ADAPTATION OF THE BUILT ENVIRONMENT TO CHANGING URBAN MICROCLIMATES

A residential high-rise case study

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Abstract

Temperatures are increasing all around the world due to climate change and are predicted to continue to rise in the future. This rise in temperature is worrying especially for urban areas around the world that already suffer from increased temperature due to the urban heat island effect. In order to adapt to these changes buildings often get outfitted with mechanical cooling, solving the temperature problems indoors but making the outdoor temperature rise even more and thereby creating a vicious cycle of increased demand for cooling and increased mechanical cooling.

This research aims to search for a way to ensure indoor thermal comfort in a passive way without worsening the UHI-effect. This is done by creating an alternative design for a case study that is planned in a Dutch urban center and measuring its impact on the urban microclimate and its indoor thermal comfort performance in a future climate scenario. The alternative design is put together by designing and testing different compositions of passive measures found in the existing literature. These passive measures compositions are then analyzed by software simulation to assess their performance and the effect they may have on the urban microclimate and in turn what this changed urban microclimate means for the implementation of the passive measures.

The final result is a building design that not only ensures indoor thermal comfort in current and future climate scenarios but also makes its surroundings more comfortable which in turn results into more manageable microclimate. Turning the vicious mechanical cooling circle into a passively cooled virtuous circle.

Keywords

Urban heat island effect, Passive Cooling, Facade, Future climate scenario, Thermal comfort

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1. introduction – Context & background knowledge

The warming of our climate system is unequivocal according to the IPCC (Intergovernmental Panel on Climate Change) and many of the observed changes to our climate are unprecedented, the oceans and atmosphere have warmed and sea levels have risen (Pachauri, Allen et al. 2014). The influence of humans on our climate system is clear, and greenhouse gas emissions from anthropogenic sources have never been higher in history. One of the changes in our climate system is the increased average temperature which has been steadily rising. it is projected that this increase in temperature to keep on rising with the best scenario being an increase of 2 ^{o}C above pre industrial temperatures. In addition extreme weather events such as heatwaves will occur more often and will last longer.

The Netherlands will face similar climate change scenarios as the rest of the world which means a higher average temperature and more frequent extreme weather occurrences such as heatwaves and extreme precipitation events. This concludes the Royal Dutch Meteorological Institute in their research towards future climate scenarios (Tank, Beersma et al. 2014)The research is based on data from the Intergovernmental Panel on Climate Change (IPCC 2014) that compares global climate data from the past and present and outlines possible future climate change scenarios.

The Netherlands has had its fair share of these heatwaves in the past, however they are becoming more frequent: 4 of the total 28 heatwaves in the history of the Netherlands occurred in the past two years. (KNMI 2019). The definition of these heatwaves is a period of 5 or more consecutive days where the temperature measured 25 ^{o}C or higher including at least three days where the temperature measured at least 30 ^{o}C. However these measurements are all made from a weather station in De Bilt which is centrally located in The Netherlands but is not necessarily representative for the entirety of the Netherlands. Temperature measurements in Dutch urban areas can be up to 5-6 ^{o}C higher during hot periods then temperatures measured in de Bilt. (Wolters, Bessembinder et al. 2011). This link between urban areas and increased temperatures is due to the urban heat island effect.

The phenomenon where urban areas experience much more extreme temperatures then its surrounding areas is called the Urban heat island effect (UHI). The UHI is caused by a variety of different aspects but one of the main ones are the material properties of the materials that are used in urban areas. These materials absorb higher levels of solar radiation in comparison to the soil and vegetation in more rural parts of the country. At night when the temperature lowers, the surfaces in urban areas radiate their heat accumulated during the day back to the air, which is a lot less effective in urban areas due to the proximity to other warm surfaces radiating heat and interfering with each other compared to more rural situations. Added to this is the fact that in urban areas sunlight is during the day often blocked from reflecting back into the sky by facades of other buildings heating them up even more. This is expressed in the Sky View Factor (SVF) Other causes for the UHI effect include: lack of vegetation that provide shade and cooling due to evapotranspiration, lack of surface water, building proximity blocking the cooling effect of the wind and extra emitted heat due to heating/cooling systems, transport and industrial activities that are distinctive for an urban area (Oke 1982, Kleerekoper 2017).

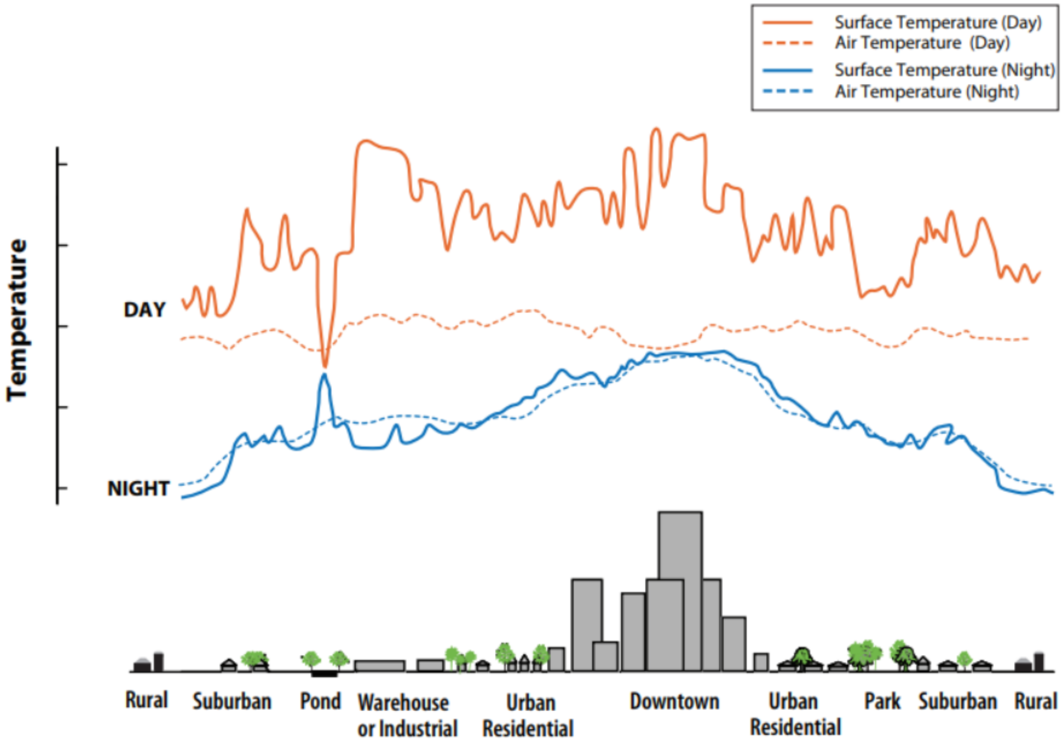


Figure 1: Effect of the urban heat island effect on temperatures in and around an urban center (EPA, 2008)

The UHI effect has a direct impact on an entire urban area, in order to differentiate the different affected parts of an urban area a distinction is made between different urban scales the UHI effect impacts. These are described by Van Hove, Steeneveld et al. (2011), the first is called the *Microscale or street canyon scale*, this is the level of a urban microclimate which is impacted by elements like roads, trees, streets water elements and building dimensions. The second is called *Local scale or neighborhood scale,* this scale groups the different microclimates together into bigger neighborhoods with similar types of urban development. The largest and third group is called *Mesoscale or city scale*, this scale embodies the entire urban area with its surroundings. This scale distinction is also made in the UHI effect itself described by Oke (1976, 1982), which can be divided in two different levels (See figure 2):

-**Urban Boundary layer (UBL)** begins at the rooftop/treetop level and stops at the altitude where the urban area no longer has an impact on the atmosphere this is usually reached at a maximum level of 1.5km. This layer is quite homogenous and connects with the urban surroundings.

-Urban canopy layer (UCL) starts from the surface level and stops at the rooftop/treetop level and is influenced by the site character (mostly building shape and surface materialization) this is the level where most people live in urban areas and temperatures can differ notably within a short distance due to shade, vegetation or building geometry

Changes to the UCL can have a direct effect on the UBL and therefore influence the rest of the city, this means changes in one neighborhood of a city can have a direct effect on the urban microclimate of another neighborhood (Kleerekoper 2017).

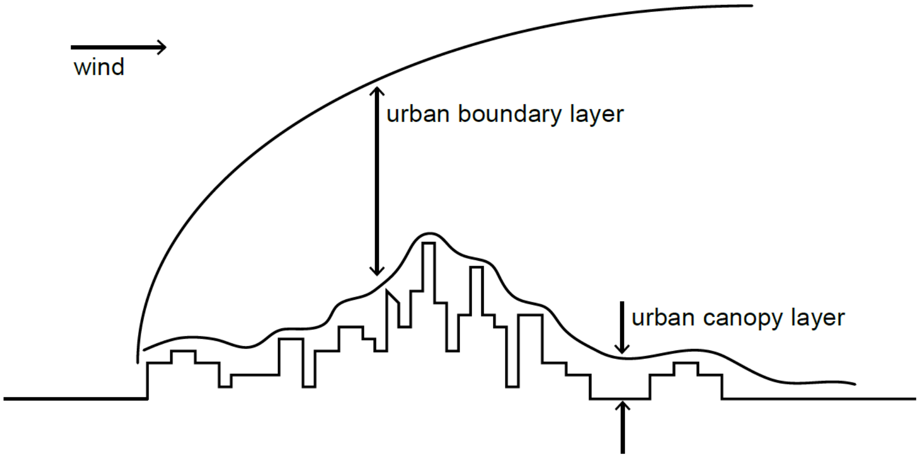
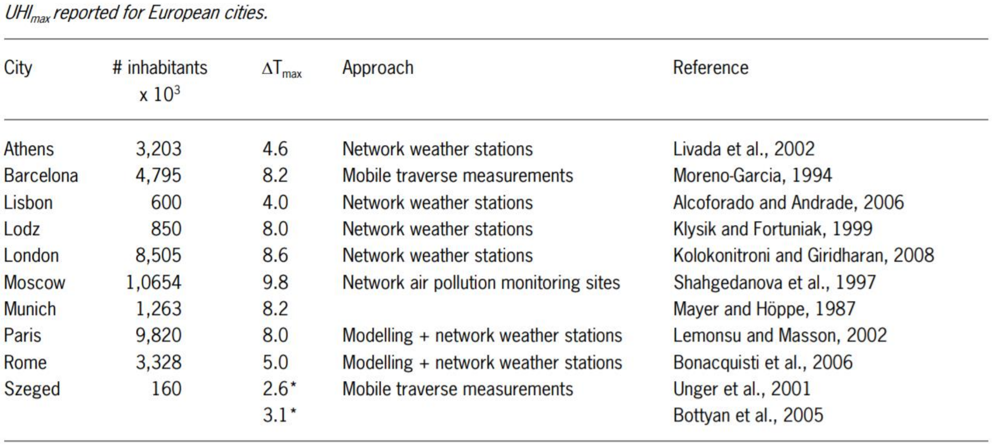


Figure 2 Different levels of the UHI- effect (Oke 1982, Kleerekoper 2017).

The UHI island intensity in an urban area is the combination of a lot of different factors interacting with each other on different urban scales, next to all the urban characteristics that cause UHI effect there is also the ‘background’ urban climate due to for example topographic elements of a certain urban area (Van Hove, Steeneveld et al. 2011). This is a distinction between different factors of the UHI effect: controllable and uncontrollable or natural factors. A closer look will be taken into the controllable factors that influence the intensity of the UHI.

The city size is one of factors that influence the intensity of the UHI effect in a particular city. Oke (1973) concludes that there is a direct relation between size (measured by population) and intensity of the heat island effect (under calm weather conditions) but this relation Is much stronger in north American cities than European ones. However this research is not very recent, Van Hove Steeneveld et al. (2011) compared more recent studies to check if this conclusion still holds up for different European cities.



UHI_{max} reported for European cities.

City	# inhabitants x 10^3	ΔT_{max}	Approach	Reference
Athens	3,203	4.6	Network weather stations	Livada et al., 2002
Barcelona	4,795	8.2	Mobile traverse measurements	Moreno-Garcia, 1994
Lisbon	600	4.0	Network weather stations	Alcoforado and Andrade, 2006
Lodz	850	8.0	Network weather stations	Klysik and Fortuniak, 1999
London	8,505	8.6	Network weather stations	Kolokonitroni and Giridharan, 2008
Moscow	1,0654	9.8	Network air pollution monitoring sites	Shahgedanova et al., 1997
Munich	1,263	8.2		Mayer and Höppe, 1987
Paris	9,820	8.0	Modelling + network weather stations	Lemonsu and Masson, 2002
Rome	3,328	5.0	Modelling + network weather stations	Bonacquisti et al., 2006
Szeged	160	2.6*	Mobile traverse measurements	Unger et al., 2001
		3.1*		Bottyan et al., 2005

Figure 3: Comparison of different reported temperature changes due to the UHI effect in cities around Europe (Van Hove, Steeneveld et al. 2011)

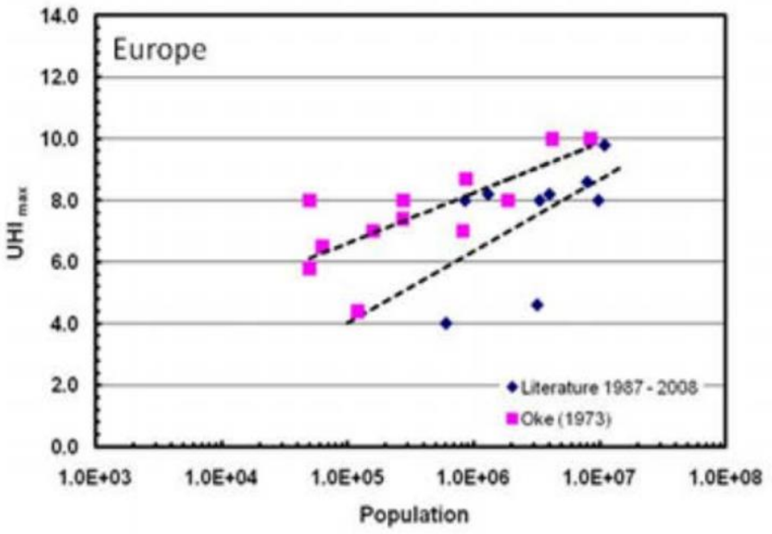


Figure 4: Comparison of temperature values from recent literature to temperatures of Oke. (Van Hove, Steeneveld et al. 2011) (Oke 1973)

In figure 4 van Hove compared more recent measurement in different cities in Europe and plotted them. In the graph it becomes visible that a more steep linear relationship is seen with values of a smaller correlation.

The urban aspects will be more thoroughly analyzed later on in this research, however it can be concluded that the urban aspects such as: typology, urban green, urban surface water, urban geometry, radiation/reflective properties of urban material have a direct impact on the intensity of the UHI effect in a city (Van Hove, Steeneveld et al. 2011)

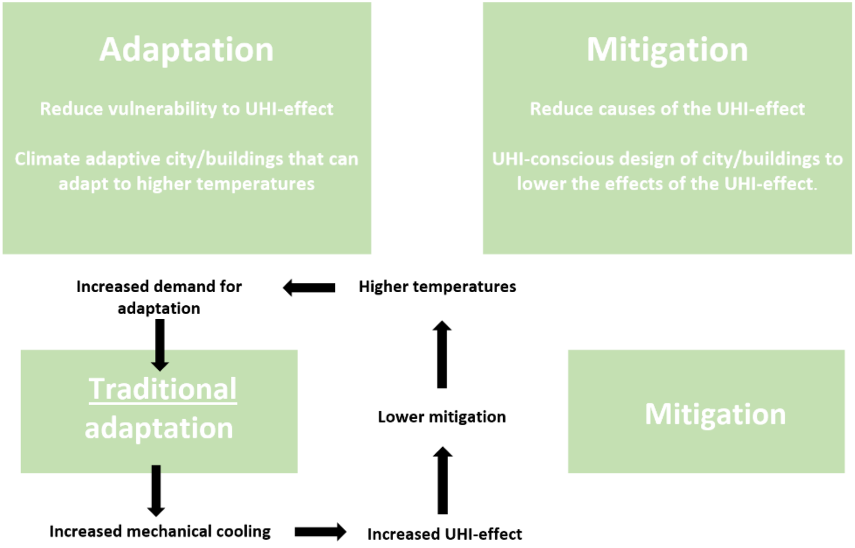
The final aspect that influences the intensity of UHI effect is anthropogenic heat. This embodies all of the heat released due to direct human interference and can be divided into three different aspects: building sector, transportation sector and metabolism (Sailor and Lu 2004). This heat is highly dependent on the time of day, seasons and even day of the week. The building sector heat can be divided into heat released from electricity consumption and heat released from heating fuels. The metabolism aspect of this anthropogenic heat is directly related to the population density however Sailor and Lu also saw that an urban core can have a daytime population that is 5-10 times higher than that of the city scale value due to people working and commuting to the urban core.

Urban Heat island effect in The Netherlands

Due to the global changing climate heatwaves worldwide will become more frequent and more intense (Fischer and Schär 2010), research from the KNMI concludes a similar trend for the Netherlands in their predictions for future climate patterns(Tank, Beersma et al. 2014). However Dutch urban centers have some differences with other urban centers researched in similar climates. The first being their close proximity to bodies of water referring to their location close to the sea but also the abundance of canals in a lot of Dutch urban centers. Another aspect is the increased urbanization of the Netherlands which will also continue in the future (Borsboom-van Beurden, Boersma et al. 2005), however this is not unique to the Netherlands. A lot of countries are experiencing increased urbanization. In the Netherlands however most large urban centers are located in close proximity to each other in the Randstad region. Urban growth in the hotspots of these regions will lead to large combined cities with millions of inhabitants which will have a direct effect on the UHI. However even without this most Randstad cities will affect one another because of their close proximity. Considering these future developments in the Netherlands regarding climate and urbanization, heat stress and thermal comfort will probably become a critical issue in many urban areas In the Netherlands(Van Hove, Steeneveld et al. 2011).

