Building Design Approaches and Performance Under Predicted Climate Conditions

Report

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CONTENT

1 Research Framework

1.1 Background

The building environment contributes to about 40% of primary energy consumption and 24% of greenhouse gas (GHG) emissions globally is related to building operation (IEA, 2008). The major building related energy consumption is for maintaining acceptable indoor comfort. To improve energy efficiency and the quality of indoor comfort, building performance simulation is the common approach in the building design/renovation project. Building performance simulation demonstrates the possible energy demand, and comfort level correlated to the design decision, and it is commonly applied in the early design phase. For example, by optimizing building envelope performance (Mărginean, 2019) and defining the suitable building geometry and material properties (Moumdjian, 2020), it is possible to reduce the building energy consumption and carbon emission while maintaining the basic comfort level.

The impact of climate change gradually being severe, due to the enormous greenhouse gas emissions, and it is shown that the heatwave happens more frequent and longer (KNMI - Heat Waves, 2021), while the coldwave seldom happens in recent years (KNMI - Cold Waves, 2021). The outdoor climate condition influences the indoor comfort situation. While the indoor discomfort usually leads to additional building operation energy, like extra cooling demand and heating demand. Consequently, causing more carbon emissions and intensifies global warming conditions. To avoid this vicious circle, buildings need to be designed or renovated to provide the same indoor comfort and equal or even lower energy demand when facing the future climate environment.

To reduce the influence of climate change on the living environment, the building design needs to consider the future condition and demands. There is some research that shows that within 20 years the amount of energy for cooling the indoor environment would rise dramatically in some areas (D'Agostino et al., 2021). To make the living environment future proof, the perdition of the future climate scenarios would make it possible for us to analyze the building energy performance under various climate conditions within the building lifespan.

1.2 Problem statement

Since the building energy consumption is strongly related to the weather environment current building energy strategy of the envelope, heating, cooling, lighting, and ventilation system would be affected by climate change. Within the context of climate change, the indoor discomfort period tends to be longer year by year (D'Agostino et al., 2021). Overheating is one of the main concerns related to the impact brings on the living environment which not only influences the comfort level but has also led to thousands of mortalities in recent years in Europe.

On the other hand, to reduce building-related carbon emissions, building performance optimization (BPO) is commonly applied to find the optimal method to use operation energy. However, the weather for BPO is mostly collected in the past 20 years, and the result of building performance simulation and optimization could be not accurate during the building lifespan period (Herrando et al., 2016). In performance prediction, the energy balance of building operation energy in Europe will have a great change, with a decrease in heating demand of 38% to 57% and an increase of cooling demand of 99% to 380% judging by location in the future (D'Agostino et al., 2021) while most of the buildings are not designed with sufficient cooling capacity in this concern. The uncertain external environmental condition causes the misjudging of design decisions, furthermore, the discomfort and potentially unsafe living environment. Additionally, there is not a concrete method to generate the most suitable design option concerning both current and future climate conditions yet.

To make our living environment future proof, the consideration of both indoor comfort and carbon emission is demanded throughout the building lifespan. But the current building design and retrofit approaches are usually lacking the analysis of the building performance in future climate conditions. Integrating the prediction of future climate conditions with BPO design would be the next step to ensuring the safety of our living environment and reducing the environmental impact of building energy demand.

1.3 Research objective and research question

- **How to determine what design characteristics have the main influence on building operation energy and indoor comfort under both current and predicted future climate conditions by using computational simulation?**

- What will climate conditions be within the lifespan of the building(s) we are designing and building now?
- How to minimize the operation energy demand throughout building lifespan under climate change conditions?
- How to optimize the comfort hours by changing the envelope component?
- What design decisions and design factors have a higher influence on energy consumption and indoor comfort?
- How to evaluate the building performance through the building lifespan?
- What is the methodology for simulation and optimization of the energy performance with different design decisions and for climate change conditions?

1.4 Research approaches and methods

This graduation project focuses on the influence on our living environment and essential consideration of reaction needs to be taken with the climate change environment. The methodology is composed of three main sections: 1. Literature review, 2. Setup and execution and 3. Result and discussion.

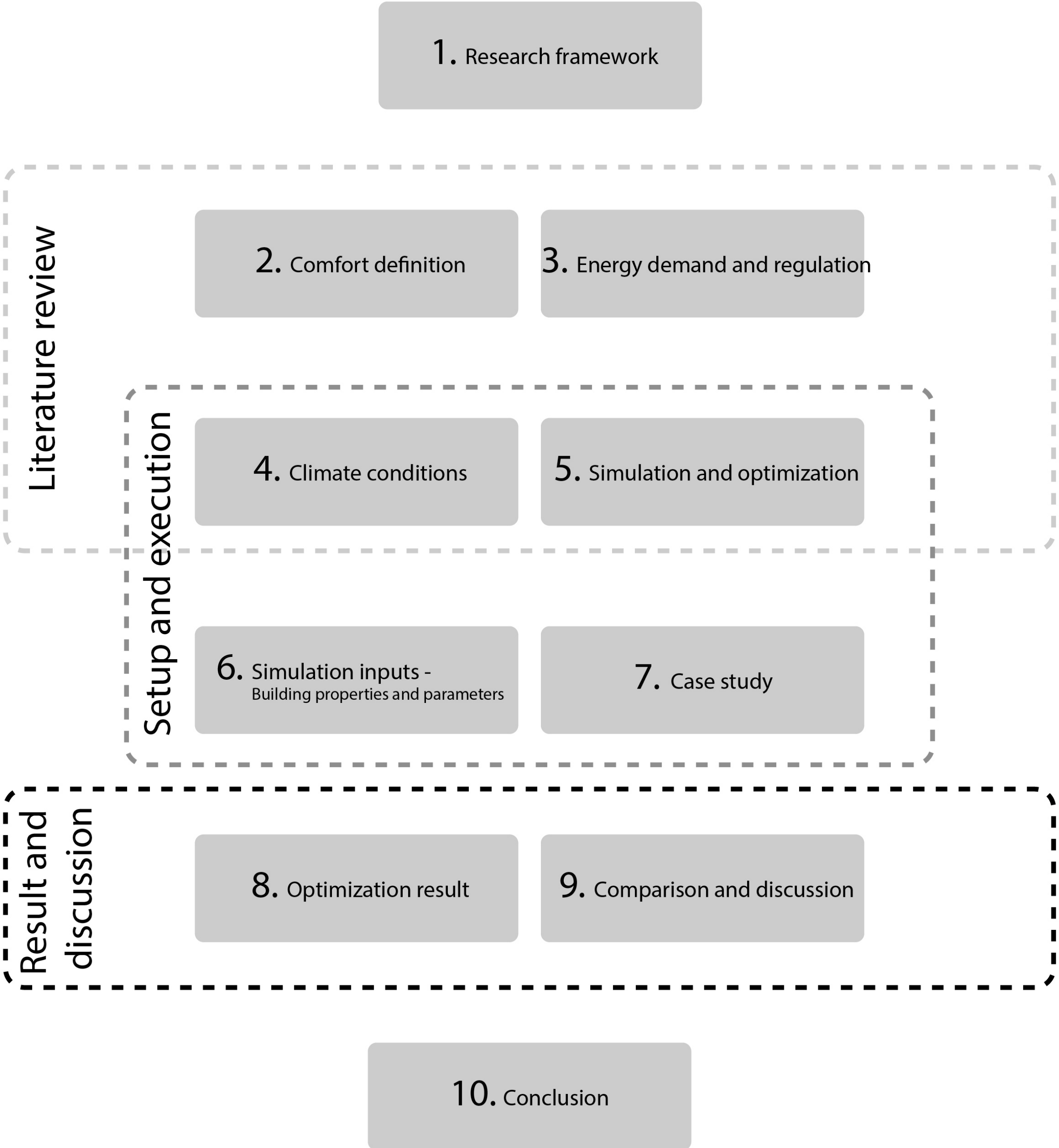


Figure 1. Report structure.

1.4.1 Literature review

The first part of the literature review is the comfort definition of the interior environment. The research of comfort definition considers the existing European and Dutch regulations and the related research, also the application references. The indoor comfort demand is stable in contrast with the outdoor environment. But the user's comfort is an elemental factor to be considered. In this chapter, there are several types of comfort to be discussed. Thermal comfort, air quality, visual, and acoustical comfort. Acoustical comfort is not the main concern, due to the focus being on the impact of climate change.

Rather than indoor comfort, building energy consumption and production are the common factors being evaluated the building performance. There are several approaches and regulations related to building energy consumption. In this chapter, the methods for how calculating the energy demand for variant purposes and the relevant standards are shown.

In order to understand the performance of the building under potential climate conditions, climate change research is the coming topic. A further step is the comparison of the pros and cons of different research and applicability to building performance studies. Following is the potential impact on the living environment with current buildings and the reference of future proof design projects.

Last but not least, the research of methods of simulation and optimization is discussed. Moreover, the common factors and settings that the building performance analysis used are also explained. The Simulation-based studying would be executed in Grasshopper environment. Understanding the theory of simulation and optimization could figure out a method to reduce the time and computation expensive. The review also shows the various inputs and expected outputs of simulation and optimization.

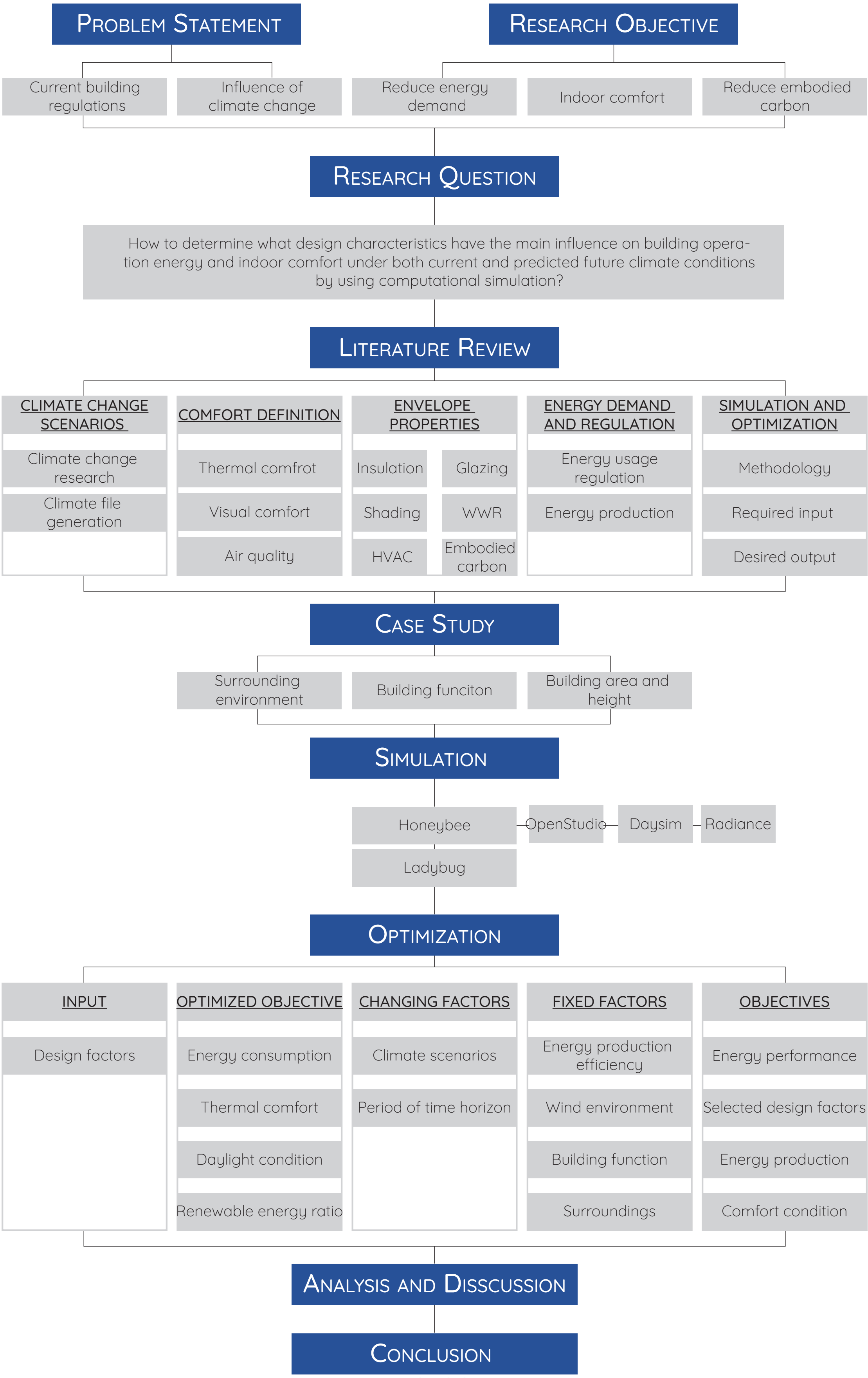


Figure 2. Methodology process.

1.4.2 Simulation and optimization

The estimation of building performance under current and future climate conditions will be carried out in a computational environment. The goal of this research is to determine what design characteristics and decisions have major impacts in the climate change context while minimizing the building operation energy through the building lifespan. It is necessary to define:

Output variables:

A set of design indices from the design library input, energy demand, and comfort condition during the period of building lifespan.

Input parameters:

The main conditional input is the variant of climate condition in each scenario and period. Other inputs are the design parameters, like building function and building area, and the environmental conditions.

To evaluate the changes caused by climate change, a building project in the early design phase is used as the study case. The study object has defined function, area, height, and location and there is room for further design decisions to be made in the early design phase. The sensitivity analysis is applied in this research. Although climate change shifts the external environment, there are still some elements that remain, for instance, surrounding buildings and landscapes. In the sensitivity, it is possible to reduce the input variables that have a lower connection with climate change thus the optimization time would decrease.

The major concern for the difference in building performance is the impact of climate change. The design scenarios used to study the variation are based on variable climate conditions. There are five potential design scenarios with different design approaches involved in the building performance optimization and simulation process. The first scenairo is the optimization based on current climate conditions and the possible solutions of renovation options under climate change. The second option is the other way around, the optimization with the predicted weather conditions and the feasible result to be renovated to this condition. A combination of current and predicted future climate condition is applied in the third option. The fourth optimization result is based on the average data of future and current climate conditions. The last option is a reference case based on current Dutch regulations under different climate situations. To demonstrate the most extreme condition, the warmest predicted climate condition as the highest value of change in the air circulation pattern scenario (WH) from the Royal Dutch Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut, KNMI) is used as the future climate condition.

The last part is analyzing and discussing all the optimal results of the design variables. The optimization results are generated based on different climate scenarios, different considerations of various priorities of the period of building lifespan, and renovation possibilities. Furthermore, the difference in design approach and the related energy and environment coast under the consideration with and without the changing weather environment.

1.5 Limitation and boundary condition

1.5.1 Weather file – accuracy, time limitation

Future climate conditions are highly related to the amount of global greenhouse gas (GHG) emission. Based on the assessment of GHG emission and atmospheric concentrations, air pollutants, and land use, there are four main Representative Concentration Pathways (RCPs) (IPCC, 2014). As the derivation of the RCPs and the climate research done by KNMI, four predicted climate scenarios in the Netherlands have been produced. This research only focuses on the highest temperature scenario. After 30-50 years when buildings need to be renovated, the thermal performance and energy performance need to be analyzed again based on the contemporary climate condition.

Furthermore, because the future climate condition is not based on measured data, the accuracy of future weather conditions could not very precise. Meteorological studies give a daily data set, while the simulation required hourly data. To generate hourly data, the “morphing” method is applied to morph the existing EnergyPlus / EPSr Weather file (EPW), an hourly weather data, into a future model. Moreover, the climate prediction research only reaches the year 2085 with an average building lifespan of 80 years.

Furthermore, the weather data used in the simulation is composed of the information collected from Rotterdam and Amsterdam. Some of the information is not collected in the local meteorology system.

1.5.2 Location

Climate design is very region and location depended. As a result, the study can only be applied to conditions in The Netherlands. The same method would be suitable for other locations with the same climate data file. To generate the future climate data, the KNMI’14 climate scenario (Taleghani, Tenpierik, & Dobbelsteen, 2013) is inappropriate outside of the Netherlands, but the CCWorldWeatherGen is possible to generate a weather file based on global climate investigation (Suárez et al., 2018).

1.5.3 Unpredictable future technology for energy generation quality and quantity and insulation material property

One of the evaluation factors for building performance in this research is the electricity produced by PV panels on the façade. This technic is developing rapidly, meanwhile, the efficiency of transferring sunlight to electricity will improve in the future as well. But this research can only apply to the current system. Furthermore, based on the same reason. the heating, ventilation, and air condition (HVAC) system used for all periods and climate conditions is the same. This research only results in the early design phase and provides norms and references for architects and designers. It does not finalize in any specific type of façade or material or system.

On the other hand, the limitation of the retrofit and renovation option in the future is based on current technology as well. The development of the construction industry could greatly improve the insulation material properties and embodied carbon, as well the energy generation techniques could reduce the carbon emission of building operation energy. However, only the application materials and technology are applied to this research.

2 Comfort Definition

The primary goal of the building is to provide a safe and comfortable indoor space for humans to develop activities. The indoor environment quality (IEQ) is defined as thermal comfort, indoor air quality, acoustics, and visual comfort (Bluyssen, 2009; Chen et al., 2016). All the indoor comfort relates to the energy consumption of heating, ventilation, and air conditioning (HVAC) systems and the usage of materials for construction. The indoor comfort greatly depends on envelope design decisions which include the aspects of window to wall ratio, glazing type, shading system, insulation, and ventilation system (Mărginean, 2019). This thesis focuses on the influence of climate change on design characteristics and building energy performance. In the optimization process, only thermal comfort, indoor air quality, and visual comfort are considered objectives.

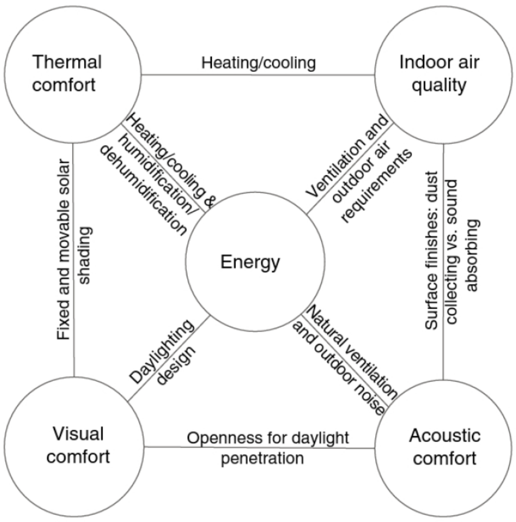


Figure 3. Interactions between forms of comfort and building energy use with example.
Figure 4.   Source: Athienitis and O'Brien, 2015

2.1 Thermal comfort

Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation." (Ramspeck et al., 2004). s warm blood mammals, the internal temperature of the human body needs to be around 37 ° C for it to function properly (CIBSE, 2013). The body constantly has heat exchange with the external environment and to maintain the internal temperature a suitable thermal condition is mandatory (CIBSE, 2013). There are two main methods are taken, climate chamber tests and field studies define as thermal comfort indicators.

The chamber test is based on steady-state laboratory thermal comfort models and standards with the human body heat exchange process, and the results are known as ASHRAE 55-199 and ISO7730. The steady-state thermal model is used to describe the response of people to the thermal environment (Conejo Fernandez et al., 2019) which means the interior condition would be totally rely on the HVAC system (Fumagalli, 2020).

In the steady-state model, two indicators are used to determine the general thermal sensation and degree of discomfort, the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). The PMV model combines 2 personal variables (clothing insulation and activity level) and 4 physical variables (air temperature, air velocity, mean radiant temperature, and relative humidity), and the mean value of thermal comfort is defined by voting of people who experience the same environmental condition. PPD is a prediction of the percentage of people who are likely to be dissatisfied with the provided thermal environment. in the European standard EN 15251 with the PPD and PMV, the thermal comfort is determined by 6 thermal parameters as in PMV (EN 15251, 2006).

Building category	Explanation	PPD	PMV
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements.	<6%	-0.2<PMV<0.2
II	Normal level of expectation and should be used for new buildings and renovations.	<10%	-0.5<PMV<0.5
III	An acceptable, moderate level of expectation and maybe used for existing buildings	<15%	-0.7<PMV<0.7
IV	Value outside the criteria for the above categories. The category should only be accepted for a limited part of the year.	<15%	PMV<-0.7 or PMV>0.7

Table 1. Building category and recommended PPD-PMV.
Adapted: EN-15251(2018)

The result of the field study is known as the adaptive thermal comfort model. The adaptive thermal comfort model was developed for designers to acquire the comfort operative indoor temperature in free-run buildings. The limitation of this method is it is not able to be applied in an air-conditioned environment (Albatayneh et al., 2019; Fumagalli, 2020). This model is applied as ASHRAE 55-2010(in America) and EN15251 (in Europe), as well as the Dutch ATG guideline (Taleghani, Tenpierik, Kurvers, et al., 2013).

Usually, the user's thermal comfort regulates the indoor air temperature with a recommended average temperature with an acceptable temperature zone. Depending on the summer and winter seasons, the value would be higher or lower. Furthermore, the comfort temperature range would have +/-1 °C differences due to different regulations.

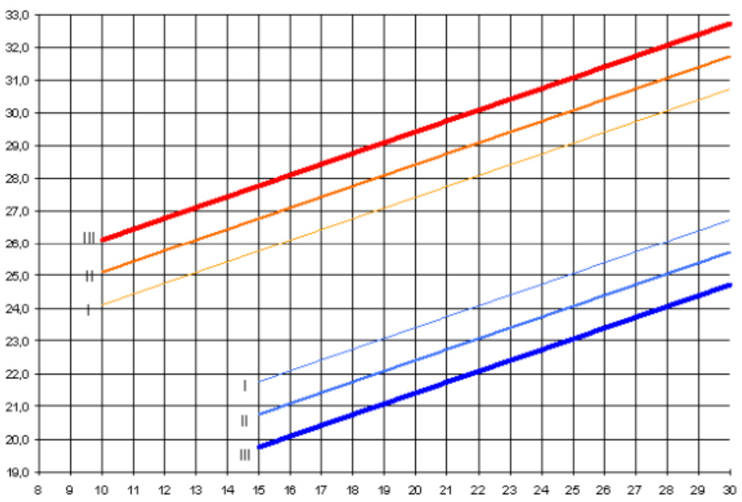


Figure 5. Linear relation of outdoor environment and indoor temperature. Source: EN-15251(2018)

Besides thermal comfort, In the Netherlands, the risk of overheating is increasing in the summer period caused of external heat gain, internal heat gain, and inadequate ventilation (Shahriari, 2020). In the Netherlands, there are two main methods to calculate the overheating hours and influence. TO-hour (temperatuuroverschrijdingsuren) is used to calculate the overheating hours with two boundary temperature conditions, 25 °C and 28 °C (RVO, 2018). Another option for overheating calculation is GTO-hour, an abbreviation of weighted temperature exceedance hours (gewogen temperatuuroverschrijdingsuren) (RVO, 2018). The weight of the factor is related to the temperature during the overheating hours, when the temperature goes higher as well as the weight factor. The requirement of the overheated for TO-hour is maximum 100 hours for office building, and 150 hours for GTO-hour. The limitation for residential buildings is 300 hours for TO-hours which refers to 450 hours for GTO-hour (RVO, 2018).

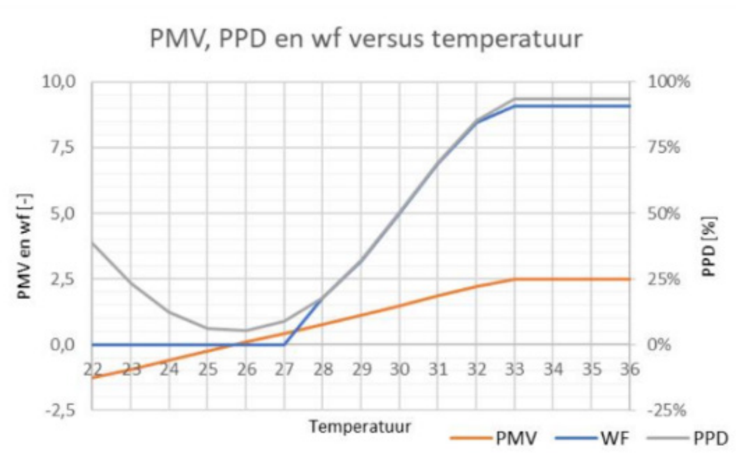


Figure 6. The relationship of temperature, PPD, and weight factor for GTO. Source: RVO 2019

2.2 Air quality

The degree of health and comfort is highly related to indoor air quality in the building. To guarantee the air quality of interior space, the basic requirement of air change rate is set according to the function of the building/area by Dutch building decree Bouwbesluit (2012) (BZK, 2012), NEN 1087. The minimum requirement of ventilation for newly constructed housing, in second category, is 0.7 dm3/s per m2 of continuous ventilation in the living room. For places like kitchen, bathroom and toilet have higher ventilation requirement of air change rate, and the value are 20, 15 and 10 dm3/s/m2.

On the other hand, the relative air velocity is an opposite limitation to the fresh air demand, under the consideration of avoiding draughts. The maximum value for air velocity regulated by Bouwbesluit 2012 is 0.2m/s in the living zone of residential space. The envelope design approach greatly influences the indoor air quality and air velocity with natural ventilation (Mărginean, 2019).

Building category	Airflow per person l/s/pers
I	10
II	7
III	4

Table 2. Recommended ventilation rate for non-residential buildings. Source: EN-15251 (2018)

2.3 Visual comfort

The light source (artificial and natural), the distribution of the light in space, and the observed light determine the indoor light quality (Bluyssen, 2009). Utilizing an adequate amount of daylight is possible to fulfill the visual comfort, as well as to reduce the potential electricity lighting demand (Moumdjian, 2020). Placing windows in buildings is the primary way to provide natural illumination and a view of the outside space. While windows not only provide daylight but also affect thermal comfort and air quality (Athienitis & O'Brien, 2015). Increasing the window to wall ratio would improve the visual comfort with natural light, while to compensate for the extra heat gain usually proper glazing type and shading system is required in some orientation of the envelope (Mărginean, 2019).

Visual comfort is strongly related to illumination and the daylight factor. Illumination is the amount of light distributed in the indoor space, expressed in lux. The daylight factor is the ratio of indoor light level to outdoor one. The minimum recommendation of daylight provided through vertical openings is regulated in the European standard EN1703. In which, the measured illumination needs to achieve 300 lux for at least half of the total area and 50% of the occupancy period on the objective plane surface. In addition, according to EN 15251 (2007), depending on the function of the space the required luminance is from 100 to 500lx (EN-15251, 2007). In the Dutch building decree Bouwbesluit (2012), the area of opening (windows) on the façade needs to be at least 10% of the floor area, with a minimum of 0.5m2 for residential buildings (BZK, 2012).

In the LEED version 4 certification (Daylight | U.S. Green Building Council, n.d.), daylight is one of the objectives in the indoor environmental quality section. There are three options to calculate the daylight result. The first option combines simulation spatial daylight autonomy (SDA) and annual sunlight exposure (ASE). The second is illuminance calculation at 9 a.m. and 3 p.m. on a clear-sky condition. The third option is the measurement of illuminance at specific times and periods of the year.

3 Energy Demand and Regulations

Although energy performance and comfort are different aspects, they influence each other deeply (Fumagalli, 2020). Providing constant indoor comfort is an essential target for building design while the outdoor climate environment is continuously changing from day to day in every season. If buildings fail to provide suitable indoor comfort, people tend to depend on HVAC system to compensate for it. To meet the indoor comfort requirement, buildings need to neutralize the outdoor influence, with the four main comfort aspects mentioned in the comfort definition chapter. Building operation energy includes heating, cooling, lighting, ventilation, cooking, appliances, and hot water provision. Usually, heating and cooling demand would take the main part of it (Chang & Wei, 2021).

3.1 Energy consumption

The building environment contributes to about 40% of final energy and 36% of CO2 emissions in Europe which means it is the key pillar of the European Union (EU) climate and energy strategy if the target of reducing greenhouse gas emissions (40%), increasing energy efficiency (32.5%) and renewables (32.5%) needs to be achieved by 2030 (D'Agostino et al., 2021; Economidou et al., 2020; L. Rodrigues et al., 2018) To reach the goal of Paris agreement the building operation energy would need to be reduced.
To provide a comfortable indoor environment, buildings consume primary and secondary

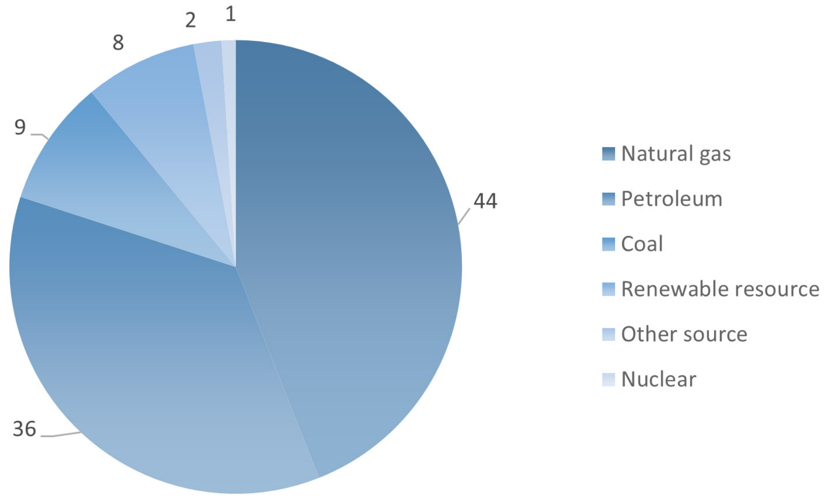


Figure 7. Figure 2.8 - Current primary energy ueage in the Netherlands.
Figure 8. Source: EBN (2020)

energy. The type of energy source and the method to use it would determine the amount of carbon emission. Currently, the main primary energy usage in the Netherlands is natural gas (44%), petroleum (36%) and coal (9%). Buildings use related sector occupies 28%, as the second biggest sector in all the energy consumption sectors, of the final energy consumption and causes 19% of the greenhouse gas emission in the Netherlands in 2019 (EBN, 2020).

Many different methods are taken in the Netherlands to generate electricity. In the past 10 years, the amount of electricity generated with renewable resources increased from 3% to 18% to become the second-highest of electricity, while the main source is still natural gas with 59% usage (EBN, 2020). To Evaluate the influence of building energy consumption on the environment, the transferring of both primary energy and secondary energy to carbon emission would be suitable to assess the building energy performance.

3.2 Energy regulation

In recent years, the Energy Performance Coefficient (EPC) is wildly applied to evaluate the energy performance of building in the Netherlands to ensure the built environment is becoming a more sustainable condition. The energy cost optimization calculation result was made into the NTA 8800 and the new regulation of BENG took place in February 2019 (RVO, 2019a). BENG regulation is required to meet for non-residential and residential buildings to hold the building license in the Netherlands. In the BENG regulation, there are three different aspects of requirements for energy demand while these aspects are coherent with each other.

The BENG1 indicator is mainly to reduce the energy waste and limit the energy demand with a calculation of energy-based of energy demand for heating and cooling related to the floor area in the unit of kWh/m2*yr (RVO, 2019b; Zaken, 2019). BENG1 depends on the design decisions of the building in building shape, orientation, envelope component, airtightness, window to wall ratio, and a standard neutral ventilation system, irrespective of the real ventilation system (Mak & Anink, 2019). The building category is regulated by the ratio of heat loss area (Als) to the usage area (Ag). As the ratio increases, the limited value of energy usage rises as well.

BENG2 limits the amount of primary (finite) fossil energy used in the building with efficient approaches, expressed in kWh/m2*yr. This energy consumption includes the energy for heating, cooling, ventilation, and water heating, in addition, to the energy cost for electrical light and humidification for non-residential buildings. To reduce the demand for primary fossil, renewable energy, like PV panels, should be an alternative option to compensate for the primary energy demand (Moumdjian, 2020; Zaken, 2019).

Ground-level homes		Residential buildings	
Geometry	Boundary value (kWh/m^2.yr)	Geometry	Boundary value (kWh/m^2.yr)
$A_{ls}/A_g \leq 1.5$	≤ 55	$A_{ls}/A_g \leq 1.83$	≤ 65
$1.5< A_{ls}/A_g \leq 3.0$	$\leq 55+30^*(A_{ls}/A_g -1.5)$	$1.83< A_{ls}/A_g \leq 3.0$	$\leq 55+30^*(A_{ls}/A_g -1.5)$
$3.0< A_{ls}/A_g$	$\leq 100 + 50^*(A_{ls}/A_g -3)$	$3.0< A_{ls}/A_g$	$\leq 100 + 50^*(A_{ls}/A_g -3)$

Table 3. Boundary values for BENG 1.
Adapted: RVO 2019

Ground-level homes	Residential buildings
≤ 30 kWh/m².yr	≤ 50 kWh/m².yr

Table 4. Boundary values for BENG 2.
Adapted: RVO 2019

BENG3 implies the minimum amount of the shared renewable energy meets the building energy demand, expressed in % (RVO, 2019a). To calculate the shared renewable energy, the Renewable Energy Ratio is needed, and it is defined as:

Renewable Energy Ratio = gross renewable energy / (primary energy use + gross renewable energy) x 100%

Ground-level homes	Residential buildings
≥ 50%	≥ 40%

Table 5. Boundary values for BENG 3.
Adapted: RVO 2019

3.3 Energy production

Integrating the renewable energy system can reduce the carbon emission caused by the primary fossil energy usage from building operations. In recent years, architects tend to generate or use renewable energy in the building location or join the energy sharing grid. Regarding renewable energy resources, the most accessible and common resource used to generate on the building site is solar energy. Solar energy can be transformed into electricity by photovoltaics (PV) or by using the heat collector to heat up spaces and water.

