analysis

5.1.1 SIA Calculation

Residential Building

Thermal Bridge

Table 11: 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			14.0469475	10.82885211

Compare the results

- Previous Result (by Lemon Consult)
- Apply correct building floor and wall area
- Apply year 2015 weather data
- Modify air tightness (infiltration)
- Historical measurement value

5.1.2 EnergyPlus Simulation Result

- Floor Area (be used in SIA calculation)
- Heating Demand
- Air Ventilation

The first set of dynamic analysis (4 sets of heating demand distribution from infiltration 0.1 to 0.4)

5.1.3 Calibration

- Steps of calibration (hourly - annually)
- Results of each variation (new lighting schedule/shading schedule etc)
- Recommended base values

5.1.4 jE-Plus Simulation Results

- Dynamic Heating Demand Variation
- Dynamic DHW Demand Variation
- Results of all parameters (range and distribution of heating demand and DHW demand)
- Correlation of parameters

6 Discussion

- Key parameters (Which parameters are the most important and which are not as important)
- Key assumptions (Are these assumption still applicable)
- Recommendation (building envelope much be accurate, a weather data update is critical etc)

7 Conclusion

- Key parameters
- Recommended set of parameters
- General Recommendations

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