1.2 Problem statement

Urban temperatures have been steadily increasing over the past year and will continue to do so due to climate change and the UHI-effect, in order to cope with these higher temperatures cities and their buildings can adapt to the new circumstances and try to mitigate by reducing the causes of these increased temperatures. However, traditional adaptation of buildings to higher temperatures, especially existing buildings, usually consist of adding mechanical ventilation and cooling.



This results in an increased UHI- effect and energy consumption leading to lower mitigation and higher temperatures and thus creating a negative spiral of cause and effect. Traditional adaptation of buildings to increased temperatures in changing urban microclimates negatively interferes with mitigation of the cause of these changes. This leads to the following research question:

Research question

“How can a high-rise residential building in a Dutch urban center integrate passive design measures to ensure indoor thermal comfort without negatively impacting the temperature of its surrounding microclimate in future climate scenarios?”

With the following sub questions:
-How will the temperature of the future urban Dutch microclimate change due to climate change and the UHI-effect?
-How to determine the indoor thermal quality under changing outdoor temperatures due to climate change & UHI-effect?
-What passive design measures could be used to ensure indoor thermal comfort in buildings in the Dutch urban areas?
-What design solutions can be used to minimize the negative temperature effects of a building on the urban micro climate?

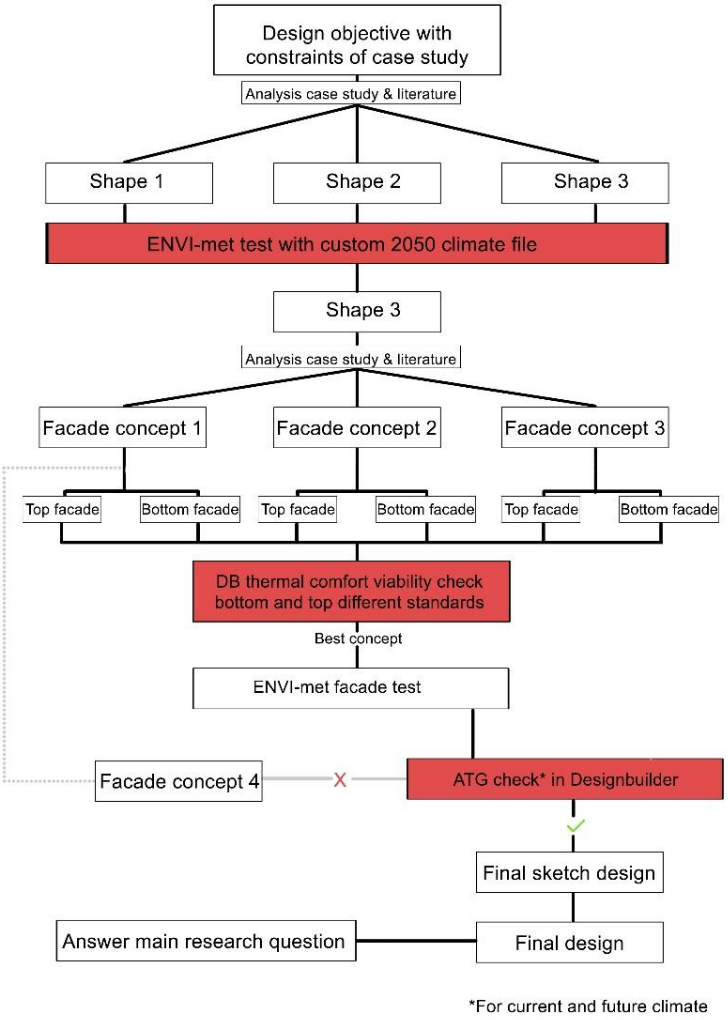
1.3 Method

The answer to the main research question will be answered by a research through design approach following the framework below. The input and constraints of this framework are based on existing literature and are summarized in the literature study chapter. The literature will be used to answer the following questions

This framework will be used to find an alternative option for an existing design that will serve as a case study. The case study that will be used is a project that is still in its design phase currently being worked on called the Hooghe Rijn, this project will be one of the highest towers in the Netherlands once constructed. Due to its location in the middle of the urban center of the Hague it is perfect for this research. The research starts with the same constraints as the case study, from there three differently shaped variants will be made based on findings from the literature and will all focus on different design aspects such as shading, wind flow and skyview factor.

These will then be analyzed and judged based on their impact on the microclimate. This is done in ENVI-met using a custom climate file meant to represent an extreme summer in 2050. These future climate files are based on KNMI data and different climate projections. In ENVI-met these climate files can be used to simulate the weather, temperature, wind speed etc. around a shape and determine the urban microclimate around it. ENVI-met is used because it can gather data on specific points around the building to piece together the micro climate around the building.

The shape with the least impact will then be used as a base design to model different single dwelling unit options including its facade. These units are then analyzed using Energyplus with the Designbuilder interface combined with the specific climate file from the chosen shape design that represents its urban microclimate and judged on their indoor comfort. The best performing version will then be modelled in ENVI-met and simulated again with the original weather file to see how much the measures lower the effect of the urban heat island on the microclimate. This last step is repeated until the results are satisfactory or meet the minimum requirements. After this a check is done if the design is also satisfactory under current climate circumstances. This leads to a very rough design of the facade which can also be viewed as a list of requirements for a final facade. These requirements are then used to design and detail a facade that meets them.
This framework is a modified version of the workflow used by Zhang et al. (2017) in their research.



2.1 Literature - Temperature change of the future urban Dutch microclimate due to climate change and the UHI-effect.

The increase in temperature due to climate change is already well known, so is the effect of the UHI on the temperature in urban areas as seen in the previous chapter. However the increase in temperature due to climate change will in turn also have an effect in the intensity of the UHI effect in urban areas. Due to a lot of changing parameters and circumstances involved it can be quite difficult to make definitive statement on the effect that the changing temperature due to climate change will have on the intensity of the UHI effect. A study looking into this correlation (Koomen, Diogo et al. 2017) concludes that climate change and increased urban development will exacerbate the current UHI effects. In this research Koomen combines data of projected temperature rise due to climate change and combines this with the projected urban growth to analyze the impact a growing city will have on the intensity of the UHI effect.

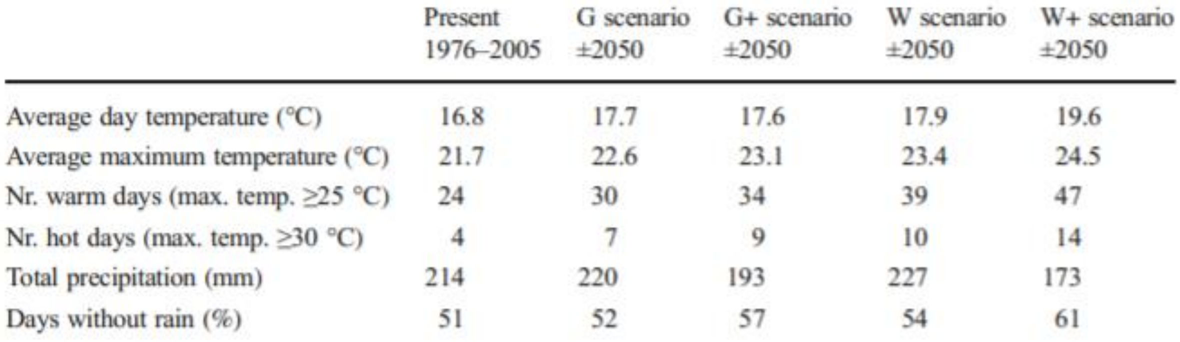
Their research was done using the city of Amsterdam as a case study, where different weather stations in various neighborhoods were set up and compared to a rural weather station close enough to experience similar weather conditions. To characterize the UHI effect the maximum UHI intensity (UHI_{max}) is used. This is the maximum difference in hourly temperatures between an urban temperature and a reference rural weather station. In this research the reference weather station was located 10km from the urban ones.

In order to make an accurate estimate of future trends in the UHI_{max} there needs to be a base dataset of the current UHI_{max} in the same area. For this Amsterdam was chosen as a case study with three different weather stations and one reference station. During a month (june 15 – july 15) in 2010 the daily UHI_{max} temperatures ranged between 1.2 and 5.2 °C which was in line with prior research for UHI_{max} in other cities in the Netherlands (Steeneveld, Koopmans et al. 2011, Van Hove, Steeneveld et al. 2011). These researchers also found that the UHI_{max} increases with a maximum temperature of around 5,3°C and similar changes on other days due to weather circumstances such as: wind speed, cloud coverage and precipitation. When eliminating these days from the research without favorable conditions (minimum weather interference) an increase of about 0.09-0.17 °C per each degree increase in maximum temperature is noticeable.

The next step is analyzing the spatial variations in these temperatures measured in the Amsterdam case study. This is done by attaching temperature measuring equipment to a bicycle and riding it through different neighborhoods and measuring the temperature every minute. The spatial differences are noticeable on the *local scale* described in Van Hove, Steeneveld et al. (2011). These temperatures are then linked to their geographical position in the city, these positions are categorized into a certain degree of urbanity to analyze their connection with the measured temperatures. This urbanity was determined by the average amount of urban surface based on the land use at a 1000m resolution and a data set containing the density and building heights via the method of Koomen, Rietveld et al. (2009). The measured temperatures are then compared to the urbanity of their measurements locations and this shows that the location with a higher urbanity such as city centers have a higher measured temperature and differ more with reference weather stations in the vicinity. The maximum UHI values reached up to 3.4 °C on the hotter days in these areas (Koomen, Diogo et al. 2017).

Future scenarios

The Royal Dutch Meteorological Institute released different scenarios for climate change in the Netherlands (KNMI 2014) based on the two uncertainties in climate change in Western Europa related to changing temperatures and air circulation patterns. This leads to four different scenarios: Moderate (G) and warm (W) based on the uncertainty of the amount of temperature increase. And '+' or no '+' depending on the change in air circulation pattern seen in the figure below.



	Present 1976–2005	G scenario ±2050	G+ scenario ±2050	W scenario ±2050	W+ scenario ±2050
Average day temperature (°C)	16.8	17.7	17.6	17.9	19.6
Average maximum temperature (°C)	21.7	22.6	23.1	23.4	24.5
Nr. warm days (max. temp. ≥25 °C)	24	30	34	39	47
Nr. hot days (max. temp. ≥30 °C)	4	7	9	10	14
Total precipitation (mm)	214	220	193	227	173
Days without rain (%)	51	52	57	54	61

Figure 5: KNMI climate scenarios (KNMI 2014) (Koomen, Diogo et al. 2017)

For future urban patterns (Koomen, Diogo et al. 2017) used an established spatial planning tool: Land use scanner. With this tool two different scenarios based on a study from (CPB 2006) were realized to simulate the future urban land use in the Netherlands. The first scenario is based on a strong global economy (GE scenario) with a growing population and economic growth combined with a liberal government, leading to a lot of urban growth. The second scenario is based on Regional Communities (RC) where the population stays relatively similar with small economic growth and governmental policies that sustain public amenities such as natural landscapes. (Dekkers, Koomen et al. 2012).

The simulations in this research show an extra 0.1-0.3 °C increase in the average temperature in urban centers due to the UHI-effect per 1 °C increase due to Dutch climate change in 2050 according to the projected KNMI scenarios (Tank, Beersma et al. 2014, Koomen, Diogo et al. 2017). This findings are in line with (Koomen, Hettema et al. 2013) that predicted an increase of 0,15 °C due to the UHI effect for each 1 °C increase in the maximum temperature. This information can in turn be combined with the current measurements on the UHI-effect in cities in the Netherlands and the future climate scenarios to get a prediction of the UHI effect in the future.

The current measurements for the UHI effect in the Netherlands differ quite a bit due to a few different factors the first being the method of measuring. This is done either via remote sensing (measuring the surface temperature) or mobile temperature monitoring(measuring the overlying air temperature) (Mavrogianni, Davies et al. 2011). The mobile temperature monitoring is used by (Heusinkveld, Steeneveld et al. 2014, Koomen, Diogo et al. 2017) for Amsterdam and Rotterdam and both resulted in UHI values between 3-5 °C depending on the days. Whereas (van der Hoeven, Wandl et al. 2015) used remote sensing and reported UHI values of 5-6 °C and nighttime UHI values of 7-9 °C for Amsterdam, this research was however focused on temperatures during heatwaves. With this information an estimation can be made but there is still a difference between the different reports.

Peak temperatures due to the UHI effect are a lot harder to predict. However this could also be expressed as number of days above a certain temperature as the KNMI uses in their climate scenarios (KNMI 2009). The KNMI makes a distinction between: warm days >=20°C, summer days >=25°C and tropical days >=30°C and has used these distinctions in their climate models. This distinction could also be used to define the UHI-effect, however, the 5°C difference between the steps might result in less accuracy. Night temperatures are also an important aspect to keep in mind when looking at future climate scenarios, (Koopmans, Ronda et al. 2018) uses the same KNMI models to analyze the future night temperature and the amount of tropical nights >=20°C.

Conclusion

The question: ”How does the temperature change of the future urban Dutch microclimate due to climate change and the UHI-effect?” has been researched by temperature measurements in cities and comparing the results with urban density data and reference weather stations. The results differ per year and location but he different sources do agree however that the increase in temperature due to climate change also increases the intensity of the UHI-effect. Most studies done in the Netherlands find that with every 1 °C average day temperature increase due to climate change another 0.1-0.3°C is added to the average due the UHI-effect.

2.2 Determining the indoor thermal quality under changing outdoor temperatures due to climate change & UHI-effect.

When talking about measuring indoor thermal comfort there two main models: The static model based on the Predicted mean vote and the adaptive model.

Static model (PMV)

PMV or predicted mean vote was introduced as the first base for defining the indoor thermal comfort of buildings and is based on the research of Fanger (Fanger 1970). This research based on the heat transfer of a human model is used to predict the thermal comfort as a combination of air temperature, radiation temperature, air speed, humidity and the clothing/activity level of users. The result of this was the ability to express thermal comfort in the relation between PMV and the PPD (Predicted Percentage of Dissatisfied). This research was done by using a climate chamber to create certain temperatures and asking test subjects about the thermal sensations they were experiencing. This research led to the PMV model which can be used to predict this thermal sensation and gives the relation between the PMV and the PPD.

Fanger's methods were often used as the basis of regulatory standards for indoor thermal comfort. In the Netherlands this was initially used as the "TO-uren" (Temperature exceeding hours) to define a comfortable indoor climate. This regulation states that in order for a building to be comfortable its indoor temperatures should be $-0{,}5 < PMV < 0{,}5$, so within half °C of the predicted mean vote. However 10% of the time (during office hours) this limit could be exceeded. This led to the following regulatory standards: the temperature of 25 °C may be exceeded 100 hours per year (during working hours) and is based on PMV=0,5 .Whereas the temperature of 28 °C may be exceeded 20 hours per day and is based on PMV=1.

However when using this method buildings that had the same amount of TO-hours would vary in terms of actual indoor thermal quality. This is due to the difference in thermal mass, in a building with a lower thermal mass the average temperatures would be a lot higher during the hours that exceeded the PMV=1 than in a building with a larger thermal mass. In order to compensate for this difference in thermal mass the weighted temperature exceeding hours (GTO) method was introduced. In this new method the amount the indoor temperature would exceed the PMV is also taken into account.

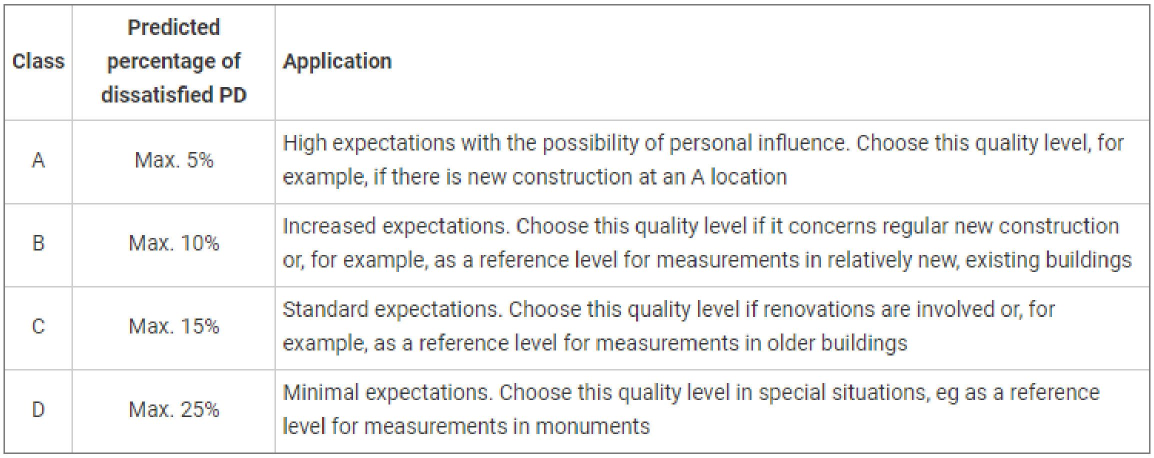
The PMV method is not without its flaws, however. Buildings vary a lot and so do their environments and measured temperatures which causes a disparity between the predicted and measured thermal quality (Yau, Chew et al. 2014). An explanation for this is that the PMV model was developed in a laboratory environment where there are restrictions in terms of environmental parameters and cannot reflect the circumstances of real buildings (Yao, Li et al. 2009). (Yau, Chew et al. 2014) also argues that the PMV model does not take psychological and behavioral adaptations into account which can have a significant impact on the thermal sensation of the user.

ATG (Adaptive temperature limit method)

The ATG model is based on the adaptive approach that states people have a tendency to adapt to changing conditions in their environment and will therefore also adapt the building they are in (Nicol, Humphreys et al. 2002).

This translates into the Dutch ATG method of determining thermal comfort. This ATG method is described in ISSO publication 74 (ISSO 2014). Two different versions are available, however the old version is not usable for running mean outdoor temperatures higher than 22 ^{o}C. Therefor the 2014 version of the ISSO74 is best to use in high temperature future scenarios. The 2014 ATG method starts with defining two different types of buildings: Alpha and Beta. The Beta building is mechanically and centrally ventilated and sealed from the outside providing minimal adaptive opportunity. The Alpha building is defined as buildings with operable windows, ceiling fans and single/dual occupant offices that offer a high amount of adaptive opportunity. These definitions are based on the research of (De Dear and Brager 1998).