The research of Goorden, J. (2016), shows the efficiency of the types of solar collectors in the comparison is from 20% to 80% while the limit condition and price differ. The research declares that even the maximum efficiency does not necessarily link to a higher cost-effective option.

The photovoltaic system is widely applied to modern residences in the Netherlands. The percentage of solar radiation that can be transformed into electricity can be from 14% up to 20%. Generally, the annual production of electricity can be expected to be 875 kWh/kWp (van Sark, 2014). The amount of produced energy is related to the types of PV panels and the way that the panels are installed (Höfte, 2018). The orientation and the angle of installation of the panels determine the radiation gain on the panels then influence the electricity generation. The external temperature influences the efficiency of transforming solar energy into electricity and the trends for the variant types of panels are similar (Elibol et al., 2017).

4 Climate Conditions

4.1 Climate change and the influence of building environment

4.1.1 Uncertainty of climate conditions

One of the main challenges that we are facing in the 21st century is climate change as the crucial and worldwide impact on the environment, economy, and human health (de Wilde & Coley, 2012; Parry et al., 2007). Weather condition changes rapidly in the recent decades compared to the entire time horizon of the earth's history, although there is no significant difference within the coming weeks or months. The study of climate change is usually based on a 50 to 100 years period (KNMI-Klimaatscenario's, 2021). Climate change can be considered as the moving of climate zones. With current greenhouse gas emissions, the 'climate velocity' is about 20km per year or 2.25 meters per hour (Lynas, 2020). The observed global mean surface temperature (GMST) in the period of 2006 to 2015 was 0.87 ° C higher than pre-industrial climate level (IPCC, 2018). If we follow the current business-as-usual trajectory, global warming is likely to be 1.5 ° C between 2030 and 2052 (IPCC, 2018).

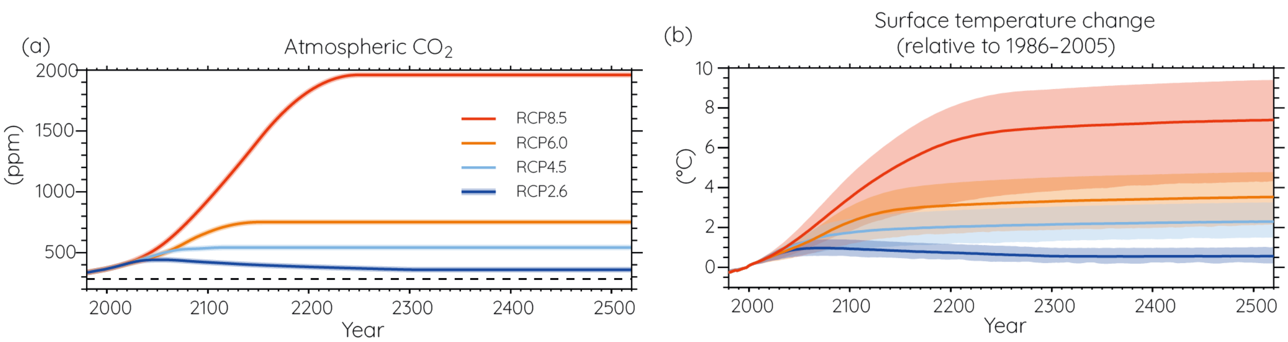


Figure 9. Prediction of future CO2 emission.
Source: IPCC ar5 (2015)

Global warming is an issue that humanity must face together, but the vulnerability of places and regions is unequal. In the Netherlands, the speed of temperature rising is almost twice than the global average temperature rise (KNMI Klimaatsignaal '21 - Hoe het klimaat in Nederland snel verandert, 2021). In places like Alaska and Canada, due to the period of snow cover will reduce, the temperature tends to rise around 10° C (Solomon et al., 2007) while the northern Mediterranean coast would rise by 5° C (Coley, 2008).

Climate change and be easier observed by the heatwave duration period and frequency per year. The climate documentation provided by Royal Dutch Meteorological Institute (Koninklijk Nederlands Meteorologisch Instituut, KNMI) shows the record from 1901 till 2021. A heatwave is a continuous 5-day period with a temperature higher than 25 ° C of which at least 3 days' temperature higher than 30 ° C (KNMI - Heat Waves, 2021). There were 29 heatwaves during the same period in the Netherlands. By using heatwave value (calculation by adding all values above 25 degrees from the series of days with a maximum temperature above 25 degrees) the weight of each heatwave can be evaluated. The trend of heatwave happens more often from once in a year to twice a year in 2018 and 2019. In 2020, the heatwave endured for 13 days with 9 days exceeding 30° C (KNMI - Heatwaves, 2021). With the global average temperature rising, it is conceivable that the heatwave value will increase year by year as well. which means the existing and under-construction buildings are at risk of overheating.

On the other hand, the coldwave was one of the focuses for building design and construction as well. A coldwave is defined as a succession of more than 5 days with a temperature below 0.0 ° C in which at least 3 days temperature below -10 ° C (KNMI - Cold Waves, 2021). Before 1970, a coldwave occurs once in a few years for 8 to 21 days with the lowest temperature -24.7° C. However, there are only 3 cold waves that happened within the recent 30 years. The latest one is 9 years ago, with 10 days duration and the lowest temperature -18.9 ° C (KNMI - Cold Waves, 2021). This trend shows the threat of building uncomfortable caused by extremely cold weather would be no longer a concern.

4.1.2 Paris Agreement

Paris Agreement was signed by 196 countries at the 21st of the Conference of the Parties (COP 21) on 12 December 2015 (COP21) and entered into force on 4 November 2016. The goal of this agreement is to hold the global average temperature below 1.5 Celsius degrees above pre-industrial levels. To achieve this goal, the emission of carbon dioxide needs to be reduced by 45% by 2030 (Key Aspects of the Paris Agreement | UNFCCC, 2021; The Paris Agreement | UNFCCC, 2021). With this ambition, the long-term greenhouse gas emission development strategies (LT-LEDS) is provided to all the invited countries, as a long-term horizon of nationally determined contribution (NDCs).

Although the Paris Agreement has been signed since 2016, the annual global energy-related carbon dioxide emission only decreased from 35.45 billion tons to 34.81 billion tons (a 2 % decrease) (Annual CO2 Emissions Worldwide 1940-2020, n.d.) Following the trend, the target of preventing global average temperature below 2 Celsius degrees can be very challenging.

However, the climate change research from the KNMI shows the chance of continuously warming of Dutch climate is inevitable in any of the predicted climate scenarios (KNMI Climate Signal’21, 2021).

4.1.3 Influence of climate change on building energy and comfort performance

Integrating building performance study with building design dedicates to predicting building indoor comfort and energy consumption in the early design phase. Besides design decisions, the building environment and climate condition are the other two main elements that determine the performance.

In the study of prediction of building performance in future climate conditions, there is variant result depending on the location, aspect, and design approaches. For nearly zero energy buildings (NZEBs), the heating demand could reduce by 38%-57% with cooling demand increasing by 99%-380%, depending on the location (D'Agostino et al., 2021). Consequently, heating and cooling capacity could have great divergence from the initial design strategy. The strategy of shading, ventilation, and the cooling system determines the indoor discomfort hour from 180 to 600 hours and would cause twice the amount of energy related carbon emission in the year 2080 in the United Kingdom (Holmes & Hacker, 2007). The range of heating demand months and peak winter days heating demand are both predicted to decrease with the influence of climate change, from 9 months to 6 months and 22 hours to 15 hours in the year 2080 scenario A1F1 and A2 in the United Kingdom (Alhindawi & Jimenez-Bescos, 2020).

4.2 Climate data set and climate change

4.2.1 Climate data format

The current energy performance analysis is based on computational programs with design parameters and hourly climate data files. The common climate data file is EnergyPlus Weather File (EPW). EPW composes of 13 types of hourly climate information. They are dry bulb temperature, dew point temperature, relative humidity, atmospheric pressure, horizontal infrared radiation intensity from the sky, direct normal radiation, diffuse horizontal radiation, wind direction, wind speed, present weather observation, present weather codes, snow depth, and liquid precipitation depth (bigladder, 2015; Jia, n.d.). These data sets are collected throughout decades. However, processing the model to all the collected data is not practical in most cases. consequently, EPW is a weather file constructed by climate data from multiple years and is considered the Typical Meteorological Year (TMY) model.

The TMY model is designed to reduce the process of simulation from running through all the collected climate conditions to most TMY. The most TMY is composed of monthly data which is closest to the average number of the same month in all the collected years. For example, if there are climate data for 10 years. The January climate data that is put into use is the one that is closest to the average monthly data in 10 years. As well as the other months. Furthermore, all the 13 types of climate information must be in the same month of the same year. By this method, it is possible to reduce the chance of selecting extreme conditions in the performance analysis.

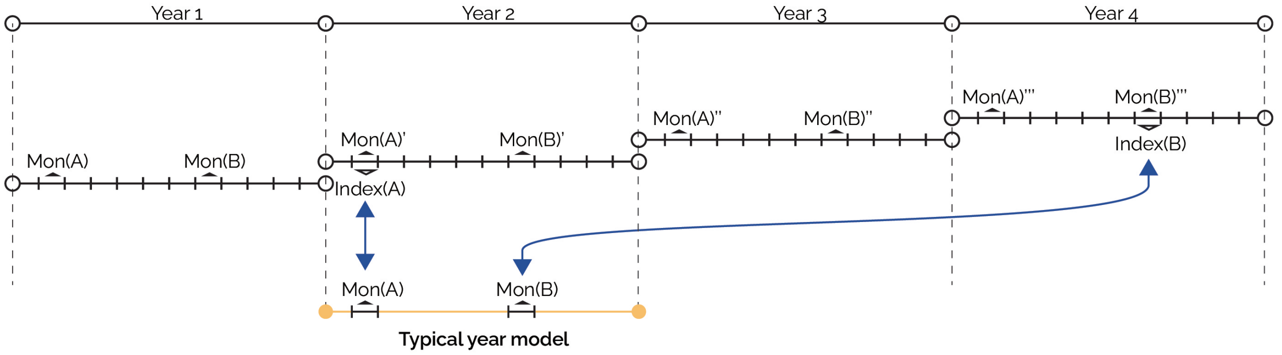


Figure 11. Methodology of construct TMY model.

4.2.2 Climate research

KNMI'14 is the future climate scenarios transformed from the report of Intergovernmental Panel on Climate Change (IPCC — Intergovernmental Panel on Climate Change, 2022) to the Netherlands. With the knowledge of global warm studies from the United Nations and the observation and research done by the KNMI (KNMI Climate Signal'21, 2021). The climate change research of KNMI'14 provides predicted climate files from 33 weather stations in the Netherlands. All the climate predictions are produced based on collected climate data.

Figure 10. 33 weather stations in the Netherlands.

The report of KNMI'14 has four variants of climate scenarios in the years 2050 and 2085 depending on the amount of GHG emission. Between these scenarios, the temperature difference in the year 2085 (the farthest year that can be predicted) is up to 2.5 °C and with at least 1 °C different from the current condition. The temperature variation depends on the season as well. There are two aspects that determine the climate scenarios, the changes of airflow pattern from a low value (lage waarde) to a high value (hoge waarde) and the global temperature rise from moderate (gematigd) to warm. With the combination of the aspects, the most moderate climate condition is called GL (gematigd and lage waared) and the warmest is WH (warm and hoge waarde) (KNMI Climate Signal'21, 2021).

The other method of generating climate data is using the CCWorldWeatherGen. This weather file generator uses IPCC of the Third Assessment Report (TAR) model summary data of the Hadley Centre Coupled Model version 3 (HadCM3) A2 experiment (Jentsch et al., 2012). To generate the weather file the method of "morphing" is applied to transform an existing EPW into a predicted future climate file. This tool can generate a weather file in the years 2050 and 2080 for building energy performance simulation (Sabunas & Kanapickas, 2017). This generator only applies the IPCC A2 scenario in the calculation and is not able to produce other possible climate scenarios (Jentsch et al., 2012).

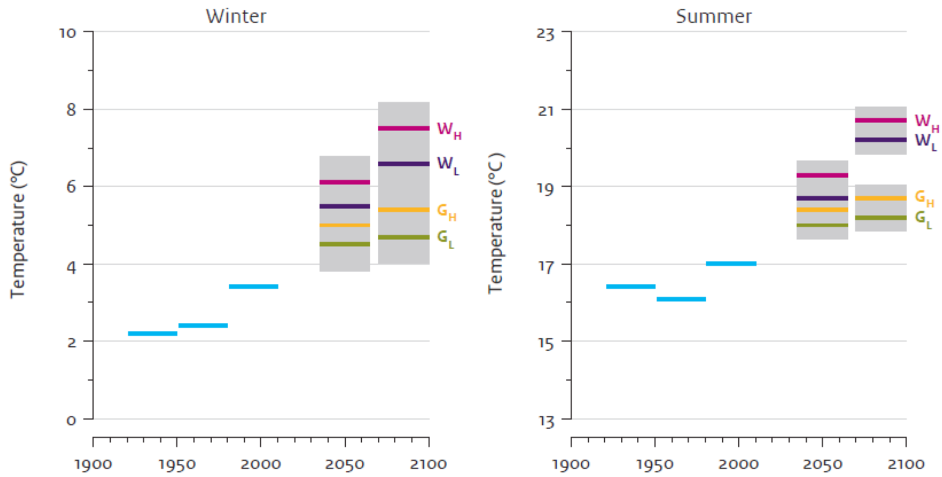


Figure 12. Climate Scenarios of KNMI'14 in Winter and Summer Conditions Source: KNMI(2014)

The morphing method by yielding weather time series encapsulates the average weather conditions of future climate scenarios while the realistic weather sequences are preserved (Belcher et al., 2005). The morphing method is applied to generate future TMY to test the influence of climate change on the building by simulating the different types of building in Hong Kong (Sabunas & Kanapickas, 2017). The morphing method is used to study the performance gap of climate change on building design analytical stages using future weather projections in Chelmsford, England (Alhindawi & Jimenez-Bescos, 2020).

4.2.3 EPW, KNMI and KNMI'14

EPW file has hourly data in the year which means the data set is composed of 8,760 data points, 24 hours with 365 days in a year, in the 13 categories of climate data set. The data set is selected from TMY to reduce the chance of using extreme climate conditions in the simulation.

In the climate change report of KNMI'14, the daily information on maximum temperature, minimum temperature, average temperature, evaporation, global radiation, and precipitation is presented. The provided climate data is based on the collected year data from the year 1980 to 2010.

The format of the KNMI climate file is different from EPW which is mostly used for building performance simulation. Also, some of the essential climate data sets for simulation are not recorded (diffuse horizontal radiation, direct normal radiation, global horizontal illuminance, diffuse horizontal illuminance, and direct normal illuminance). To produce these data sets would require further calculations based on existing research.

4.3 Morphing climate data

The simulation of building performance is predicted climate conditions would need to process with the climate file composed of the projection of climate data. In this chapter, the morphing method, a mathematical approach, is used to describe how to use the current climate data set together with climate change research from KNMI to generate EPWs for predicted future climate conditions. Besides the TMY being used to morph the future climate file, an extreme year model is also generated.

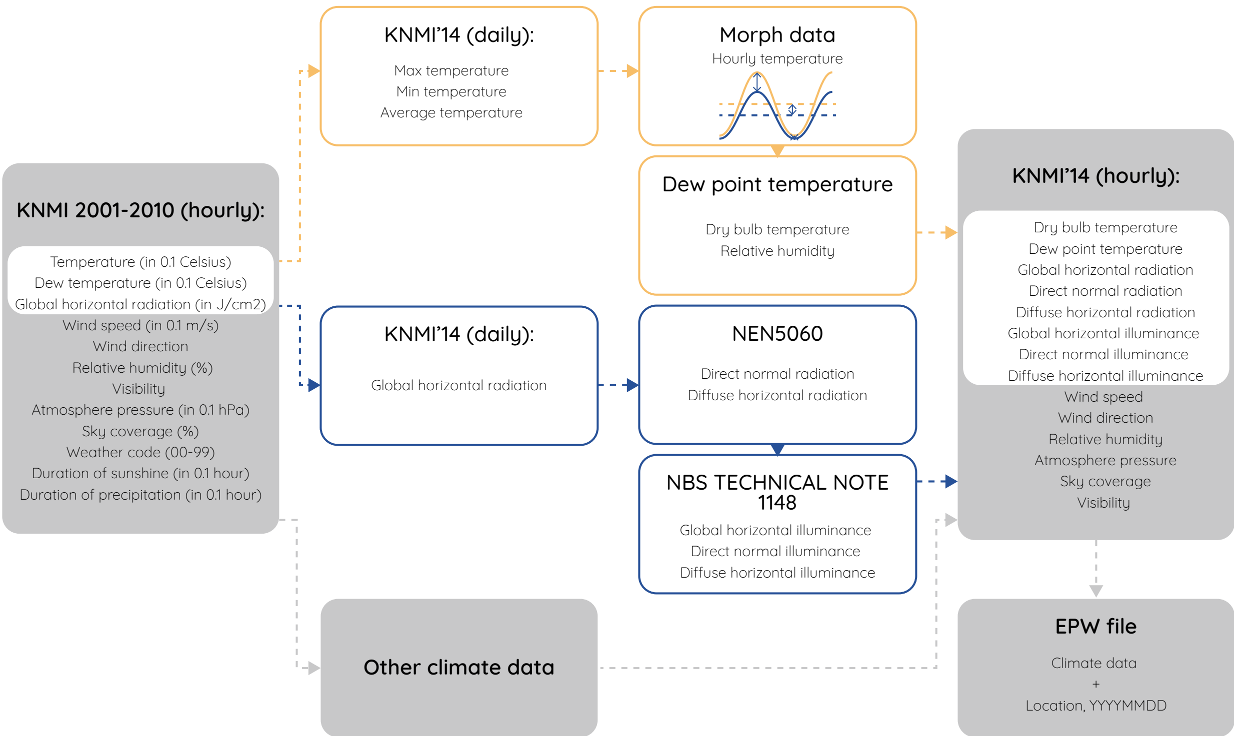


Figure 13. Workflow of generate weather files.

4.3.1 Temperature

In the KNMI'14, the prediction of temperature data sets contains three factors, the daily average, daily maximum, and daily minimum temperature in KNMI'14. The comparison of trend of data sets within KNMI'14, KNMI, and EPW is shown in Figure 14. To process the simulation of building performance in future climate conditions, hourly future climate data is required.
The climate data is a number of series. Since the pattern of the climate data set will be the same, the current maximum and minimum values can be replaced by the known target maximum and minimum values. Other data will be used morphing method to generate the predicted one. The morphing method is using the current climate data set projecting to the prediction one while the climate pattern is the same. The method used in this research is scaling the data series with the ratio of the sum of current temperature and the sum of prediction temperature, besides the maximum and minimum values. With this method, the mean square error is less than 0.0001.

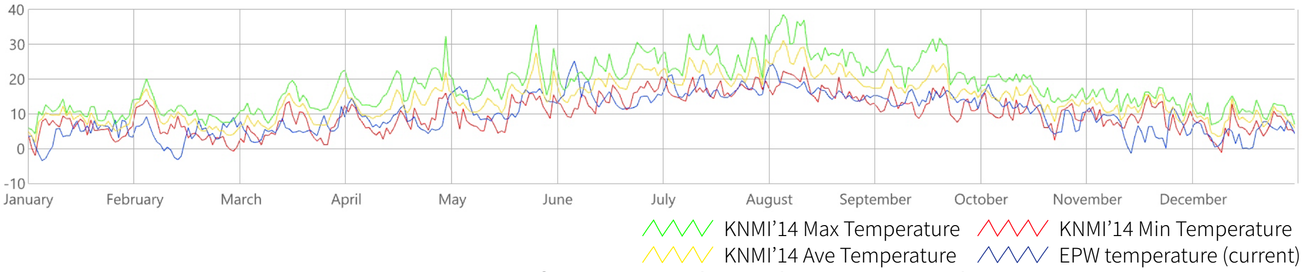


Figure 14. Comparison of temperature data with EPW, KNMI, and KNMI'.

4.3.2 Radiation

The radiation data provided in KNMI'14 is the average daily global horizontal radiation data series. The morphing is based on scaling the original data series based on the ratio of the daily average. The units for radiation information provided by KNMI are in K/m^2, and the common unit used in the simulation is w/m^2.

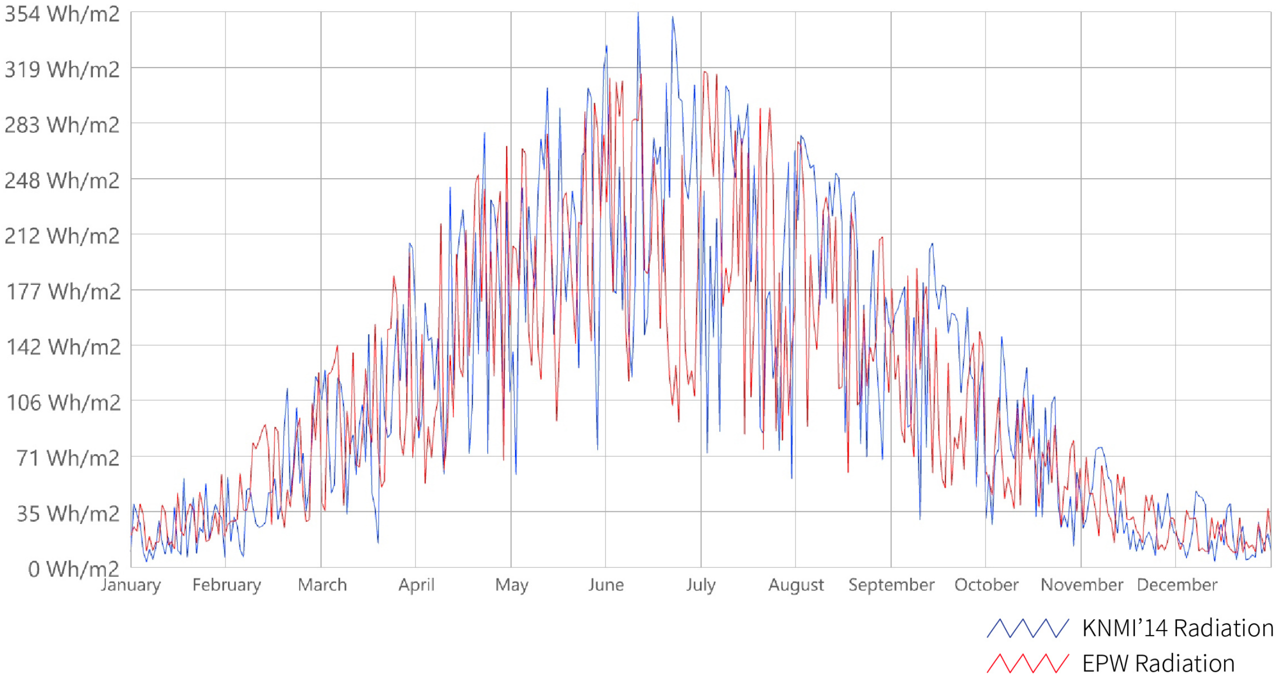


Figure 15. Comparison of radiation with EPW, KNMI, and KNMI'

The climate information of direct normal radiation and diffuse horizontal radiation is required to process the simulation. Producing direct normal radiation and diffuse horizontal radiation from global horizontal radiation is highly dependent on location and atmospheric conditions. The Dutch standard of Hygrothermal performance of buildings – Climatic reference data, known as NEN-5060(NEN 5060, 2018), shows the procedure for converting global radiation to diffuse and direct radiation. The calculation is based on the Netherland's atmosphere and geographic condition.

4.3.3 Illuminance

Illuminance is the main factor for daylight evaluation. Usually, it is defined as global horizontal illuminance, direct normal illuminance, and diffuse horizontal illuminance. Illuminance is related to solar radiation, humidity, and sky conditions (Treado & Kusuda, 1981). Perez luminous efficacy model is used to study illuminance data prediction based on solar radiation data (Seo, 2018). But the calculation is more complicated and heavier. In NBS TECHNICAL NOTE 1148, a factor of 110 lumens/watt for calculating global radiation to global illuminance is given based on the typical sample day condition (Treado & Kusuda, 1981). And 105 lumens/watt for direct solar radiation. While the sky condition would influence the factor. On cloudy days, the factors would decrease, meanwhile, the diffuse horizontal illuminance would increase.

4.3.4 Constant factors

Due to the difficulty of climate condition prediction or lacking relevant research, some data sets in the predicted climate file are composed of the current condition. The data of wind speed, wind direction, related humidity, atmosphere pressure, sky coverage, and visibility are applied to the current conditions. These data sets are not included in the KNMI'14 scenarios, and it is not suitable to combine variant research results into one condition. on the other hand, in general, have less effect on building performance. For example, wind speed and wind direction would not be the main influence factors since the simulation is based on a mechanical ventilation system.

4.3.5 Conclusion

Based on the current climate file and the prediction of future climate research, it is possible to generate local climate file for simulation in the Netherlands. From the collected weather data, the structure of TMY year model present in Table 6 and an extreme year model, in Table 7, is created as a comparison condition.

January	2004
February	2004
March	2004
April	2004
May	2005
Jun	2009
July	2005
August	2003
September	2003
October	2007
November	2003
December	2003

Table 6. Typical year structure

January	2007
February	2007
March	2007
April	2007
May	2007
Jun	2008
July	2008
August	2002
September	2002
October	2002
November	2002
December	2002

Table 7. Extreme year structure

This research generated four climate conditions based on different climate design aspects, and all the projected climate condition is based on 2085 WH. The first condition is based on TMY of the years 2001 to 2010. The second is composed of the warmest months in the same period. This model shows the worst climate scenario in 2085. The third is a mix-year model which combines the current climate condition and the prediction in the first climate option. In this model, the colder winter of the current condition and warmer summer in 2085 are combined. The last is an average climate condition. In this scenario, the average temperature, and radiation in current and future conditions are used.

In Figure 16 to Figure 18, the result of current temperature condition and the prediction temperature condition of 2085WH and extreme are shown. There changing in the percentage of warm hours (over 24°C) and cool hours (below 20°C) is obvious. Until 2085, the percentage of cool hours is expected to decrease by 10% with a rise of percentage of warm hours of 7%. Furthermore, the extreme year model seems have a trend of having early summer, but the ratio of temperature condition is similar to 2085WH.

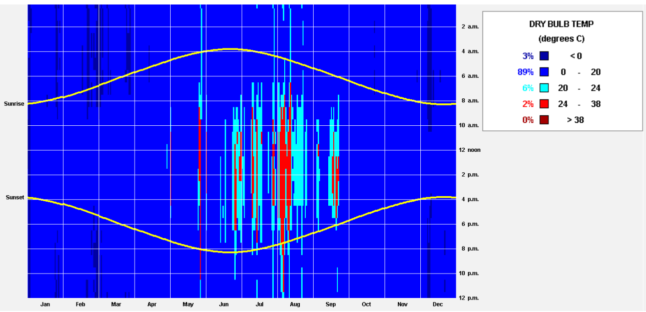


Figure 16. Dry bulb temperature timetable plot, current model. Generated with Climate consultant 6.0

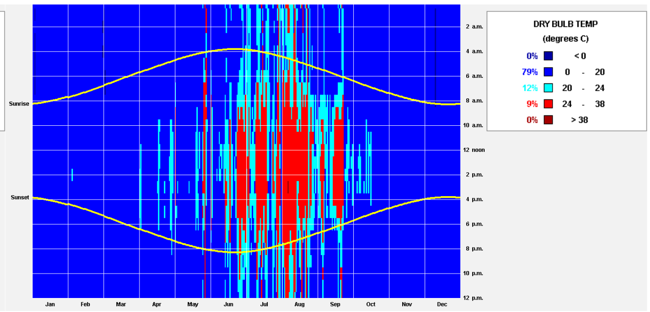


Figure 17. Dry bulb temperature timetable plot, 2085 WH model. Generated with Climate consultant 6.0

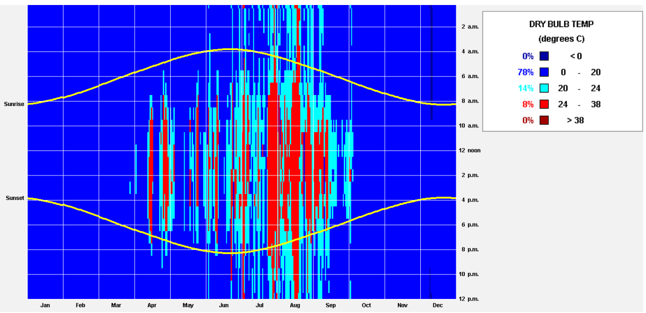


Figure 18. Dry bulb temperature timetable plot, 2085 extreme year model. Generated with Climate consultant 6.0

5 Simulation and Optimization

5.1 general background

… both the power and the complexity of building performance modeling and simulation arise from its use of many underlying theories from diverse disci-plines, mainly from physics, mathematics, material science, biophysics, human behavioral, environmental and computational sciences (Hensen & Lamberts, 2011).

Computational simulation and optimization are commonly applied in both the early design phase and later ones to estimate the building performance. The powerful simulation tool can be used for many purposes. Within the spectrum of applications, for instance, there are: optimization of façade performance and generated design decisions (Mărginean, 2019), performance studies of the influence of building height and surrounding conditions, and the correlation of building shape and orientation with the energy demand and energy production (Moumdjian, 2020), energy efficiency and cost effectiveness optimization (Rodriguez Garcia, 2018), and prediction of energy consumption in climate change environment (Bamdad et al., 2021), comparison of building performance and energy demand in multi locations under the influence of climate change (D'Agostino et al., 2021), options of low energy demand retrofit of buildings by mitigating climate change and urban overheating (Ascione et al., 2018).

On the other hand, simulation results provide a series of design variants, but to determine the "best" or preferable range of outcomes of design options the optimization process is required. Optimization is the method to ease the iterative process of evaluation and simulation to figure out the preferred performance design options (Attia et al., 2013). In the simulation, modeling, and optimization process, there are two main aspects of design factors that have impacts on the thermal and energy performance, geometrical (e.g., building shape, orientation, weather and occupant behavior) and non-geometrical (e.g., building envelope property, heating and cooling system) (Macharias, 2013). Generally speaking, optimization methods come in two main categories, single-objective optimization (SOO) and multi-objective optimization (MOO). SOO is mainly for linear relation with a single design factor to figure the maximum or minimum option in the constrain (Attia et al., 2013). SOO is applied to design that has one factor that has domain and critical impact on the design decision. Multi-object optimization is aiming to determine the option when the presentation of trade-offs between two or more conflicting objects is developed on Pareto efficiency or Pareto optimality ("Multi-Objective Optimization," 2021). In building project optimization, MOO is more prevailing than SOO, since building design projects usually have more than one factor influencing building performance.

In the MOO study of building performance, Hypervolume Estimation (HypE) and Non-dominated Sorting Genetic Algorithm II (NSGA-II), are the common genetic algorithms being applied. The Fast Non-dominate Sorting and the Crowding Distance Assignment are applied to all the population in NSGA-II (Skolpadungket et al., 2007). NSGA-II is possible to find out the result faster and also to generate a wider coverage of the objectives (Deb et al., 2002; Wortmann & Natanian, 2020). However, this algorithm is more suitable for optimization with two objectives. In the cases with three and four objectives, the accuracy of optimization comes to the worse for this algorithm (Bader & Zitzler, 2011). To compensate for this problem, objectives shall be set as constraints or limitations. In Grasshopper environment, the NSGA-II is applied to the plug-ins named Wallacei and Opossum 2.0.

In the performance analysis of a different number of dimensions, or called objectives, HypE has the best performance when there are more than 2 dimensions (Bader & Zitzler, 2011). However, HypE needs a longer execution time to process the same number of generations in the comparison done by Bader and Zitzler,2011. In Grasshopper environment, the plug-in Octopus applies this metaheuristic.

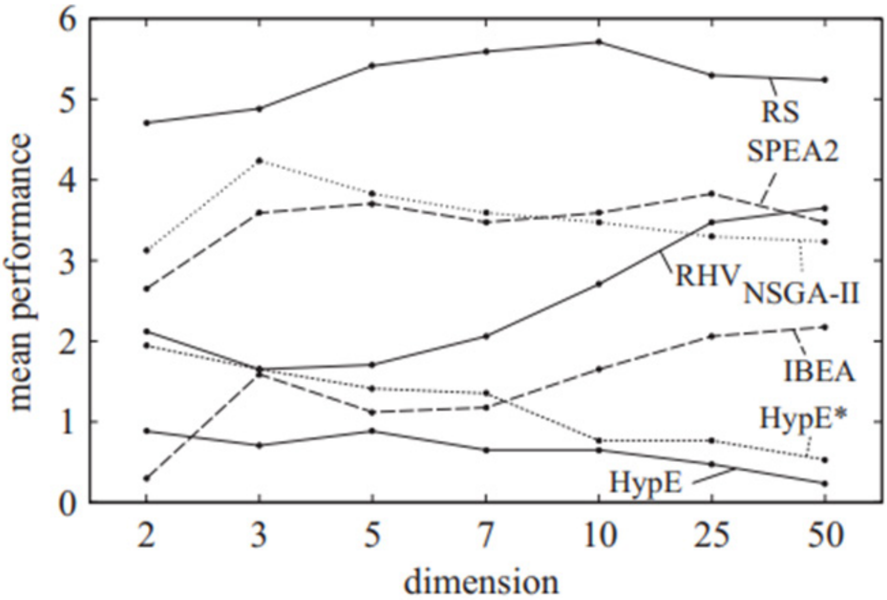


Figure 19. Mean performance score over all test problems for different number of objectives. The smaller the score, the better the Pareto-set approximation in terms of hypervolume. Source: Bader & Zitzler, 2011

5.2 Building energy consumption simulation

In the design phase, the physical environment condition and energy consumption are still not measurable. With the knowledge and technology of parametric modeling, a series of algorithms carry the design factors to process the calculation for the estimated comfort and the energy consumption. The building performance simulation is used to study the correlation between design decisions and building performance. A review of simulation-based energy performance building shows that the energy consumption can be further reduced by 20-30% by optimizing the design decision based on the performance study (Nguyen et al., 2014).