In order to define the different qualities of the thermal indoor quality three classifications have been made A, B,C and D defined by their acceptance rate and application. The acceptance rate means that a certain percentage of the user will accept this temperature, so for example 90% acceptance rate means that during 100% of the hours the building is used 90% of the users will accept the temperature as comfortable thus taking factors into account the PMV method does not. These acceptance rates correspond to different building classes listed below:



Class	Predicted percentage of dissatisfied PD	Application
A	Max. 5%	High expectations with the possibility of personal influence. Choose this quality level, for example, if there is new construction at an A location
B	Max. 10%	Increased expectations. Choose this quality level if it concerns regular new construction or, for example, as a reference level for measurements in relatively new, existing buildings
C	Max. 15%	Standard expectations. Choose this quality level if renovations are involved or, for example, as a reference level for measurements in older buildings
D	Max. 25%	Minimal expectations. Choose this quality level in special situations, eg as a reference level for measurements in monuments

The temperature limits of these classes are dependent on a weighted outside temperature taking the temperatures of the days before taken into account. This weighted average outside temperature or running mean outdoor temperature is called θ_{rm} and is calculated by the following formula:

$$\theta_{rm} = 0{,}253 \cdot \{\theta_{ed\text{-}1} + 0.8 \cdot \theta_{ed\text{-}2} + (0.8)^{2} \cdot \theta_{ed\text{-}3} + (0.8)^{3} \cdot \theta_{ed\text{-}4} + (0.8)^{4} \cdot \Theta_{ed\text{-}5} + (0.8)^{5} \cdot \theta_{ed\text{-}6} + (0.8)^{6} \cdot \theta_{ed\text{-}7}\} \; [° C]$$

Where:

$\theta_{ed\text{-}1}$ = average outdoor temperature yesterday [° C]
$\theta_{ed\text{-}2}$ = average outdoor temperature day before yesterday [° C]
$\theta_{ed\text{-}3}$ = average outdoor temperature two days before yesterday [° C]
etc.

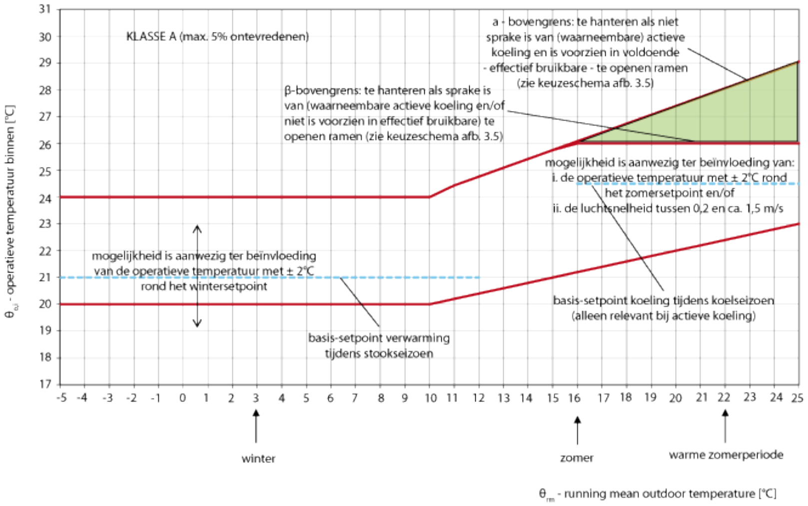
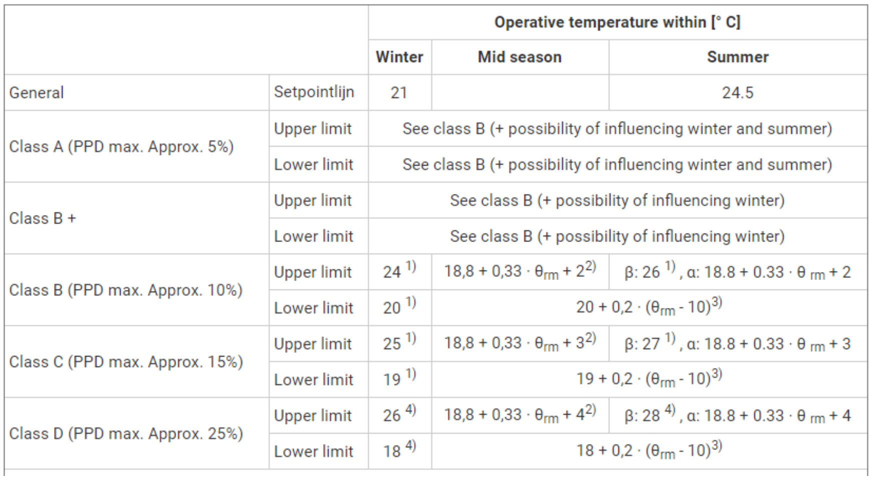


Figure 6: ATG class A limits graph (ISSO 2014)

With this θ_{rm} the weather and temperature of multiple days is taken into account, this way the psychological factors are included into the method. Because if people are experiencing hot weather for multiple days their standards for accepting a more extreme indoor temperature will change (Yao, Li et al. 2009). Another aspect is the clothing choice that people will adjust after a few days of hotter weather. This θ_{rm} can then be used in combination with the hourly indoor temperature to assess its indoor thermal comfort and assign a class to it. The upper and lower limits per class differ per building type and season, only A and B have overlapping temperature limits but differ in the percentage allowed over this limit. The limits per class and the formulas behind them can be seen in the table below.



		Operative temperature within [° C]		
		Winter	Mid season	Summer
General	Setpointlijn	21		24.5
Class A (PPD max. Approx. 5%)	Upper limit	See class B (+ possibility of influencing winter and summer)		
	Lower limit	See class B (+ possibility of influencing winter and summer)		
Class B +	Upper limit	See class B (+ possibility of influencing winter)		
	Lower limit	See class B (+ possibility of influencing winter)		
Class B (PPD max. Approx. 10%)	Upper limit	$24^{1)}$	$18{,}8 + 0{,}33 \cdot \theta_{rm} + 2^{2)}$	β: $26^{1)}$, α: $18.8 + 0.33 \cdot \theta_{rm} + 2$
	Lower limit	$20^{1)}$	$20 + 0{,}2 \cdot (\theta_{rm} - 10)^{3)}$	
Class C (PPD max. Approx. 15%)	Upper limit	$25^{1)}$	$18{,}8 + 0{,}33 \cdot \theta_{rm} + 3^{2)}$	β: $27^{1)}$, α: $18.8 + 0.33 \cdot \theta_{rm} + 3$
	Lower limit	$19^{1)}$	$19 + 0{,}2 \cdot (\theta_{rm} - 10)^{3)}$	
Class D (PPD max. Approx. 25%)	Upper limit	$26^{4)}$	$18{,}8 + 0{,}33 \cdot \theta_{rm} + 4^{2)}$	β: $28^{4)}$, α: $18.8 + 0.33 \cdot \theta_{rm} + 4$
	Lower limit	$18^{4)}$	$18 + 0{,}2 \cdot (\theta_{rm} - 10)^{3)}$	

Figure 7: Different classes and their limits (ISSO 2014)

Conclusion

After looking at both methods the choice between the static model and the adaptable model seems clear. The adaptive model takes more factors into account when determining indoor thermal comfort such as psychological and behavioral aspects for example. For this research in particular (that uses increased summer temperatures due to climate change and UHI-effect as a parameter) it is useful that this method takes the temperature of multiple days into account. Both models are available in different analysis software so this is not a determining factor. Therefore the choice for the adaptive model is a logical one.

2.3 Design solutions to minimize the negative temperature effects of a building on the urban micro climate

The UHI-effect is a large part of the urban micro climate in cities around the world, it is therefore essential to take the UHI-effect into account when intervening in this urban landscape in a way that that urban centers can adapt to the UHI effects. In this chapter different adaptation measures on an urban scale will be analyzed and compared. A lot of these adaptive interventions have other positive side effects however for the scope of this research the focus will lie on the thermal effects of their urban surroundings.

The research focusses on all aspects of minimizing the UHI-effect, however passive cooling and thereby minimizing heat emission from a building due to indoor cooling will be discussed in another chapter. The scale of the research is a building and its direct surrounding however in order to form a complete view larger scales will also be discussed.

Based on the measures and literature review of (Kleerekoper 2017) and (Climate proof cities 2014)

Vegetation

Vegetation helps to cool its urban environment by evapotranspiration, transpiration and by shading materials from short-wave radiation that would have been absorbed. During the night it enables heat to escape faster through long-wave radiation because of the high sky view factor of open fields (Kleerekoper 2017). The application of vegetation in an urban environment can differ a lot: parks, street trees, grasslands, etc. The exact cooling effect is hard to determine due to the many different factors at play, however the average cooling effect due to vegetation is between 1-6 °C, however this is highly dependent on the amount, type, outside temperature, etc.

Larger vegetated areas in urban environments such as parks or urban forests have a much lower air and surface temperature compared to their surroundings, these areas can form a Park Cool Island (PCI). (Bowler, Buyung-Ali et al. 2010) compares different studies of the PCI effect to show that this cooling effect ranges between 1-6 °C. The effect of the PCI on its surroundings is heavily dependent on things like airflow, climatological circumstances, layout/composition and its surrounding buildings. These can all be considered when designing vegetation as an urban intervention such as an open grass field layout that receives the full sun radiation load but can easily cool down at night or an abundance of trees creating a lot of shade but blocking the airflow through a city (Kleerekoper 2017).

Incorporating trees into a street design is another way of introducing vegetation into a city to help mitigate the UHI-effect. Trees in urban areas could reduce the air temperature up to 4 °C by intercepting solar energy and providing shading as well is cooling its surroundings by evapotranspiration (Wang, Akbari et al. 2016). However these street trees do have some downsides as they block airflow through the city, add city maintenance and damage or make their surroundings dirty. However with the right selection of tree these problems can be mitigated. (Kleerekoper 2017)

Another way of incorporating vegetation into an urban area is through green roofs or facades. By covering these building elements with vegetation a cooling effect for both the building and its surroundings can be achieved by evapotranspiration of the leaves, blocking the building from short wave radiation and preventing absorption and converting heat into latent heat by using evaporation

(Kleerekoper 2017). Another upside is the added insulation value from green roofs/facades helping keep the interior cooled when outside temperatures are high.

Water

Design measures based on water are able to minimize the negative temperature effects of the UHI-effect in a few different ways: evaporation, acting as heat buffer and when there is a large water mass in the urban area or by transporting the heat out of an area by moving the heated water such as a river. Water has a cooling effect of about 1-3 °C with an effective area of around 30-50 meters. The effectiveness of cooling by water is a lot higher when the amount of surface area is high or the water is dispersed in the air (like a fountain for example). Evaporation is also influenced by airflow, weather and its urban context. (Kleerekoper 2017)

Water can also be incorporated into building designs in order to cool its surrounding and the building itself, however it is important for a design like this to incorporate a shading system in order to prevent rapid overheating of the water due to its small water mass.

A downside of large waterbodies in a city is that they are slow to react to heating during daytime and therefore also cool down very slowly meaning that during the day they will absorb heat albeit slowly and at night release this heat depending on the size of the body of water this could mean it would support the urban heat island effect at night (Steeneveld, Koopmans et al. 2011). Another downside of increased water presence in cities is the growth of mosquitos in these areas due to the added water.

Implementing large water elements just for cooling purposes is not really a viable solutions because the high cost and land use in a city. However making optimal use of existing water bodies in cities by building in close proximity to them and preserving their place in the city is something that can be done. A cheaper alternative is using smaller elements like fountains to cool high traffic areas or spaces that suffer problematically from the UHI-effect. (Kleerekoper 2017)

Urban geometry

Urban Geometry or built form has a two main levels at which it can impact the urban heat island effect: radiation/shading and air flow which are all both accumulation variables.

Radiation and lack of shading can heat up surfaces in the urban environment that accumulate this heat and radiate it further heating up its surroundings. Building density and geometry of these buildings have a direct relation to the amount of radiation a surface receives, radiation can be trapped for example by reflections between buildings and the street surface this happens when building geometry blocks the sky and results in reduced radiative heat loss. This phenomenon is called a street canyon.

This street canyon effect can be minimized by increasing the ratio of height to width in a street design and thereby shading the street with its surrounding buildings . However this has the negative effects of reducing airflow, increasing solar reflections between surfaces and trapping the anthropogenic heat created in the street. Kleerekoper (2017) concludes that there is no generally applicable H/W ratio for every situation, it is highly dependent on climate, orientation, materialization, etc. A separate H/W analysis in combination with other interventions such as shading elements is vital in combatting the street canyon effect and heat stress on a street level.

The urban geometry directly influences air flow in a city. Wind can transfer heat out of the city or on a smaller scale out of a street canyon. Accounting for wind flow in a design can ensure thermal comfort in and around the building. However in The Netherlands stimulating this wind can lead to unwanted and dangerous situations due to heavy winds when cooling is not needed.

Increased ventilation can also be achieved by mixing the air of the urban canopy layer and the urban boundary layer. This can be done by altering the canopy layout of the urban area in question by varying their layout and height according to a H/W ratio. The H/W ratio of 0.2 or less ensures a good mixing of both layers and provides ventilation throughout the street (Xiaomin, Zhen et al. 2006). However changing the H/W ratio of an existing street is extremely costly, and is best taken into account when designing new streets or during extensive renovations.

Material and color

Materialization of a city can lead to an increased UHI-effect, this is due to a few characteristics of the materials. One of these is the hardness of materials which does not allow cooling by evaporation, resulting in heat accumulation of these hard materials. Albedo is also a factor when analyzing the impact to the UHI-effect of a material. Short-wave radiation is more easily absorbed in low albedo materials whereas high albedo materials will absorb short-wave radiation a lot slower (Kleerekoper 2017). Thermal admittance is another factor when looking at the UHI-effect impact, materials with a high thermal admittance can absorb a lot of heat during high temperatures acting as a thermal buffer but will also take a long time to lose this heat when the outside temperature has decreased increasing the temperature during the night. (Kleerekoper 2017)

The color of a material can also have an impact on the thermal air quality. Surface temperature and radiation load are directly related to the color of the material but it can also be used to generate airflow by increasing differences in surface temperatures by using this difference in color as a way to heat up surfaces differently.

Conclusion

The four categories: vegetation, water, urban geometry, material/color form the base of minimizing the negative temperature effects of the UHI-effect and can be used as a tool to divide the different measures. However the practical use as design tools differ heavily between categories. For example urban geometry in city centers are rarely completely designed from scratch, they are rather the product of organic urban growth. So the impact of a single building and its surroundings will be minimal. In addition to that will the focus of increased wind flow also create wind nuisances during times of heavier wind. The same goes for large water/vegetation areas that are rarely implemented in a dense urban context if they were not there already. So as design tools material and color will be the main categories to use in combination with water and vegetation on a smaller scale (building and its direct surroundings).

2.4 Passive design measures to ensure indoor thermal comfort in buildings in the Dutch urban areas

The building envelope forms the barrier between inside and outside, one of its main tasks is to keep the buildings thermal air quality at a desirable level even if the outside temperature is not. This task will become more difficult due the increasing temperatures as an effect of climate change and the UHI-effect. Therefore the role of building envelope will become even more important over the coming years. This adaptation of the building envelope is a way to reduce our vulnerability to the negative effects of a changing climate (NASA N.D.) Another way to respond to climate change is mitigation where the goal is to “Reduce emissions of and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere” (NASA N.D.). However, this research is focused on the adaptation of the building envelope to ensure indoor thermal comfort by passive cooling.

To realize this climate adaptation of buildings by passive cooling it is first important to highlight the difference between active and passive cooling and further elaborate on the different ways passive cooling can be used. Passive measures use the initial design of the building to maximize energetic gains and minimize losses by optimizing building layout, orientation, solar control, etc. Whereas active measures are based on influencing the indoor thermal climate by mechanical equipment (Prieto, Knaack et al. 2018). However in real world applications there are also some passive measures that make use of small pumps or fans to optimize performance which presents some gray area, Givoni (1994) states that the term passive does not mean exclusion of small pumps and fans if it enhances the performance of the measure. This leads to another distinction between two groups within passive cooling based on the use of these pumps/fans. The first being passive cooling without help from equipment known as ‘bioclimatic design’ or just as ‘passive cooling’. The second category uses pumps or fans to increase its effectiveness in systems like geothermal, evaporative and radiative cooling. This category is known as passive cooling systems (Givoni 1994, Prieto, Knaack et al. 2018).

This difference can be even further expanded through the terms of low/high exergy, whereas some measures use low valued exergy sources from its environment as heat sources and sinks, and others use high valued exergy sources such as electricity (Kalz and Pfafferott 2014, Prieto, Knaack et al. 2018)

In order to find an overview or categorization of the different passive design measures, multiple sources have been used including Climate proof cities (CPCC 2014), the research of van Hoof, Blocken et al. (2014) and Prietro, Knaack et al. (2018). In the end the decision for the framework of Prietro, Knaack et al. (2018)was made because of its broad categorization including all of the different parameters and its extensive use of other literary sources.

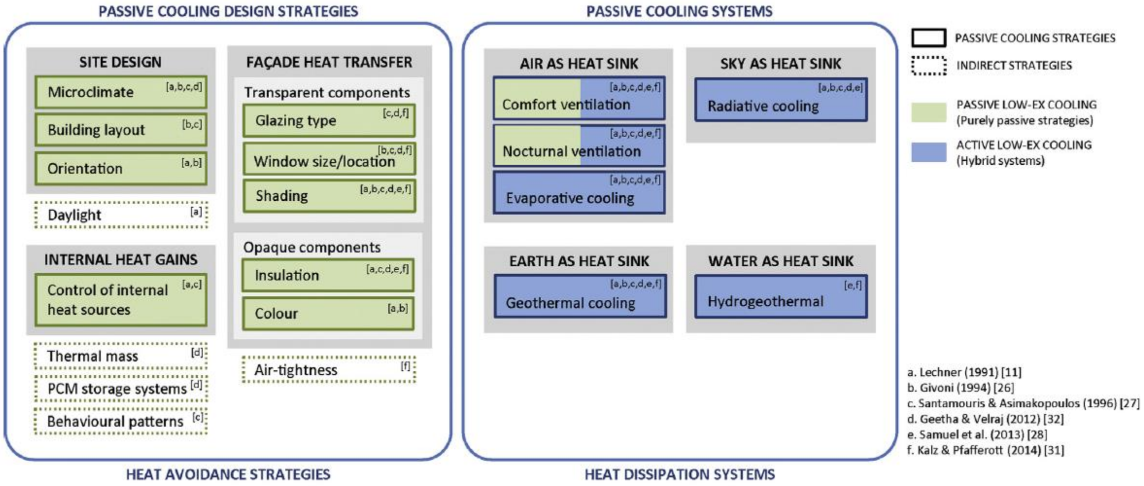


Figure 8: Categorization of different design measures of passive cooling (Prieto, Knaack et al. 2018)

Passive Cooling design strategies – Heat avoidance strategies

Microclimate

This Passive cooling strategy is something that has been elaborated on in previous chapters, the most important controllable aspects of this are use of water, vegetation, urban geometry and material/color. This could be done one a neighborhood scale, the direct surroundings of the building or directly with design choices of the building itself by using vegetated roofs and/or facades or by choosing materials/colors that reflect short wave radiation more easily (Lechner 2014, Kleerekoper 2017). With these strategies a less intense UHI effect can be achieved thereby lowering the cooling demand of the building.

Orientation

The orientation of the building has a direct impact on a number of other factors such as: shading, daylight, heating/cooling etc. The right orientation is therefore also highly dependent on the use of the building but also on the climate where it will be built. In colder climates it might be optimal to have the largest facade pointed toward the orientation with the most sun hours whereas this would be the other way around in hotter climates. A thorough analysis of the requirements and usage of a building is required before deciding its optimal orientation to realize a minimal cooling load. (Lechner 2014)

Daylight

Daylight design in a building has a direct relations to aspects such as shading, glazing type, orientation etc. It is important to first research the buildings heating and cooling demand during different seasons and its relation to the local climate. After this different design decisions can be made about orientation, window location, different glass types etc. to maximize daylight gains while minimizing unwanted heat loss in winter or heat gain in summer. (Lechner 2014)

Control of internal heat sources

Internal heat sources in a building consist out of different elements not part of the building itself generating heat such as people, equipment or lighting. In winter these heat sources are useful for lowering the heating demand however in summer these sources can in turn increase the cooling load of a building. Controlling these sources is a way of minimizing the cooling load desired in summer. This could be done by using low thermal emission equipment, switching to LED lighting, encouraging users to work at home during hot weather, etc. (Lechner 2014)

Shading

Shading is a way to reduce the overheating effect the sun has on translucent parts of the facade in summer. It is a very useful tool to incorporate into a passive cooling strategy, because many buildings suffer from overheating in summer and use mechanical solutions however by using shading in a well-designed way the need for cooling can be greatly reduced. Shading strategy is also part of the larger picture which includes: daylight, orientation, window size, etc. Shading solutions are an effective heat avoidance strategy but can interfere with other elements such as daylight, because a decrease in sunlight reaching a window to reduce a cooling load also means a decrease in daylight for example. Therefore it is important to look at the different demands of the building and make a conscious design choice about the different implementations of shading solutions (Lechner 2014). Additionally the Dutch NTA8800 has a separate categorization of the different types of shading and their effectiveness.

Glazing type

The glazed surfaces of a building are usually a significant part of the façade therefore the thermal properties of these glazed surfaces affect the amount of solar radiation that penetrates tot the interior of the building (Geetha, Velraj et al. 2012). There is a wide range of different glazing options that can be chosen in order to minimize the amount of solar radiation that gets through the glazed parts of the facade and lowering the cooling demand. These range everywhere between single pane glazing, vacuum glazing, electrochromic windows to even transparent insulation materials. In order to make an informed design decision on the subject other intertwined factors such as daylight, shading, orientation, etc. need to be taken into account as well (Lechner 2014). When just looking at passive cooling highly reflective or tinted glazing might be ideal to minimize solar heat through the windows, however this might in turn also limit daylight, and could simply be solved by shading elements. Extensive glazing that incorporates triple glass could even have a negative effect trapping the heat inside a building. Glazing type is therefore one of many parameters that can be tinkered with in an integrated passive cooling design.

Window size/location

Another way to minimize the cooling load in summer is reducing the window size or choosing a more shaded location on the building envelope. However windows are essential for buildings and limiting them would also limit daylight intake. However design choices can be made that put functions with a lot of windows on sides without direct sunlight or put windows in more shaded parts of the facade (Lechner 2014).

Insulation

Insulating a building has the purpose of increasing the thermal resistance of its envelope in order to keep a desired temperature in the building. Insulation can be both positive and negative in terms of passive cooling. Because Insulation keeps heat inside, it is very useful in winter however when the building suffers from overheating it can be more difficult to cool due to its insulation trapping the heat inside. But when a building is already at a desired temperature it is easier to maintain this cooler temperature (Lechner 2014). Dutch building codes already requires relatively high insulation levels for floors, roofs and facades which include their translucent parts so any new building design should also incorporate insulation in its passive cooling strategy.

Color

The color of a building elements has an impact of the amount of solar energy it will absorb, white roofs will have half heat gain of black roofs for example. White colored materials will reflect more light and can also have a positive impact on daylight in and around the building. This can be defined as the albedo of a material, some examples from (Lechner 2014) of the albedo of materials can be found below. Using high albedo materials can help a building lower its cooling demand in summer and can be very useful in a passive cooling strategy design. The UHI effects of color have been discussed in the previous chapter.

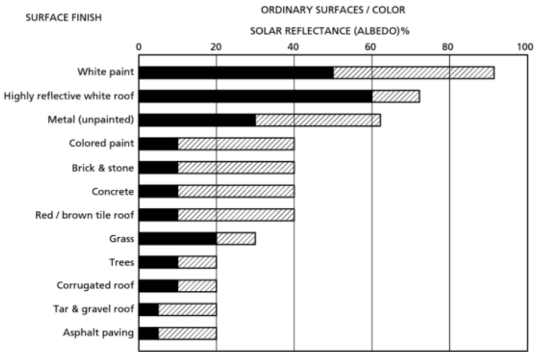


Figure 9: Solar reflectance of different materials (Lechner 2014)

Building layout

The layout of a building has a direct relation to the ventilation conditions throughout the building (Santamouris and Asimakopoulos 1996). A building that has an open plan where air can flow freely combined with well-placed openings is the best for passive ventilation/cooling. However practicality usually dictates that floors have internal walls so that a floor can be divided into different useful spaces. But airflow should preferably not be restricted in this way and partitions can even be used to channel the flowing air throughout the building. This in combination with the larger spaces on the windward side should maximize the ability to use natural ventilation by adjusting the building layout.

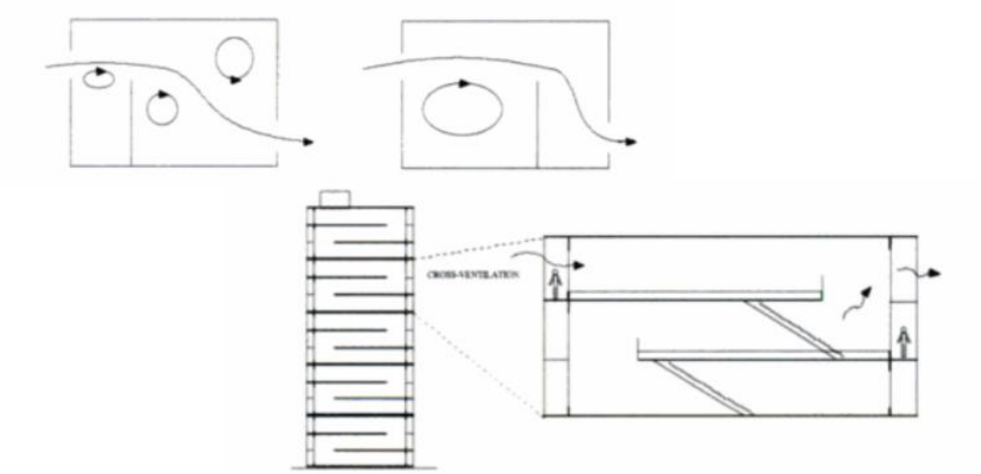


Figure 10: Different measures to increase airflow through a building. (Lechner 2014)

Thermal mass

The thermal mass of a building can be used in passive cooling solutions. The thermal mass in a building usually comes from heavy and dense materials such as concrete floors/walls and masonry. Materials in buildings with a large thermal mass have the ability to absorb a lot of heat and slowly release this when the temperature drops. So when the temperature starts to rise in the morning and afternoon the thermal mass will cool down its surroundings due to absorbing all the heat. When the temperature drops and the thermal mass is heated it will slowly release this heat. One of the cooling demand limiting strategies that can be used involving thermal mass is pre cooling (Geetha, Velraj et al. 2012). This strategy involves lowering the temperature before peak temperature hours in an office (8a.m.-2p.m.) and then limiting cooling during peak temperature hours (2p.m.-5p.m.) thereby letting the thermal mass do most of the cooling during high demand hours.

PCM

A way to increase the thermal storage effect of a building other than just using heavy/dense building materials is incorporating materials with a high thermal inertia, such as phase change materials (PCMs) (Geetha, Velraj et al. 2012). PCMs thermal storage effect is based on its ability to change phase due to temperature changes and either absorbing or releasing thermal energy when changing phase. PCMs can be integrated in most parts of the building envelope to increase its thermal storage however the most used and most effective are PCMs in wallboards, roofs, ceilings and windows.

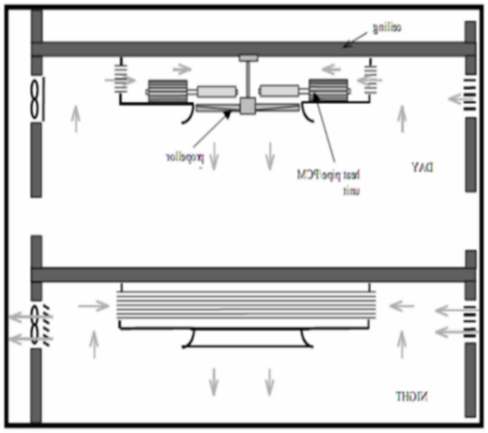


Figure 11: PCM use in a ceiling (Geetha, Velraj et al. 2012)

Behavioral and occupancy patterns

(Santamouris and Asimakopoulos 1996) states that the behavioral response of people is one of the most effective ways of dealing with high temperatures. These include things like making use of different cooler spaces during peak temperature hours, sleeping outside during warm nights or even working at home during hot days. This could be included into a building design by nudging users with a smart building system that for example will schedule meetings in rooms on the cooler side of the building during hot days. However these behavioral patterns are a the result of an uncomfortable indoor situation (going to different room because it is too hot) that should be avoided in the first place.

Passive cooling systems – heat dissipation strategies

Ventilative cooling

Comfort ventilation is based on using air as a medium to cool down a building and its users. It uses outside air to flow through the building directly over its users to increase evaporative cooling on the skin. Although this does provide thermal comfort daytime air could actually be heating the building, therefore outside air could also be mechanically cooled before being introduced into the building (Lechner 2014). This is where the difference between passive and active cooling becomes clear, completely passive comfort ventilation is based on just opening windows and letting the natural airflow cool the building down. However in some climates wind is sparse or not enough so fans are introduced to enhance and control the airflow through a building, this could still considered to be passive according to the definition of (Givoni 1994). A completely active system would be the further addition of an air-conditioning unit that cools down the air before being introduced in the building. There are also combined systems that can switch between active and passive measures depending on the circumstances called hybrid ventilation.

Nocturnal ventilation

Nocturnal ventilation is mutually exclusive with comfort ventilation and works quite the same, it is based on the fact that during the night the air temperature is much lower than during the day. Therefore this cool night air can be used to flush out the heat from daytime and cool the building down then during the day very little outside air is introduced in the building. This allows the mass of the building to act as a heatsink for the building users and in the inside air. Similar to comfort ventilation however is the use of fans and air-conditioning. If in the local climate not enough wind is present to allow enough air through the building to cool down fans are needed to increase its effectivity (Lechner 2014). However nocturnal cooling can also have negative effects. In this regard the NTA8800 has different conditions of minimizing the negative effects before implementation is considered. These are: implementation of nocturnal ventilation may not lead to an increase of vermin or insects, burglary proof implementation of systems is mandatory, the solutions have to be rain proof and the operating controls have to be within a reasonable reach of the use (no higher than 1,8m).

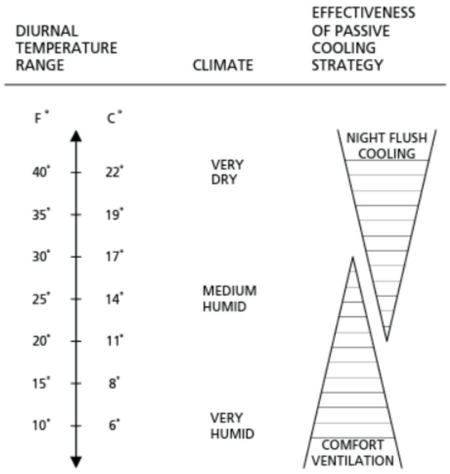


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Figure 12: Comfort ventilation versus night ventilation (Lechner 2014)

Evaporative cooling

Evaporative cooling is based on the evaporation of water, when it evaporates sensible heat from its surroundings is drawn and converted into latent heat in the form of water vapor causing the temperature to drop (Lechner 2014). This phenomenon can be used in two different ways to cool a building down. Water can evaporate inside a building or in the air intake the air will be both cooled and humidified, this is direct evaporative cooling. Indirect evaporative cooling is when a building or its indoor air is cooled by evaporation without humidification of the air. Evaporative cooling is a lot less energy intensive than conventional cooling methods and uses cheaper equipment however it is limited to dry climates.

Geothermal cooling

Geothermal cooling uses the ground just below the surface as a heatsink in the summer (and as a source of heat in the winter) coupled with a heat pump, since the ground is colder than the air in summer. Water is the medium for this heat and a few different options are available depending on the local conditions (amount of groundwater, ease of drilling, nearby bodies of water, etc.). Since all the equipment is indoors or underground they last long and require little maintenance and the fact that the electricity in the system is only used to pump heat and not create it, it requires a lot less energy than traditional systems. Hydro geothermal cooling is very similar and based on groundwater (Kalz and Pfafferott 2014).

Radiative cooling

Every object emits and absorbs radiant energy when the net flow of radiant energy is larger outwards then inwards it will cool down. This is the principle behind radiative cooling where the roof of a building that is hot from the sun shining on it all day radiates it energy back into the night sky using it as a heat sink (Lechner 2014). This can be done in a passive and active way, where the simplest passive way is just to paint the roof of a building white. Since it does not negatively affects the nightly radiation rate but it does absorb less solar radiation during the day (Geetha, Velraj et al. 2012). Other radiative cooling systems include: movable insulation, movable thermal mass and a flat plate air cooler.

Conclusion

The framework introduced in this chapter from Prieto, Knaack et al. (2018) is an excellent tool to categorize the different passive cooling measures. This framework could therefore also be used to set the parameters of an analysis. However most measures should not be looked at individually, for example things like: orientation, building layout, window size/location/shading etc. are influenced by each other heavily. Without one uniform passive cooling strategy measures might interfere and either negatively affect each other or form redundancies. The same thing goes for the link between heat dissipation system and the heat avoidance system. All these single elements should fit into a larger passive cooling strategy that is determined on the basis of: building type, surroundings, climate, etc. After this becomes clear a fitting heat dissipation system can be chosen with complementary heat avoidance strategies.

2.5 Software

ENVI-met

A large part of the research is looking into the impact a building has on its micro climate. This will be done by using the microclimate model program ENVI-met. In ENVI-met a 3d representation of an environment including buildings, vegetation, materials , etc. can be modelled and exposed to certain weather conditions and analyzed. The ENVI-met software suite consists out of a few different programs the most important are:

Spaces: Modelling of the 3d environment and adding climate data.
Leonardo: Visualizing data for analyses
ENVIGuide: Setting up the simulation parameters such as: date, duration, weather file, etc.

ENVI-met is used because of a few different reasons, the first being its accuracy and track record in the climate science field. This program has been tested and compared with the real life measurements and held up realistic values (Kleerekoper 2017). Another reason is the level of data it provides, it can give both the base data to create new individual microclimates on different heights and visualize the large microclimate around the entire area. Compared to other similar programs it provides the best combination of simulation aspects that make up the entire microclimate simulation. Where a program like SOLWEIG might give the same accurate radiation simulation it does not take airflow into account. More specialized CFD (computational fluid dynamics) programs like ANSYS Fluent could give more accurate wind flow data however that level of detail is not needed and would slow the process down (Kleerekoper 2017)

The starting ENVI-met inputs are based on literature however it is important to keep in mind that conclusions and data about microclimate from other studies are not always comparable between each other. This is because a micro climate in such a complex environment can react differently to inputs than a micro climate in another complex urban environment. Things like context, weather and other elements can drastically change the effectiveness of measures, adding a tree in an empty street or adding a tree to street that already has trees will have a different outcome for its microclimate for example (Kleerekoper 2017). This why the initial input is based on previous work and the ENVI-met analysis is used to check what works in this specific context of the case study.

Design builder

Another step of the process involves a thermal comfort analysis of a dwelling design, with the focus on its facade. This design, based on the outcome of the initial ENVI-met analysis, will be modelled and researched using EnergyPlus 8.9 with the graphical interface of Designbuilder 6.1. With this energy simulation program accurate analysis can be made regarding heating, cooling, ventilation, lighting and water use. For this research it is used to determine the effectiveness of the facade in a passively cooled design and maintaining comfortable indoor temperature. This is done by testing different facade configurations of both upper and lower level dwellings and analyze their indoor thermal comfort performance via the ATG method.

3. Introduction case study

In order to use and test the research framework a case study is needed, not only to provide the necessary starting input and design constraints but also to provide a realistic scenario where an alternative design can be found using the framework of this research. By adhering to the same constraints in the form of maximum plot size, minimum floor space, etc. the alternative design will be subject to the same design challenges.