Building performance simulation and optimization are composed of three main aspects, the environment, building geometry and materialization parameters, and building performance (comfort and energy) and demand (occupancy and systems). Meanwhile, these factors interplay with each other (Bamdad et al., 2021; Daly et al., 2014).

The factor of environment can be considered into two main aspects, the built environment, and the physical environment. The building environment is about the surrounding environment of buildings, and landscape. The environment would influence the local physical environment factors that the building receives. A study of the influence of surrounding buildings on building performance design approach shows that the surrounding height has a positive correlation with the heat gain and received daylight with the window to wall ratio, especially with the south façade (Moumdjian, 2020). The physical environment is related to the climate condition, light environment, and acoustic environment and usually, it is considered a constant factor in the area or region. To ensure the building can provide adaptive indoor comfort with the outdoor physical environment, the building design would need to include multiple criteria to deal with different comfort demands. The research from (Christoforidou, 2019) shows the study/design

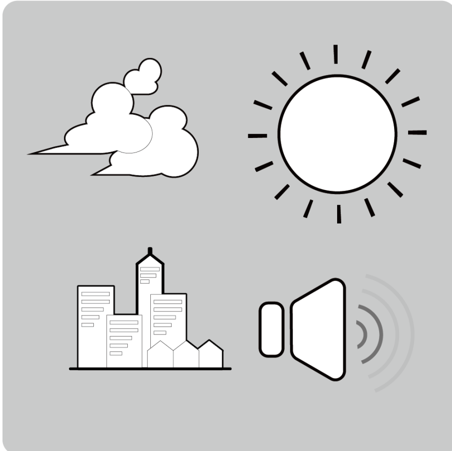


Figure 20. Environmental factors.

The building geometry parameter has four main factors, building shape and orientation, building envelope, building height, and layout. The building geometry parameter is mainly determined by the architect's preference in most cases, but this decision has a major influence on building performance. The building orientation and shape have an influence on energy consumption and energy production, however, the amount of consumption and production usually have similar trends (Moumdjian, 2020). The combination of energy-saving solutions of envelope design for high-rise buildings in temper climate zone can reduce energy usage by up to 40% (Raji et al., 2016). The wind speed and direction (Bottema, 1993), as well as the temperature, would be different regarding the building height from the ground floor.

The comfort requirement is related to the layout of the building since it decides the function, activities and occupant time of space (Fumagalli, 2020). The building performance and demand aspect are related to the comfort demand. energy consumption, and energy production. Indoor comfort or user's comfort is related to thermal, lighting, air quality, and acoustic (Bluyssen, 2009; Chen et al., 2016). Building functions regulate the comfort demand for specific space, period, and degree. Energy demand which is frequently used as the optimal objective in simulation is related to the building operation energy for providing acceptable indoor comfort. To ensure the indoor comfort level, the installation of heating, cooling, and ventilation system in most buildings are inevitable because of the impact of the exterior environment on the heat gains and losses(Pastore & Andersen, 2019). To compensate for the energy consumption, buildings are required to generate energy locally integrating with techniques like PV panels or other sources (Moumdjian, 2020).
In a computational environment, the energy demand of the buildings can be predicted by determining building design, environmental conditions, and the satisfaction of thermal comfort. In the Netherlands, Fumagalli explored the effect of space layout design of

residential on energy demand with parametric environment of Grasshopper. The framework of Performative Computational Architecture (PCA) is divided into three main steps as, the form generation by parametric model, energy consumption estimation, and defining the sub-optimal design objectives with optimization algorithm. In Mărginean's research shows the optimization result based on the simulation of energy performance and indoor comfort, with residential in different levels of a high-rise building. And as the result, it brings on the preferable envelope design factors from the library of input variables in the simulation process. the working environment is in Grasshopper with Honeybee and Ladybug as energy and thermal comfort simulation, and Radiance and Daysim for daylight analysis. The possible options were run with Colibri Iterator, and Design Explorer was used for the data set comparison. For the project of defining the guideline of zero energy building design in a hot humid climate, the energy performance is executed in the software of DesignBuilder with the simulation engine EnergyPlus.

The energy performance study of this research in the computational realm is based on the result of the validated simulation engine of Honeybee, the plug-in of Grasshopper. Honeybee is able to simulate building energy, thermal comfort, the HVAC sizing through EnergyPlus (EnergyPlus, 2013/2021) with OpenStudio (OpenStudio, n.d.) and simulate daylighting and glare with Radiance.

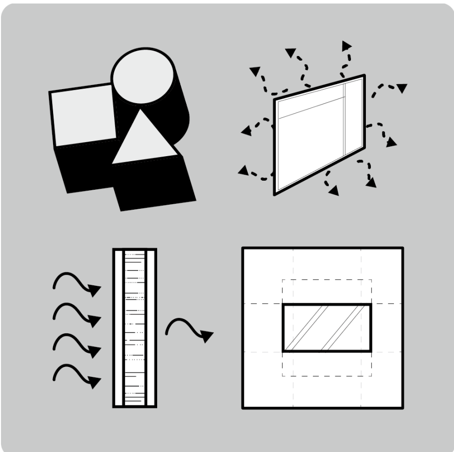


Figure 21. Building geometry parameters.

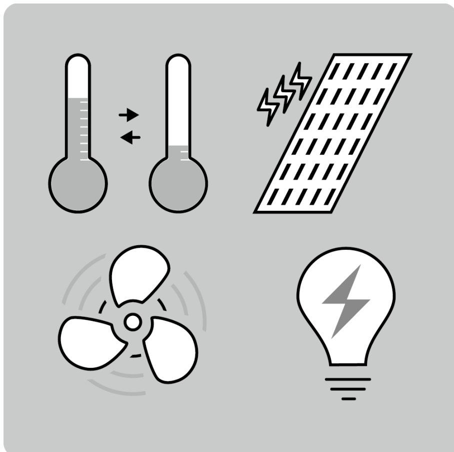


Figure 22. Building performance and demands

5.3 Energy simulation under climate change

In this chapter, the influence of climate change on building energy consumption, and the changing of design approaches are shown. To ensure human living environment quality, future proof design regarding climate change has been subject to some research to define the influence and the approaches that need to be applied. The theory of prediction of future climate conditions and the methods of producing climate data are mentioned in chapter 2.1. To use in building performance simulation and optimization, the future climate data should be edited in the same format as the current weather data file, EPW file for example.

Holmes & Hacker compared the energy performance and comfort of five existing low-energy buildings, with different functions and different design approaches under climate change conditions until 2080 in the United Kingdom. This research is based on three climate design factors: sunshade, roof and ground insulation, and ventilation strategy. In all the cases, the trend of increasing hours of overheating, growing cooling demand, and improving insulation and ventilation strategy are identical. Further, it is found that the roof thermal mass, U value with 0.2W/m^2/k and thickness of 200mm, can reduce overheating hours by around 30% which is slightly better than only the sunshade option in the simulation of future climate conditions. To reduce the energy cost and minimize the discomfort hours, night cooling, sunshade, and proper insulation are all required in a warming climate condition.

In Chile, (Verichev et al., 2021) figured that because of the influence of climate change, the climate condition tends to be changing continuously. Reducing the operation energy, the suitable U-value of the external wall changes from 0.49 W/m^{2}K to 0.78 W/m^{2}K in the year 2016 and 2035-2050 period. Furthermore, the improvement of insulation in the wall can reduce embodied carbon caused by energy demand by 20%.

Moazami et al. (2019) explored the possibility of single-floor building units with robust energy performance under climate change with performance optimization approaches. The optimization process has two main aspects, the unchangeable one as optimal envelope properties and the optimal daily control setting, heating, cooling, and shading. In sum, the combination of these two systems can reduce up to 56.8% of the mean value and 95.9% of the standard deviation of primary energy use then the building followed 1980 regulation, and the options of control optimization and envelopment optimization have 54.1% and 52.7% reduction.

Ascione proposed a method to determine the minimum global cost and carbon dioxide emission for a five-floor building in Italy. With multi-object optimization, it cuts 37.8% of cooling and heating demand with less than 3% of yearly discomfort hours until the farthest the year of 2035.

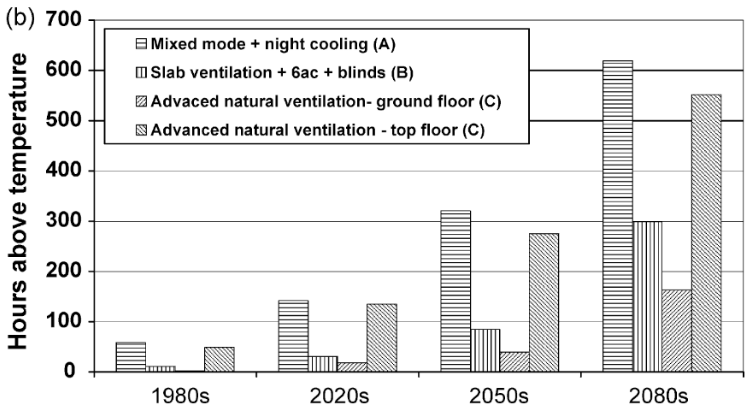


Figure 23. Building geometry parameters.

In conclusion, the building performance simulation and optimization provide an assessment of the comfort, and energy consumption of the design decision. And by comparing and selecting the design options, it is possible to come up with a more comfortable, and low environmental impact living environment. The simulation and optimization can be run by only changing certain design factors or environmental parameters. In this way, the weight of influence of each factor can be evaluated, and usually, the factors with lower influence will be considered as constant or be removed from the process.

As the effect of climate change makes our living environment less comfortable and unbearable in some conditions, the design approaches and methods need to integrate with future climate conditions. The prediction of future climate conditions is based on GHG emissions, and there are serval scenarios. Usually, the most extreme and most moderate scenarios would be the ones that are being taken into the simulation to make our environment be prepared for the most extreme condition and most moderate.

In the early design phase, building performance simulation shows the relationship between design decisions and the environment. Hence, it is a common approach to evaluating and improving design proposals. Due to building design being composed of numerous antagonistic parameters and they would lead to even greater various simulation results of building performance, the process of finding the "best" solution is a complex and heavy evaluation and simulation process (Macharias, 2013). Using the iterative nature of the procedure, the optimization process can be automatically executed by computer programs.

The optimization is the process of minimizing the output of simulation, energy consumption, and embodied carbon, by finding the preferable input, building design factors (Moazami et al., 2019). Different from common optimization project which is usually only based on a single climate condition, the future-proof design need to take care of the energy performance from now to the future condition and study what would be the approach with the lowest carbon emission and best indoor comfort performance throughout the building lifespan.

5.4 Simulation methodology

To integrate the consideration of climate change research in the building design and analysis process, the perspectives of climate conditions taken as the based condition would influence the final performance. To compare the decision and the performance there are five approaches applied in this thesis. These scenarios are processed through multi-objective optimization and are evaluated with the performance based on energy consumption, thermal comfort, daylight condition, and energy production from PV panels in current and future climate conditions.

As the Figure 24 illustrating, the first design scenario is the baseline design which is dependent on the original design and the Dutch and European building regulations. This set is used as a reference to compare with the other scenarios to judge if the design decision would influence the performance or not. The second design scenario is based on the current climate condition, from 2001 till 2010, with the possibility of the renovation based on the year 2085 with WH climate condition. The next, the third, scenario is a future based and finding the suitable renovation options for the building in the current climate condition. The fourth scenario is processed under a mixed-year model. The model of the mixed year combines the winter season of the current condition and the summer season of the predicted condition of 2085WH. An average year model is applied for the fifth scenario. Compared to the previous option, this option has smaller changes in the climate condition. The result of MOO processed under different climate conditions would give variant results with pros and cons therefore providing the performance features of design decisions.

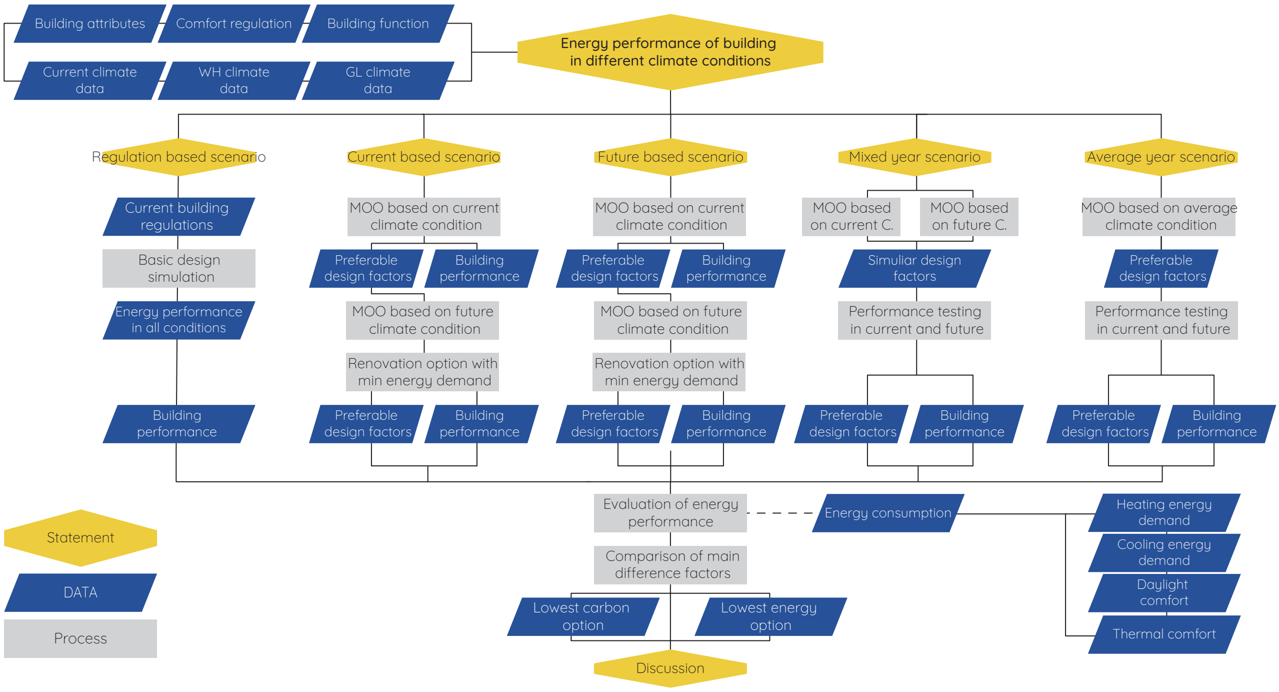


Figure 24. Workflow of optimization and analysis in five design scenarios.

5.5 Simulation workflow and objectives

The building performance analysis is an integration of multiple objective performance studies. The workflow of the selected software and plugin is presented in Figure 25. As the figure shows, most of the process is working in the Rhino environment with the plugin Grasshopper which is suitable for parametric building design and building performance analysis in early design phase. To analyze the building performance, the knowledge and regulations mentioned in chapters 2, 3, and 4 are required and this chapter shows the condition and simulation setup and limitations.

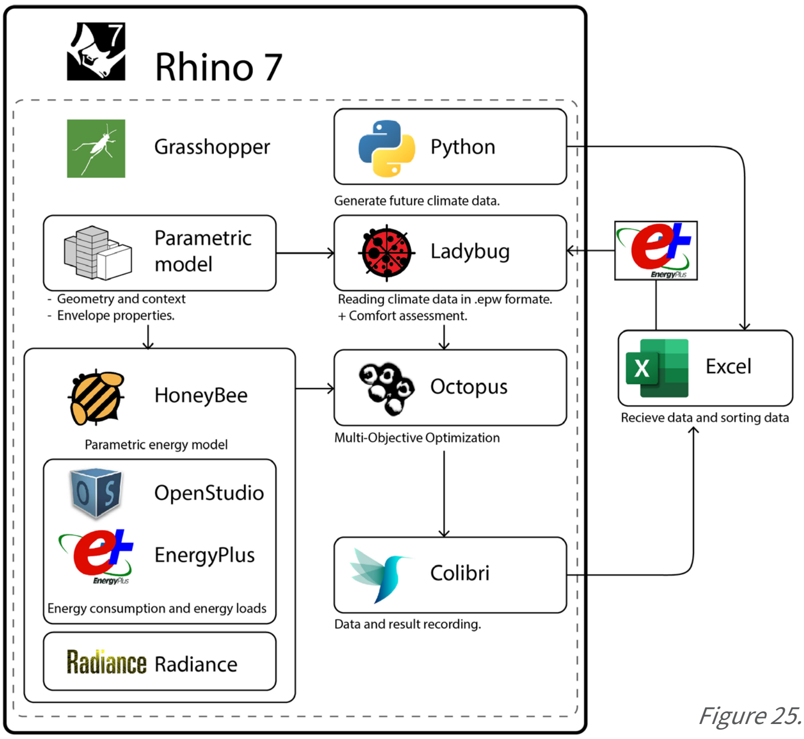


Figure 25. Scheme of software and plugin workflow.

5.5.1 Thermal comfort

The thermal comfort simulation is executed in Grasshopper environment with OpenStudio Model (OPM) which gives out the result of air temperature, operative temperature, radiant temperature, and relative humidity. The ladybug plug-in in Grasshopper is able to calculate the thermal condition with PPD-PMV model. The thermal comfort period should be taken into account as the occupied period. The conditioned schedule for residential use in this paper is from 5 am to 23 pm (ISS0, 2011). Moreover, TO-hour is applied in this thermal comfort evaluation to reduce the overheated hours in a year. The detail of TO-hour regulation is in the chapter 「2.1 Thermal comfort」.

To calculate the PMV for each room, the value of airspeed, metabolic rate, clothing insulation, and PPD threshold is needed. The value of air speed is referred to Bouwbesluit with 0.7 dm3/s per m2 for the occupied spaces and for collection of spaces is 0. Dm3/s/m2 (BZK, 2012). The PPD threshold is referred from Table 1 and the III category, PPD<15% and PMV between -0.7 and 0.7, is applied to this project.

Type of building/space	Metabolic rate	Category
Residential buildings: living spaces (bedroom, kitchen etc.)	1.2	II
Residential buildings: other spaces (storage, hall etc.)	1.6	II

Table 8. Recommended design value for indoor thermal condition.
Adapted: EN-16798(2018)

The metabolism of humans in the space is related to the function and activities in the room. In the norm of NEN-EN 16798 of European regulation(NEN-EN 16798-1, 2018), in Table 8, the metabolism for residential is defined in two main categories. The value of the metabolic rate used in the simulation is 1.3.

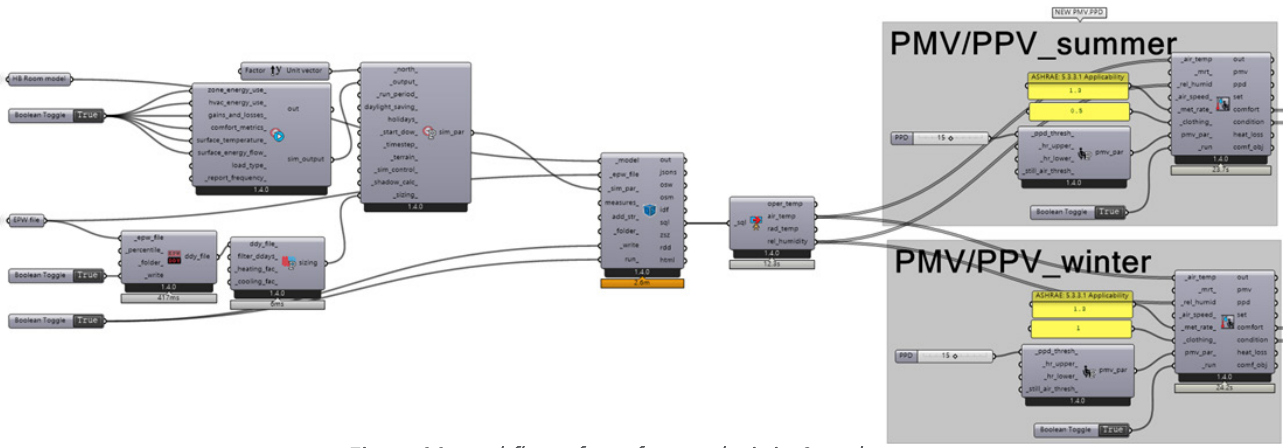


Figure 26. workflow of comfort analysis in Grasshopper

The thermal comfort analysis is only applied to the occupied period of the building and spaces. The simulation gives an annual hourly temperature, and humidity data set. Honeybee, the plugin of Grasshopper, is able to read this data matching with the airspeed, metabolic rate, and clothing factor of the specific situations and gives out the comfort level in PMV. The evaluation is based on PPD-PMV in winter and summer periods, due to the clothing condition tends to change with the external weather situation. In general condition, the clothing insulation in summer is 0.5, shorts and T-shirt, and in winter is 1, three pieces suits. If the clothing insulation remains constant for the whole year, the threshold of the comfort period would decrease and not be accurate. To analyze the annual comfort level of the building or the room, the result of the indoor condition needs to be split into two or more sets, if want to be more specific in some cases, to evaluate the PMV result in different clothing conditions. The given comfort result from Honeybee is in Table 10 in which only the factor 0 is the comfort condition.

	Honeybee result _ Predicted Mean Vote (PMV)						
Result value	-3	-2	-1	0	1	2	3
Meaning	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

Table 9. Given PMV result from Honeybee.

	Honeybee result _ Condition				
Result value	-2	-1	0	+1	+2
Meaning	Too dry (But thermally neutral)	cold	neutral	Warm	Too humid (But thermally neutral)

Table 10. Given Condition result from Honeybee.

5.5.2 Energy consumption

Building energy consumption on simulation has 9 major categories, cooling, heating, lighting, electrical equipment, gas equipment, service hot water, fan electricity, pump electricity, and mechanical ventilation load in the unit of kWh/m2 per year. In the BENG1 regulation, evaluation of energy consumption for buildings, the energy consumption of cooling, and heating is considered. To measure the usage of building operating energy efficiency, the total used energy is divided by the usable area in the building. In general, the energy consumption is preferable to be as low as possible.

To set up the energy consumption for the building projects, the requirement of an indoor environment needs to be declared as the potential usage of equipment. The setpoint temperature for the HVAC system is 20°C for heating and 26°C for cooling.

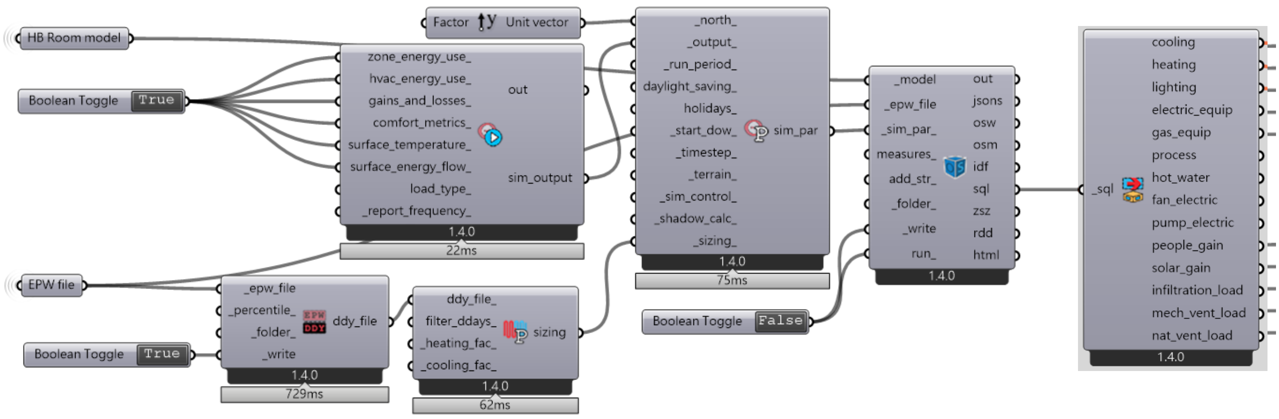


Figure 27. Workflow of energy consumption analysis in Grasshopper

5.5.3 Daylight condition

Visual comfort is one of the criteria of indoor comfort related to artificial lighting and sunlight. To evaluate the comfort related to sunlight influence, two objectives are taken into account to estimate daylight inlet in the space, SDA and ASE. SDA assesses whether the space receives sufficient daylight during the occupied period annually or not. The aim of the condition is 300 lux for 50% of the occupied period. The space with sufficient daylight does not need artificial lighting in the daytime. AES makes sure the space does not obtain too much direct sunlight which would cause visual discomfort (glare) and potentially overheating. The method

New construction, core and shell schools, retail, data centers, warehouses, distribution centers, CI, hospitality		Healthcare	
SDA (for regularly occupied floor area)	points	SDA (for perimeter floor area)	Points
55%	2	75%	1
75%	3	90%	2

Table 11. Daylight points in LEED v4.
Adapted: LEED v4

of evaluation is referenced from LEED BD+C: New Constructionv4 -LEED v4 and the result for comparison are put in the points between 0 to 100. The calculation is in Table 11. In this research, the daylight performance calculation is based on the SDA and give point from 0 to 100. But if space obtains too much direct sunlight, the point will be cut by half. This way would be easier to find the optimal fenestration options.

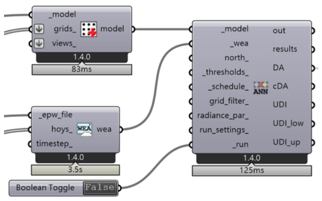


Figure 28. Workflow of SDA in Grasshopper

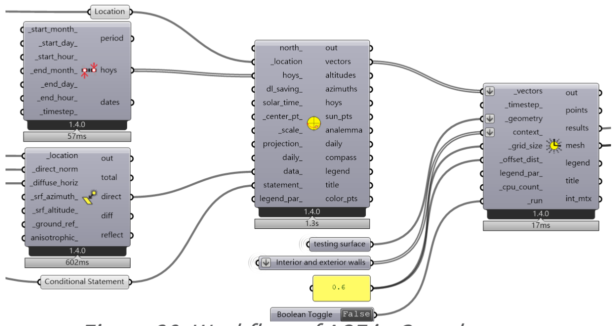


Figure 29. Workflow of ASE in Grasshopper

5.5.4 Efficiency of PV panel

The study of energy production of PV panels focuses on the panels installed on the façade and the ratio of interior floor area in the unit of kWh/m2 per year. Some design decisions, like the window to wall ratio and orientation, would have an impact on the efficiency of the panels. To compare the influence of climate change and design decisions on efficient energy production, some properties of PV panels are set as constant, the type of panel, and angle. The area of the PV panel in the simulation is equal to 80% of the southern façade (excluded window). With the orientation of the building, a certain percentage of the panel will be placed on the eastern or western façade.

The building orientation and façade area influence the efficiency of PV panels. In the simulation, the area of the PV panel would be equal to the façade facing south. Because the efficiency is influenced by shading caused by the building or surroundings the placement of panels is different from the orientation of the building geometry. The detail of the efficiency of transforming solar radiation energy into electricity by PV panels is shown in chapters 2.4.3 and 6.1. In this simulation, the efficiency of the transfer rate of solar radiation to electricity is 15% with -0.5%/°C of temperature coefficient and 90% of the geometry surface. The setting of the DC to AC derate factor is 0.55.

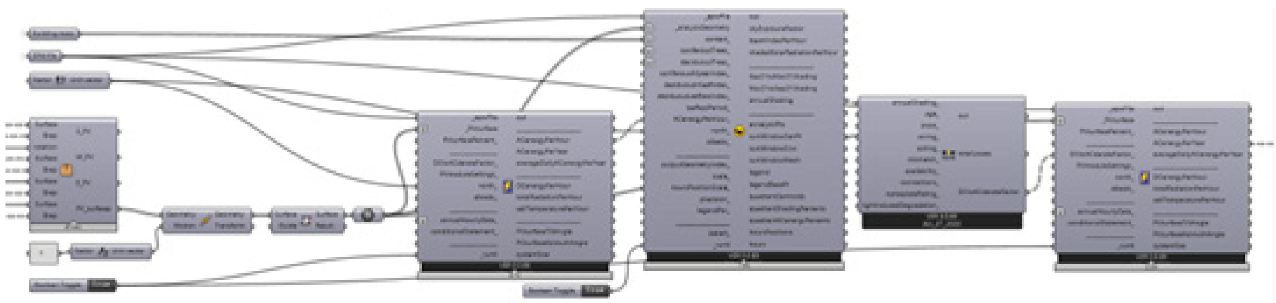


Figure 30. Workflow of PV panel efficiency in Grasshopper

5.5.5 Simulation setup (schedule and program)

Building performance simulation is related to building programs and using schedules. The common program input includes people per floor area, lighting and equipment per floor area, ventilation per floor area, ventilation per person, and infiltration rate. In Grasshopper environment, it is possible to use Honeybee components to simulate the interior schedule and program. The following paragraphs are going to describe the setup principles.

5.5.5.1 People per floor/area

To determine the people per floor area, the calculation method in NTA8800 (NEN, 2020), chapter 7.2 is applied. The calculation results in the average occupants per calculation zone in the Netherlands. This calculation is defined by the ratio of unit's area with the number of residential functions as less than 30 square meters, between 30 to 100 square meters, and beyond 100 square meters. The method of calculate average number of occupants per calculated zone for residential function is as follows:

$$\frac{A_{g,zi}}{N_{Woon;zi}} \leq 30m^2 : N_{P;woon;zi} = 1$$

$$30\ m^2 < \frac{A_{g,zi}}{N_{Woon;zi}} \leq 100m^2 : N_{P;woon;zi} = 2.28 - \frac{1.28}{70} * (100 - \frac{A_{g,zi}}{N_{Woon;zi}})$$

$$100\ m^2 < \frac{A_{g,zi}}{N_{Woon;zi}} : N_{P;woon;zi} = 1.28 + 0.01 * \frac{A_{g,zi}}{N_{Woon;zi}}$$

$A_{g,zi}$ the usable area of the calculated zone in m^2.
$N_{woon;zi}$ is the number of residential function in the calculated zone zi.
$N_{p;woonzi}$ the average number of occupants per calculated zone per residential function.

Furthermore, the internal heat gain from the people would also influence the indoor comfort and energy usage for heating and cooling. The internal heat gain, known as metabolism, is influenced by the number of people in the space and the activity. The metabolism is variant with functions in the building and it is from 100 watts per person to 180 watts per person (Fumagalli, 2020). This research is not aiming to find out the indoor layout of housing, instead, the metabolism is using an average number of 120 watts per person.

5.5.5.2 Equipment and light energy per floor/area

In our daily life, many different kinds of electrical equipment are used in our living environment. However, unlike the heating and cooling demand is regulated and has more research on the expectation of energy consumption, the demand for electricity tends to be non-uniform. In the NTA 8800, for office projects, a reference energy usage of 5W/m2 for equipment usage and 1.25 W/m2 for lighting energy demand are provided. But the as-sumption of energy consumption for equipment and lighting for residential per floor area is not regulated in the NTA8800. Furthermore, the evaluation of energy consumption for residential buildings only considers heating and cooling demands in BENG1 regulation. For the building simulation. the energy demand for equipment, in this case, is set at 0 watt/square meter constantly.

5.5.5.3 ventilation per floor/area

Ventilation demand for residential is defined as ventilation per square meter and ventilation per person. In the simulation, it is common to apply only one of the factors. For residential simulation, it is more common to use ventilation per square meter. The ventilation rate for occupied spaces and unoccupied spaces are different. The minimum air changing rate for each place based on occupancy in residential is shown in the Table 12.

Category	Living room and bedrooms, mainly outdoor air flow	Kitchen	Bathroom	Toilet	Parking space
Unit	l/s/person	l/s	l/s	l/s	l/s
II	7	21	14	7	3

Table 12. Recommended ventilation value for residential buildings.
Adapted: Bouwbesluit (2012)

5.5.5.4 Infiltration rate

Infiltration rate represents the air leakage and heat leakage of building envelope. The higher number means the higher leakage which would influence the building performance of thermal comfort and energy consumption. The typical given value is based on building under 4 Pascal pressure.

Building type	Tight building	Average building	Leaky building
Intensity of infiltration (m3/s per m2 façade area)	0.0001	0.0003	0.0006

Table 13. Envelope Infiltration rate.
Adapted: Honeybee_energy.Load.Infiltration Module —
Honeybee Energy Documentation

5.5.5.5 Conditioned schedule

The conditioned schedule in simulation represents the time that the space is occupied in a day. In this period, heating, cooling, ventilation, and lighting is turned on and the consumption of energy is counted. For the schedule applied for residential units starts from 5am till 23pm in both weekdays and weekend (ISS0, 2011).

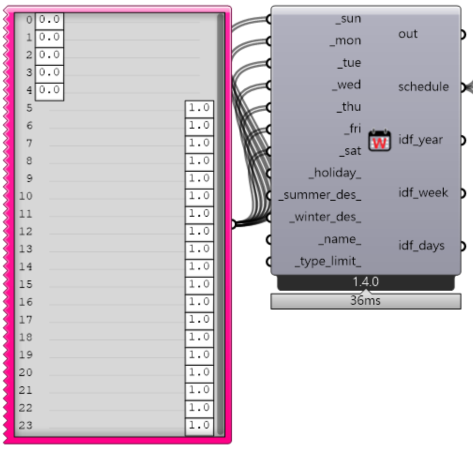


Figure 31. Schedule setting in Grasshopper

6 Simulation Inputs - Building properties and parameters

6.1 Building geometry

To build up a twin building in the simulation environment there are some factors set as constant and some need to have further research. In the parametric model, the floor area remains the same in all cases, as well as the size of rooms and common spaces.
The building mass would create self-shading, influence wind conditions, and change the total surface and incidence angle of sunlight (Lin et al., 2021).