A case study for this research needs to have a few characteristics in order to optimally use the research framework and the passive cooling measures that go with it. These characteristics include: being situated in an environment that suffers from heat stress due to the UHI-effect and preferably early in the design phase on both urban and building level. This way the impact of the building can be analyzed much more effectively and changes in the design can still be made without altering the basic concept of the building.

The case study building is the “Hooghe Rijn” currently in the early design phase. This building is realized by team comprised of OZ Architects, SENS Real Estate, Stebru and the municipality of the Hague. All of the building information is provided by DGMR that advises the team on building physics and energy aspects. The information that is used in this research is from 15-01-2020 or before. During the research the development of the building will continue however this information will not be used due to the difficulties of a changing design in combination with long modelling/simulation times.

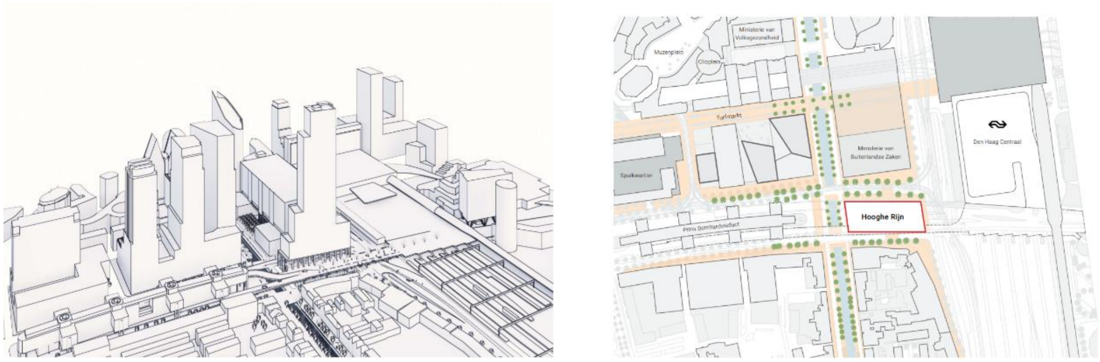


Figure 13: Case study design wit hits surrounding (Gemeente Den haag et al. 2020)

The Hooghe Rijn building is part of a larger urban development in The Hague rolled out over the coming years called the Central Innovation District. The building is located close to the central station and many of the Dutch ministerial offices. On its plot is currently the Prins Bernard overpass, however this will be partially demolished to make room for the development. The building will be filled with a mix of functions, starting at the bottom with commercial and office spaces, on the higher levels a hotel and the rest will consist of a mix of housing.

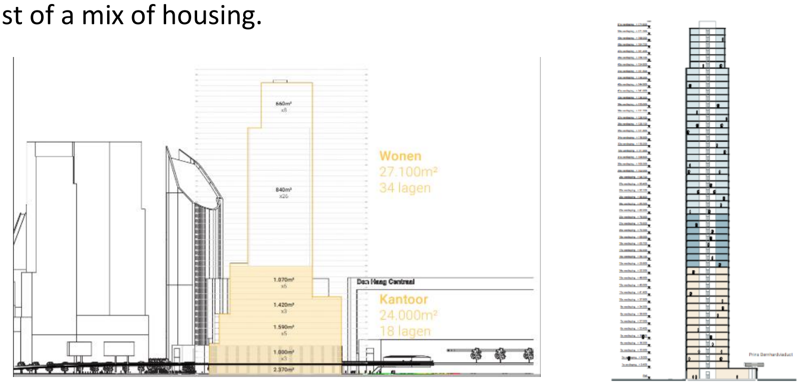


Figure 14: Case study design sections (Gemeente Den haag et al. 2020)

This case study fits all of the characteristics required. The location of the “Stationsbuurt” is one of the neighborhoods in the Netherlands that suffer the most from the UHI-effect (Kleerekoper 2017). This combined with the complex urban geometry of the neighborhood provides a unique challenge with large room for improvement of the microclimate. The building is also still in its early design phase, meaning a lot of decisions are not yet set in stone. This means studies towards alternative designs using passive cooling will be more easily realized. This also means that the design can be more tailored towards negating the UHI-effect. Finally this building is part of a larger urban development in the center of the Hague. This means some urban aspects of the design could also be taken into account when designing alternatives and thereby having an even greater impact in negating the UHI-effect.

In this case study two apartment dwelling units from a representative floor will be used to analyze the indoor thermal comfort and propose a new design focused on passive cooling. A dwelling unit is used instead of commercial or office space, this is because there is a large deficit of housing in The Netherlands especially in urban areas. Added to this is the fact that most of the housing in these urban areas will be apartment style units because of the lack of space. This way the results of this study can be relevant in other developments as well to meet the demand for increased urban housing.

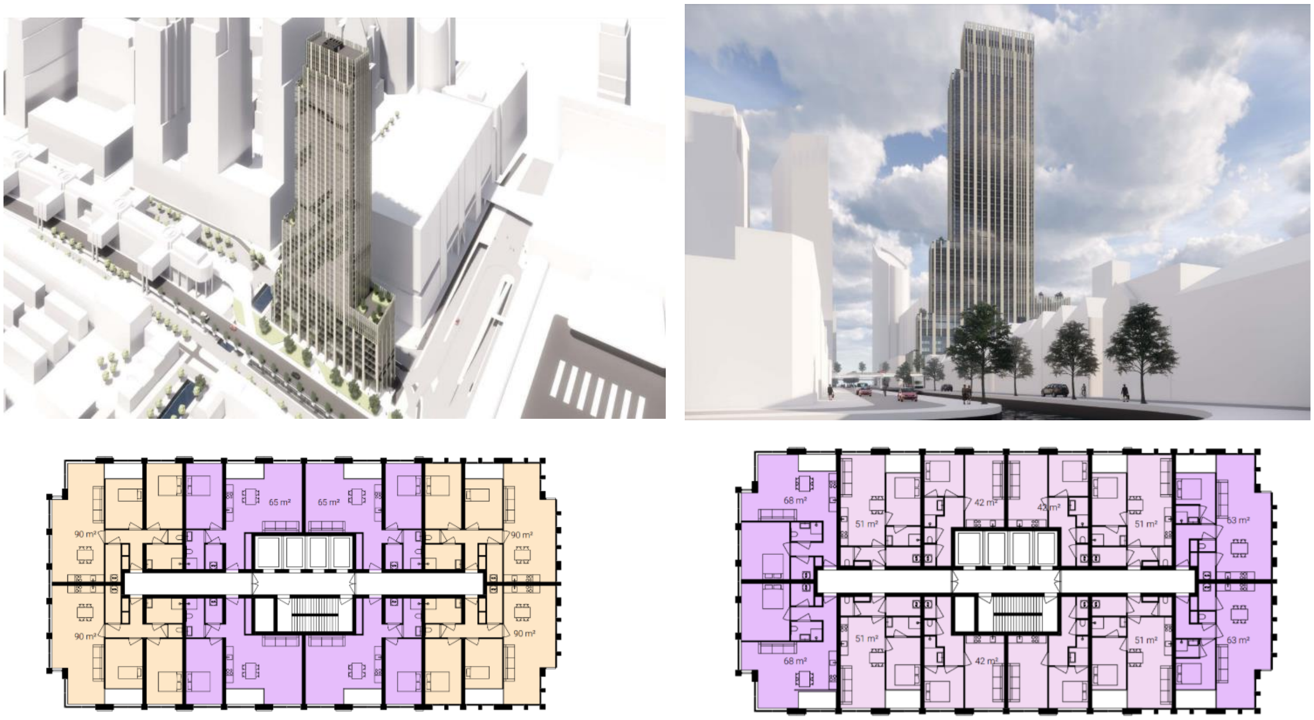


Figure 15: Case study impressions and floor plans (Gemeente Den haag et al. 2020)

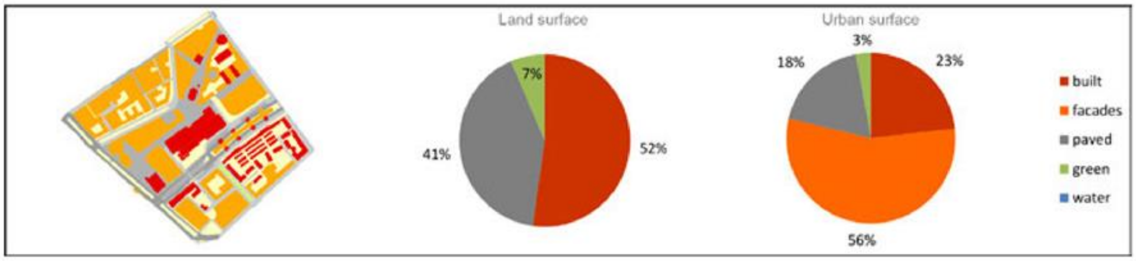


Figure 16: Surfaces of the Stationsbuurt (Kleerekoper 2017)

General Constraints

The general constraints can be divided into two different parts the first being constraints of the size of the design in order to keep it comparable to the existing design. The initial goal is to create an alternative design to the existing design of the Hooghe Rijn. If the alternative design is much smaller or uses different constraints it becomes a lot harder to realistically compare the two. The second general constraint is that of the municipality of the Hague. The Hague has a set of rules for the design of skyscrapers in order to maintain a certain skyline look of the city, following these rules for the first shape designs of the alternative option is a way to ensure a realistic scenario and will filter out option that might work as a 3D building shape but is unable to be build. Finally it also ensures a better comparability with the existing design because it should follow the same rules. This document is called "Eyeline Skyline" (2017, Municipality of The Hague) and it consists of a few different topics, ranging from biodiversity to aesthetics of the building. For this first step in the research only the "typology" rules have a direct impact on the shape of the different building shape options.

The complete constraints can be found in Appendix 6, in short they are:

-Cannot exceed existing plot size

-Must be within 10% of volume in m^3 of the existing design

-Must have similar division of functions compared to existing design

- Minimum of 9 maximum of 25 meters "city layer"

- Maximum tower diagonal length of 56m under 70m of height and 45m diagonal length above 70m

-Tower can only take up 50% of space of the "city layer"

More information on this document can be found in appendix 6.

4.1 Methodology – Software & climate files

Testing ENVI-met

ENVI-met is a program with quite a steep learning curve, simulation times are long, crashes can be frequent and unexpected and results might not always show up. So before modeling and starting the first simulation round a lot of testing was required. This was done for a few reasons, the most important being the stability of the simulations when starting with first simulations. The first simulations are done on three different computers and each take 100+ hours so simulations crashing or failing has an immediate impact on the research timeline. The second reason is all the possibilities within ENVI-met and finding the right balance between detail level and simulation time.

The whole testing setup can be found in Appendix 5, the most important conclusions from the tests were: A base model of the surrounding buildings and foliage that is stable and detailed enough, simplifying the wind speed to cut simulation time in half, the simulation duration, size of the model, weather data input. Etc.

Weather files

The climate and weather around a building have a large influence on its design and energy performance these are therefore essential in a thorough analysis of a building. Even more so because buildings are designed and build to last for quite a long lifespan, that is why it is important to create a testing scenario in which both the current climate situation can be used to evaluate a buildings performance and future scenarios. The weather of a certain year can be compiled into a weather/climate file that consists out of different hourly weather data of a certain location such as: temperature, wind speed/direction, humidity, etc. These weather files can then be used in building/urban simulation programs to set the right circumstances of a certain scenario.

Current climate files are easily accessible via the website of the KNMI (KNMI 2019). However the difficulty comes from finding scenarios for future climates. This is because the climate in say 30 years is extremely hard to predict. Average temperatures can be predicted in a certain range however the extend of human influence over our climate in the future remains uncertain.

In order to use this information in a computer analysis it is not as simple as just increasing the average temperature by the predicted average increase of a previous year, this would be an oversimplification and invalid to use in a building/urban performance simulation.

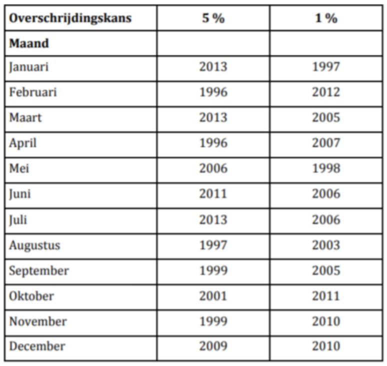
The first option is to use the climate data of the year 2006, this year was extraordinarily hot with temperatures of up to 37 °C degrees and two separate heatwaves in the same summer. In terms of summer temperature, drought and precipitation this summer is very similar to that of a summer in 2050 modeled by KNMI (KNMI 2006, Tank, Beersma et al. 2014). However this would be a simplification.

Another option is to take the climate data of a year from the past decade and use the "CCWorldWeatherGen" tool developed by the Sustainable Energy Research Group from the University of Southampton (Jentsch, James et al. 2013, SERG 2013) specifically designed for building performance simulations. In this tool the old climate data can be combined with the different IPCC climate scenarios and be morphed into a climate data file from the year of the climate scenario (2050). This option even gives the choice of climate scenario to implement. However this tool is not specific to the weather/climate of the case study (The Netherlands).

Finally there is the weather file workflow described in Van Den Ham et al. (2012) that uses the online KNMI transformation program (KNMI 2019). This program converts daily temperature data from historical databases to future climate data according to the four different climate scenarios (see context p.x). However this program explicitly takes the difference between average temperatures and extreme temperatures into account. This program is then used to find the daily difference in temperature between a set of baseline reference temperatures measured between 1976 and 2005 and the daily temperature data of one of the climate scenarios between 2031 and 2060 (more climate data years have become available). Now these daily temperatures increases can be added to the hourly temperatures of currently measured weather data on their respective days in order to create future climate data based on different scenarios.

This method is very similar to the previous except for some important differences. The first being that it uses KNMI data specifically tailored to the Netherlands so measurements of the main weather station De Bilt are being used to compare the data therefore it should be more applicable in this case study. Also because this method calculated changes from historical measured data, the same historical data that is also used to measure compliance with the Dutch building code (Bouwbesluit) such as NEN5060 it can be used to verify if buildings will still be thermally comfortable in future climate scenarios. This combination of climate data transformation and the NEN5060 is perfect to create a weather file to test the case study.

The NEN5060 provides different reference climate years to be used in thermal comfort calculations, these reference climate years consist of months from different years to be as representable as possible. However there is also the more extreme 5% and 1% reference climate years. In order to create the warmest future scenario in terms of temperature the 1% reference can be used as a base to then apply the temperature transformation of the warmest climate scenario from the KNMI tool.



Overschrijdingskans	**5 %**	**1 %**
Maand		
Januari	2013	1997
Februari	1996	2012
Maart	2013	2005
April	1996	2007
Mei	2006	1998
Juni	2011	2006
Juli	2013	2006
Augustus	1997	2003
September	1999	2005
Oktober	2001	2011
November	1999	2010
December	2009	2010

Figure 17: Reference climate years for indoor thermal comfort NEN5060

The starting point is creating a 1% climate reference file for the Hague consisting of 12 months of different years according to the NEN5060. The hourly temperature of this climate file is already determined by the guidelines of NEN5060 and can be easily set up. However in order to create a climate file that realistically resembles a future weather scenario on the location of the case study other climate parameters from the location need to be used in conjunction with the temperatures from the NEN5060 months. So the measured climate data (temperature excluded) on the case study location of the three summer months for example (June 2006, July 2006 and august 2003) will be used together with the

NEN5060 data. This data can be gathered from weather station close to the case study location. Two things were important to keep in mind in this step, the first being that the climate data needed to match the time and date of the months given by the 1% year of the NEN5060 and the second being the location. Unfortunately there is no (accessible) weather data for the center of the Hague that covers those months, so the two alternative options are Rotterdam and Hoek van Holland. The analysis (found in appendix 4) points to Hoek van Holland being the closest match so this data will be used in combination with the temperature of NEN5060.

This file now represents all the weather data of a very hot summer, however in order to create a very hot summer in a future scenario the method described in Van Den Ham et al. (2012) needs to be used. This starts with downloading two sets of data files from the KNMI database the first a measured reference temperature file set and the second a worst case future climate data set. These are then compiled in excel and subtracted to find the daily ΔT in °C. After this the specific ΔT's of the corresponding dates of the 1% weather file are exported and added to the previously created weather file of the case study. This is done by adding the specific daily ΔT to every hourly measurement of that specific day then all of the data is combined in Elements a weather file editor program to create the starting climate file. Now the climate file is ready to be used as an analysis tool.

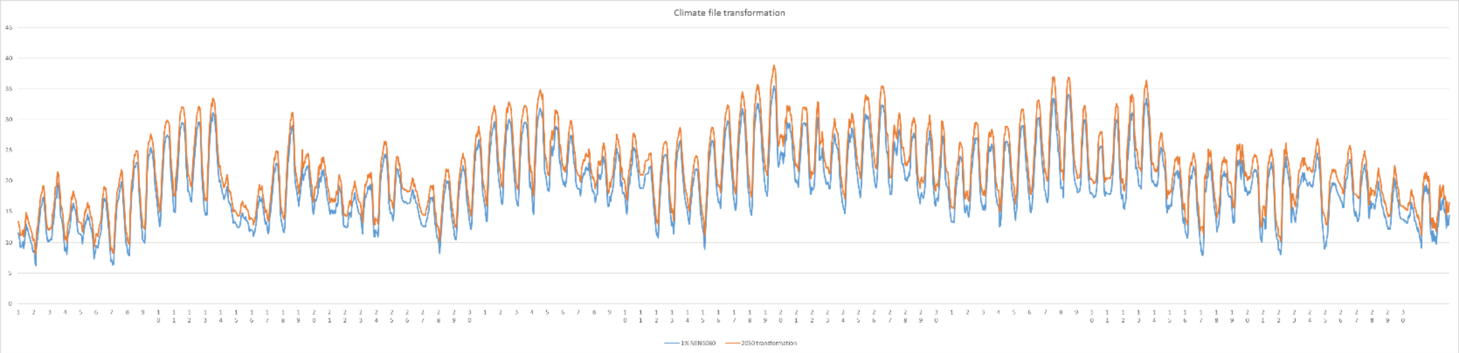


Figure 18: Air temperature change in June, July and August compared to NEN5060 climate file

Something to keep in mind is that these temperatures are based on air temperature. This neglects the effects of wind, humidity and radiation which can change the way people experience these temperatures and can differ from person to person. However only the air temperature is taken into account when testing with the adaptive thermal comfort model so this does not cause any interference.

Implementing weather files in ENVI-met

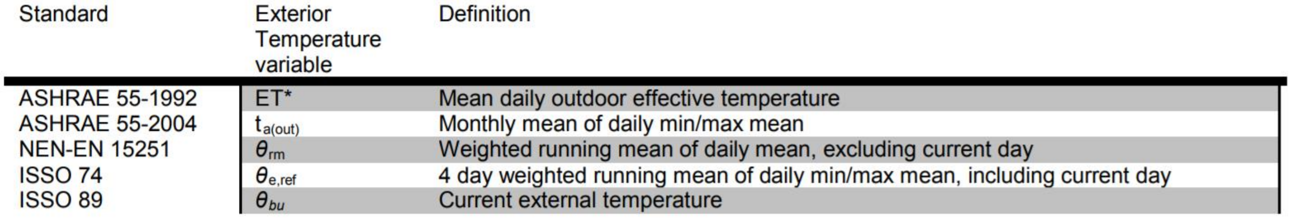
Using weather files in combination with ENVI-met can improve the viability of certain simulation by representing the real life climate of a test location as realistically as possible. In this research the climate files go one step further and are being used as a tool to switch between the urban scale (ENVI-met) and building scale (Design builder). However during the testing phase of ENVI-met several boundaries were discovered. After finishing the model and doing some test rounds it became clear that simulation time would be the limiting factor, even when doing multiple simulation simultaneously on multiple computers. This is because the simulation time is 1:1 with real time, meaning that a weeklong simulation in ENVI-met will take an entire week in real life. However by simplifying the simulation a bit the calculation time can be brought down to about half of that of half time. These settings can be found in appendix 1.

Exporting the weather files in order to analyze them and use them further on in Designbuilder is done by using receptors. These can be placed in the model and will give a numerical output of the temperature every ten minutes at every 2 meters. In every model that used in this research there are four receptors placed around the case study site. This way all of the different microclimates can be easily and precisely be compared by using excel. After analyzing these receptors they can be used to reconstruct the microclimate around the building using the climate file editor program 'Elements'.

Design builder

In order to use an accurate representation of the climate around the building the climate file from the chosen ENVI-met design can be extracted and assembled into a new climate file. Because this climate file comes directly from the receptors around the chosen ENVI-met building it will give an accurate estimation of the microclimate around the building. This climate file will be used as input for a Designbuilder model with its matching simulation period. This also allows for smaller more specialized microclimates based on altitude.

Using the ATG method described in ISSO 74 in combination with Designbuilder can be challenging however. This is because while Designbuilder is equipped with tools to analyze data with some adaptive comfort methods it does not have a function for the ATG method. It mostly uses the ASHRAE adaptive comfort models which are based on the same underlying principal however it uses a different method to define the daily outside temperature. In the table it shows the different ways some methods use to define their daily outside temperature. The method used in this research is also different as it takes the temperatures of the seven previous days into account. In the table ISSO74 can be seen however this is the older method which is not suited for relatively high temperatures.



Standard	Exterior Temperature variable	Definition
ASHRAE 55-1992	ET*	Mean daily outdoor effective temperature
ASHRAE 55-2004	$t_{a(out)}$	Monthly mean of daily min/max mean
NEN-EN 15251	θ_{rm}	Weighted running mean of daily mean, excluding current day
ISSO 74	$\theta_{e,ref}$	4 day weighted running mean of daily min/max mean, including current day
ISSO 89	θ_{bu}	Current external temperature

Figure 19: Difference in calculating the exterior temperature in different adaptive comfort standards. (ter Mors 2010)

Because of this difference the ATG method analysis will be done via Microsoft Excel. In an Excel sheet the daily 7 day weighted outside temperature can be calculated and plotted against the hourly inside temperatures from the resulting data of Designbuilder. This results in a graph that shows the percentage of hours outside the comfort levels and thereby also the ATG building class of the design.

4.2 Shape design

The research by design process begins with the building shape, the building shape is a combination of three different aspects of passive cooling from the framework of Prieto, Knaack et al. (2018) which is used as the categorization of this research. Building shape is the first step in this research combining: microclimate, building layout and orientation, in the framework these are combined as site design but because most of the site is already pre-determined the focus in this step will be the shape of the design which includes building layout and orientation, this shape will then be tested on its impact of the microclimate.

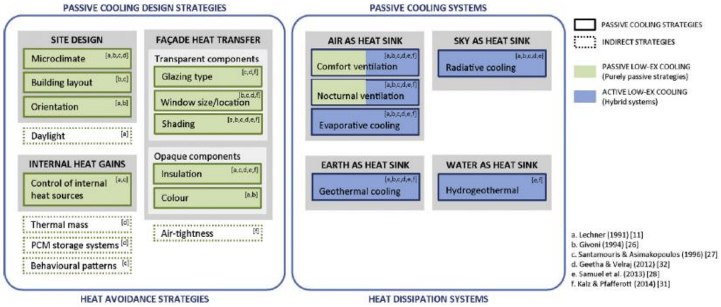


Figure 20: Passive cooling categorization framework. (Prieto, Knaack et al. 2018)

Because the area of an urban city center is extremely complex in terms of microclimate the different building shape designs can't just be based on implementations from literature or a single analysis. Where something might work in an open field it might not work in a residential area or a larger city center like the location of the case study. In order to get an idea of what building shapes might work to lower the temperature of the urban microclimate in the area of the case study different versions need to be tested in these complex environments.

Testing building shapes in complex urban environment can be done in ENVI-met however not without some limitations of the software such as calculation time. In the testing phase of ENVI-met it was concluded that for a simulation with sufficient inputs/enough complexity the calculation time will be around half of what it would take in real time. This means that a 24 hour simulation cycle will take around 12 hours in real time with a 30 minute setup time however the setup time is not influenced by the duration of the simulation.

These calculation times combined with the fact of limited computer time use of computers with ENVI-met licenses at the TU Delft means that a limited number of shapes and sizes can be tested. However with knowledge from existing literature, the ENVI-met analysis of the existing design and the constraints given by the case study many building shapes/designs can be eliminated. Based on these parameters three different versions will be designed and tested in ENVI-met with the same external inputs.

Building shape - Three proposed versions

After careful analysis of the existing literature and the current design a total of three different alternative building shapes have been designed. Every design focusses on solving different aspects/causes of the urban heat island effect. In order to accurately compare these designs and determine which shape lowers the temperature of the microclimate the most.

Shape 1: HR11

This design is focused on making the building as short as possible while still following the Eyeline Skyline rules and the floor space requirements to maximize the sky view factor of the surrounding surfaces. In order to do this while following the different constraints two towers were used instead of one, thereby minimizing the profile of the building in its urban surroundings. These two towers can then be further designed with the research of Kleerekoper (2017) that experimented with setups consisting of two buildings situated close to each other of similar and different lengths. A lay out where the larger building shades the smaller building and additional airflow is created between these buildings can result in an improved urban microclimate. In shape 1 both of these approaches are combined in a single shape while still adhering to the restrictions set by the research boundaries. The question of this shape will be if the increase in compactness will make a difference in the sky view factor large enough for a noticeable temperature decrease and of course if the two towers lay out will have a significant effect on the local temperature.

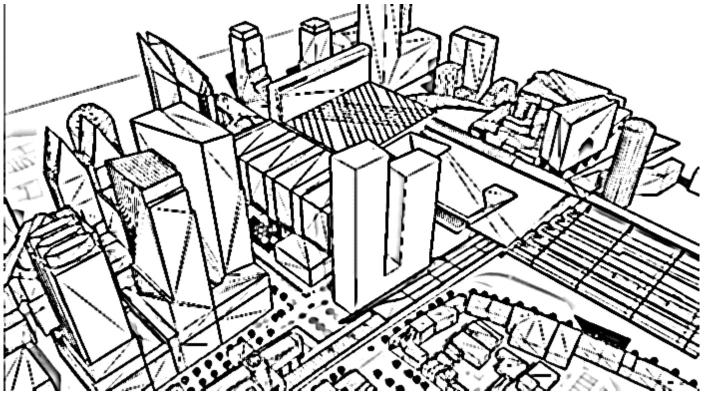


Figure 23: Hooghe Rijn model number 11

Shape 2: HR12

Shape 2 is based on an optimized shading solution for both the facade and the area around the building which suffers from the urban canyon effect. Using the shading analysis as a guideline a shape can be found that is tallest on the south/west side of the plot and makes most use of the shadow casted by the surrounding buildings. This shape also blocks solar radiation reaching the alleyway during the afternoon, which should alleviate its urban canyon effect found in the ENVI-met analysis. To be able to compare this shape best with the original design similar divisions of masses have been made this can be seen in the horizontal lines in the shape. The question of this shape is whether the improved shading is enough to make a temperature difference also because this shape exposes a large portion of the building to long solar radiation hours.

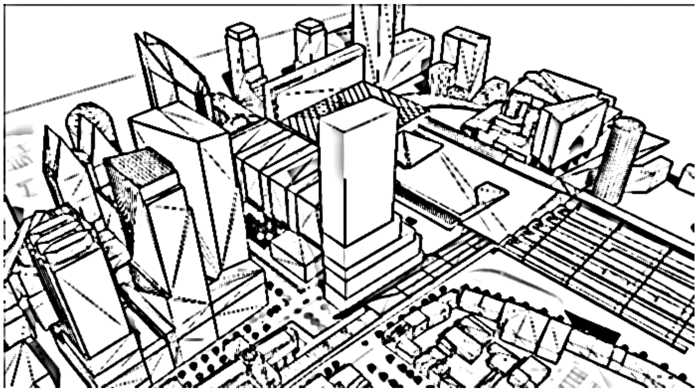


Figure 24: Hooghe Rijn model number 12

Shape 3: HR13

The final shape design is focused on exposing as much of the building as possible to the dominant wind orientation. In a city like the Hague which is situated very close to the north sea there is a clearly dominant wind direction (south-west). By mirroring shape 2 only the smallest side of the building is not directly exposed to the dominant wind side whereas all the other facades face direct wind from the north sea. Mass blocks similar to shape 2 are also used in this design to keep the comparison as realistic as possible and to eliminate other interfering factors. The question of this shape if the cooling by wind is enough to offset the heating on the south facing facades, especially during hotter days where the wind speed can be significantly lower.

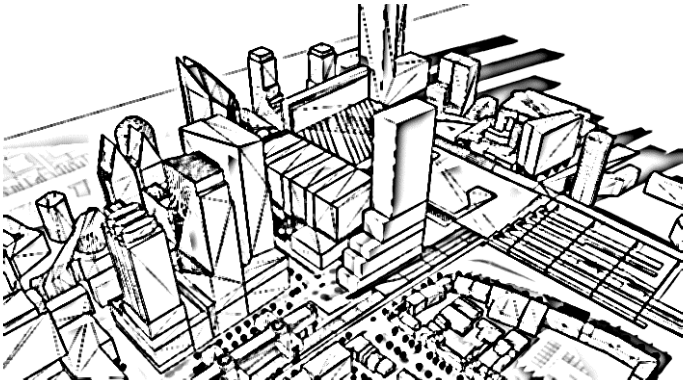


Figure 25: Hooghe Rijn model number 13

4.3 facade design

The next step in this research is to analyze the facade possibilities starting from the determined shape of the building from the previous step. This is done by creating three different facade options based on the literature study and via the passive design categorization of Prieto, Knaack et al. (2018) where this step will focus on the facade heat transfers part of categorization. These facade options will then be simulated with the exported climate data of the microclimate around the determined shape of building from the previous step and be analyzed on their indoor thermal comfort performance according to the ATG method of adaptive comfort (ISSO74, 2014).

These different facade options will be tested on a representative dwelling in this building shape in order to make an assessment of the ramifications of the facade on the interior thermal comfort. Designing a facade that will cover the entire building based on simulation performance will need more than just a single dwelling simulation in order to be accurate. Therefore the decision is made to use two simulated dwellings one at a low altitude (below 22,5m) and one at a high altitude (52,5-77,5m). This is done because of the difference in microclimate between the lower and upper part of the building determined in the previous chapter. These two different simulation setups will be used with the same dwelling but on a different altitude and with a different microclimate input file. This also allows changes in the facade when reaching higher floors of the building to optimize the facade to its microclimate.

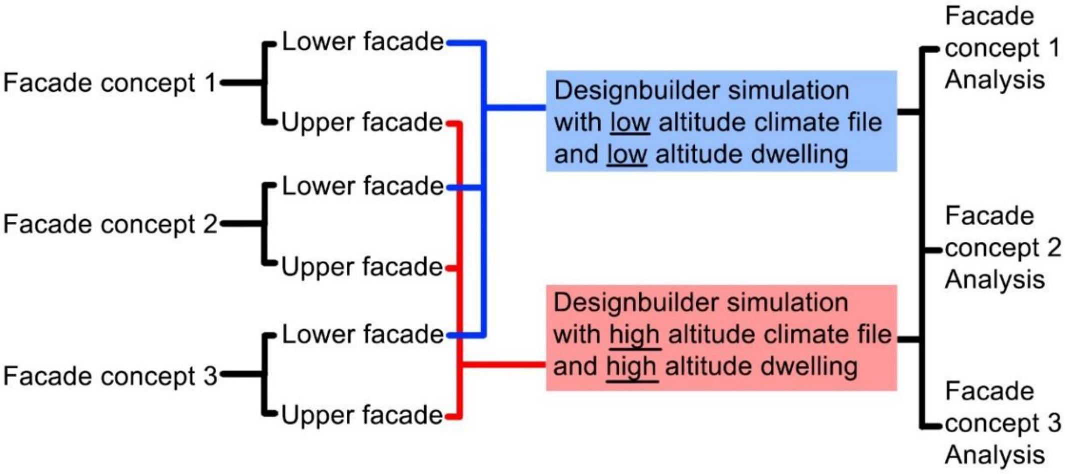


Figure 26: Facade analysis framework

However creating two completely different facades for the same building is not desirable as well. This is why the both facade parts are based on an overlying facade concept, this determines the general strategy of the facade design, materialization, sizing of elements etc. Within this facade concept smaller changes can be made to accommodate the different circumstances that the changing microclimates can bring.

In order to compare the different facade concepts and model them as realistically as possible in designbuilder different categories that translate from the literature to designbuilder are used. The aspects from the categorization of Prietro, Knaack et al. (2018) are: glazing type, window size/location, shading, insulation, colour and air-tightness. These categories can be simplified to their window/wall ratio, thermal conductivity, etc.

Design builder input

Aspects such as internal heat gains from equipment and occupancy are kept identical between facade options. These are set at an occupancy of 0,065 people/m^2.

Glazing Type – This is done via the openings tab in Design builder where glazing type per opening can be specified. This specification is done by choosing existing glazing products or filling in custom data. The parameters for this category are U-value, g-value and light transmission. These are either taken from existing products inside Design builder or custom made by filling in the parameters from glazing products not present in Design builder.

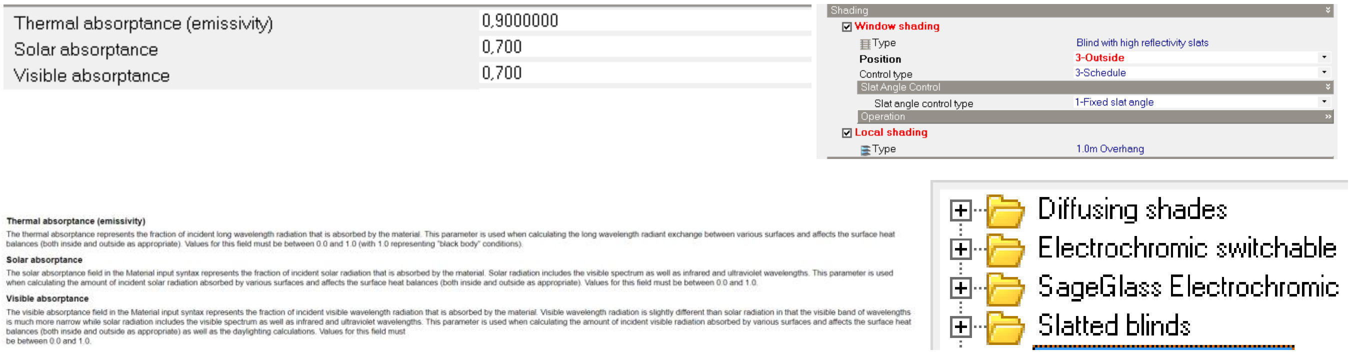
Window size/location – This is specified in Design builder using the openings tab. Here the size and location can be specified per facade. The specific parameter to determine the facades per concept is the window to wall ration of both the entire dwelling and the individual facade. Openings in these dwellings are specified in the ventilation category.

Shading – This category is not determined by set parameters but with custom inputs as the options are quite extensive in Design builder. Some limitations are in place however only direct window shading and local shading is used, the window shading is only external. The parameters to be defined by the facade are the schedule of the shading and the type of shading.

Insulation - The opaque components are all done via the construction tab in Design builder where only the insulation (U or R) value and the external colors are used as inputs. The minimum insulation value has to adhere to the Dutch building code according to the NTA 8800. However as a parameter for the facade options the input will be a single R value for the opaque part of the façade.

Color – This category determines how the external layer of the facade will interact with external solar radiation. However in Design builder the color of the material has no effect on its actual color in the simulation as this is not simulation in this way. Instead it uses a combination of: Emissivity, solar absorptance and visible absorptance. These values will be used as parameters for this category.

Air-tightness – This value will be set for all of the facades as it is not really part of a façade concept. For this parameter the base value in Design builder will be used for ‘excellent’ airtightness due to it being a new construction.



Thermal absorptance (emissivity)	0,9000000
Solar absorptance	0,700
Visible absorptance	0,700

Shading

☑ Window shading

Type: Blind with high reflectivity slats

Position: 3-Outside

Control type: 3-Schedule

Slat Angle Control

Slat angle control type: 1-Fixed slat angle

Operation

☑ Local shading

Type: 1.0m Overhang

Thermal absorptance (emissivity)

The thermal absorptance represents the fraction of incident long wavelength radiation that is absorbed by the material. This parameter is used when calculating the long wavelength radiant exchange between various surfaces and affects the surface heat balances (both inside and outside as appropriate). Values for this field must be between 0.0 and 1.0 (with 1.0 representing "black body" conditions).