In normal weather condition, since the Netherlands is the climate zone of moderate maritime, the heating present a bigger share of energy consumption than the cooling (Moumdjian, 2020). The heat gain and loss of buildings are determined by the total external building surface. In Moumdijan's research, it shows that the building orientation of the same building layout would have a difference in operation energy consumption of 60.7 and 73.2 kWh/m2 per year which is and comfort level from 78.8% to 82.7%. This result is due to the building geometry and orientation influencing the irradiation and illumination on the building façade. In the Netherlands environment, the southern façade has the highest solar heat and light gain.

Placing PV panels on different façades with different building orientations of building influences the annual energy production. A simulation of the evaluation the relation between the rotation of the building and energy production of PV panel based on the Amsterdam weather conditions is done. Among the simulation, the total area of PV panel remains the same. In the first set, Figure 33, PV panels stay on the same façade while the building is rotating, and in the second set the panel changes with the rotation.

In the result of first group, Figure 32, it shows that with the rotation of the building the total energy production would increase or decrease depends on the angle between panels and South with the lowest yield of 40% in 45 degrees of rotation. On the other hand, if the PV panel can be placed determined by the orientation of the building, for example, in the 45 degrees rotation condition, the southeast and southwest façade would have the same area of PV panel, the yield of panels can be more stable, as the results in Figure 33. The highest percentage of yield decreasing is 14% compared to the case of facing south. Comparing these two approaches, the annual energy production difference can be up to 215%. To optimize the yield, the strategy of PV panel placement changes with the building orientation in the simulation. As a result, there is at least one façade and not more than two facades would have PV panel at the same time. The smaller angel between south and the normal direction of façade, the bigger PV panel area is, and the total panel area is equal to the opaque area of southern façade.

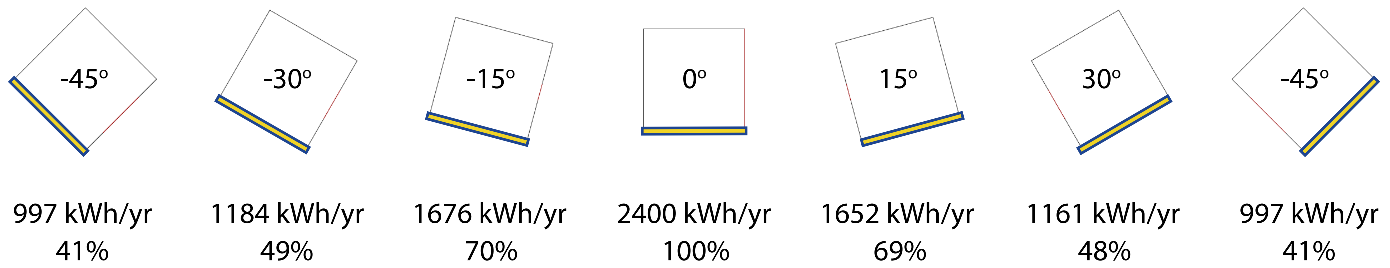


Figure 32. Energy production and building orientation with fix PV panel area on single facade.

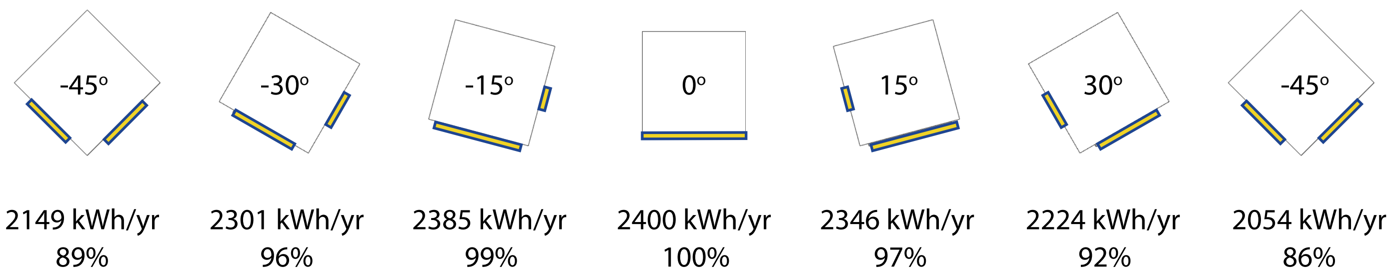


Figure 33. Energy production and building orientation with PV panel area changing on facades

PV panels

6.2 Envelope regulation and energy saving

The envelope is the interface that would determine the heat flow between interior and exterior conditions. In general, the thermal insulation property of the building's envelope plays a crucial role in the building energy performance by controlling heat loss and heat gain. The research of Wilhelm (2016) found that the demand for insulation properties varies in different climate zones, with some locations that would be suitable for anti-insulation design (Friess et al., 2017). Considering the approaching climate change environment, the common sense of insulation approaches would be to be examined.

Energy-saving solutions for envelope design of high-rise buildings in temperature climates can reduce up to 40% of energy us (Raji et al., 2016). The building energy consumption is composed of operational energy and embodied energy for the construction materials. The operation energy is the sum amount throughout the entire service life with energy cost on lighting, cooling, heating, and ventilation systems and it constitutes 80-90% of the total energy associated with the structure (Tuladhar & Yin, 2019). The construction process and embodied carbon of the construction materials only cost 10-20% of the total energy on average, but the properties of the envelope can greatly influence the operation energy demand and the building embodied carbon (Tuladhar & Yin, 2019).

6.2.1 Opaque façade properties

The Bouwbesluit (Dutch Building Decree) defines envelope insulation property in three main parts, façade, roof, and ground floor, with Rc-value of 4.7 m2K/W, 6.3 m2K/W, and 3.7 m2K/W for new construction, and 1.4 m2K/W, 2.1 m2K/W, and 2.6 m2K/W for renovation (BZK, 2012). The difference in the Rc-value requirement is due to the heat gain and heat loss to the atmosphere and the ground is uneven for different parts of the envelope.

Thermal insulation	Quality level		
	Basic	Good	Excellent
Opaque part	$Rc_{Floor} \geqq 3.7\ m^2K/W$ $Rc_{Facade} \geqq 4.7\ m^2K/W$ $Rc_{Roof} \geqq 6.3\ m^2K/W$	$Rc_{Floor} \geqq 4.5\ m^2K/W$ $Rc_{Facade} \geqq 6.5\ m^2K/W$ $Rc_{Roof} \geqq 8.0\ m^2K/W$	$Rc_{Floor} \geqq 5.5\ m^2K/W$ $Rc_{Facade} \geqq 8.5\ m^2K/W$ $Rc_{Roof} \geqq 10.0\ m^2K/W$

Table 14. Category of thermal insulation for opaque part of envelope.
Adapted and translated: Bouwbesluit (2018)

6.2.2 Transparent façade properties

Besides the thermal influence from opaque material, in most cases, the window has a high impact on the interior comfort condition and operation energy in the glazing type and window to wall ratio (WWR). Glazing type is defined by multiple parameters, three of the most used factors are thermal transmittance (U-value), Solar Heat Gain Coefficient (g-value) and visible transmittance (VT). To make windows have a zero-energy effect on the buildings, the U-values and g-values have domain influence (Arasteh et al., 2006).

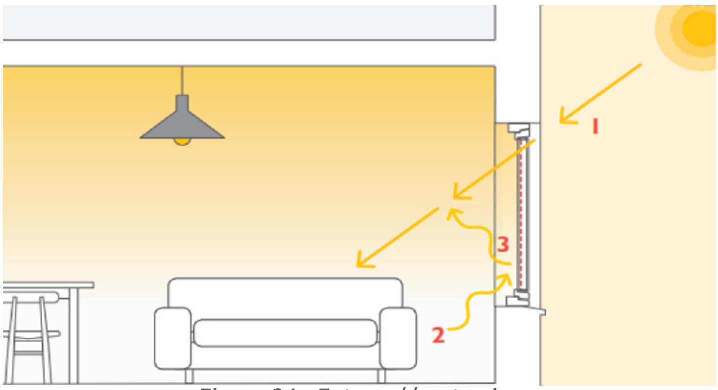


Figure 34. External heat gains.
Source: NHBC 2012

Comparing to the opaque part of the façade, the window components tend to have higher thermal transmittance which is known as U-value. To reduce the risk of overheat caused by the undesirable solar heat gain in summer, a lower U-value is often applied to the modern buildings to control the heat losses from the window components. A reference categories of window U-value from Nederlands Vlaamse Bouwfysica Vereniging (Dutch Flemish Building Physics Association) (NVBV) is in Table 15.

Thermal insulation	Quality level		
	Basic	Good	Excellent
Window	$U_{w;Max} \leq 2.20\ W/m^2K$ $U_{w;Ave} \leq 1.65\ W/m^2K$	$U_{w;Max} \leq 1.65\ W/m^2K$ $U_{w;Ave} \leq 1.20\ W/m^2K$	$U_{w;Max} \leq 1.1\ W/m^2K$ $U_{w;Ave} \leq 0.8\ W/m^2K$

Table 15. Category of thermal insulation for transparent part of envelope.
Adapted and translated: NVBV (2018)

G-value is the factor of the Solar Heat Gain Coefficient to glazing system. The range of g-value is from 0, no solar radiation transmittance, to 1, full transmittance of solar radiation. The required g-value is different by the case location, function, orientation, and weather condition (Höfte, 2018). A common g-value for double glazing insulated windows would be 0.6 and 0.5 for a triple glazing window. It is possible to further reduce the value by adding coatings.

The visible transmittance indicates the amount the visible light transmits to the window in the value from 0 to 1. The lower transmittance the lower value it is given. Adding coating or tint to the glazing can reduce the amount of inlet visible light spectrum (Nahlik et al., 2017). The VT value influences the performance of daylight simulation on both SDA and ASE.

6.3 Window to wall ratio

The building envelope determines the influence from external to internal space.
Windows provide view, daylight and heat gain to the internal space and the amount of these three have a positive correlation to the WWR. As the component determines the amount of heat gain and light gain, the window to wall ratio influences the amount of building operation energy and indoor comfort.

Due to the external environment is not equal on each side of the building, the building would have different window to wall ratios on different sides of the façade under physics and energy consideration(Moumdjian, 2020). An example of the relationship between the window to wall ratio, façade orientation, and the height of surroundings in the Netherlands is presented by Moumdjian. In the research, the southern façade has the lowest WWR in all scenarios, while the north has the highest. The research also shows that the amount of heating demand and cooling demand is higher when the WWR is bigger than 50%. Controversially, if the ratio is lower, then the lighting energy tends to be higher than others.

In the simulation, the WWR is set in three types, 20%, 35% and 50%. Considering the window height and width would influence the inlet daylight, the windowsill and window height are constant. When the WWR changes, the width is adjusted.

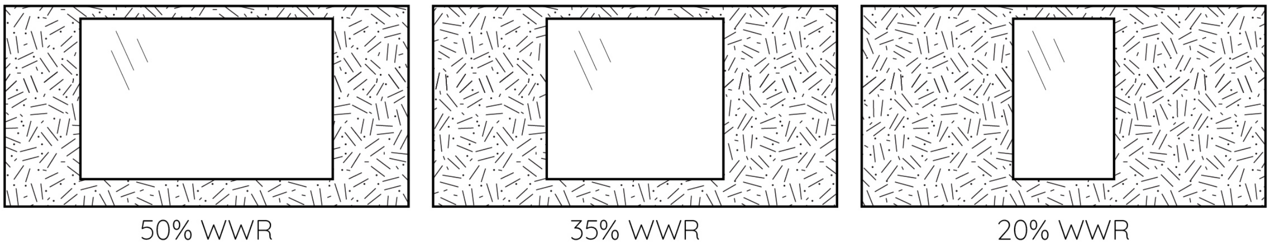


Figure 35. 50%, 35%, and 20% of WWR diagram.

6.4 Shading system

Shading system is used to control the interior environment by adjusting the heat and light gain from solar radiation. Amount different types of shading approaches, the external shadings system has the highest effectiveness in blocking solar radiation outside the building (Hausladen, 2005). A suitable sunshade system can balance the amount of direct radiation and diffuse radiation penetrating through the fenestration to interior spaces. In general, shading devices are able to (López Ponce de Leon, 2016):

- Improve Daylight Quality Control
- Improve Indoor Thermal Comfort
- Improve building's general energy performance
- Generate a productive work environment

External shading devices have two main categories, the movable shading system, and the fixed shading system. Since the sun angle and the air temperature differ from seasons, movable shading systems tend to have higher efficiency to control inlet heat and light. However, the equipment expense and high maintenance requirement are the disadvantages of this system (Hausladen, 2005; Shahriari, 2020). Due to the solar zenith angle and solar azimuth angle changes, the fixed shading devices are diverse depending on the orientation of façade. In the Northern Hemisphere, horizontal sunshade, like overhang and louvers, is commonly used on the southern façade, and vertical sunshade, like fin and eggcrate, is used on eastern and western façade (López Ponce de Leon, 2016).

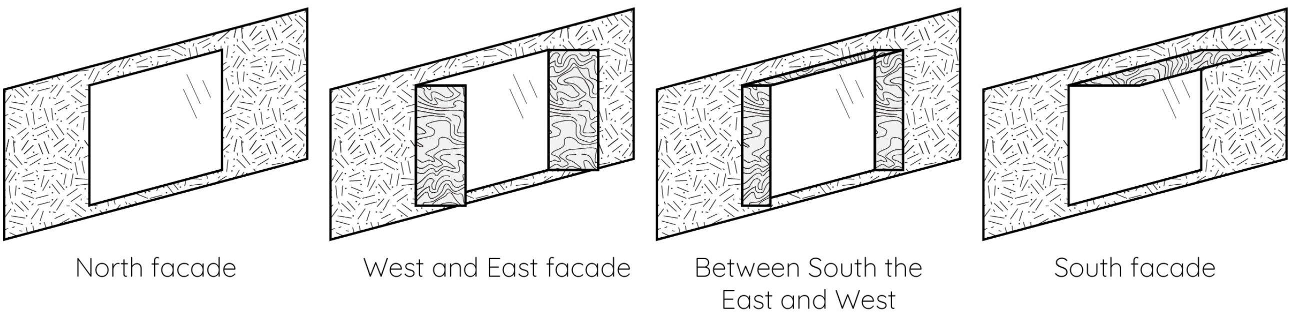


Figure 36. Shading system for different facade orientation

6.5 Ventilation system

To provide comfortable indoor environment during the occupied period, the buildings demand operation energy to prevent spaces from overheating and cold condition. The HVAC system maintain the indoor air quality, indoor temperature, and humidity in the acceptable range. The setpoint temperature of heating and cooling has variety values in different countries and places. The TO calculation gives a reference temperature of 25 °C and 28 °C for overheating. On the other hand, the PPD comfort for B class, or called Good class, provides a comfort temperature range from 23 to 26°C . Basing on these two regulations, the cooling setpoint of the building is set as 26°C and the heating setpoint is 20° C.

The type of HVAC system determines the efficiency of energy usage on heating, cooling, and ventilation with variant type of energy resource. Since this research focuses on the early design phase, the type of HVAC system is not decided yet the Ideal Loads Air system is applied to the simulation. The Ideal Loads Air system is a theoretical model. Rather than calculate the consumption of gas, or electricity energy, it is used to understand the requirement of thermal energy to fulfill the thermal energy demand in the analysis zones. As a result, the analysis of heat balance and peak load are suitable to implement this system to.

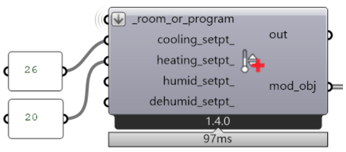


Figure 37. Temperature setpoint.

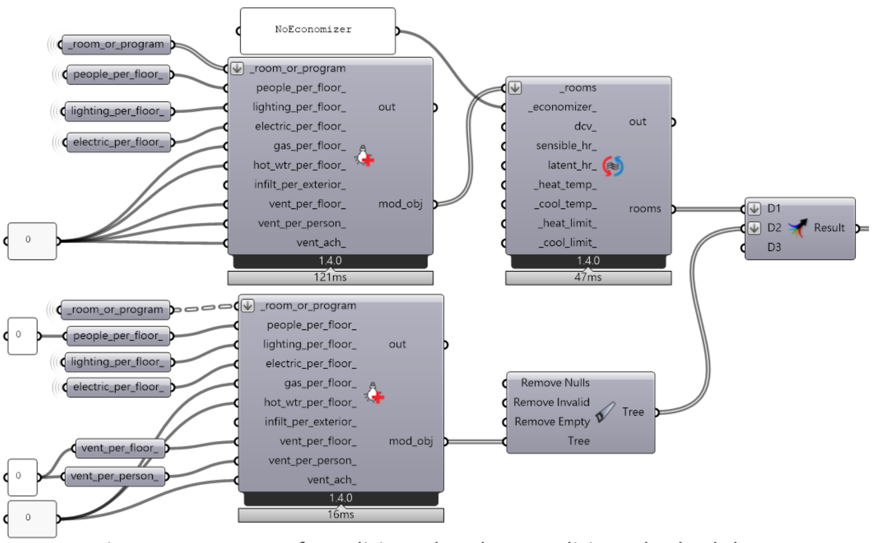


Figure 38. Merge of conditioned and unconditioned schedule.

6.6 Building context

The studying of building performance is highly related to the external environment, not only on a macro-scale but the microclimate also plays an important role. The context and the analysis part of the building are dedicated to the microclimate condition. In the research of Shahriari, the floors with the same layout at different heights have distinct results in thermal comfort levels. It is found that the rooms on the southeast corner of the building have a higher risk of overheating with global warming and the extra approaches to prevent heat gain are demanded(Shahriari, 2020). For high-rise buildings, the performance analysis should be taken with lower levels and higher levels. The lower level shows the impact of the context, shading of the surroundings for example, and the higher level provides a generic view of the condition.

6.7 Insulation property and embodied carbon

The global building sector and construction industry accounted for 30% and 6% respectively of the global total energy consumption in 2015 (Pouniou, 2019). The embodied carbon or called embodied energy is the primary energy consumed (carbon released) from direct and indirect processes associated with a product or service and within the boundaries of cradle-to-(factory) gate, cradle-to-(installation)site, and cradle-to-grave (Hammond et al., 2011). Embodied carbon and embodied energy are used to evaluate the sustainability of various materials used in construction in the unit of MJ/kg (Tuladhar & Yin, 2019).

Embodied carbon is deeply related to the whole progress of the building construction. The embodied carbon starts adding up when the extracting raw materials to transport, then to manufactory building materials and components. After that, the embodied carbon will keep adding on with transportation, on site construction execution, and demolishment of buildings (Circular ecology, 2019). The most common insulation materials in the European market are fossil fuel derived materials, due to the unit price and the conductivity property (Grazieschi, 2021) To find the most sustainable approach for the building, the envelope materials need to consider both thermal performances and embodied carbon. The embodied carbon of materials is based on the Inventory of Carbon and Energy (ICE) database developed by the Department of Mechanics of the University of Bath (UK) (Hammond et al., 2011). The ICE database is commonly applied to the life cycle analysis method, especially for determining the embodied carbon of buildings (V. Rodrigues et al., 2018)

7 Case Study Object

7.1 Original design of the project

The case study object is a development project mainly composed of residential and parking buildings in Zwijndrecht, the Netherlands, and the information is provided by OMRT. The total building area is around 53,784 m^2 with the residential function of two-bedroom houses, three-bedroom houses, four-bedroom houses, roadhouses, and penthouses. The building types include towers from 8 floors to 13 floors and roadhouses and penthouses with 5 floors. This project is in the early design phase and analysis period, in which the design possibility needs to be explored and it is necessary to determine the design criteria as well. The original design layout is as shows.

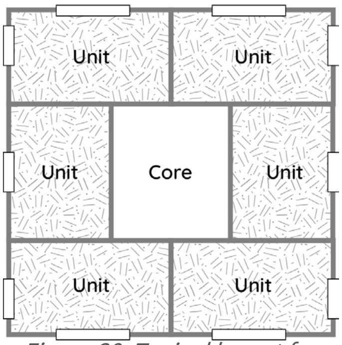


Figure 39. Typical layout for tower buildings.

The case study object, the tower, is the second one on the right side in Figure 31. The building has two roadhouses connected on the sides. The single floor area of tower buildings is 576 m^2, with 6 units each with 80 m^2 sharing one core and the floor height is 3 meters. Each floor has 6 units, and the layout is illustrated in Figure 31. With this layout, the window division follows the partition walls between the units. With the height difference in the tower, it is possible to study the impact from the context on the performance.

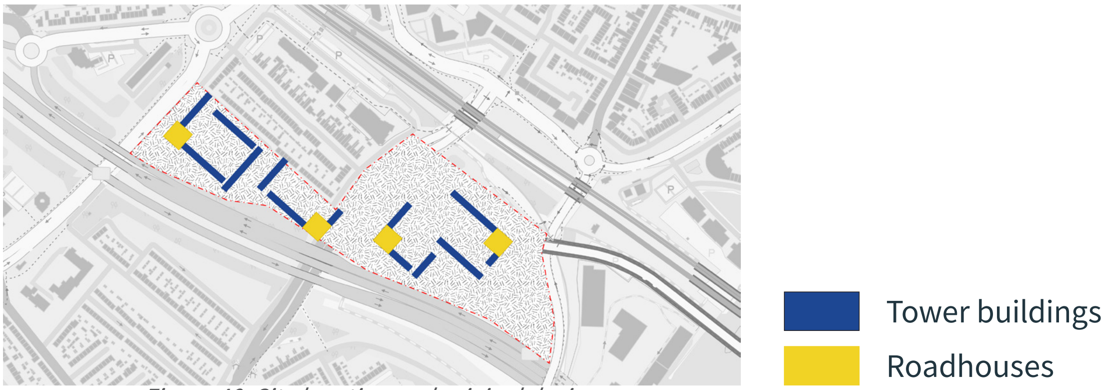


Figure 40. Site location and original design

7.2 Building floors and context

To study the performance of a tower building, the height of the building is taken into account. Different level of floors has a distinct impact by the external environment. The context would cause shade and reduce the heat gain and light gain in the building. In the study case, the tower buildings are connected to roadhouses on two adjacent sides of the surfaces. The roadhouses influence the solar radiation gain of the houses of the tower building on the lower levels. A single floor from the lower floors is selected as the reference floor for performance optimization and evaluation. Amount the lower floors, the ground floor would consume more energy to maintain indoor comfort since it is attached to the ground. The ground material tends to have higher thermal mass and lower temperature than the air temperature. Consequently, the ground floor is not suitable to consider as a reference object, and the first floor is selected to be the one.

On the higher level, the tower has nothing attached and has a lower environmental impact from the context. Although the wind speed and radiation conditions would change with height, the difference is incomparable to the influence caused by physical surroundings. The higher levels are directly reflected by the climate change impact on energy consumption and thermal comfort in general. However, the top floor has the most external surface area which causes a higher impact from direct sunlight and heat loss to the atmosphere. Due to this difference, instead of the top floor, the floor under the top floor is more suitable as the reference floor in the optimization. In the simulation, the context environment is applied to the lower floors and not to the higher floors. This setting can reflect the impact caused by the context of the building performance

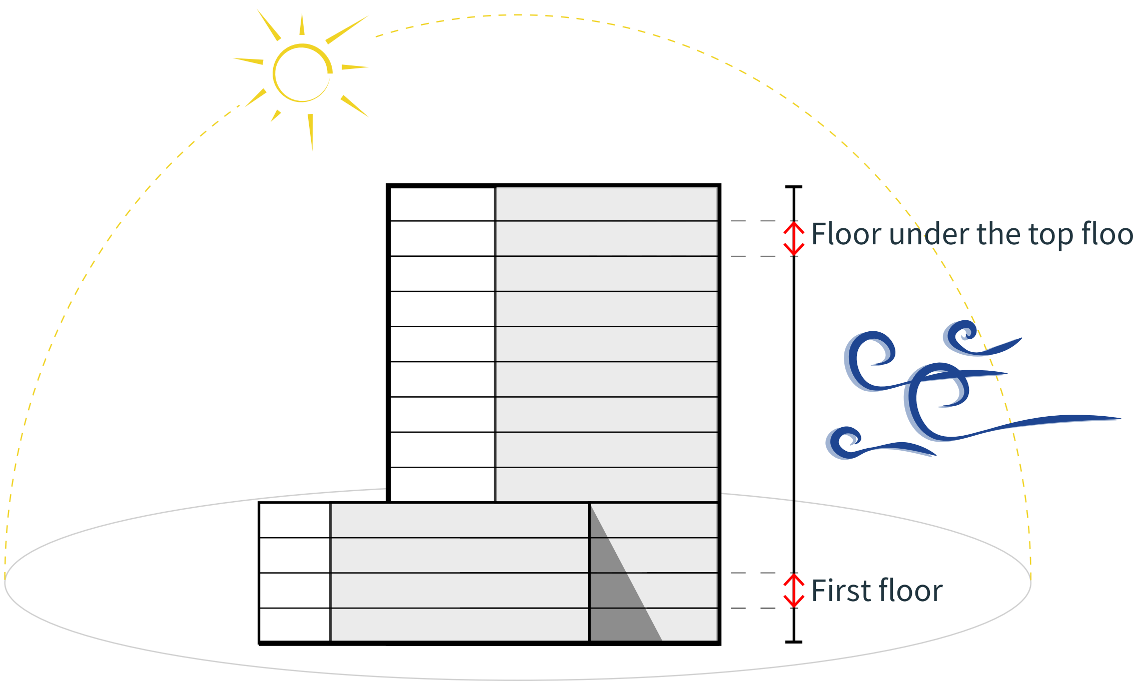


Figure 41. Building side drawing diagram.

7.3 Design parameters

Regarding the climate change impact, designers and developers want to figure out the future-proof possibilities in the design process to make the building more sustainable in long term. Although the project already has a basic design, the conversation about the potential influence and the improvement is open. In the simulation and optimization, there are some building parameters are used as input variables. Concluding from the previous chapters, the case study condition and the sensitivity analysis in chapter 7.4, the selected parameters and range are presented in Table 16.

Items	Range				
Length	20	24	28	-	-
Rotation	-30°	-15°	0°	+15°	+30°
WWR (wall 1)	20%	35%	50%	-	-
WWR (wall 2)	20%	35%	50%	-	-
WWR (wall 3)	20%	35%	50%	-	-
WWR (wall 4)	20%	35%	50%	-	-
Rc-value (Wall/façade/ roof) (m^2K/W)	3.5/4.5/6.0	5.0/5.0/8.0	6.0/8.0/10.0	-	-
U-value (W/ m^2K)	0.6	1.0	1.4	-	-
G-value	0.4	0.6	0.8	-	-

Table 16. Design parameters and range.

7.4 Sensitivity analysis

In the early design phase, designers and engineers need to define the criteria parameters of the building characteristics. With the performance-based design approach, these parameters are determined after the analysis of the result on building performance, energy consumption, and cost. However, the process of analysis can be a very heavy and expensive process when the amount of composition of design parameters is humongous. Analysis of the relationship between input parameters and the performance result would find out that some of the input parameters have relevant low or even no influence on the building performance. When this relationship has been found, these parameters can be set as constant or preferable values in the optimization process. The calculation time of optimization can be cut by this analysis, also the research can be more focused on the parameters which have a higher effect.

7.4.1 WWR and performance

The sensitivity analysis of WWR is taken in a single climate condition with a fixed length and width of the building geometry and the insulation value stays constant. In the analysis, it is found that the WWR can have an impact on energy consumption per floor area up to 15 kWh/ m^2 per year. Almont all the factors, the window to wall ratio on the south facade has a great influence on energy consumption, and thermal comfort. However, due to the chance of direct sunlight exposure would increase with the increase of southern WWR, the daylight result does not have a linear relation to it. For cases that do not rotate, it is possible to set the WWR of each façade as constant when the optimal is determined. However, in this paper, the rotation of building geometry is one of the input variables, the WWR which proves a satisfying indoor environment adjusts with the façade orientation.

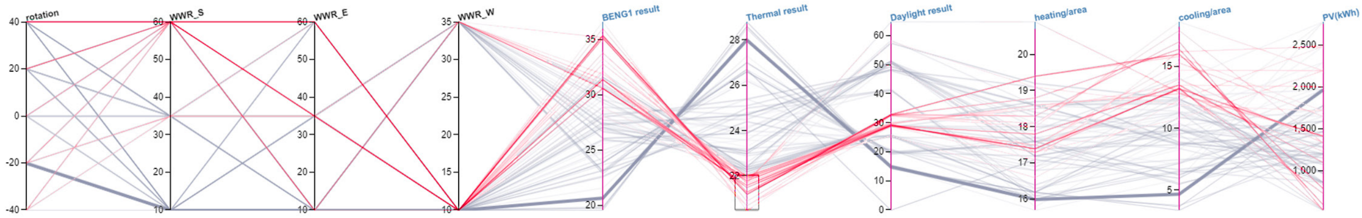


Figure 42. Sensitivity analysis of WWR.

7.4.2 RC-value and performance

The geometry-related parameters are constant in this analysis to declare the weight of insulation properties on performance. The range of Rc-value for the floor is 3.5 to 6.0 m2K/W, the range for the wall is 4.5 to 8.0 m2K/W, and the stretch of roof RC-value is from 6.0 to 10.0 m2K/W.

The sensitivity analysis of the Rc-value found that the Rc-value for wall, roof, and floor has no major influence on total energy consumption, thermal comfort, or indoor daylight. But it may have an influence when the external environment changes. In sum, the variation caused by the RC-value difference is not taking a major influence, and it is more suitable to process the optimization with more distinct values. The analysis floors are not top floor nor ground floor, consequently, the Rc-value for floor and roof are not directly relevant to performance.

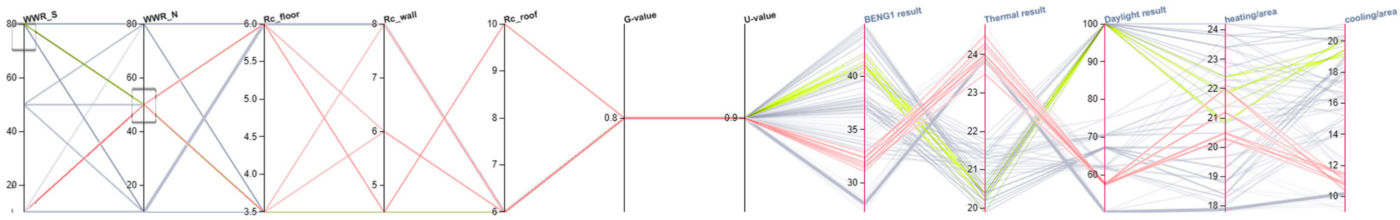


Figure 43. Sensitivity analysis of insulation properties.

7.4.3 Shading system sensitivity analysis

In the research on climate change, the changes are majorly caused by GHG emissions, while solar radiation is a constant influence on the environment. Although the type of shading system has an impact on the indoor thermal comfort, daylight comfort and energy consumption, the effect of sunshade devices directly relates to the shading size, angle, and place with solar zenith angle and solar azimuth angle (Valladares-Rendón et al., 2017). Since earth orbit and earth rotation are consistent throughout the target of the research period, it is possible to determine the best or most suitable options for shading logic and apply them to all the conditions. As a result, it is possible to remove the shading system from the input variable in the optimization process and linked it to the rotation of building geometry.

The previous research shows that a proper shading strategy can considerably increase indoor comfort and reduce the operation energy consumption. The building geometry taken into the analysis is with no rotation and the length and width are 25m and 22m. The WWR applied is 35% for all four facades. The shading system of analysis is done before the conclusion is drawn in chapter 6.4.

In the analysis, there are three types of shading systems, horizontal shading on top of the windows, vertical shadings on two sides of the window, and no shading system. In Figure 44, the clear correlation between southern shading and energy usage, and thermal comfort is shown.

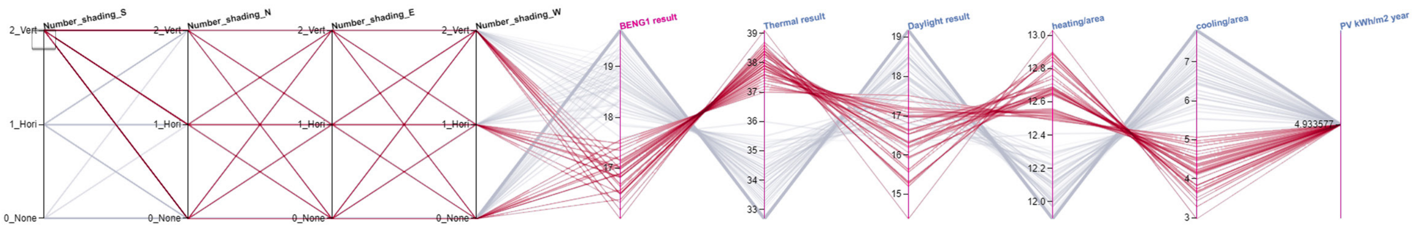


Figure 44. Sensitivity analysis of shading system.

The Figure 44 and Figure 45 present the conditions when the shading system is fixed while the options for eastern and western are dynamic. The result shows that the impact of shading on eastern and western façades has about a half to a one-fourth of the southern one.

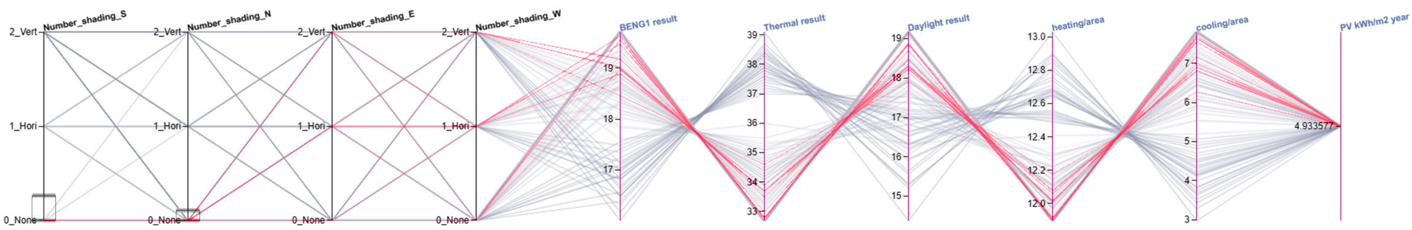


Figure 45. Sensitivity analysis of shading system, none shading on northern and southern facades.

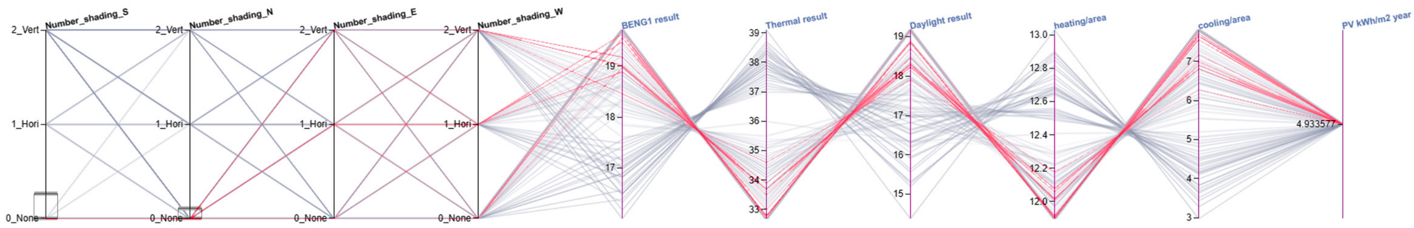


Figure 46. Sensitivity analysis of shading system, vertical shading on northern and southern facades.

As a result, it is suitable to apply fixed shading systems in the optimization process, and the type of shading is related to the orientation of the façade. With the façade orientation from south to east or west, the shading system shifts from horizontal on the top of the window to two sides of the windows. For the façade orientation from east and west to north, the total area of shading on the sides reduces and meets zero when the façade is facing to the north.

7.4.4 Geometry and climate conditions sensitivity analysis

In the geometry and climate scenarios analysis, the input variables are the climate files, the rotation of the building, and the length, which influence the width, of the geometry. The climate condition has a low impact on daylight when the length and width of building geometry are fixed. The value of thermal comfort and energy consumption alter with the climate condition, regardless of the building geometry setup. When the length of the building is fixed, the performance of the building interferes with more climate conditions than the building rotation. Furthermore, the building orientation influences the daylight result and the efficiency more than other objectives.

Both climate conditions and building geometry interfere with the final performance greatly in different aspects. Although there are some factors that only manipulate on few objectives it is not appropriate to remove or reduce the input parameters for these two factors.

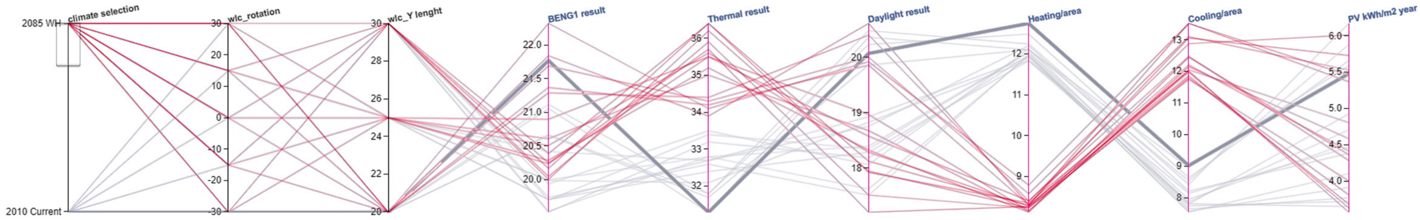


Figure 47. Sensitivity analysis of building geometry and climate conditions I.

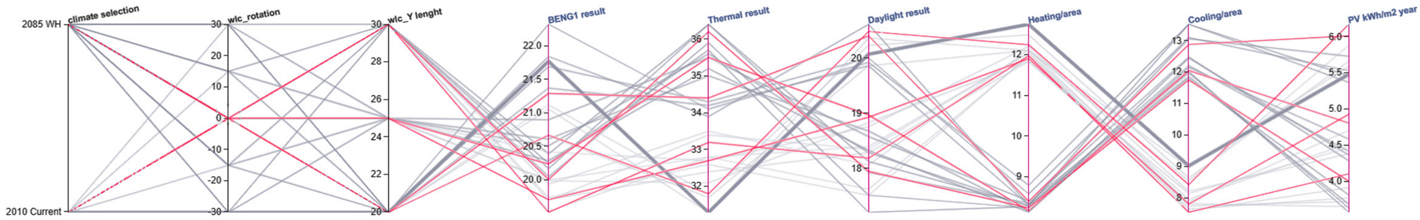


Figure 48. Sensitivity analysis of building geometry and climate conditions II.

8 Optimization Result Analysis

8.1 Introduction of methodology

The design decisions determine the building energy consumption and indoor comfort for the entire building lifespan. The made decisions depend on the climate conditions that the designer and engineers take into consideration. To study the building performance with variant design decisions and climate conditions, the workflow of MOO is building in Grasshopper environment with variant input, shown in Figure 49. To find the suitable design approach, the design decisions are set as input variables for the optimization and the variables are building length, building orientation, WWR of each facade, and envelope properties. The optimizations are done in multiple climate scenarios and with and without the impact of surrounding buildings.

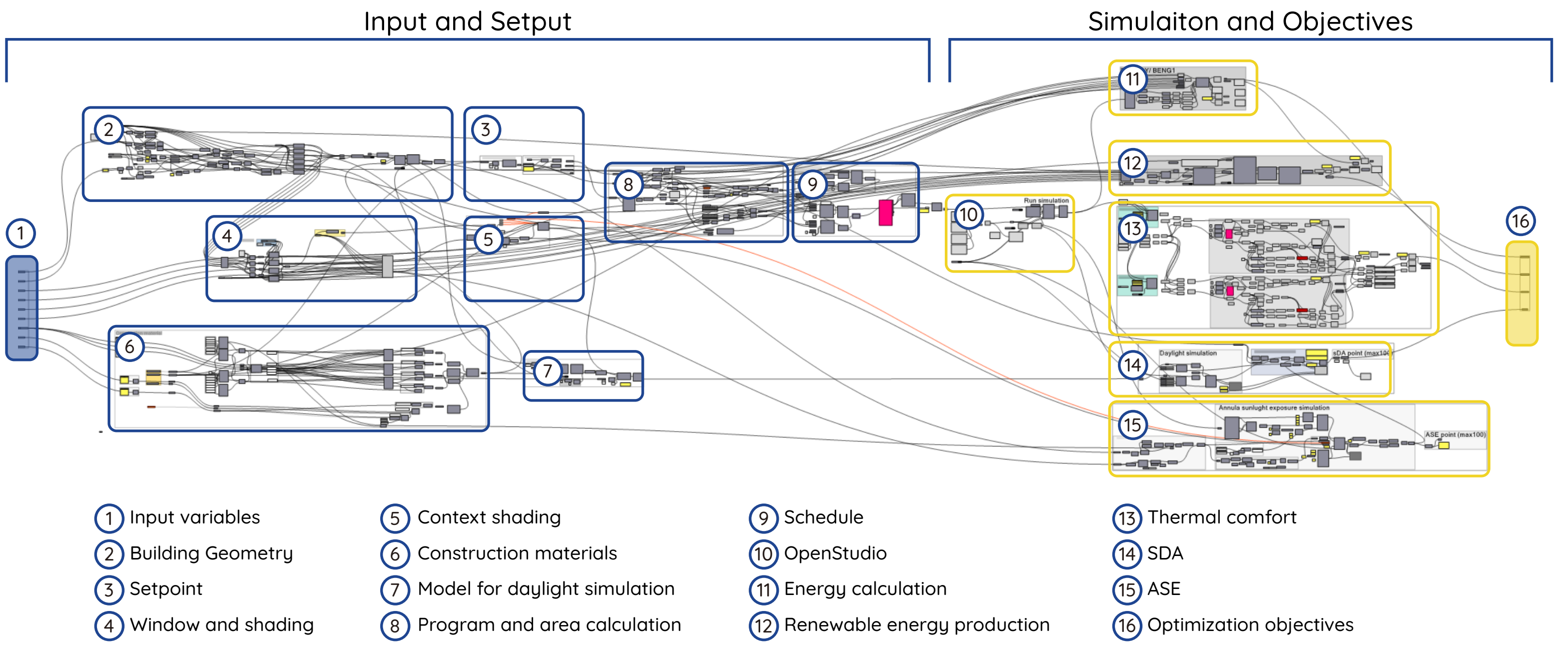


Figure 49. Workflow of simulation and opitmization in Grasshopper

The following paragraphs start with the baseline and original design scenario. The design factors are already determined. It gives a general idea of the changes in building performance under the current and predicted climate condition of 2085 WH. The second scenario is the renovation scenario based on the current condition and shows what would be the options and possibilities the projects are building and designing now would face in a near future. The scenario which is based on the future climate condition is the one after. Then is the mixed year scenario and the average year one.

For each scenario, the selected results from the Pareto front of MOO reflect the consequence of the design decisions. The result is evaluated in multiple aspects, the total energy consumption, heating, and cooling demand, the global thermal comfort, the warm hours,

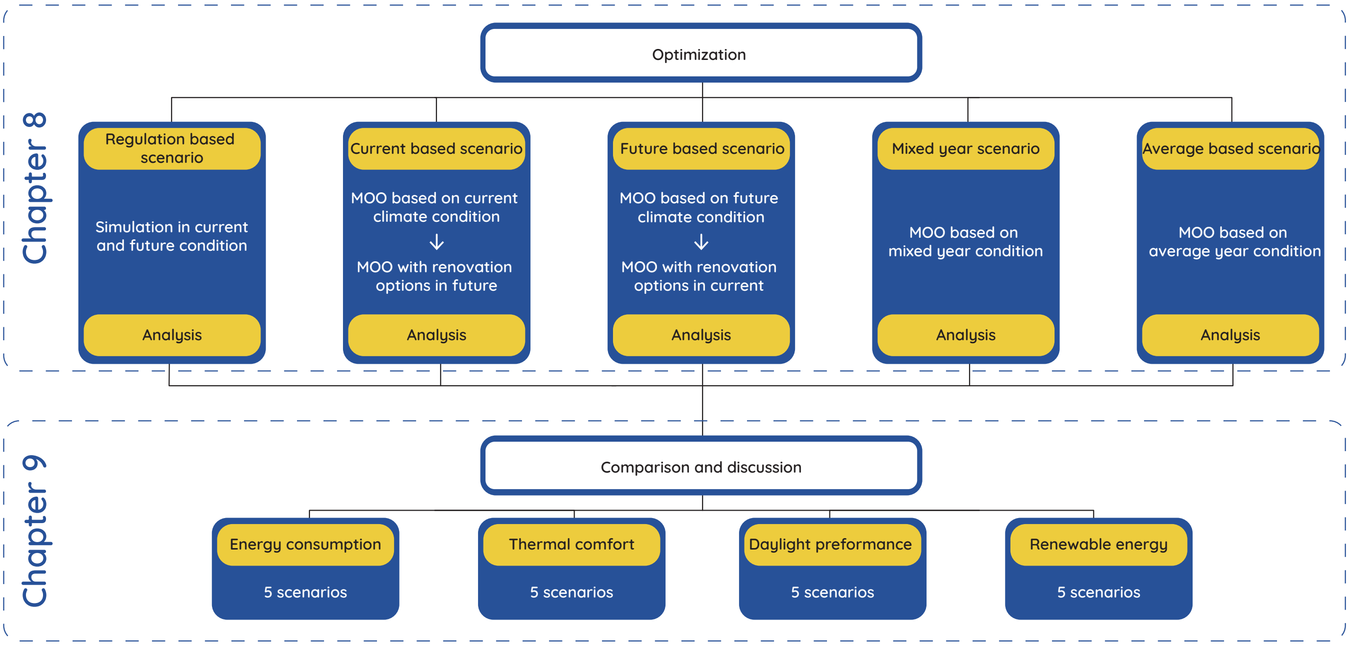


Figure 50. Workflow of optimization and analysis in chapters 8 and 9.

the cool hours, the overheating hours, the daylight performance, and the ratio of renewable energy usage. The performance and the preference design parameters of the result from each scenario are evaluated with the average value from the baseline scenario individually.

In chapter 9, the discussion of each evaluation aspect is made to compare the result based on different design approaches. This comparison shows the pros and cons of variant design approaches for this case study project. Amount all the objectives, finding the best design solution is difficult, but this analysis gives out an overall view of the result. Furthermore, would be beneficial for the designers to make the final decisions.

8.2 Baseline scenario

The baseline scenario is following one of the original design options in Zwijndrecht and this project is given by OMRT. The floor area is a constant value, 576 m2, and the length and width of original design are equal, 24 meters. The building has a rotation angle of 48.33 degree from the north direction. Regarding to the insulation properties, the basic requirement of Bouwbesluit regulation is applied with 3.7 m2K/W for floor component, 4.7 m2K/W for external wall component and 6.3 m2K/W for the roof component. The U-value is referred from the average of basic demand from NVBV and Bouwbesluit with 1.65 W/m2K. The In the window to wall ratio is not regulated, and usually it depends on the preference of architects or the analysis result. In this simulation, the WWR is the only flexible factor which lead to different performance in the result. From the Res.1 to Res.3 to WWR increases from 20% to 35% then to 50%.

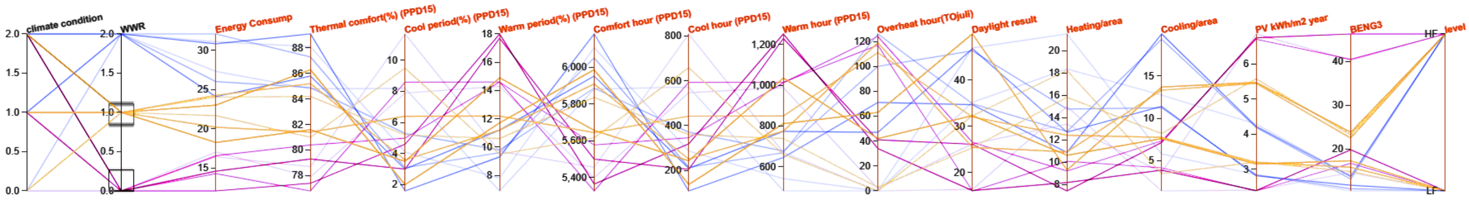
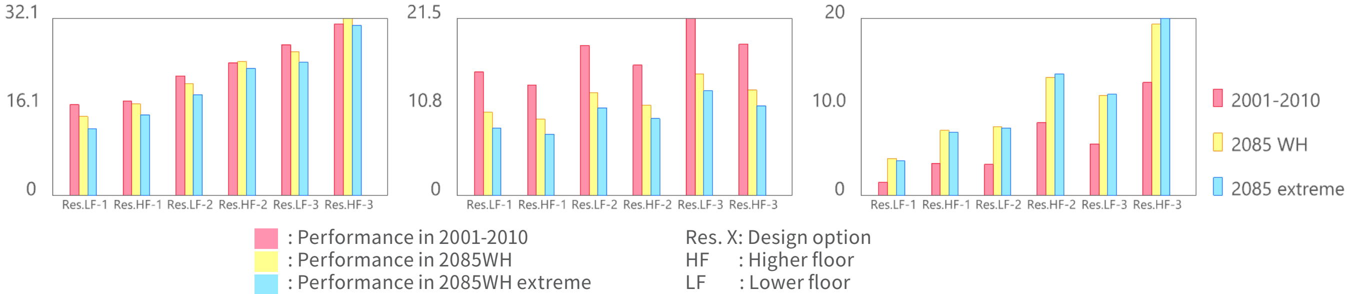


Figure 51. Baseline scenario, design and performance

In the Figure, the window to wall ratio shows a major influence on the objective performance throughout three climate conditions. Although the performance changes under each weather condition, the range of variation is within certain boundaries.



The total energy consumption for the baseline scenario has a very steady trend when facing climate change. The variation is less than 10% changes for most options. However, the decrease in heating demand is more than 40% and the increasing amount of cooling demand is from 34% to 65% demands on the design parameters. The result gives a big change in the energy demand in different usage, meanwhile, the building would need different design approaches or types of equipment to fit in different climate conditions.

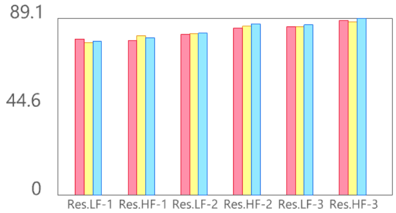


Figure 52. Comfort period (%)

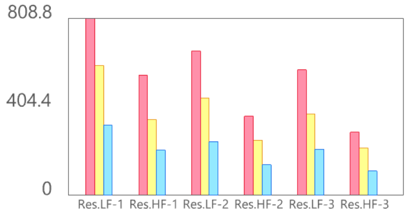


Figure 53. Cool hours

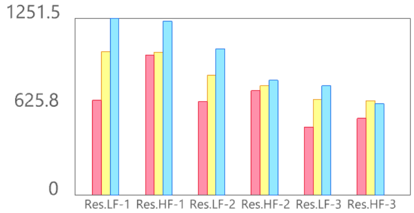


Figure 54. Warm hours

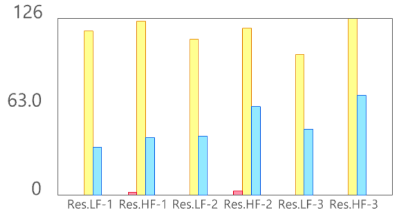


Figure 55. Overheating hours

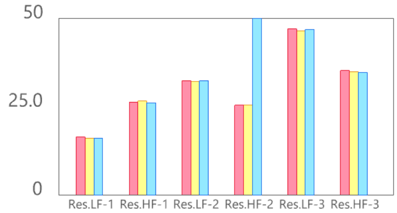


Figure 56. Daylight performance

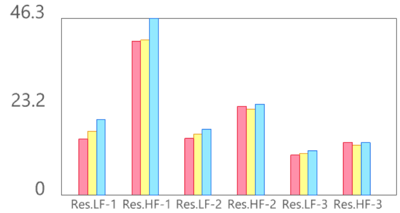


Figure 57. Percentage of renewable energy usage

In Figure 52, Figure 53, and Figure 54 the trend of the total comfort hour has a very slight increase with the change of WWR but doesn't have many changes under different climate conditions. The lowest percentage is 76.8% of the occupied period in the option of 20% WWR in 2085WH weather. The decreased proportion in the cool period (3%) and increase in the warming period (3.5%) between current and 2085 WH are very similar. The result of the higher floor has an average of 4% better performance in total thermal comfort. The trend of thermal comfort is the same on both higher floors and lower floors. But the changing of cool hours and warm hours are smaller in the higher ones which means the higher floor thermal condition seems to be more stable.

The overheating hour in all options is over 100 hours in the weather condition of 2085WH. Noteworthy, the higher floors have more overheating hours in all the design options.

On the other hand, climate change does not influence much the efficiency of PV panels and the daylight gain in the indoor environment. Due to the roadhouse adjacent to the study object, the efficiency of PV panels on the lower floor façade has only half of the production of the ones installed on a higher floor. An interesting figure shows in the daylight result of the higher floor with 35% of WWR in which the ASE met the regulation and the point does not multiple by a 50%.

8.3 The current based scenario

The current based option is a design decision based on current climate conditions, the TMY weather selected from 2001 to 2010 in Rotterdam. In the current condition, there are 8 re-sults selected from the Pareto front out of 50 populations with 10 generations. The perfor-mance of these results is presented underneath. The selected results are processed MOO in the next weather condition, the 2085WH, to find the renovation option possibilities to im-prove the performance. The results are evaluated in multiple aspects, the total energy con-sumption, heating, and cooling demand, the global thermal comfort, the warm hours, the cool hours, the overheating hours, the daylight performance, and the ratio of renewable energy usage.

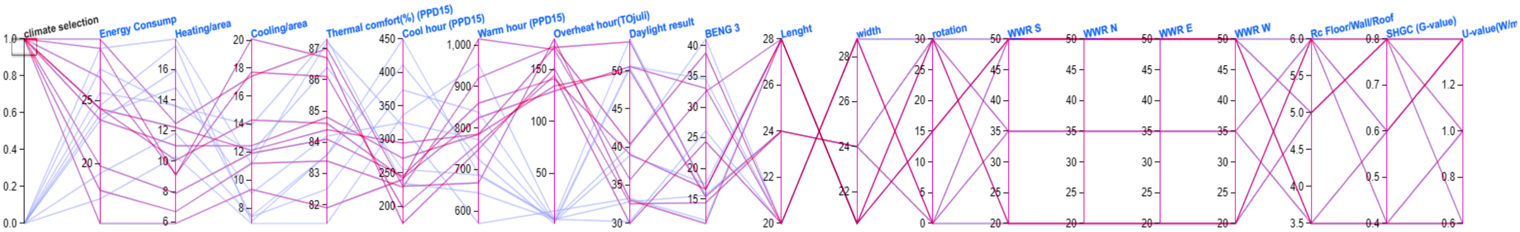


Figure 58. 2085WH scenario higher floor, design and performance

8.3.1 Geometry evaluation

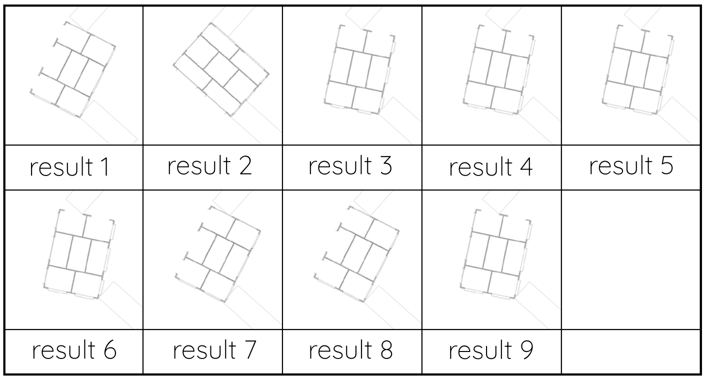


Figure 59. Lower floors layout

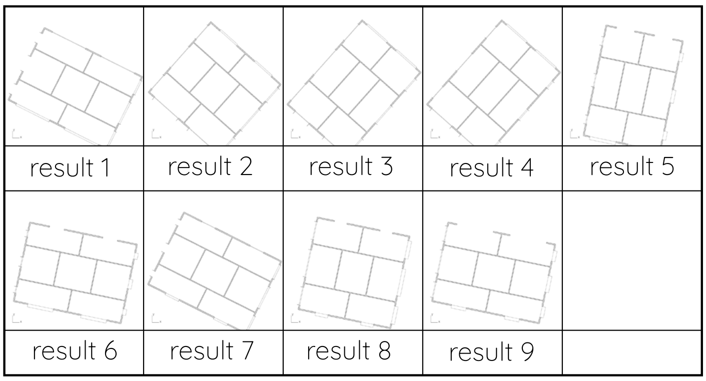


Figure 60. Higher floors layout

The options selected from the optimization results are the ones along the Pareto front. These options have better performance in different objectives, and this results in the variation of building geometry in the first climate condition. In the set of higher floor layouts, more than half of the results have a wider southern facade and the set of lower floors has a reverse trend. For the Rc-value, the three of the higher floor sets pick the option with the lowest values. But the major of the lower floor sets chose the highest value.

8.3.2 The result from current based MOO

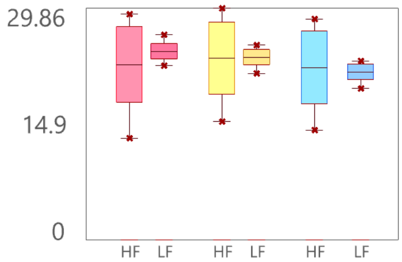


Figure 61. Energy consumption (kWh/ m².yr)

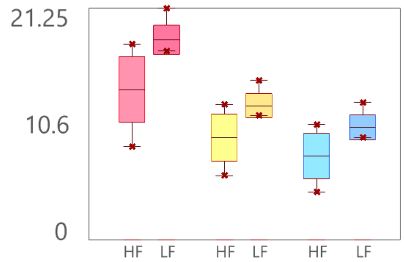


Figure 64. Heating demand (kWh/ m².yr)

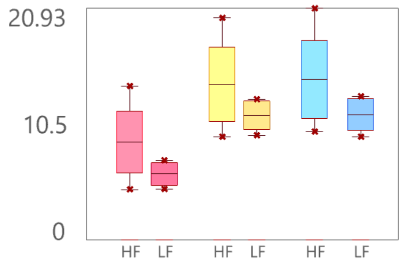


Figure 67. Cooling demand (kWh/ m².yr)

: Current based results in 2001-2010
: Current based results in 2085WH
: Current based results in 2085WH extreme

HF : Higher floor (current based)
LF : Lower floor (current based)

The total energy consumption in the result of current-based optimization is stable, in which the higher floor has 0.8kWh/m2 per year, on average, of energy decrement and the lower floor has 0.75 kWh/m2 per year of increment, on average. The changing range of the operating energy is from a 2% of decrease to a 16 % of increment. These condition does not mean the influence of climate change is minor, but the increase in cooling demand is almost the same as the decrease in heating demand. In the case of higher floors, the heating demand drops by 4.42 kWh/m2 per year and the cooling demand rises by 5.23 kWh/m2 per year from 2010 to 2085.

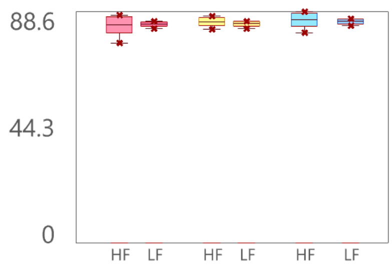


Figure 62. Thermal comfort (%)

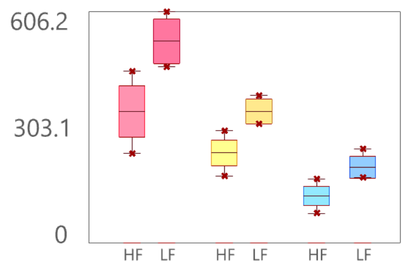


Figure 65. Cool hours

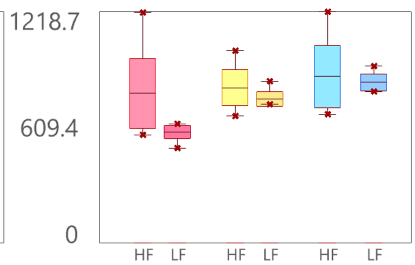


Figure 68. Warm hours

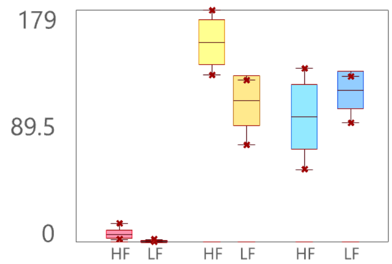


Figure 63. Overheating hours

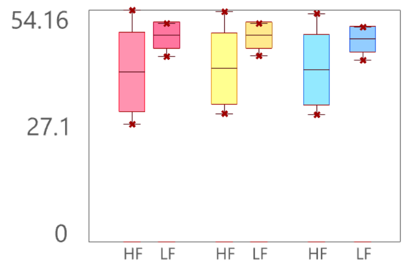


Figure 66. Daylight performance

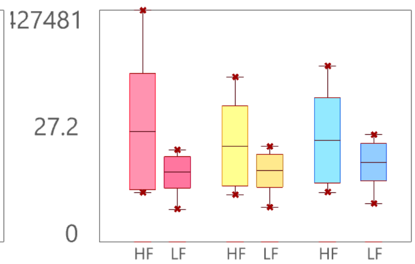


Figure 69. Percentage of renewable energy usage

: Current based results in 2001-2010
: Current based results in 2085WH
: Current based results in 2085WH extreme

HF : Higher floor (current based)
LF : Lower floor (current based)

With the HVAC system, the total comfort hours can remain when facing the challenge of climate change. The percentage of comfort hours stays more than 80% of the occupied time. In Figure 63, it is clear that the external environment and the design decisions have more impact, especially the overheating hours, on the higher floors and the lower floors are more stable. However, when facing climate change, the variation of the cool hours on the lower floors is bigger. This issue could be due to the main heating source changes from the solar radiation to the heat in the air.

The average daylight result is below the LEED standard, 50% of the conditioned area. The performance on the higher floors has a wide range, this result could be due to the direct annual solar exposure being too high. And to improve this result, a more efficient shading system would be beneficial. .

The strategy of placing PV panels mentioned in chapter 6.0 secure the efficiency of energy production but the window to wall ratio, orientation and context still have a certain impact on it. In general, the amount of renewable energy generated on the higher floor facade can be 1.5 more than the lower ones. And this reflects in the ratio of renewable energy usage to the total energy consumption in Figure 69.

8.3.3 The renovation options from current based MOO

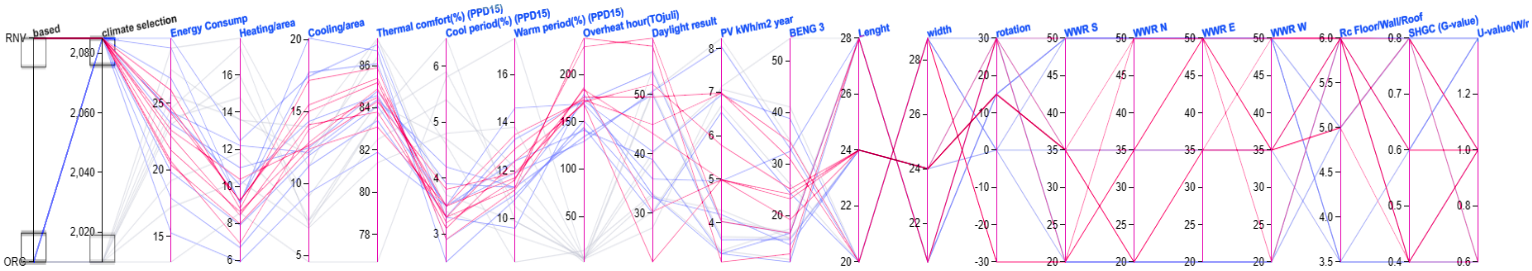


Figure 70. Current scenario higher floor, comparison of original and renovation

This chapter shows to what extent the renovation approaches can prevent uncomfortable indoor environment and reduce potential energy consumption facing climate change. In the first optimization, the building layout and orientation are fixed but the parameters of the building facade have a chance to be renovated in the future and be suitable for the future climate conditions by changing the WWR and/or the thermal conductivity of the envelope components.

Figure 70, the comparison of the performance of the original options and after renovation. The color refers to the same original design options and the renovation options based on them.

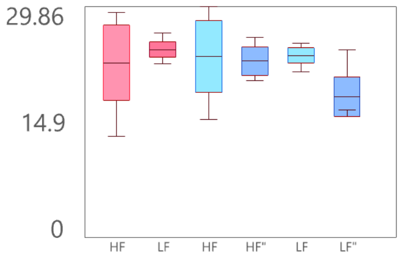


Figure 71. Energy consumption (kWh/ m².yr)

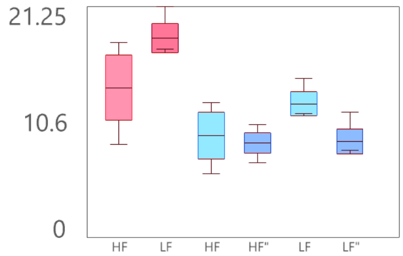


Figure 72. Heating demand (kWh/ m².yr)

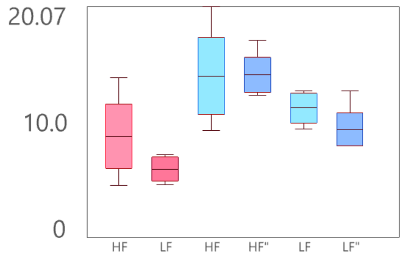


Figure 73. Cooling demand (kWh/ m².yr)

: Current based results in 2001-2010
: Current based results in 2085WH
: Renovation results in 2085WH

HF : Higher floor (current based)
HF": Higher floor after renovation
LF : Lower floor (current based)
LF": Lower floor after renovation

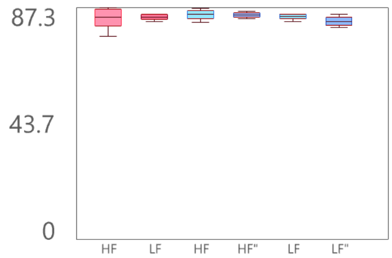


Figure 74. Thermal comfort (%)

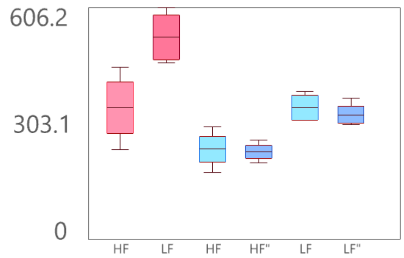


Figure 75. Cool hours

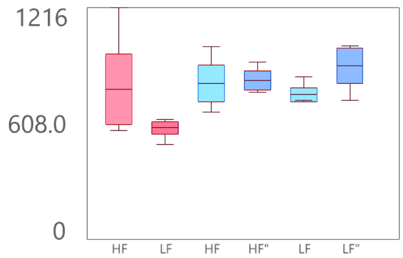


Figure 76. Warm hours

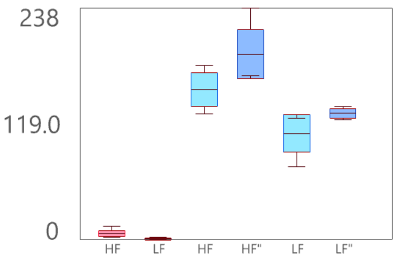


Figure 77. Overheating hours

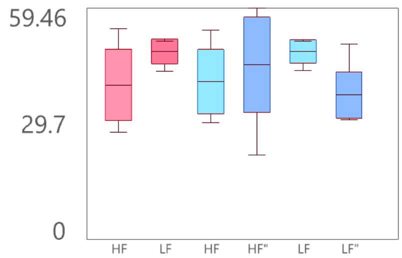


Figure 78. Daylight performance

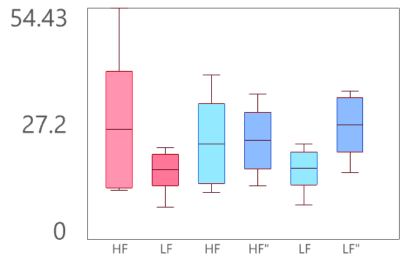


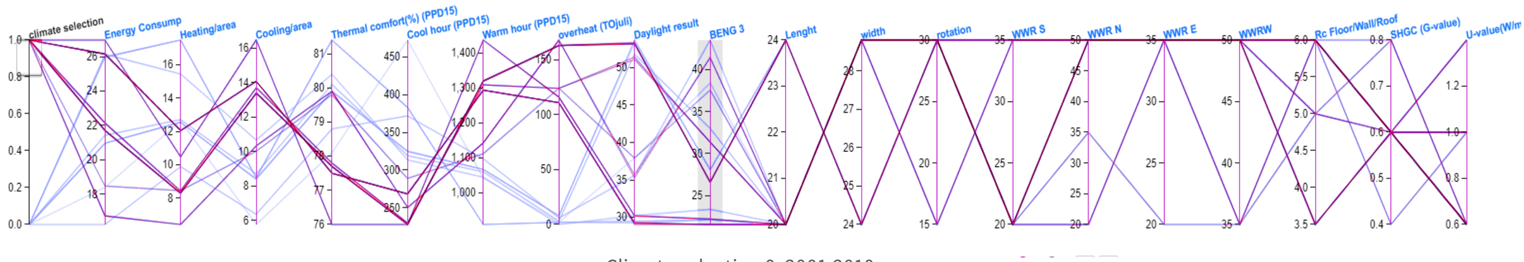
Figure 79. Percentage of renewable energy usage

In this case, changing the envelope properties has a minor influence on the performance in the future climate condition. In the figure, it is clear that the aspects of performance that considered as objectives are improved but others do not necessarily have the same trend.