Solar absorptance

The solar absorptance field in the Material input syntax represents the fraction of incident solar radiation that is absorbed by the material. Solar radiation includes the visible spectrum as well as infrared and ultraviolet wavelengths. This parameter is used when calculating the amount of incident solar radiation absorbed by various surfaces and affects the surface heat balances (both inside and outside as appropriate). Values for this field must be between 0.0 and 1.0.

Visible absorptance

The visible absorptance field in the Material input syntax represents the fraction of incident visible wavelength radiation that is absorbed by the material. Visible wavelength radiation is slightly different than solar radiation in that the visible band of wavelengths is much more narrow while solar radiation includes the visible spectrum as well as infrared and ultraviolet wavelengths. This parameter is used when calculating the amount of incident visible radiation absorbed by various surfaces and affects the surface heat balances (both inside and outside as appropriate) as well as the daylighting calculations. Values for this field must be between 0.0 and 1.0.

Figure 27: Designbuilder options

Natural ventilation setup

There are two general approaches to modeling natural ventilation in Design builder: scheduled and calculated. In this simulation the calculated method is used this because it will make use of the wind data from the climate file of the previous step in combination with the modelled windows and openings from the facade model representing an accurate estimation of the natural ventilation capabilities of the design.

In the HVAC tab the natural ventilation without heating and cooling is selected, heating is necessary for buildings in the Netherlands however this simulation will be about a summer week and not be needed. Parameters for natural ventilation can be specified by setting the percentage of windows that are openable and their schedule. The model will assume perfect handling of the openings meaning that whenever the outside air temperature will exceed the inside temperature the natural ventilation will stop and whenever the outside air temperature drops back below the inside temperature it will resume natural ventilation. Finally mechanical ventilation will be turned on and put on minimum fresh air per person in order to create demand for fresh air. The term mechanical ventilation is misleading in this context and would be more equivalent to “hygienic ventilation”. This step ensures that there is still demand for fresh air during hotter times of the day and will avoid the simulation closing the windows for an extended period of time.

Geometry setup

The entire building is modelled in order to accurately represent geometry and incorporate two representative dwellings. Two dwellings have been modelled of exactly the same size (66 square meter) on the western facing part of the building. The first dwelling is on the 3rd floor and the second dwelling on the 53rd floor. The rest of the building is modelled as adiabatic and will not be included in the thermal calculations. The surrounding dwellings on the same floor have been modelled with a similar facade.

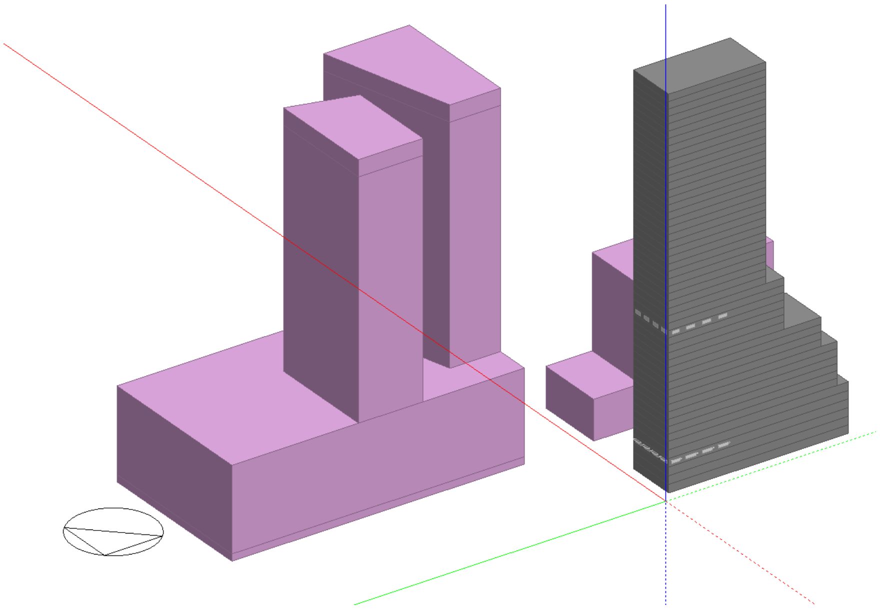


Figure 28: Designbuilder shape and surrounding buildings including The lower and upper floor with windows

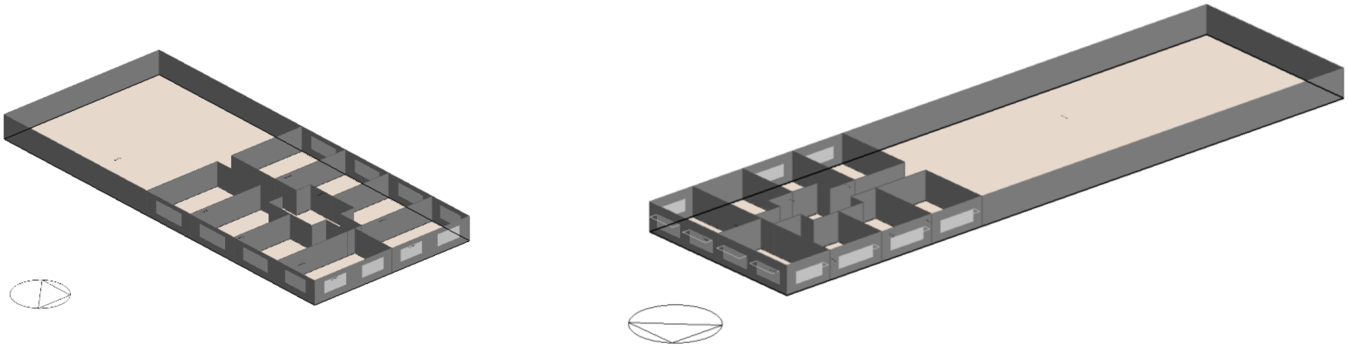


Figure 29: Designbuilder floor plans of the lower (right) and the upper (left) floors

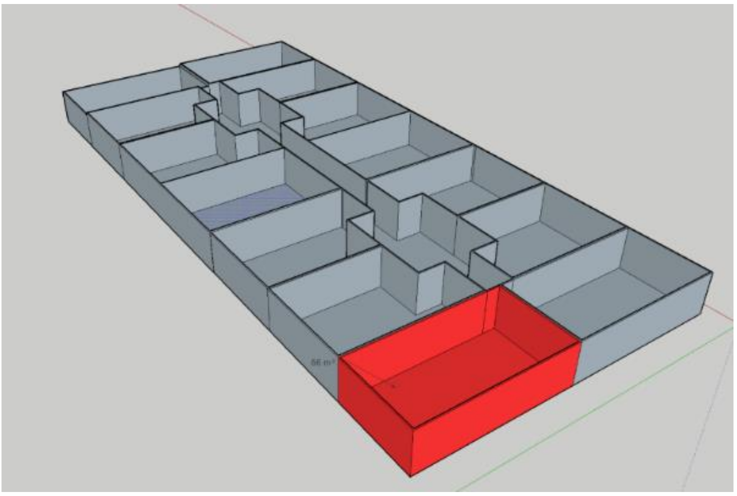


Figure 30: Sketchup draft of floorplan dimensions

Facade concept 1

The first facade concept is based on maximizing the amount of airflow and using a high window to wall ratio combined with a high percentage of openable window space. Due to the high amount of window space in the facade shading is necessary to control the indoor temperature. However due to daytime (mornings and evenings) ventilation it cannot interfere with airflow therefore overhangs are used situated over the windows. Due to the use of overhangs on windows it is necessary for the glass to use some coating as it will be subject to some solar radiation the overhang does nog cover. Standard NTA8800 building code insulation is used in addition to this. The external layer of the facade will need a high emissivity in order to minimize the solar gain and lower the temperature of the microclimate around the building. This is done by using greenery on the closed parts of the facade or white painted aluminum panels depending on the height.

Glazing Type – Coated glass with a good U-value necessary: SGG XT 60-28 6/16/4 with an U value (including sills) of 1,349 W/m^{2}K. G-value = 0,275

Window size/location – Extensive ventilation strategy , many available windows: window to wall ratio of 50% with 50% opening of glazing area.

Shading – Due to high amount of windows and daytime ventilation strategy overhangs located above each window with a length of 0,5 meter are used.

Insulation – Due to heavy ventilation no excessive insulation is needed: the minimum insulation value for the facade is used that complies with the Dutch building code (U=1/4,7= 0,21 W/m^{2}K)

Color – High emissivity: Opaque parts of the facade can be either covered in white painted aluminum or use a green facade system. This is done depending on their altitude with regard to their maintenance and effect on their surroundings.

Air-tightness – This is set at excellent for all of the facade concepts due to the newness of the building and its build quality.

Upper/lower layer difference: floors on higher altitudes are fairly similar however there are some minor differences. UHI-mitigation measures are significantly less effective and unnecessary because the UHI-effect is negligible at these altitudes. However the temperature is also lower at these higher altitudes therefore an increase in window to wall ratio can be realized. This increase takes the window to wall ratio from 50-60% and the opaque parts of the facade are covered in white painted aluminum instead of a green façade system.

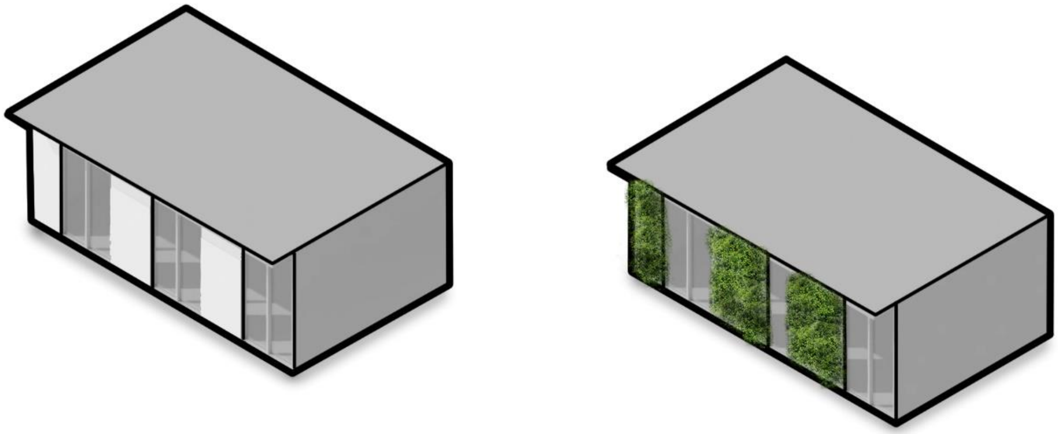


Figure 31: Lower facade (right) and upper facade (left)

Facade concept 2

The second facade concept is based on nocturnal ventilation. This means that during the day natural ventilation is minimal because the outside air probably has a higher temperature than the inside air. However during the night when the outside air has cooled down the natural ventilation takes place. In order for this strategy to work it is important to have a facade with a high insulation value to keep the temperature low during the day for both the transparent and oblique parts. Ventilation mostly takes place when solar radiation reaching the windows is minimal therefore shutters or blinds are a good shading option because these are very effective and do not interfere with the ventilation method. This is because there is no interference between shading elements and natural ventilation. Finally the emissivity of the façade should be maximized in order to combat overheating or be used to cool down the microclimate around the building.

Glazing Type – During the day the windows are mostly closed, this enables the design to use efficient solar shading such as blinds during times of heavy solar radiation gain. Therefore tints and lowE coatings are not used in combination with these shading types. A high U-value is vital however: SageGlas Climatop classic SR2.0 No Tint triple glass U=0,688 W/m^{2}K. g-value= 0,365

Window size/location – In order to keep the building as thermally comfortable as possible during high temperature days the window to wall ratio should be relatively low but still large enough to allow for enough natural ventilation. Therefore a window to wall ratio of 30% is used with 50% openable.

Shading – The shading can be used during the day without interference from natural ventilation, Therefore blinds with highly reflective slats are used set to block solar radiation.

Insulation - Due to nocturnal ventilation strategy extensive insulation is needed. Therefore a facade with an R_c of 6 is used (U=1/6= 0,167 W/m^{2}K).

Color – Similar to that of the previous facade where minimizing solar gain is the priority. So either white painted metal coverings as the external part of the facade are used or a green wall system.

Air-tightness – This is set at excellent for all of the facade concepts due to the newness of the building and its build quality.

Upper/lower layer difference: The difference between the facade on the upper side and the lower side comes from the difference in external factors. The most important factor of this is outside temperature which is lower on the upper side of the facade. Therefore a higher window to wall ratio can be realized, this is set at 70%. Similar to the other facade the green facade can be switched to white painted metal/aluminum panels because of the reduced effectiveness on the microclimate.

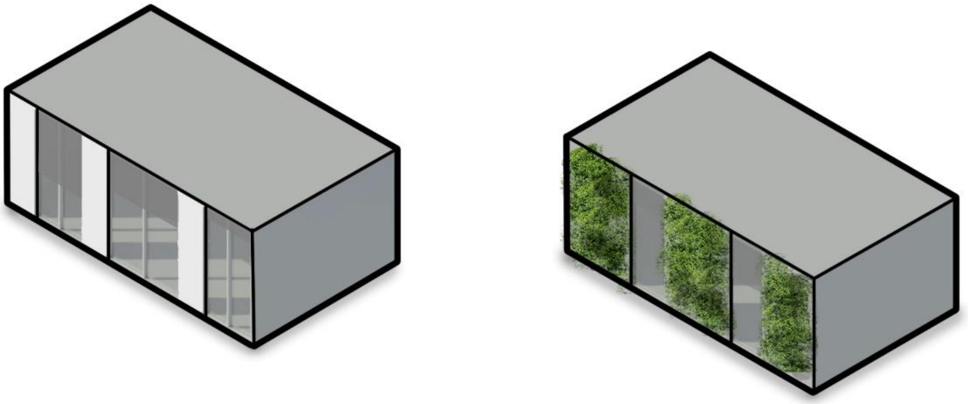


Figure 32: lower façade (right) and upper façade (left)

Facade concept 3

The third facade concept is based around a more classic design of a skyscraper facade with a lot of glazing combined with new design elements such as green walls to minimize its effect on the microclimate. In order to still ventilate naturally a significant percentage of the glazing has to be openable. The glazing in this facade is extensive and therefore needs a high insulation value, this combined with a similarly high insulation value ensures comfortable temperatures. Another aspect of this extensive glazing is the need for solar shading, as it covers a large part of the facade and therefore endures a lot of solar radiation so shading in the form of screens or slats is implemented. Added to this is the fact that because there is so much glazing a lower percentage of openable windows is needed. Finally the color will have a similar approach to that of the previous facade focusing on minimizing the absorbance of solar radiation or lowering the temperature.

Glazing Type – Due to extensive glazing of the façade good insulating glazing is needed however a tint is not necessary because of the use of shading screens: SageGlas Climatop classic SR2.0 No Tint triple glass. U=0,688 W/m^{2}K. g-value= 0,365

Window size/location – 70% window to wall ratio with a 50% openable rate

Shading – Throughout the day extensive shading is needed for the glazing in the building. Blinds with highly reflective slats are used set to block solar radiation are used.

Insulation –In order to maintain the indoor thermal comfort from influence of solar radiation during the day high insulation values are needed: Therefore a facade with an R_c of 6 is used (U=1/6= 0,167 W/m^{2}K).

Color – Similar to that of the previous two facade where minimizing solar gain via the facade is the main priority. White painted metal coverings as the external part of the facade are used or a green wall system depending on the parts of the façade that suffer the most from the UHI-effect.

Air-tightness – This is set at excellent for all of the façade concepts due to the newness of the building and its build quality.

Upper/lower layer difference: Because of the lower temperatures in the higher altitudes around the building a higher thermal conductance can be implemented and thereby increasing the window to wall ratio to 90%. This is combined by using the white aluminum/steel panels instead of the green façade system, this is because of the lessened effect of the UHI-effect at those altitudes.

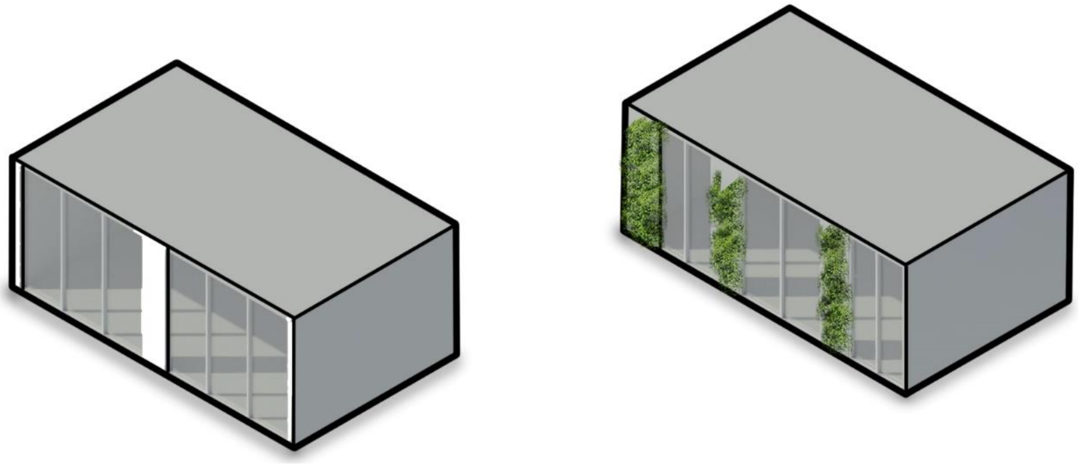
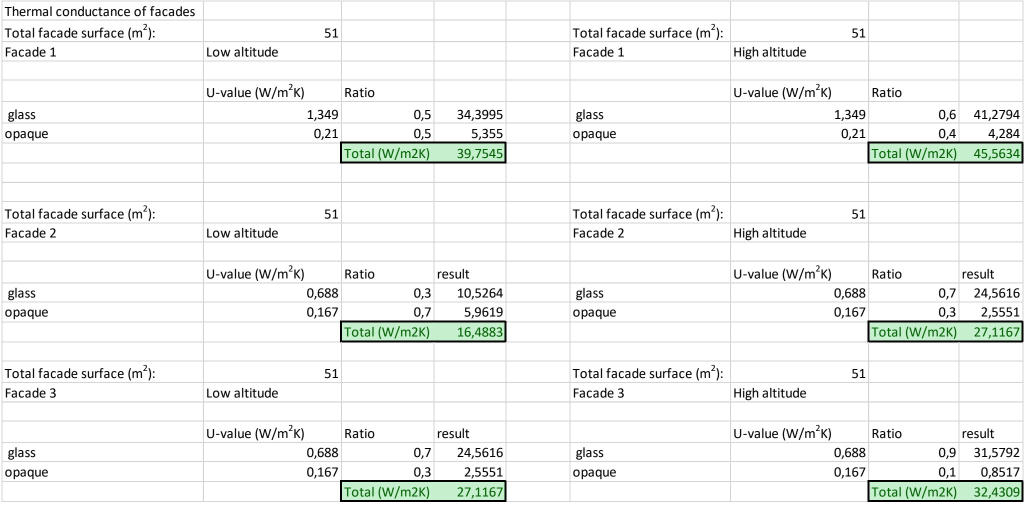


Figure 33: Upper façade (left) and lower façade (right)

In order to get a complete image of the different facade options and their differences a small hand calculation is used to compare the thermal conductance of the facades. The exact same dwelling is used in these tests, the only difference is the altitude between the high and low altitude dwellings.