With the renovation approach, the energy consumption is possible to be reduced both heating and cooling demand. The percentage of the comfortable period remains the same and hardly has any improvement. While the overheating hour is relevant high after renovation. The results also show that it is possible to enhance the daylight performance and percentage of renewable energy usage. But based on the existing design is that better daylight performance always comes with a risk of increasing overheating hours. Furthermore, a higher daylight performance also leads to a decrease in energy production from PV panels because the area of the opaque walls decreases.

8.4 The future based scenario

The predicted future climate condition is a much warmer environment than the current one. A building designed based on this weather condition has different parameters than the one designed in the current condition. In this scenario, the MOO is operated with the 2085WH weather file. There are 9 selected options from the optimization with the performance shown in the following chapters. Considering the building will be built soon, the selected options from 2085WH MOO are processed with the current climate conditions with more constraints in the input variables to find the suitable option to build in near future and be renovated in the later building life. The selected options are shown as in appendix 02.



Climate selection 0: 2001-2010
Climate selection 1: 2085WH

Figure 82. 2085WH scenario higher floor, design and performance

8.4.1 Geometry evaluation

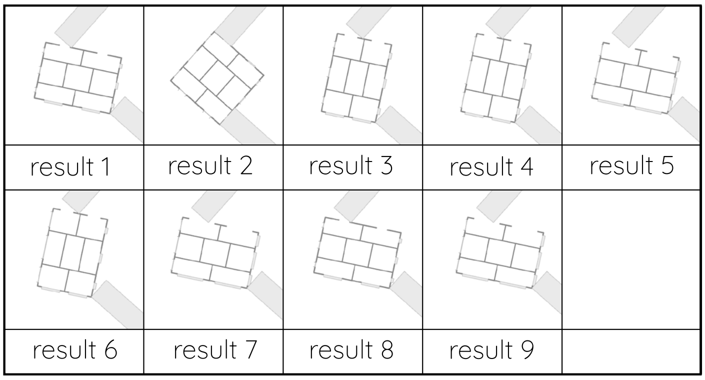


Figure 80. Lower floors layout

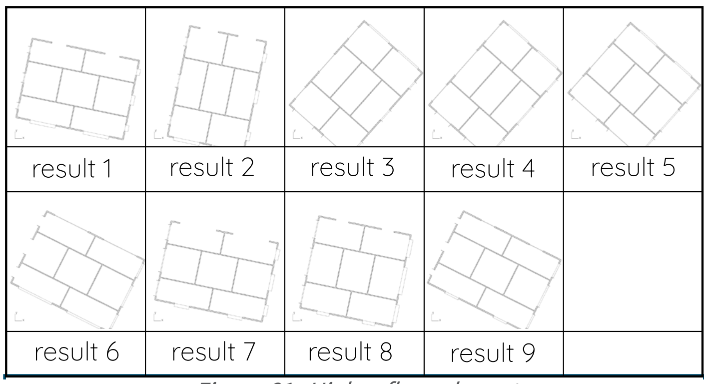


Figure 81. Higher floors layout

In Figure 80 and Figure 81, the layouts have variant options on both floor levels. This result is very different from the general design approach that is taken in the Netherlands. The common approach is having a narrow southern facade and a wider eastern and western facade. The window to wall ratio is directly related to the rotation of the building geometry, in the cases of lower floors, the influence from the context has an additional impact. In general, on the eastern facade and western facade, the WWR tends to be bigger since it can inlet more daylight and less heat than on the southern facade.

8.4.2 The result from future based MOO

The optimization process is based on the 2085WH weather condition. The operation energy could remain similar amount in current and future conditions. The total energy consumption and energy for space heating amount for higher floor options is more constant in all options. Although the total consumption for higher and lower floors is close, for the lower floor the demand for heating in the current condition is four times more than cooling. While this difference reduces to 30% in the future condition. The switch of the energy usage is worth paying attention to in the design phase.

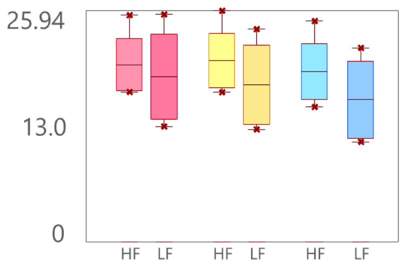


Figure 83. Energy consumption (kWh/ m^2.yr)

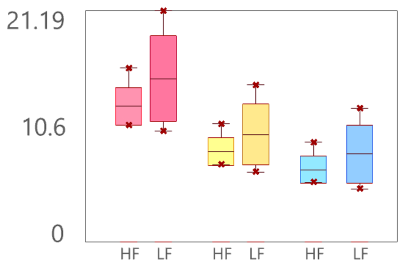


Figure 84. Heating demand (kWh/ m^2.yr)

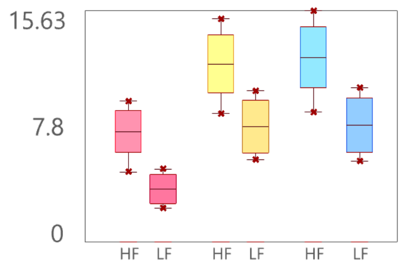


Figure 85. Cooling demand (kWh/ m^2.yr)

2001-2010 2085 WH 2085 extreme

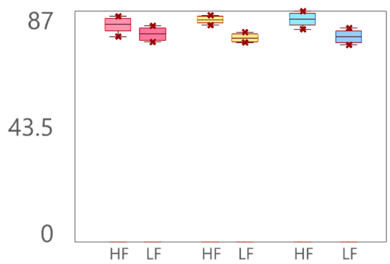


Figure 86. Thermal comfort (%)

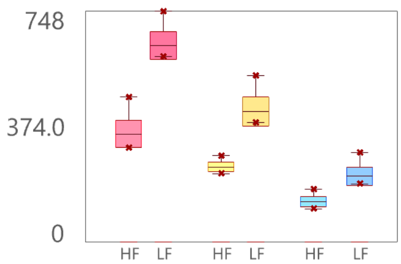


Figure 87. Cool hours

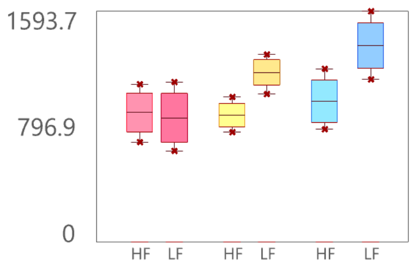


Figure 88. Warm hours

In the optimized results, the percentage of thermal comfort could even rise when the weather is warmer, only on higher floors. In figure 65, the cooling hours for higher floors (5% of the occupied period) and lower floors (9% of the occupied period) are very different. In this scenario, the cool hours will reduce in the future climate condition but the warm hours would be relevant the same. Amount the warm hours, the number of overheating is higher in the higher floor conditions.

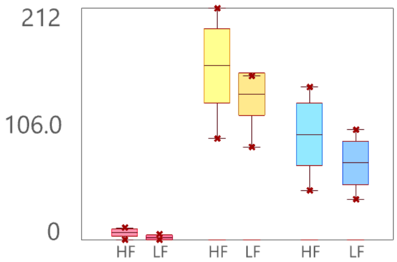


Figure 89. Overheating hours

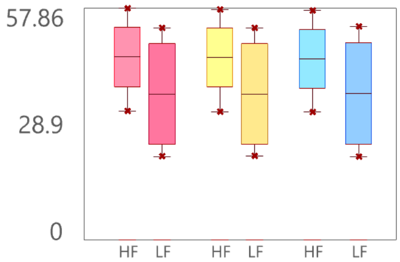


Figure 90. Daylight performance

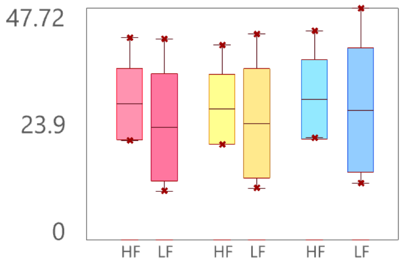


Figure 91. Percentage of renewable energy usage

The daylight performance is within 32.25% to 57.86% for higher floors and 20.84% to 53.0% for lower floors. The variation in performance is very wide but this result stays constant in different climate conditions.

Renewable energy can cover at least 20% of the building operation energy usage and it is possible to cover up to 41% in some cases for the higher floor cases. In the lower floor cases, due to the shade caused by the neighboring buildings, the lowest covering rate is 10% only.

8.4.3 The renovation options from future based MOO

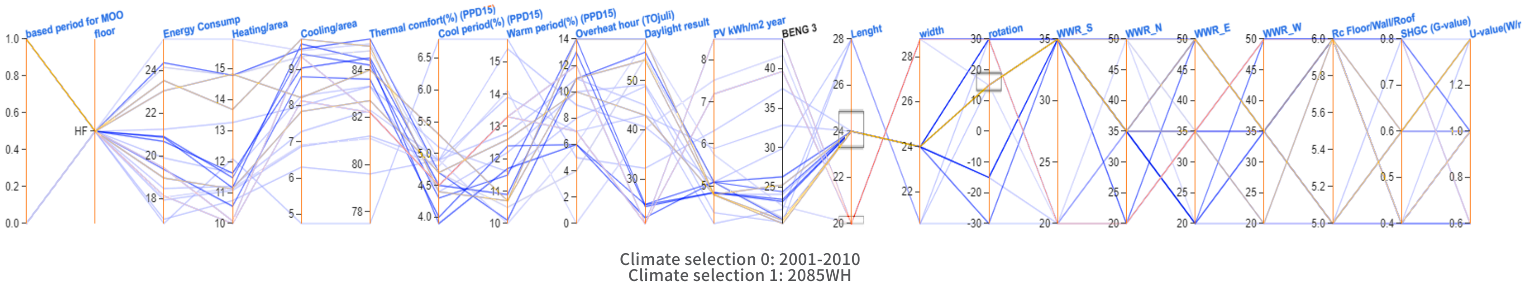


Figure 92. Future scenario higher floor, comparison of original and renovation

Based on the 9 results selected from the MOO in 2085WH with factors of the building geometry and orientation are fixed, these options are processed in the current climate condition to run the MOO again. The results selected in the future scenario have a better performance in the weather condition of 2085 but these design decisions are not necessarily suitable for the current climate environment. The Parallel coordinate plot shows that the building layout and orientation determine the main energy consumption and thermal comfort level initially. The renovation approaches have more impact on the daylight performance and the renewable energy usage rate.

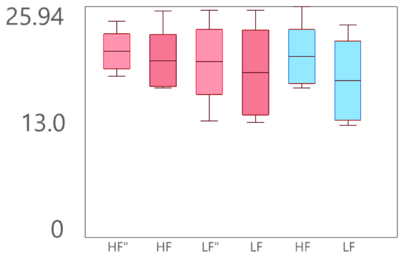


Figure 93. Energy consumption (kWh/m^2.yr)

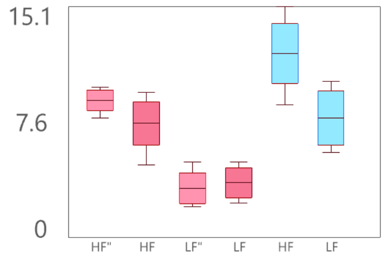


Figure 94. Heating demand (kWh/m^2.yr)

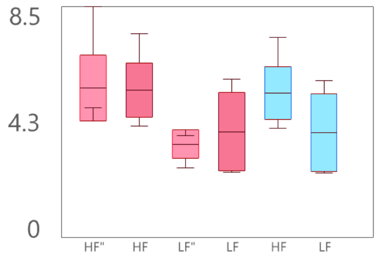


Figure 95. Cooling demand (kWh/m^2.yr)

: Pre-renovated results in 2001-2010
: Future based results in 2001-2010
: Future based results in 2085WH

HF : Higher floor (current based)
HF": Higher floor after renovation
LF : Lower floor (current based)
LF": Lower floor after renovation

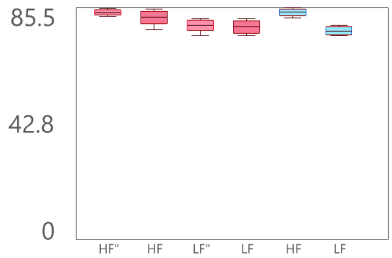


Figure 96. Thermal comfort (%)

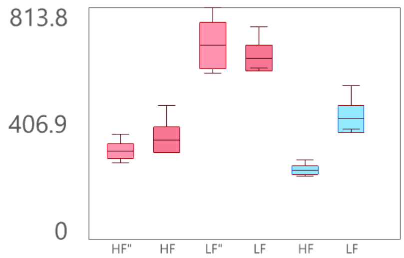


Figure 97. Cool hours

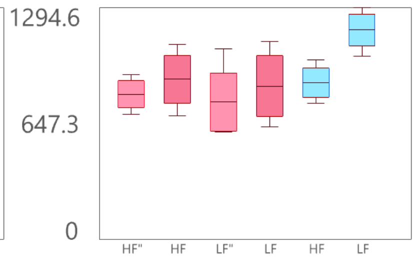


Figure 98. Warm hours

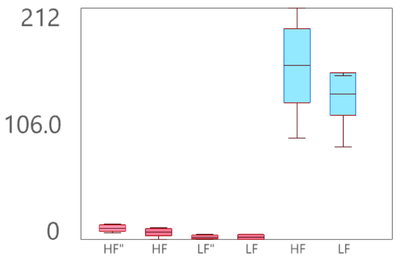


Figure 99. Overheating hours

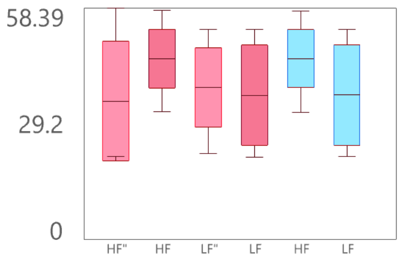


Figure 100. Daylight performance

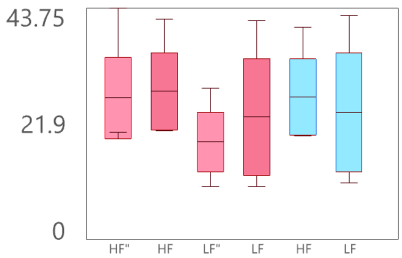
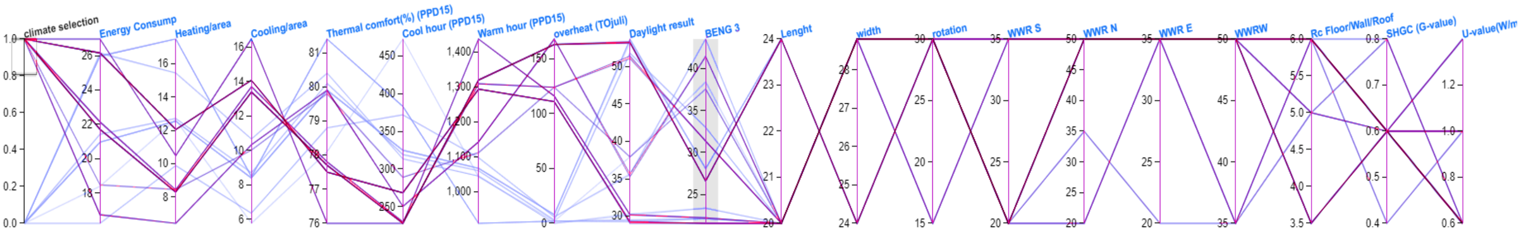


Figure 101. Percentage of renewable energy usage

For the energy consumption of both heating and cooling usage, the improvement that renovation options lead to is very limited. The improvement of the building operation energy consumption is less than 1%. The same trend happens in the thermal comfort part, for temperatures between 20 °C and 26 °C , the renovation approaches only improve by 0.5%, on average, for the cool hours and warm hours. On average, the renovated options reduce the uncomfortable hours by around 150 hours annually. The daylight performance and percentage of renewable energy usage can be improved by having a more suitable design in the current climate condition.

8.5 Mixed year scenario

The mixed year model is composed of the data of the colder period from the current climate data set and the data of the warmer period from the predicted future climate condition. This scenario has the biggest temperature range of all the scenarios. This scenario is testing the possibility of processing the optimization with the extreme weather condition and comparing the results.



Climate selection 0: 2001-2010
Climate selection 1: 2085WH

Figure 104. Mixed year scenario higher floor, design and performance

8.5.1 Geometry evaluation

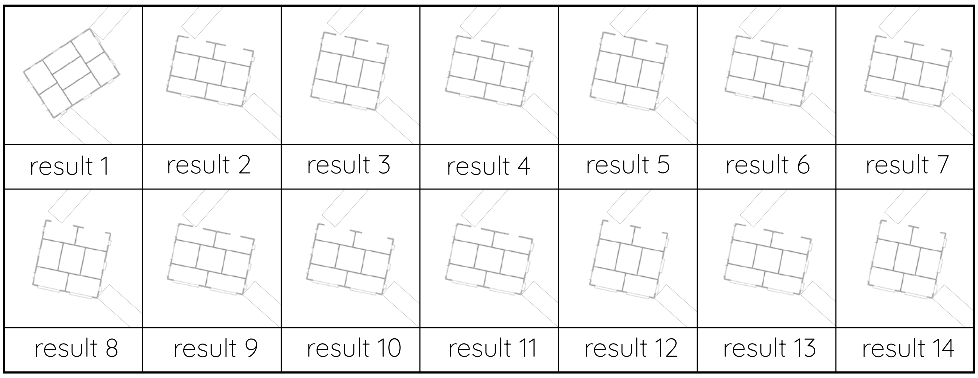


Figure 102. Lower floors layout

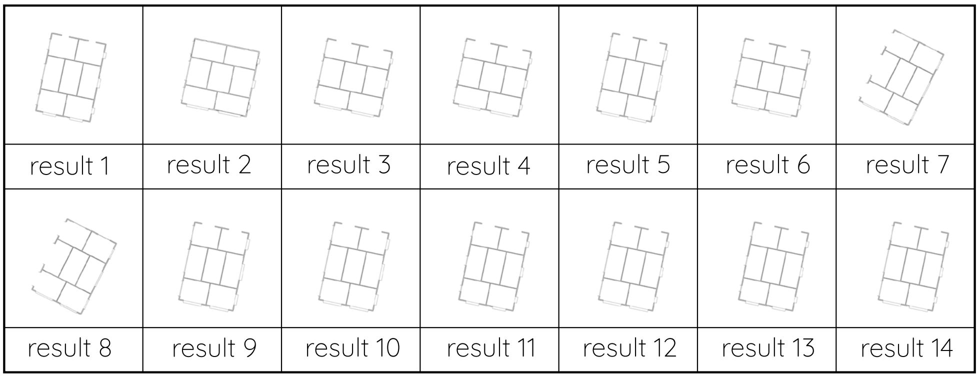


Figure 103. Higher floors layout

The higher floors and lower floors have different results from the building layouts selected from the Pareto front. On the lower floors, the options seem to have a wider southern facade and a bigger window to wall ratio. These results from the building properties are the opposite of the normal design decisions that would be made in the environment of the Netherlands. The efficiency of PV panels as an objective in the MOO process would be the main reason for this outcome.

In the contrast, the higher floor options have shorter southern facades, and window to wall ratios are preferable to being smaller. The orientations of the selections are close to 0 degrees of rotation from the north vector. The variation of building geometry on the higher floors is narrower than on the lower floors, which reflects how the external environment shapes the design performance.

8.5.2 Performance evaluation

The energy consumption per floor area of the selected options for the higher floors is shown in Figure 105 to Figure 107 in which the energy usage in the current condition, in general, is the lowest. The increased amount of total energy consumption in the 2085WH environment is 0.5 kWh/m2 per year. Although the total energy consumption does not have a big difference, the variability of heating demand and cooling demand is enormous. The heating demand drops by 35% and the cooling demand rise by 59% within the 63 years. Since the mixed year model contains the warmest and the coldest conditions, the heating demand is close to the current result and the cooling demand is about the same as the 2085WH result. Meanwhile, the mixed year model has the highest global operation energy consumption and the result from this model can used to study the highest cooling demand and the highest heating demand in the building lifespan.

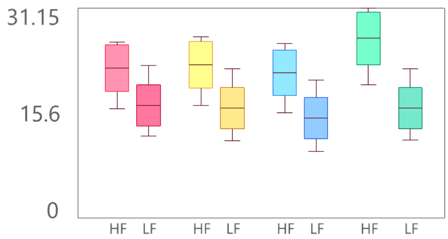


Figure 105. Energy consumption (kWh/ m^2.yr)

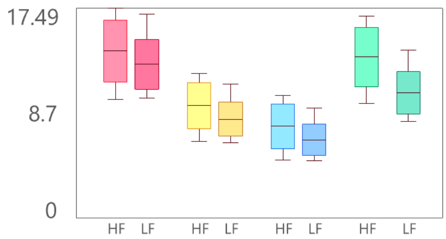


Figure 106. Heating demand (kWh/m^2.yr)

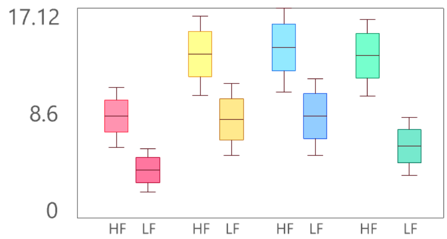


Figure 107. Cooling demand (kWh/m^2.yr)

:Selected results in 2001-2010
:Selected results in 2085WH
:Selected results in 2085WH extreme
:Selected results in Mixed year

HF : Higher floor (mixed year based)
LF : Lower floor (mixed year based)

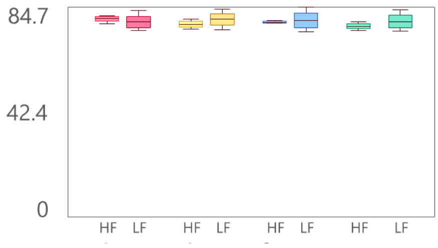


Figure 108. Thermal comfort (%)

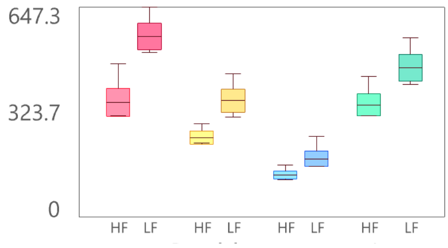


Figure 109. Cool hours

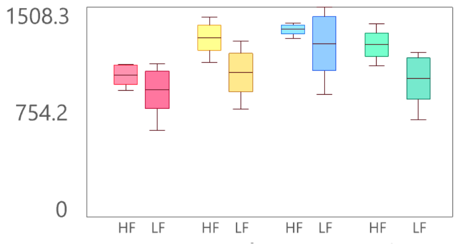


Figure 110. Warm hours

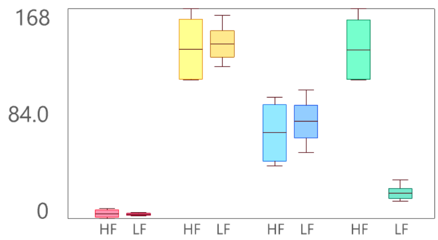


Figure 111. Overheating hours

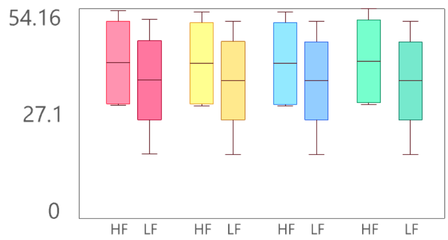


Figure 112. Daylight performance

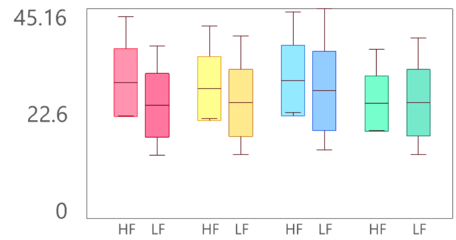


Figure 113. Percentage of renewable energy usage

In Figure 108, the thermal comfort condition for lower floors has a wider range of performance depending on the design parameter combination than the higher floors. In general, the mixed year model proved an average result for the performance for the designing building of current and future climate environments. The percentage of comfort hours, with a mean value of 80.0% to 77.8% for the higher floor, is stable when the climate condition changes. The ratio of cool hours decreases by 1.5% from 5.1%, and the proportion of warm hours increases to 14.9% from 13.2% on the lower floors. The uncomfortable hours, especially the warm hours, during the occupied period are too high.

Compared to the change in temperature, the solar illuminance does not have much differ-ence in each climate scenario. Consequently, this reflects on the similarity of daylight per-formance from the mixed year in three different climate conditions. A similar trend shows in the amount of renewable energy production. However, since the total energy consump-tion in the mixed year model is higher than the real amount, the percentage of renewable energy usage would be lower than reality as well.

The performance of PV panels is highly impacted by the context and it leads to some of the panels being totally under shade. As a result, the energy generation on the lower floor is lower than in the higher floor conditions. Due to climate change, solar radiation is influ-enced, and the amount of radiation is decreased in the future environment. Consequently, the electricity generated by the PV panels has slightly declined by 0.1 kWh/m2. The total energy consumption causes the major variation in Figure 113. This result could be caused by the inaccuracy of software simulation and should be con-sidered no different.

8.6 Average year scenario

The climate environment is changing rapidly, usually, the collected data set is too large for performance analysis to process. Under this concern, the average year model is created with the average value of current climate data and future predicted climate data. The selected results are processed with the average year climate model and evaluated with current, future, and extreme year models. The result of the average year model can be used to predict future performance. The result that is given out from average optimization is close to the average of current and future conditions.

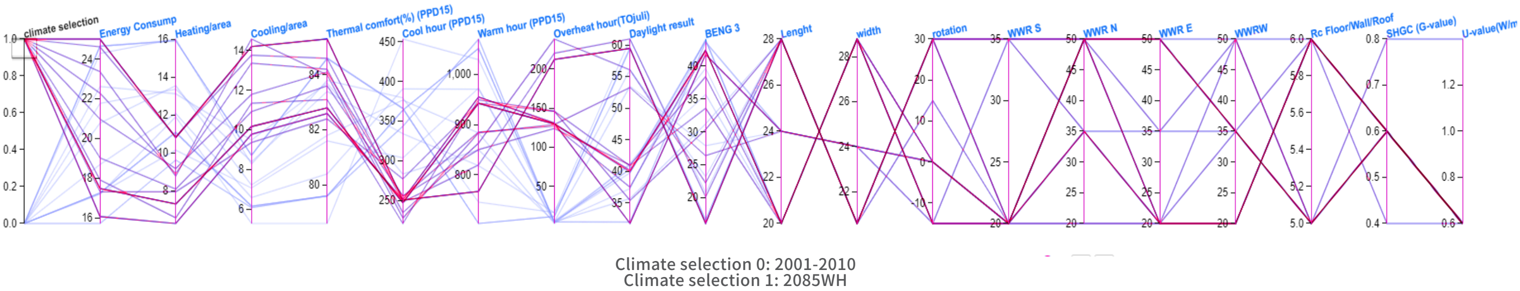


Figure 114. Mixed year scenario higher floor, design and performance

8.6.1 Geometry evaluation

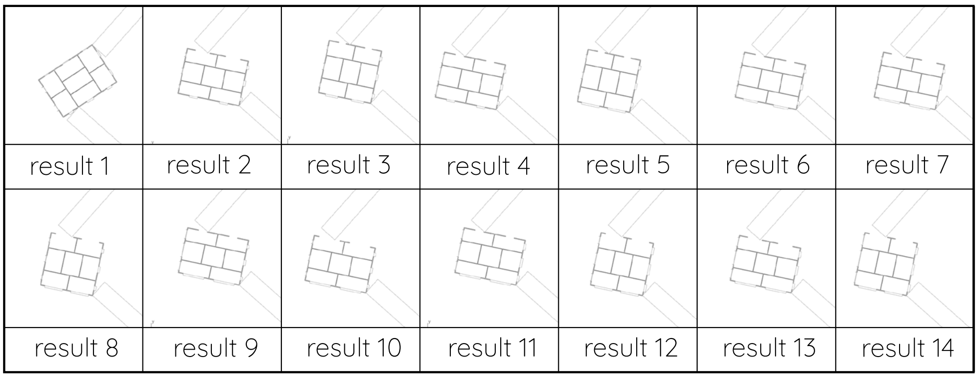


Figure 115. Lower floors layout

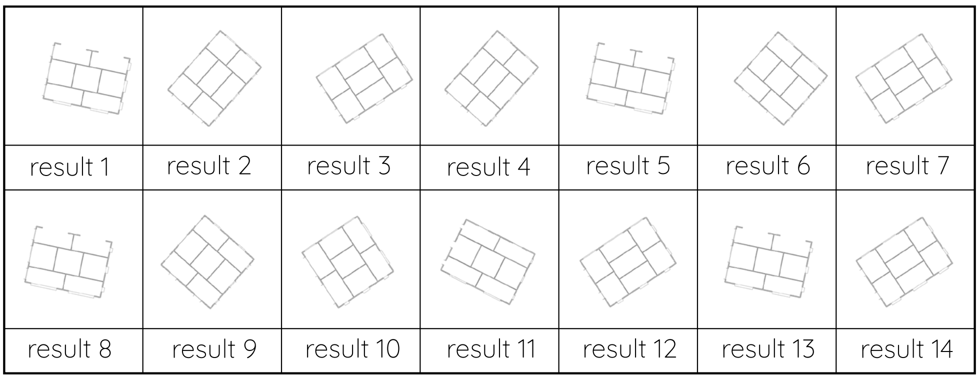


Figure 116. Higher floors layout

The selection of lower floor plans has a similar trend which has a middle or longer length of the southern facade facing right to the south direction. The layouts of the higher floors have two major types, the square layout with less rotation from the original design and the rectangle layout with the wider facade facing south. This result could reflect that the heating demand and the cooling demand are very similar.

8.6.2 Performance evaluation

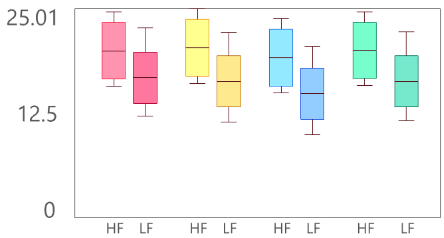


Figure 117. Energy consumption (kWh/ m².yr)

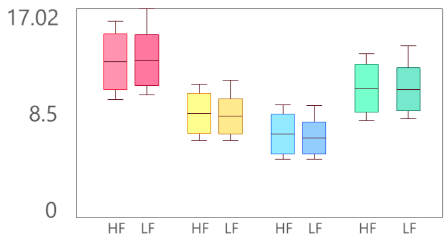


Figure 118. Heating demand (kWh/m².yr)

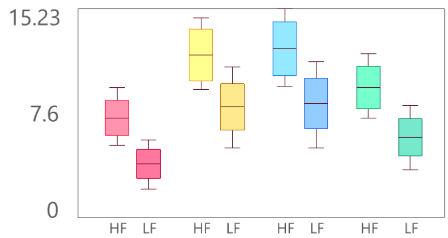


Figure 119. Cooling demand (kWh/m².yr)

:Selected results in 2001-2010
:Selected results in 2085WH
:Selected results in 2085WH extreme
:Selected results in Mixed year

HF : Higher floor (average year based)
LF : Lower floor (average year based)

In Figure 117, higher floors and lower floors conditions, show that the total energy consumption for the results from the average year scenario has a different trend from others. This difference is because the decreased heating demand and the increased cooling demand from current to future climate are not balanced, and the results are more suitable for warmer climate environments. The energy consumption in the current climate condition is higher than in 2085WH. On average, the energy consumption of the higher floor is higher than the lower floor.

For both higher and lower floor conditions, the heating demand in the current is more than in the future, and the cooling demand is the other way around. The cooling demand for the higher floor is higher than the lower floor demand but the heating demand is similar.

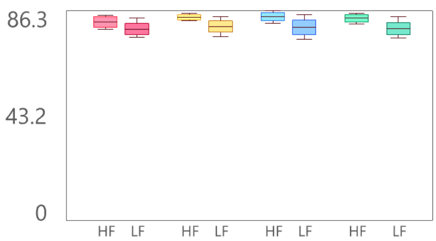


Figure 120. Thermal comfort (%)

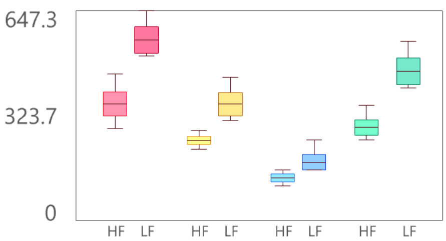


Figure 121. Cool hours

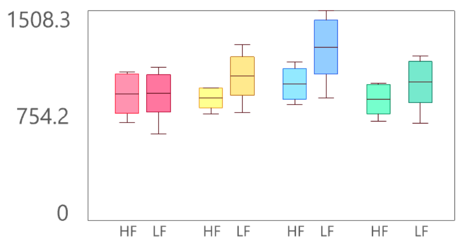


Figure 122. Warm hours

In the average scenario, the thermal comfort is stable in the selected design options. The average percentage of comfort period for selected results for higher floor is 81.7% and 78.8% for lower floor in current condition. The percentage changes to 83.7% and 79.8% in the 2082WH condition. The overheating hours rise from 7.8 and 3.3 hours (higher floor and lower floor) in current condition to 161.2 and 140 hours in the future condition.

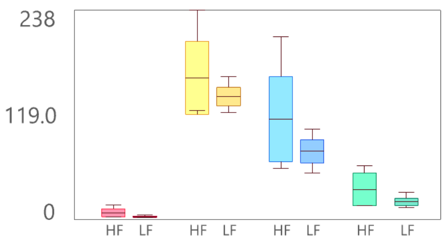


Figure 123. Overheating hours

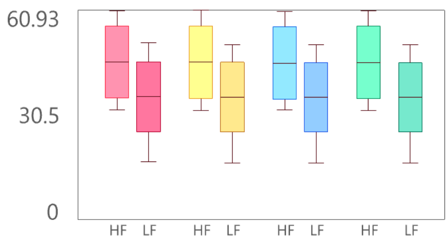


Figure 124. Daylight performance

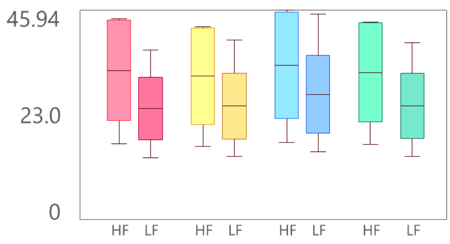


Figure 125. Percentage of renewable energy usage

:Selected results in 2001-2010
:Selected results in 2085WH
:Selected results in 2085WH extreme
:Selected results in Mixed year

HF : Higher floor (average year based)
LF : Lower floor (average year based)

The daylight results have a very wide range between all the selected options from 32.0% to 59.5%, higher floor condition, and 16.8% to 51.5%, lower floor condition. The daylight performance stays constant in all scenarios, the difference within is less than 1.0%. The average scenario gives an accurate prediction of the daylight performance.

Among the selected design variables, the ratio of renewable energy usage has a very wide range, from 16.0% to 44.0%. The amount of electricity generated by the PV panels is the main reason, which is from 4.1 kWh/m2 to 8.2kWh/m2 per year.

9 Comparison and Discussion

This chapter focuses on the distinctness and similarity of each aspect of performance, the energy consumption, comfort condition, daylight performance, and ratio of renewable energy usage, between the scenarios. Besides analyzing variations of the performance within a single scenario, the comparison between each scenario gives another point of view for designers. In this aspect, the correlation between the design decisions and the performance is more clear. It is possible to judge the pros and cons of these approaches. Since the optimization conditions are different in each scenario, the focus and the performance can be expected with variable results. Focusing on the changing of performance under climate change influence, the current and the prediction of the 2085 environment are applied but the extreme year model is excluded. Since the context conditions have revelant constant impact to the result, the higher floors and the lower floors are discussed seperately.

9.1 Energy consumption

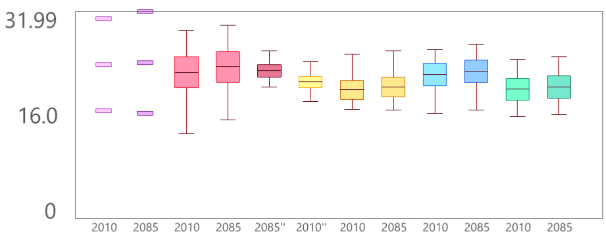


Figure 126. Energy consumption_higher floors

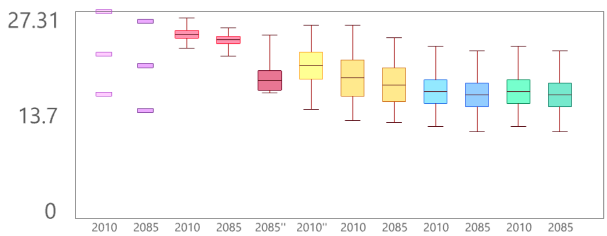


Figure 127. Energy consumption_lower floors

:Results from Baseline scenario
:Results from Current based scenario
:Results from Future based scenario
:Results from Mixed year scenario
:Results from Average year scenario

2010 : Performance in 2001-2010
2010'' : Pre-renovated performance in 2001-2010
2085 : Performance in 2085WH
2085'' : Renovation performance in 2085WH

The energy consumption chapter includes the building operation energy consumption, heating demand, and cooling demand. The priority of energy consumption usage is dependent on the external environment.

The baseline design has a very wide range of energy consumption which may be caused by the low thermal resistance of the envelope components. For the options applied with the mixed year model and average year model, the energy consumption has a chance to reach the lowest in both climate conditions amount all options. The renovation approaches give a possibility to reduce energy consumption. Judging the total energy consumption, the future scenario and average year scenario have a lower amount of demand on the higher floors, and the mixed year scenario and average year scenario have lower demand on the lower floors.

The decreasing trend for heating demand in both heights of the floors is the same, and the cooling demand is the opposite. To reduce the total energy usage, the target is to try to reduce heating as much as possible and limit the increasing usage in cooling. For the higher floor condition, the scenarios based on 2085WH and the average year model can have lower heating demand in 2085.

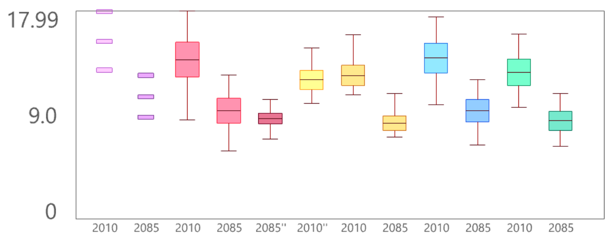


Figure 128. Heating demand_higher floors

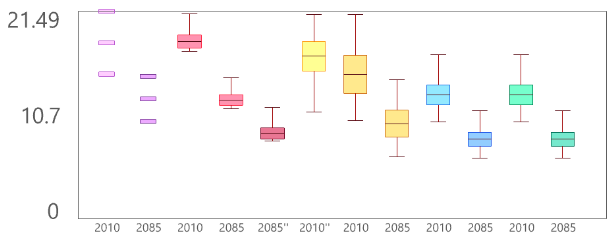


Figure 129. Heating demand_lower floors

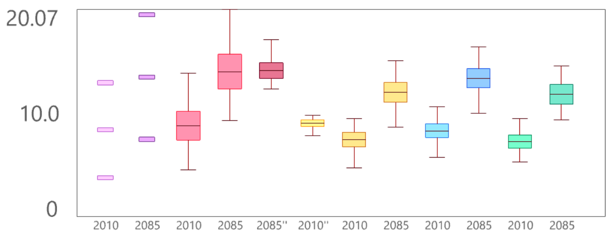


Figure 130. Cooling demand_higher floors

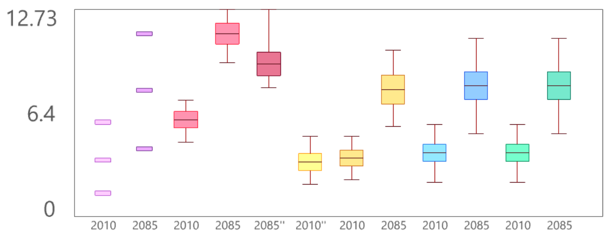


Figure 131. Cooling demand_lower floors

9.2 Comfort condition

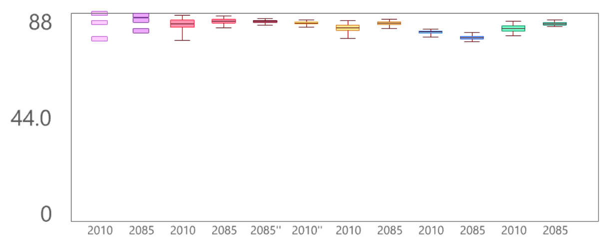


Figure 132. Thermal comfort_higher floors

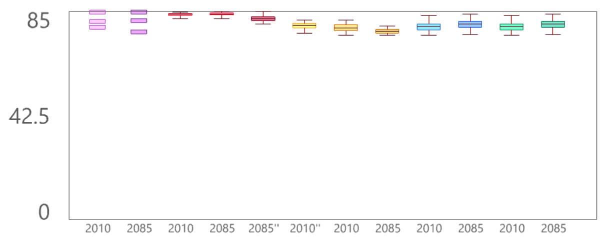


Figure 133. Thermal comfort_lower floors

:Results from Baseline scenario
:Results from Current based scenario
:Results from Future based scenario
:Results from Mixed year scenario
:Results from Average year scenario

2010 : Performance in 2001-2010
2010'' : Pre-renovated performance in 2001-2010
2085 : Performance in 2085WH
2085'' : Renovation performance in 2085WH

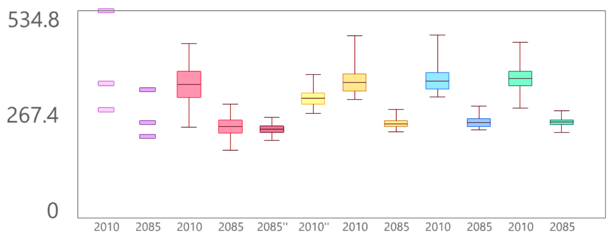


Figure 136. Cool hours_higher floors

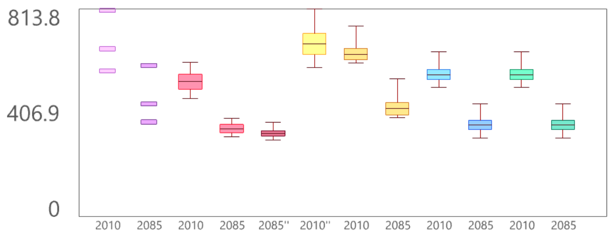


Figure 137. Cool hours_lower floors

The thermal comfort percentage of the occupied period is one of the objectives in the MOO, and the results of the optimization are mostly beyond 80%. In some cases, it can reach 85%. To improve the thermal comfort, the hours of cool and warm periods need to be reduced. In the figures above, although the floor height influenced the performance, the trends caused by climate change are the same.

To reduce the cool hours in the current condition, the current based scenario offers the best results. The average year scenario and future based scenario give the lowest warm hours in the year 2085. However, the result of cool hours from the future scenario is the highest in 2010 and the mixed year scenario has the longest warm period in the year 2085.

The overheating hours on the higher floor is a common problem in all scenarios. In Figure 134 and Figure 135, the difficulty of fixing the current based optimization result is harder than other options. When overheating becomes the main issue for the interior space, future based performance design can find the lower hours. But on average results, the mixed scenario and average scenario are comparable to the future one.

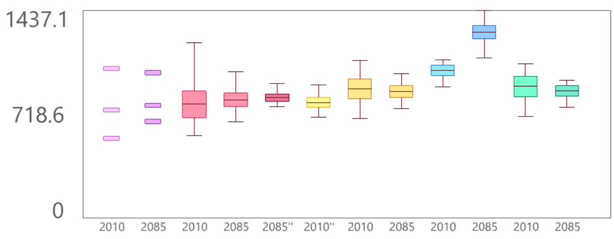


Figure 138. Warm hours_higher floors

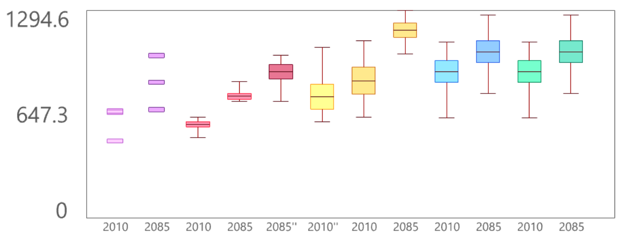


Figure 139. Warm hours_lower floors

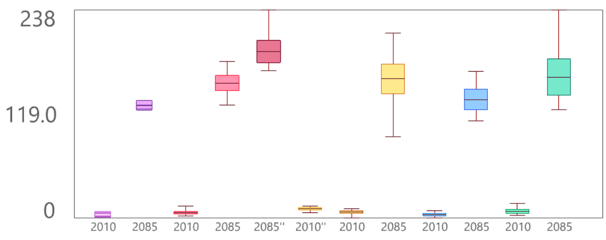


Figure 134. Overheating hours_higher floors

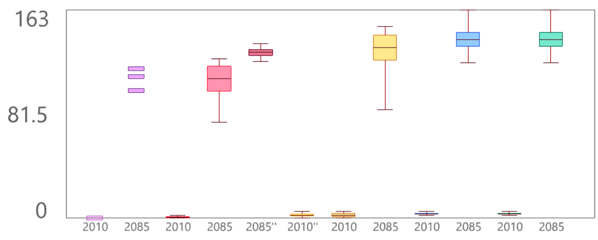


Figure 135. Overheating hours_lower floors

9.3 Daylight performance

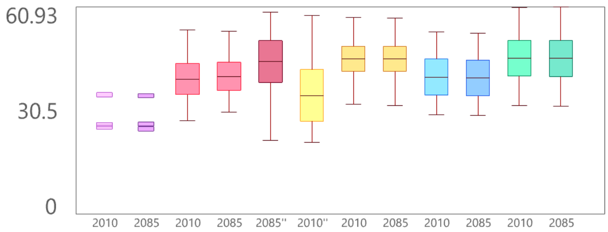


Figure 140. Daylight performance_higher floors

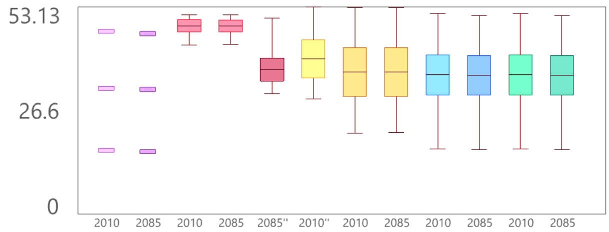


Figure 141. Daylight performance_lower floors

:Results from Baseline scenario
:Results from Current based scenario
:Results from Future based scenario
:Results from Mixed year scenario
:Results from Average year scenario

2010 : Performance in 2001-2010
2010'' : Pre-renovated performance in 2001-2010
2085 : Performance in 2085WH
2085'' : Renovation performance in 2085WH

In Figure 140 and Figure 141, the influence of context on the daylight performance is distinct. The results of the optimization are mostly below the requirement, 50% of the conditioned area, which could be caused by the quality of the shading system set in the simulation models. With this shading system, the average year scenario has the best performance on higher floors. In the lower floor conditions, the mixed year model and average year model have similar outcomes. Combining the higher floors and lower floors results, the future based scenario can give satisfying results.

9.4 Ratio of renewable energy usage

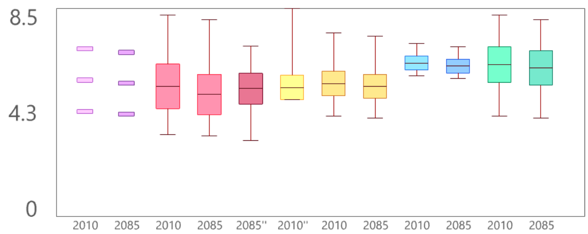


Figure 142. Energy produciton_higher floors

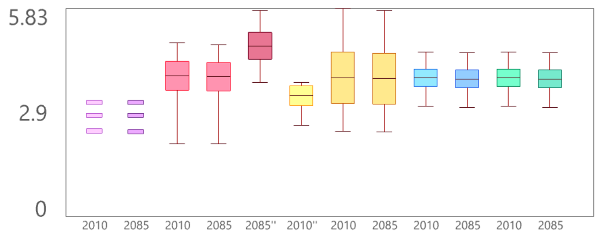


Figure 143. Energy produciton_lower floors

Figure 144. Percentage of renewable energy usage_ higher floors

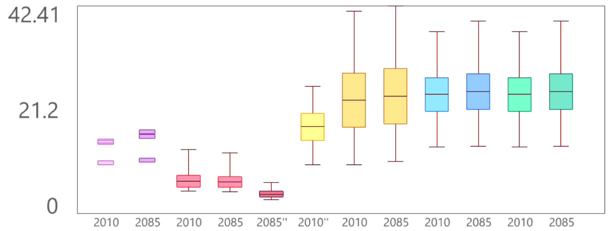


Figure 145. Percentage of renewable energy usage_ lower floors

The ratio of renewable energy usage is related to the building operation energy, the energy production which is determined by the wall area and orientation. The energy produced by the PV panels can increase the ratio but if the energy consumption is too high then the result would be lower than expected, as the renovation option in the current scenario. The percentage of renewable usage in baseline design on the higher floors is very comparable to some of the selected results. But the percentages in baseline and current based models are the lowest groups in the lower floor sets.

The efficiency of energy production on the higher floors is higher. Applying suitable methods, the coverage of energy consumption can be more than 27%. Judging from Figure 144, the majority of the results in mixed year scenarios have a higher percentage of renewable energy consumption. The cover range is from 21.0% to 44% on higher floors in both climate conditions. Furthermore, the building geometries in the mixed year result are mostly facing the south, 13 out of 15 options.

10 Conclusions, Limitations, and Further Research

10.1 Conclusion

The aim of this study is to define the influence that came along with climate change and how should the building design reflect this issue. Under this consideration, the design environment is no longer constant, and the performance evaluation and optimization need to be processed under multiple conditions before the conclusion is drawn. A workflow is designed to support designers and engineers to understand what would cause indoor discomfort or extra energy consumption in both the current and the near future in the living environment. The optimization shows that the optimization result, the building performance, is highly related to the selected climate condition. To make our living environment suitable for now and future-proof, the building performance analysis should not only be based on the current climate condition. The research question formed for this topic is: How to determine what design characteristics have the main influence on building operation energy and indoor comfort under both currents and predicted future climate conditions by using computational simulation?

This research built up two workflows in the Grasshopper environment to produce weather files and analyze the building performance with current and predicted future climate conditions and find the preferable options with MOO. The first workflow shows how to generate EPW files with climate information from KNMI, current conditions, and KNMI'14, future conditions. The workflow can calculate all the required information from the KNMI format and compose it into CSV file format. The only step that needs to do outside of the Grasshopper script is converting the CSV file to an EPW file with EnergyPlus.

The second part of the workflow is the MOO building performance in different climate conditions, only for the early design phase. Considering the major impact of climate change on the living environment, the objectives are building operation energy, thermal comfort, daylight performance, and the percentage of renewable energy usage. To find the suitable design approach, the design decisions are set as input variables for the optimization and the variables are building length, building orientation, WWR of each facade, and envelope properties. The optimizations are done in multiple climate scenarios and with and without the impact of surrounding buildings. The results from MOO show the relationship between the selected climate environments and the performance of building design.

10.1.1 Climate change and influence

Climate change is an issue we are currently facing and, according to the predictions, this will have increasingly severe consequences in the coming decades. GHGs trap the heat from the sun near the surface of the earth and make the air warmer. The information from KNMI and the prediction of future climate conditions in 2085 from KNMI'14 is used in the first workflow to generate the simulation climate files. From the climate data set generated, in the 2085WH scenario, the annual hourly percentage of outdoor temperature more than 24 degrees will rise from 2% to 9%, an additional 613 hours, in the Netherlands. And the period that the temperature is below 20 degrees drops by 13% which is equal to 1138 hours. On the other hand, the variation in solar radiation between current and the prediction of the future environment is minor. Meanwhile, solar illuminance has a similar trend.

The research on climate change is highly region-dependent, in this research, the predicted future climate condition can be only applied to the Netherlands. To simulate the building performance in the other cities in the Netherlands, the target climate information from KNMI'14 needs to be processed with the Grasshopper scripts created by the author to produce the CSV file first. Then the CSV file needs to be processed to EnergyPlus Weather Statistics Conversion to generate the EPW file. For The projects in other countries, the CCWorldWeatherGen would be an easier option to convert the current climate condition to a future one.

The climate condition has a major impact on the design decisions during the design of the building, and it also influences the living environments. The climate condition used as the study environment would determine whether the building requires more capability in preserving heat or cold. The climate condition refers to two main aspects of the building performance: indoor comfort, and energy consumption. To study the performance of design buildings, four design scenarios based on different climate conditions are generated, current based, future based, the mixed year, and the average year. The results of the optimization of these scenarios are compared to the baseline option.

The baseline building design, in which the building envelope properties match the Dutch regulations, can provide a comfortable environment for more the 75% of the time it is occupied. Under the climate change environment, the total comfort hours stay relatively stable, with a shift of around 2%. However, depending on the climate condition used, the number of warm hours in the later period of the building lifespan can rise by 20%, 100 hours.

The overheating hours, for temperatures over 28 ℃, is the main problem our living environment encounters in the warmer environment that is caused by climate change. For the simulation building, the overheating hours in the current condition are mostly below 10 hours in a year. But in the year 2085, even for well-performing options in the current condition, the number of warm hours can easily exceed 150. However, the optimization with the objective of total comfort hours does not naturally lead to lower overheating hours. Reducing the overheating period would require an extra selection in the iterations.

Under both climate conditions, the current and the future, the building operational energy consumption in the selected options has around a 5% difference, 16% for extreme cases. Although the total energy consumption is almost constant, the variations in heating demand and cooling demand are significant. The heating demand in the case study has a maximum of 35% of decrease and a maximum of 105% of additional cooling demand according to the 2085WH weather file compared to the current weather file.

10.1.2 Climate responsive design

The building geometry and the orientation are major determinants of indoor comfort and energy consumption. The heat gain and heat loss on the building surfaces depends on the area and the receiving angle between the surface and heat source. The preferable building layout is related to both climate conditions and the context. In the higher floor condition, the well-performing building layouts mostly have narrower southern and northern façades and wilder on the east and west. However, the results from the lower floor are reversed, and it is due to the specific local context, would not be suitable to apply to the other locations.

To compensate for discomfort and energy consumption caused by the changing weather conditions, the renovation approaches, current based scenario, and future based scenario, are helpful. The thermal resistance of the wall in the current climate tends to be higher, 6 m2K/W, as it is beneficial to a high heating demand condition. Under climate change weather, the cooling demand increases, and the selected Rc-value for the wall components are 5.0 m2K/W. The suitable window to wall ratio on the facades can improve the performance as well.

The shifting of energy demand requires attention to the building design and suitable heating and cooling equipment. The result of the energy demand in this paper is using an Ideal air model, but, in a real project, the flexibility of space and energy supply for the HVAC system and related equipment should be involved in the design.

10.2 Limitations

Due to the time constraint and the scale of master thesis research, this study of building performance in future climate environments has some uncertainties and limitations in the workflow and result. There are three main parts of the limitations are mentioned below.

First of all, the uncertainty is caused by the variation of climate change possibilities. In this research, only the warmest climate scenario, WH, is taken in the simulation. The result does not reflect the necessary condition and performance of the building environment in the future. But a reference for designers and engineers to have a broader perspective in the analysis and design phase and then integrate the suitable approaches in the design strategy to make the living environment future-proof. Furthermore, the influence of climate change is not only the temperature and radiation. For further research on the impact of climate change on our living environment, the precipitation, wind conditions, and air quality are needed to be considered as well. However, due to the limitation of time and scale of the master thesis, these parts of research and corresponding design are simplified and removed.

Secondly, because of the performance analysis done with the project in the early design phase, there are some design approaches and factors that are simplified. For example, introducing more efficient exterior sunblind systems could improve the performance with lower cooling demand, better thermal comfort, and higher daylight performance. The research on optimizing the indoor comfort and operational energy consumption with a suitable sunblind system has been done in other research papers with current climate conditions in variant locations. Still, these results are not suitable to use and draw a conclusion of what strategy would be suitable for future conditions. To find out to what extent the sunblind system and other design factors, like glazing types, have an impact on the building performance throughout the lifespan, additional research and simulation are required.

Thirdly, the accuracy of the values of energy consumption and indoor comfort may not be highly accurate. The energy consumption does not represent the actual consumption of the object building after construction. In the research, the energy usage of the building is a simulation result of the balance energy generated from Honeybee. In the early design phase, the installation system and electric equipment are not determined. Consequently, the energy usage of heating, cooling, lighting, and other electricity usages cannot be defined in detail. Based on existing research and regulations, the estimation and the average energy usage and efficiency of installations are applied in this research. The condition influences the accuracy of the performance of indoor comfort, especially for thermal comfort. In the simulation, the HVAC system of IdealAirSystem is applied in which the capacity, efficiency, and economizer are not defined. Although the final value of the simulation might not be authentic, they are still truth worthy for predicting and comparison of the building performance.

10.3 Further research

The research on building performance in building lifespan shows some intriguing aspects in both design approaches and the analysis part. To prepare our habitations for the future climate situation, there are more features that need to be discovered under this research direction.

To have a further understanding of the climate change impact on our living environment, research of performance on a finer-designed project, with an interior layout and shading system, for example, would be beneficial. In this way, the indoor comfort can be studied in finer meshes and it is possible to compare the results room by room or even in square meters. The influence of climate change on indoor comfort and energy consumption can be studied in detail and figured out the practical solutions. This proposal would be suitable for projects that require renovation to adapt to future weather environments.

Parallel research of analysis on different building types can be an extent of this paper. The building type determines the facade properties, occupied period, comfort demand, energy usage, and related regulation. Since the area of glazing façade is larger in most cases of office buildings, it is possible to have distinct results from the residential projects. If the research is based on the same location and same geometry setting, the comparison of building performance with various functions under the climate change influence could be an inspiring research topic.

The other direction that can be taken is the development of a lifespan assessment tool for building performance. In this research, there are three design scenarios, current, average, and 2085WH, used to evaluate the correlation between design and performance. As the result of chapter 9, these three scenarios lead to better performance in different periods and the designer can decide which period of the building lifespan would be more important or if the project needs to have a big renovation in the future. The workflow presents the building

the building performance analysis is done. In this phase, the complexity of design is lower which means the main focus of building design is the massing, WWR, and orientation. But for building performance, there are certain approaches that would have a great influence on the design strategy if they are determined earlier.

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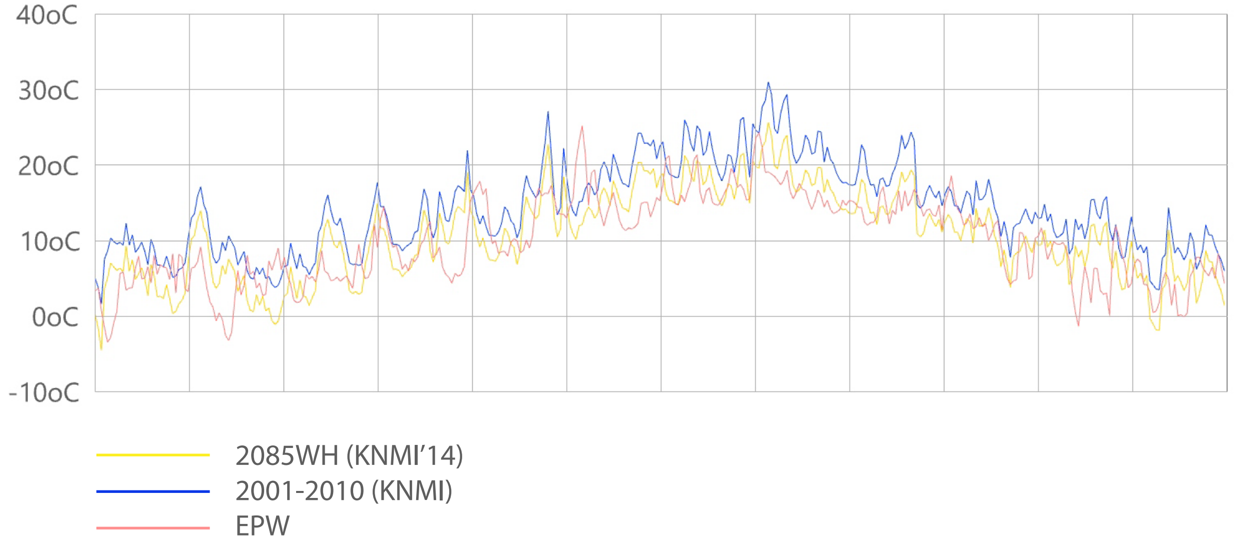
Appendix

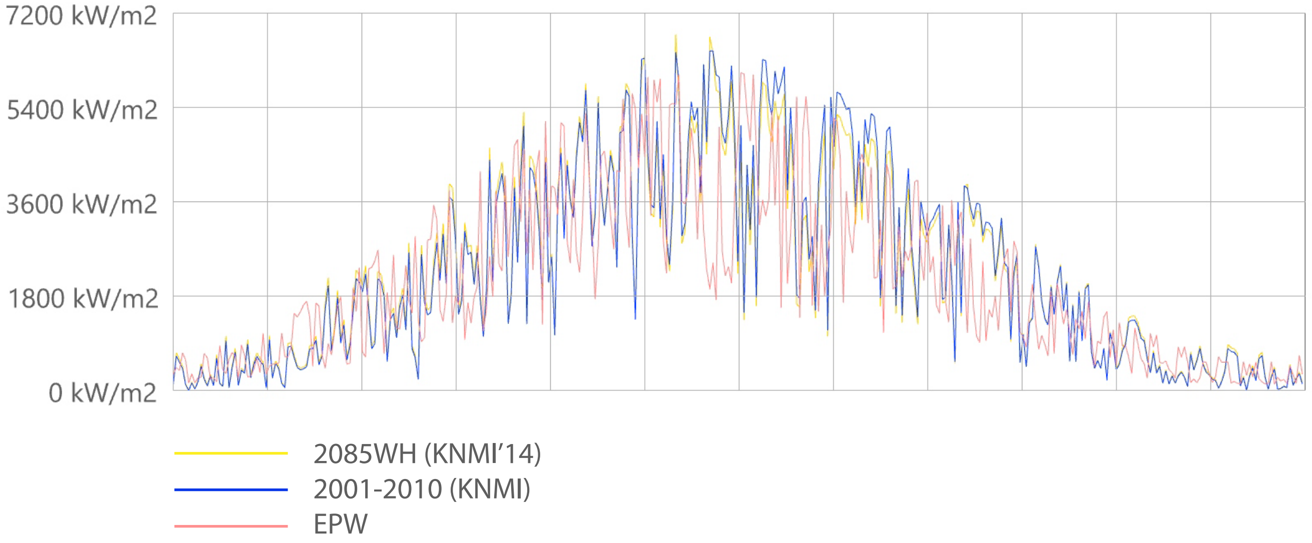
Appendix 01_Generated Climate Results

The results of the generated climate files used in the simulation are put into graphics and shown below. Firstly, the comparisons in dry bulb temperature and the horizontal global radiation present the difference between the current climate condition with the EPW file and the information from KNMI from 2001 to 2010 and the prediction of future climate conditions, the 2085WH from KNMI'14. The average difference between 2085WH and 2001-2010 KNMI is 3.67 °C and the difference between 2085WH with EPW is 4.29 °C .

Comparison of dry bulb temperature in different climate conditions



Comparison of gloabal horizontal radiation in different climate conditions



To understand the detail of the climate files applied to each scenario the climate information is processed with Climate Consultant 6.0 to generate the graphics. The climate conditions show under are current, 2085WH, 2085WH extreme, mixed year model and average year model. The Temperature timetable plot describes the hourly temperature in the whole model year and gives the percentage of hours within the temperature range. The graphic of monthly diurnal average gives a hourly average based information for temperature and radiation in each month.

Current climate condition

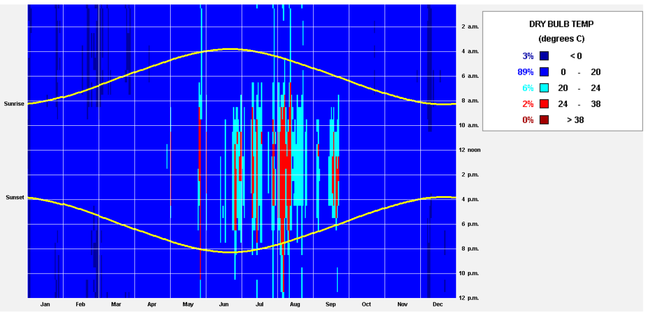


Figure 146. Temperature timetable plot_2001-2010

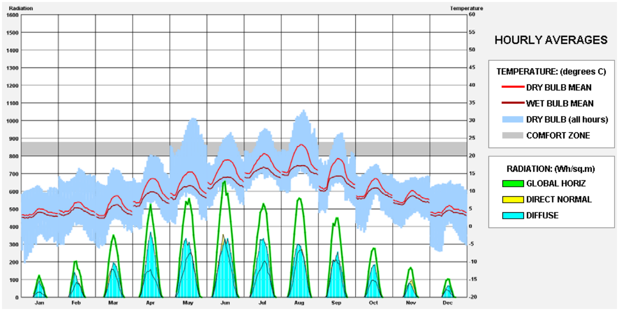


Figure 147. Monthly diuranl average_2001-2010

2085WH climate condition

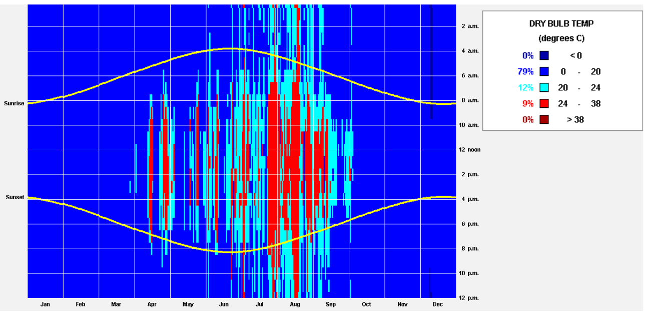


Figure 148. Temperature timetable plot_2085WH

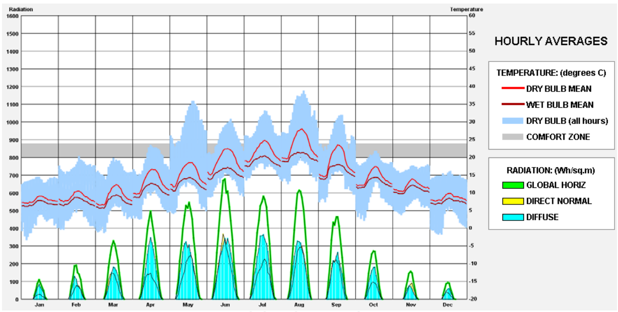


Figure 149. Monthly diuranl average_2085WH

2085WH extreme climate condition

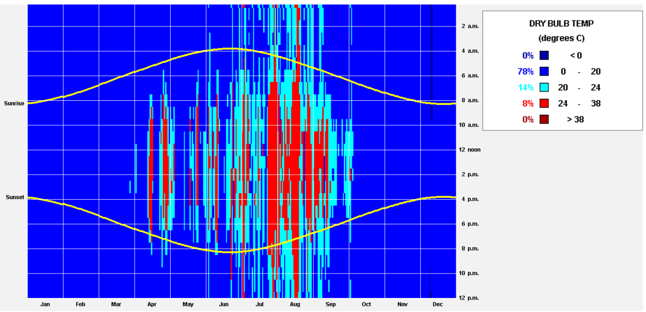


Figure 150. Temperature timetable plot_2085WH extreme

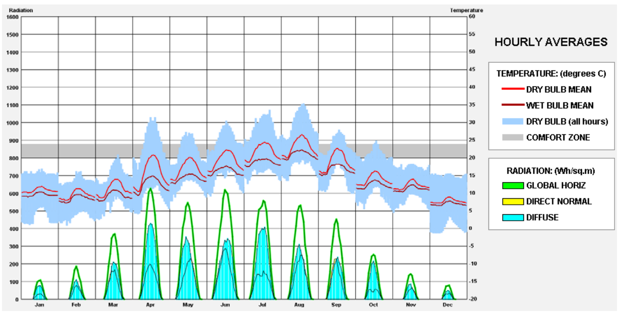


Figure 151. Monthly diuranl average_2085WH extreme

Mixed year model climate condition

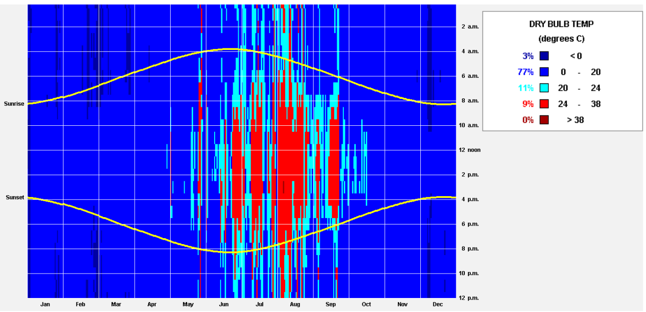


Figure 152. Temperature timetable plot_Mixed model

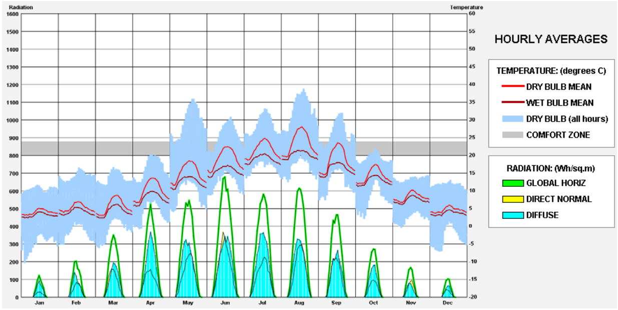


Figure 154. Monthly diuranl average_Mixed model

Average year model climate condition

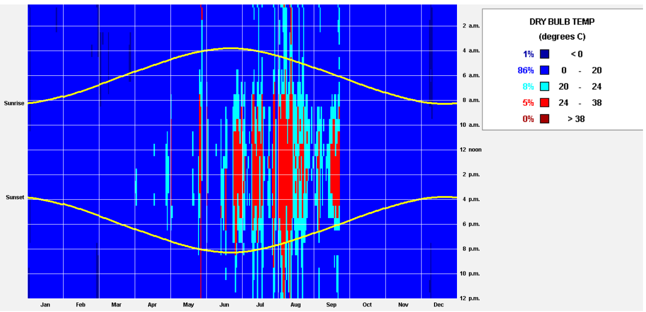


Figure 153. Temperature timetable plot_Average model

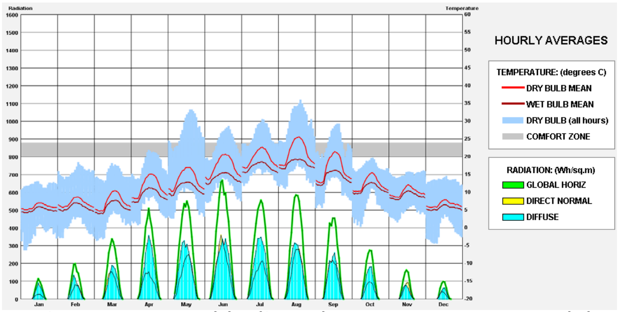
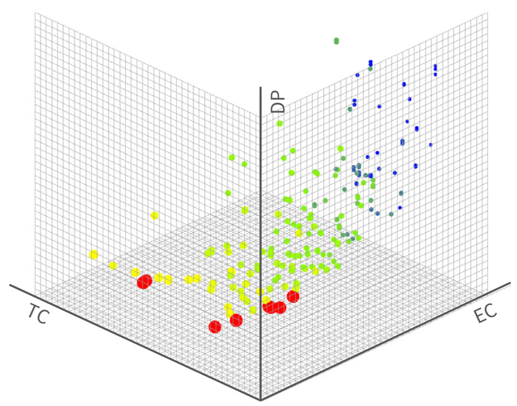


Figure 155. Monthly diuranl average_Average model

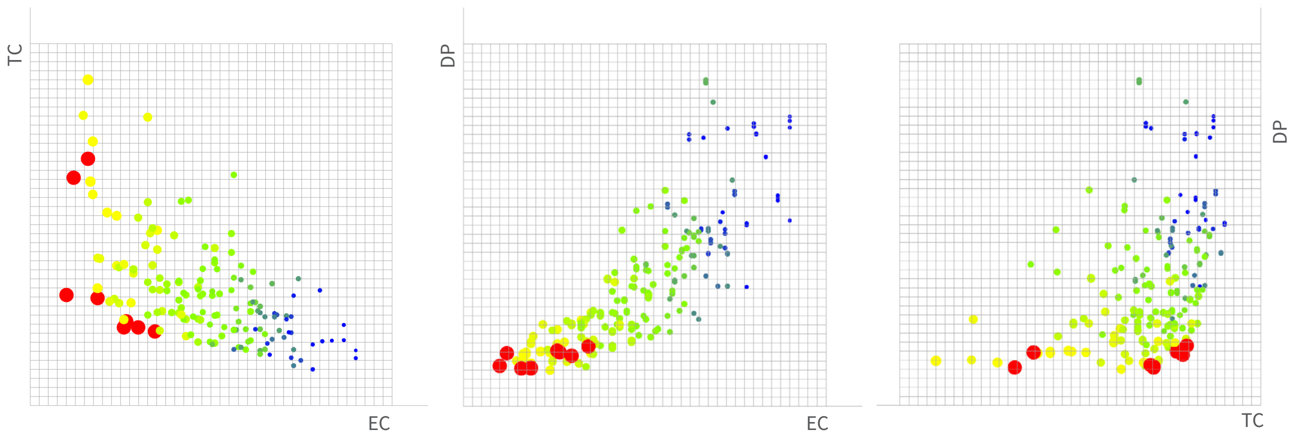
Appendix 02_Optimization results

The figures in this chapter present the results from the MOO process in this thesis to determine the preferable options in a specific climate condition. The results follow the sequence of the four scenarios, current based, future based, mixed year, and average year. In all the optimization processes, the objectives are the same as mentioned in the previous chapters, energy consumption, thermal comfort, daylight performance, and percentage of renewable usage. These objectives correspond to the x-axis, y-axis, z-axis and color of the points in the figures. The selected options are highlight as red or with yellow bubble.

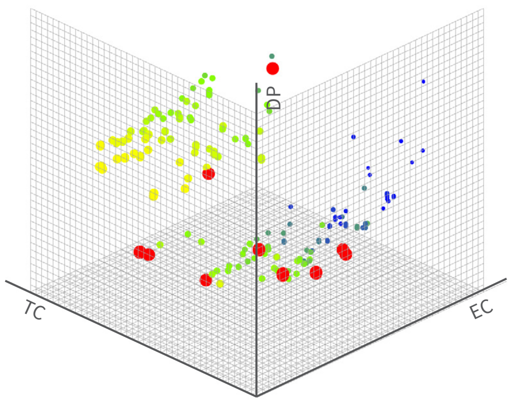


Scenario: Current based
Weather: 2001-2010
Floor: Lower floor
Phase: Original

EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

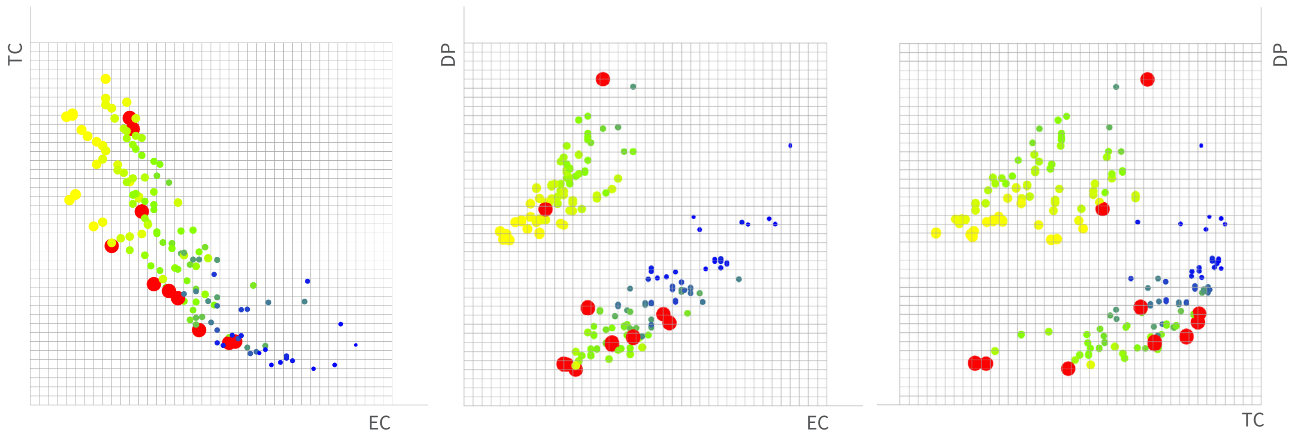


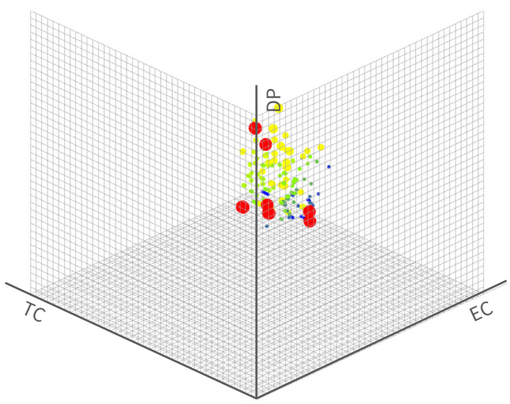
In the current based scenario, there are 8 results selected from the Pareto front out of 50 populations with 10 generations. The performance of these results is presented underneath. For the discussion about the performance in detail is in the chapter 「8.3 The current based scenario」.



Scenario: Current based
Weather: 2085WH
Floor: Higher floor
Phase: Renovation

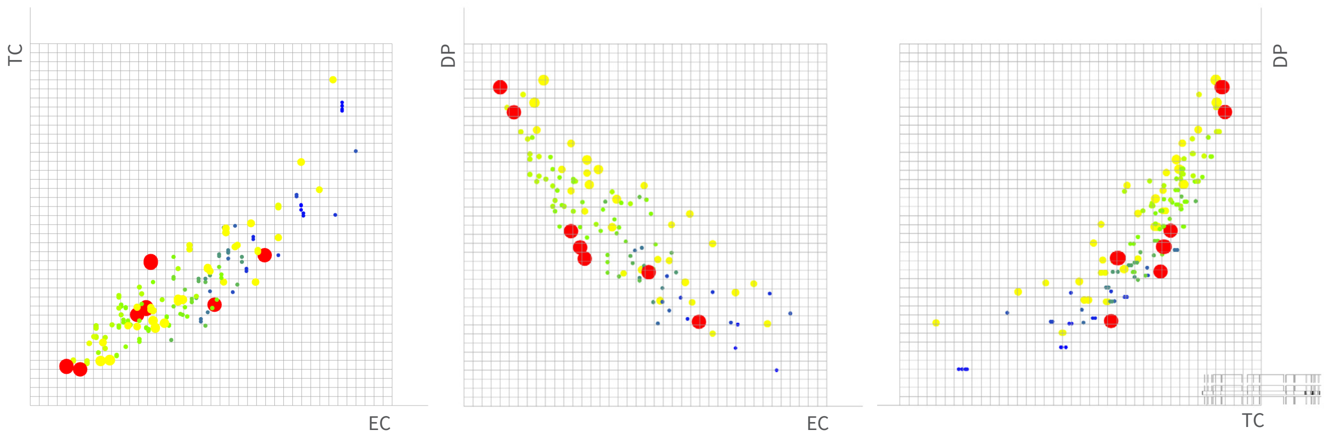
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

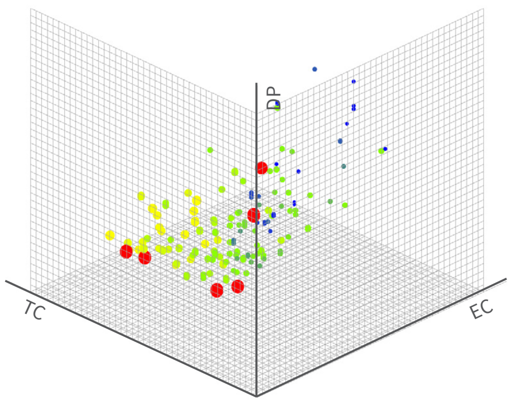




Scenario: Current based
Weather: 2085WH
Floor: Higher floor
Phase: Renovation

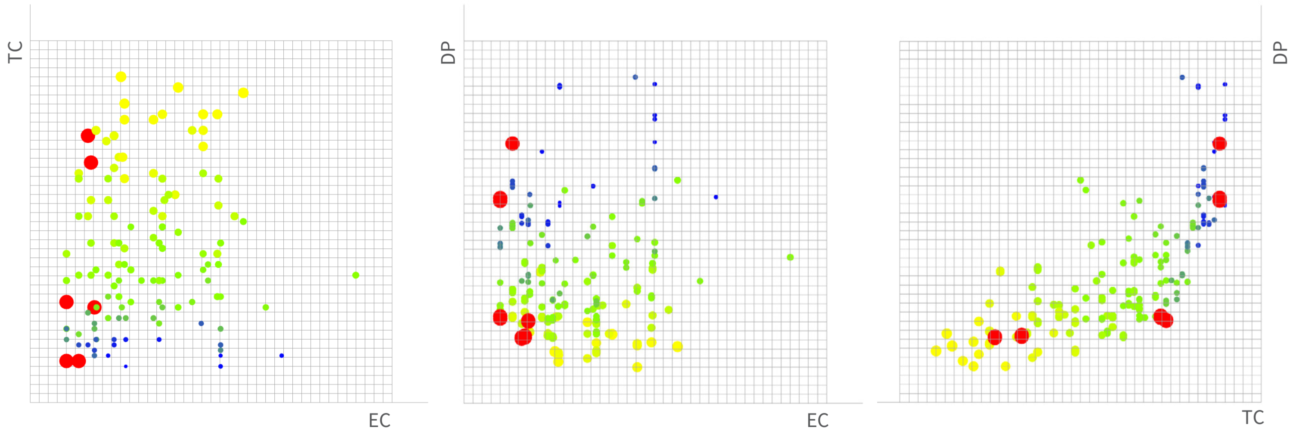
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

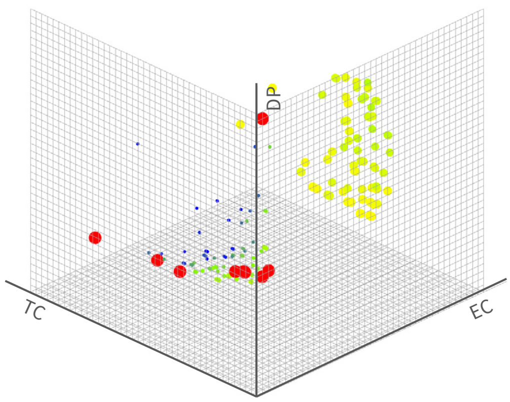




Scenario: Future based
Weather: 2085WH
Floor: Lower floor
Phase: Renovated

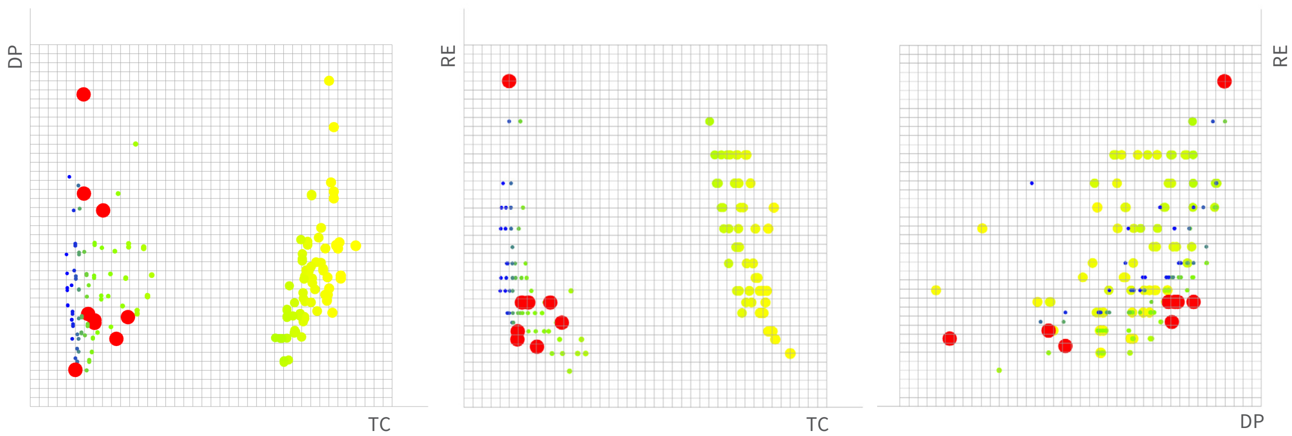
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

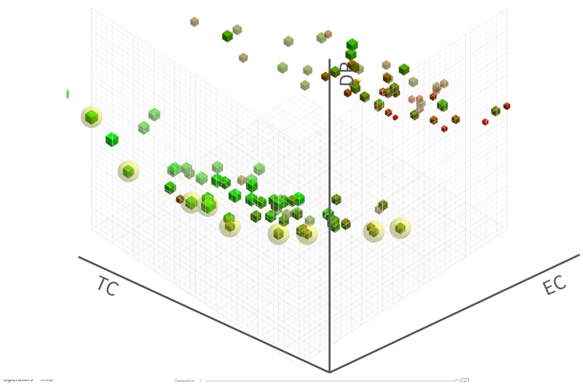




Scenario: Future based
Weather: 2001-2010
Floor: Lower floor
Phase: Before renovation

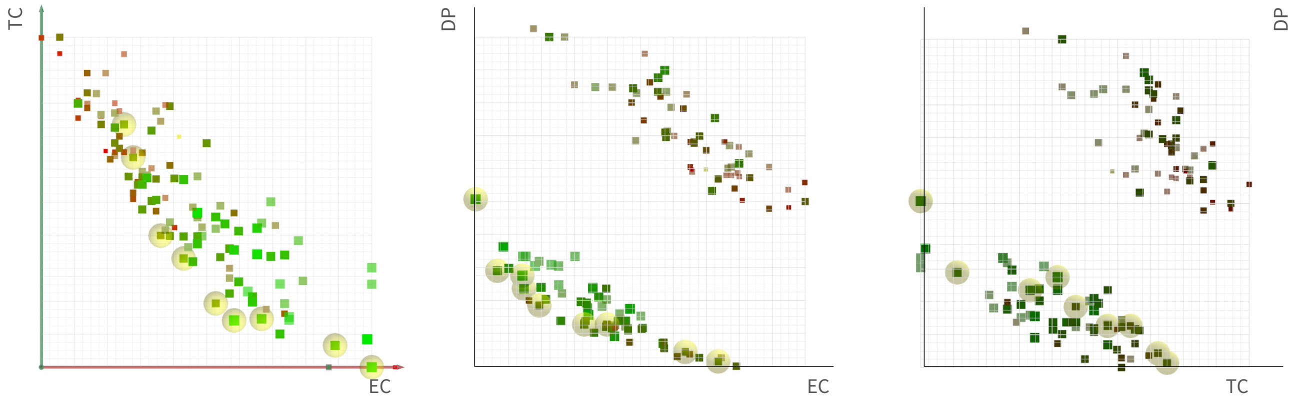
TC : Thermal comfort (%)
DP : Daylight performance (point)
RE : Percentage of renewable energy usage (%)
: Selected options

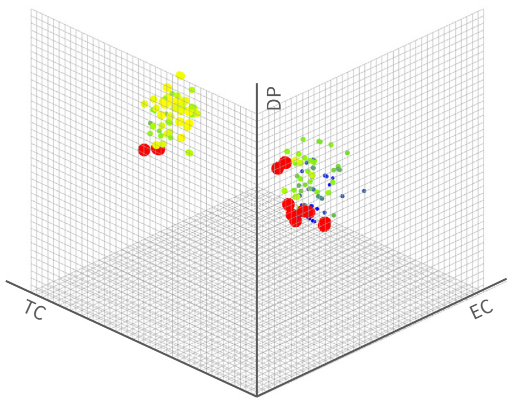




Scenario: Future based
Weather: 2085WH
Floor: Higher floor
Phase: Renovated

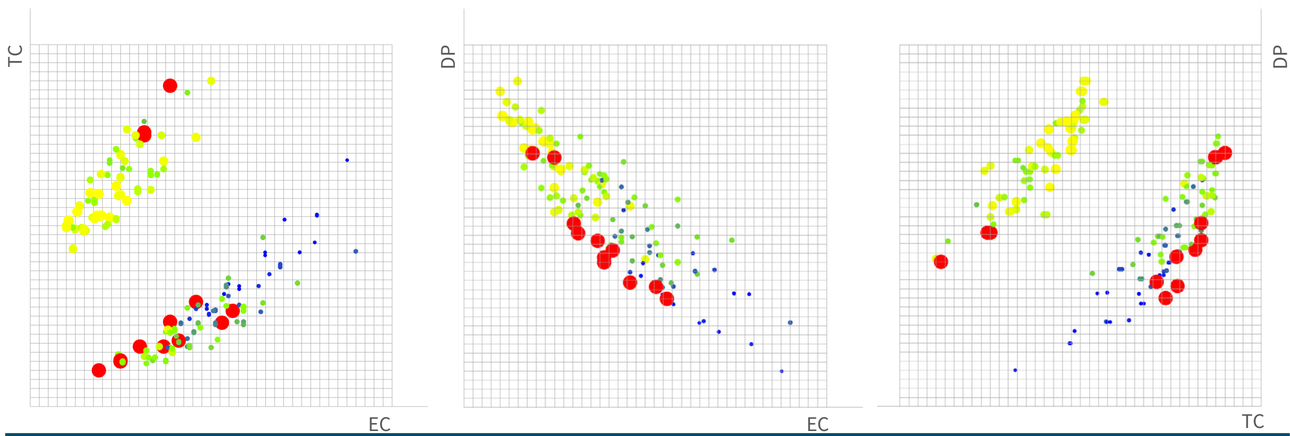
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

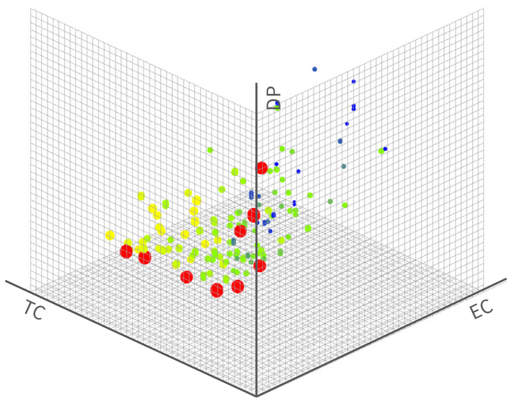




Scenario: Future based
Weather: 2001-2010
Floor: Higher floor
Phase: Before renovation

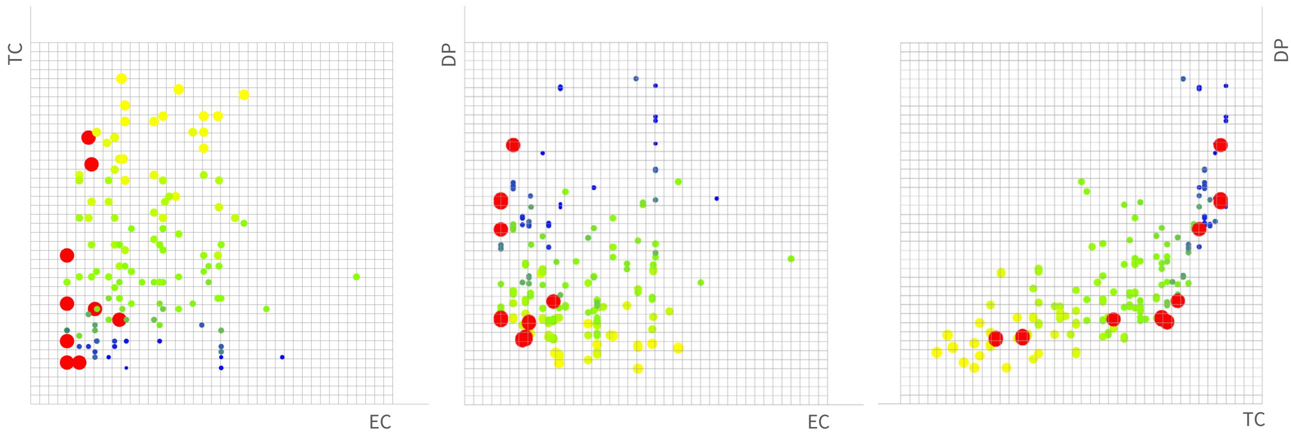
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

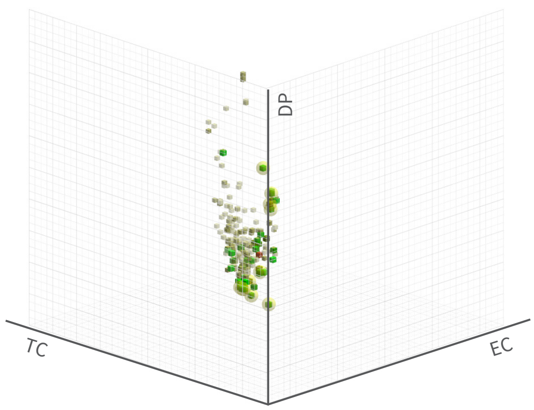




Scenario: Mixed year
Weather: Mixed year model
Floor: Higher floor

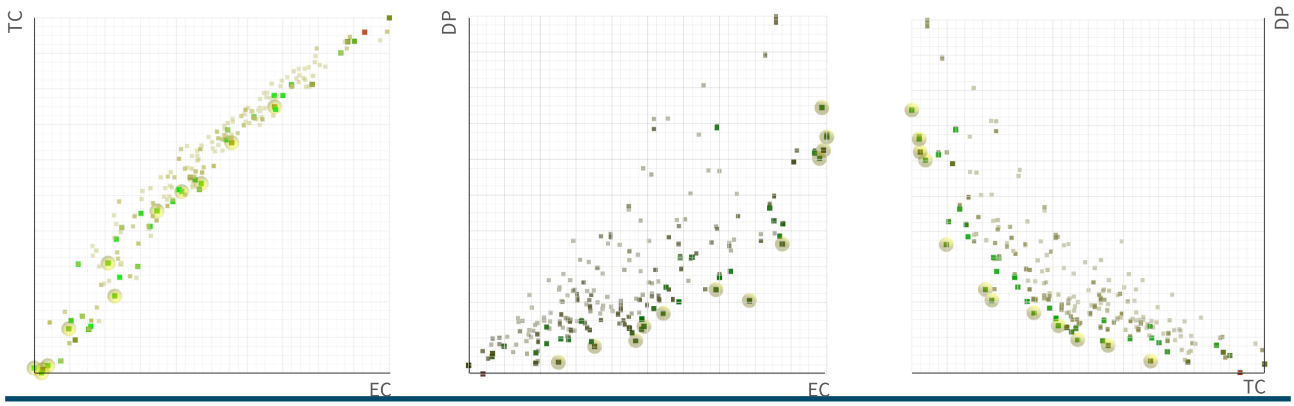
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

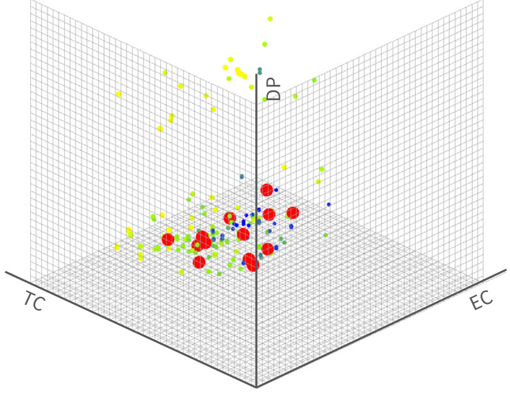




Scenario: Mixed year
Weather: Mixed year model
Floor: Lower floor

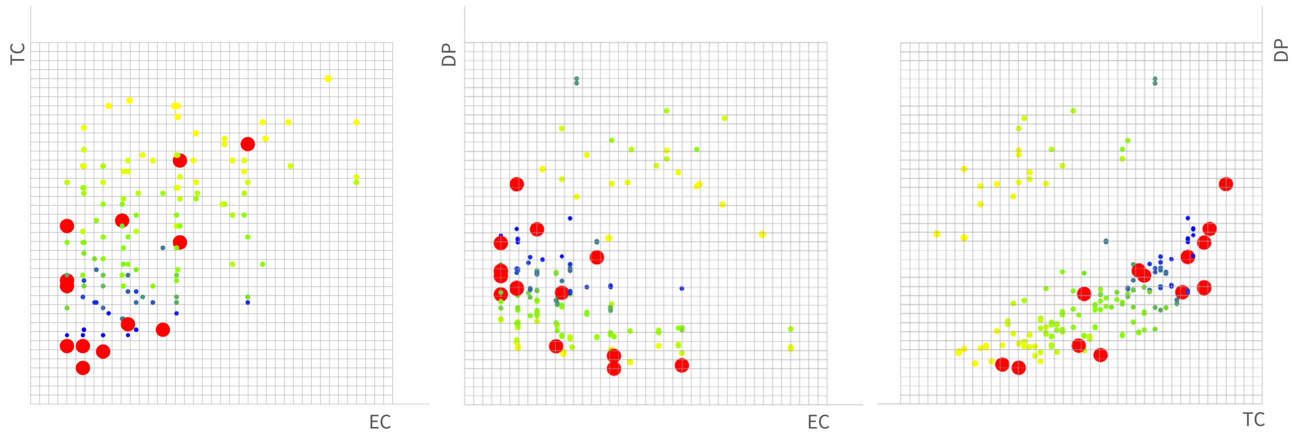
EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options

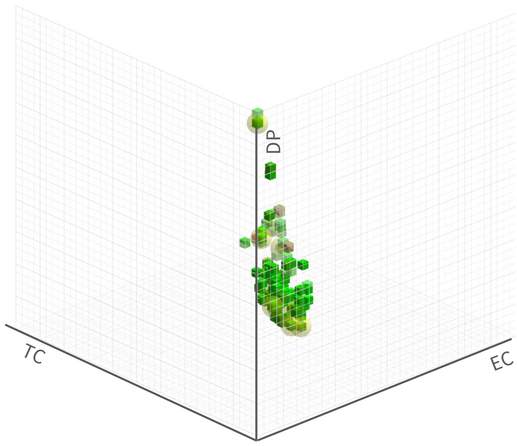




Scenario: Average year
Weather: Average year model
Floor: Higher floor

EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options





Scenario: Average year
Weather: Average year model
Floor: Higher floor

EC : Energy consumption (kWh/m2/year)
TC : Thermal comfort (%)
DP : Daylight performance (point)
: Percentage of renewable energy usage (%)
: Selected options