Thermal conductance of facades								
Total facade surface (m^2):	51				Total facade surface (m^2):	51		
Facade 1	Low altitude				Facade 1	High altitude		
	U-value (W/m^{2}K)	Ratio				U-value (W/m^{2}K)	Ratio	
glass	1,349	0,5	34,3995		glass	1,349	0,6	41,2794
opaque	0,21	0,5	5,355		opaque	0,21	0,4	4,284
		Total (W/m2K)	39,7545				Total (W/m2K)	45,5634
Total facade surface (m^2):	51				Total facade surface (m^2):	51		
Facade 2	Low altitude				Facade 2	High altitude		
	U-value (W/m^{2}K)	Ratio	result			U-value (W/m^{2}K)	Ratio	result
glass	0,688	0,3	10,5264		glass	0,688	0,7	24,5616
opaque	0,167	0,7	5,9619		opaque	0,167	0,3	2,5551
		Total (W/m2K)	16,4883				Total (W/m2K)	27,1167
Total facade surface (m^2):	51				Total facade surface (m^2):	51		
Facade 3	Low altitude				Facade 3	High altitude		
	U-value (W/m^{2}K)	Ratio	result			U-value (W/m^{2}K)	Ratio	result
glass	0,688	0,7	24,5616		glass	0,688	0,9	31,5792
opaque	0,167	0,3	2,5551		opaque	0,167	0,1	0,8517
		Total (W/m2K)	27,1167				Total (W/m2K)	32,4309

Figure 34: Thermal conductance of the different facade options

Climate file transformation

In order to analyze the facades on their indoor thermal comfort performance an analysis is done according to the method described in ISSO 74 (see literature earlier in this report). The method described in ISSO 74 is the ATG method or a way to assess thermal comfort via the adaptive comfort model.

In order to make an accurate assessment of the indoor thermal comfort of these facades an outdoor running mean temperature is needed. This outdoor running mean temperature is a weighted average outdoor temperature from the last seven days. However the data from the ENVI-met analyses only covers 7 full days (24 hours per day) meaning that this analysis can only be used on the last day of data set. This does not provide enough coverage to accurately make an assessment of the thermal comfort. However when comparing the two climate data files a constant difference between the daily average temperatures can be seen. The data that is used for this analysis (daily average outside temperature) differs around 0,8 °C per day for the lower altitude climate file and 1,1 °C per day for the higher altitude climate files. Therefore it is possible to use this same constant ΔT to transform the temperature of the days before the simulation week in order to get the weighted average outside temperatures.

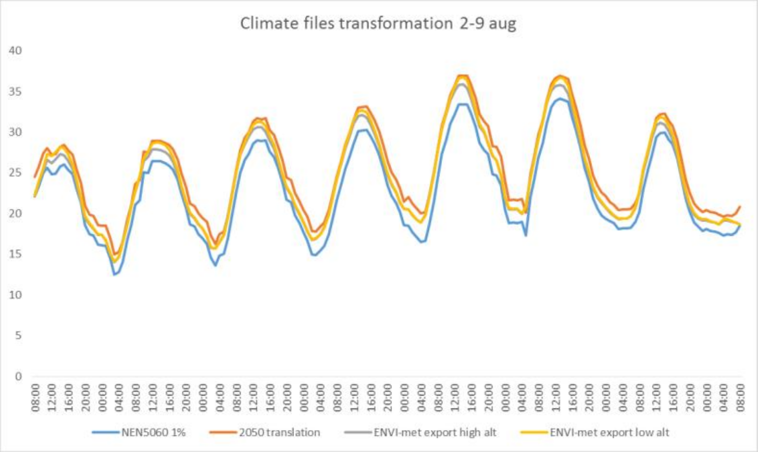


Figure 35: Climate file transformation throughout different steps

The complete analysis data of these climate files can be found in in appendix 8. In the image below a clear overview is given on these data transformations done in order to get a usable dataset for the ATG analysis. The overview on the next page gives the transformation for a low altitude climate file which is 0,8 ^{o}C where a high altitude climate file would be 1,1 ^{o}C.

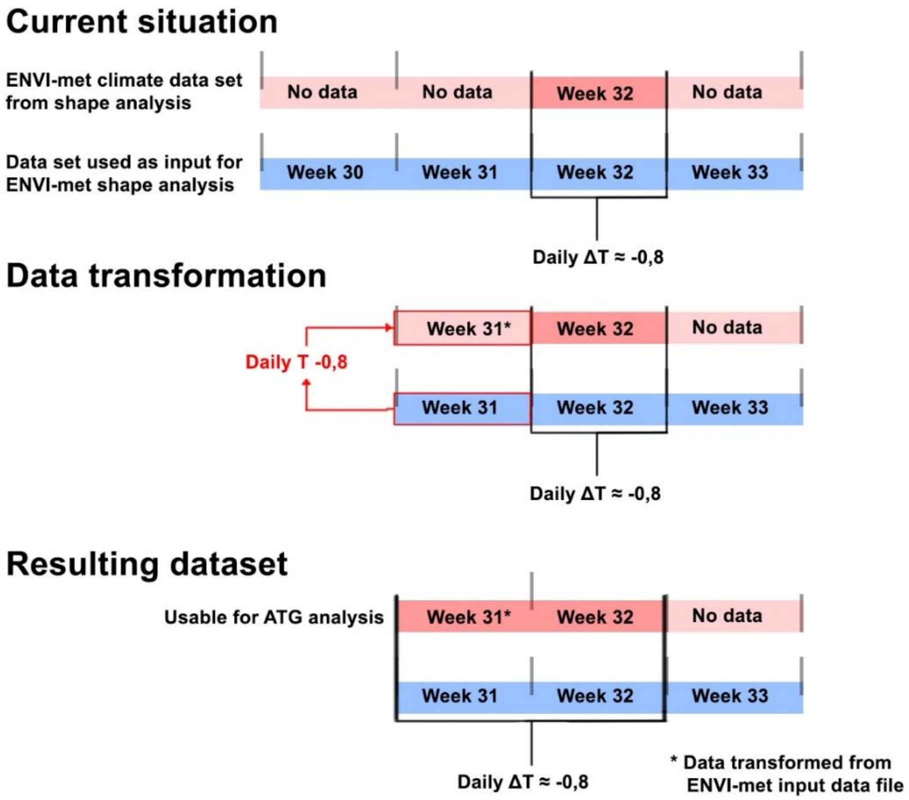


Figure 36: Climate file data transformation for ATG analysis

Consequences of data transformation

After these data transformations there are a few points to address regarding the consequences this has for the results of the ATG analysis. The daily difference in temperature between the two climate files is large enough to not use them interchangeably, and given that the indoor temperature data gathered by the Designbuilder simulation used the shape analysis climate file as input it is best if this climate file is also used (as best as possible) to assess its thermal comfort.

The data used for the actual comfort hours are still measured from the analysis with the corresponding climate file from the shape analysis. The transformed data is used only to establish a running mean outdoor temperature.

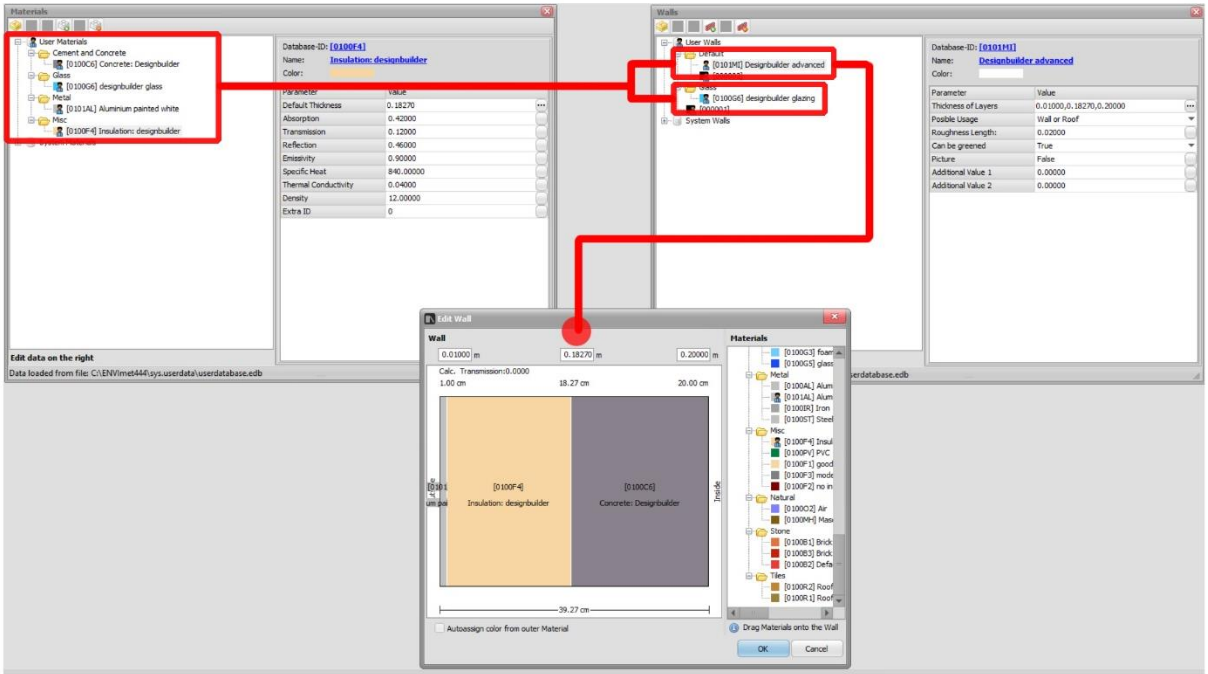
However it will still impact the results of the ATG analysis. It is now assumed that the week before the Designbuilder analysis the daily ΔT will stay similar to that of the analyzed week (Heatwave temperatures). The weather is unpredictable and it is unknown if ENVI-met would give similar temperature results for that week. The research however seeks to use a hot future weather scenario and that is not really compromised by this data transformation. Therefor the results will be impacted by this transformation but not in a way that invalidates the results for use in this research.

2.4 New microclimate analysis

The next step in process is taking the selected facade concept and translating this to ENVI-met that analyze its effect on the microclimate. The ENVI-met simulation will use the same settings and parameters as the previous ENVI-met simulations except for a few changes.

These changes have to do with the way ENVI-met simulates facades in its engine. Previously only generic masses were used with identical properties in a 2.5D configuration. In order to properly model the facade however the model needs to be transformed to a fully 3D one. In this 3D model of ENVI-met different materials can be assigned to different facade parts. To recreate the facade from the previous step as close as possible custom materials are made with the same properties as the materials in Designbuilder. These materials are then combined into a wall that can be placed as a facade of the building shape in ENVI-met. This is done for both the opaque and transparent sections of the facade, for the green wall a standard model from ENVI-met is used. The process of creating these custom facade parts is shown below and uses the database manager program from the ENVI-met software suite.

Putting the facade pieces on the building shape according to the Designbuilder model is quite straightforward, however an exact split between the upper and lower facade was not yet established. In this model the lower facade is implemented until 20 meters in height. The lower facade uses the Designbuilder opaque facade elements covered with a green wall. This is due to the intensity of UHI-effect being located at lower altitudes and therefore the green wall measures being the most effective. In addition to this is the fact that green walls are harder to maintain and grow the higher they get so the cutoff point is set at 20 meters. After this the high altitude variant of the facade is implemented where the opaque parts will not have green wall covering and the window to wall ratio is 70%.



Database-ID: [0100F4]
Name: Insulation: designbuilder

Parameter	Value
Default Thickness	0.18270
Absorption	0.42000
Transmission	0.12000
Reflection	0.46000
Emissivity	0.90000
Specific Heat	840.00000
Thermal Conductivity	0.04000
Density	12.00000
Extra ID	0

Edit data on the right
Data loaded from file: C:\ENVImet444\sys.userdata\userdatabase.edb

Database-ID: [0101MI]
Name: Designbuilder advanced

Parameter	Value
Thickness of Layers	0.01000,0.18270,0.20000
Posible Usage	Wall or Roof
Roughness Length:	0.02000
Can be greened	True
Picture	False
Additional Value 1	0.00000
Additional Value 2	0.00000

0.01000 m
0.18270 m
0.20000 m
Calc. Transmission:0.0000
1.00 cm
18.27 cm
20.00 cm
[0100F4] Insulation: designbuilder
[0100C6] Concrete: Designbuilder
39.27 cm
☐ Autoassign color from outer Material

Figure 37: Creation of custom materials and walls in ENVI-met

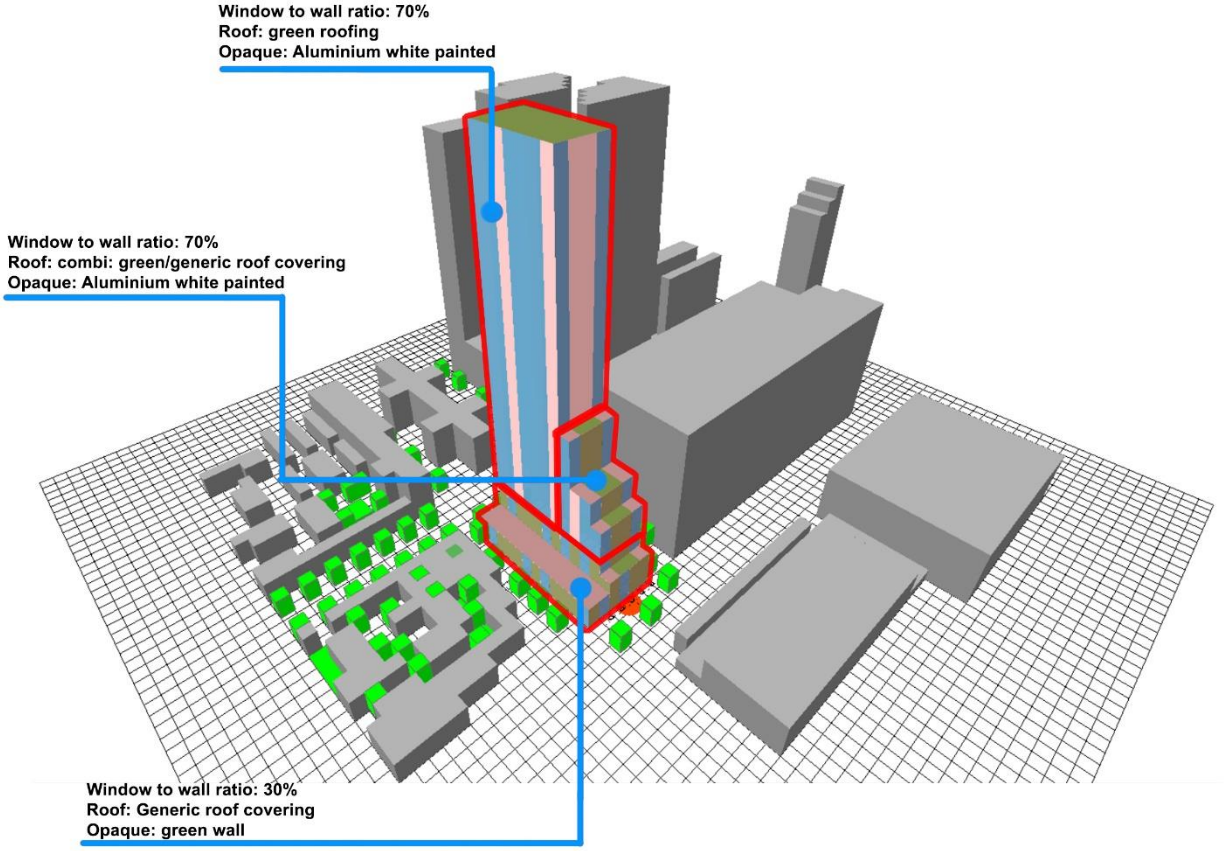


Figure 38: Translation of facade option to ENVI-met model

In this image the division of facades and its implementation in ENVI-met can be seen. Additionally the surroundings were also optimized to reduce the effects of the UHI-effect. However the initial design already implements trees, vegetation elements and water where it can so only a few extra trees were added. Further changes would create unrealistic surroundings for a building in this location.

5. Results – current design

This analysis is only focused on the shape of the current design and its impact on the urban micro climate. In ENVI-Met a few different aspects of the urban heat island effect can be analyzed, the first being the air temperature which can be seen in in figure 41 and 42. It shows that around the building design the temperatures tend to be a bit higher but not drastically compared to other areas, the air temperature information combined with the air speed information from the same time period. Here it shows that on the right corridor the wind flows faster and it is still quite warm this is also due to increased shading on the left area. And both the left and right area of the current design of the building are part of the problem areas in the urban geometry.

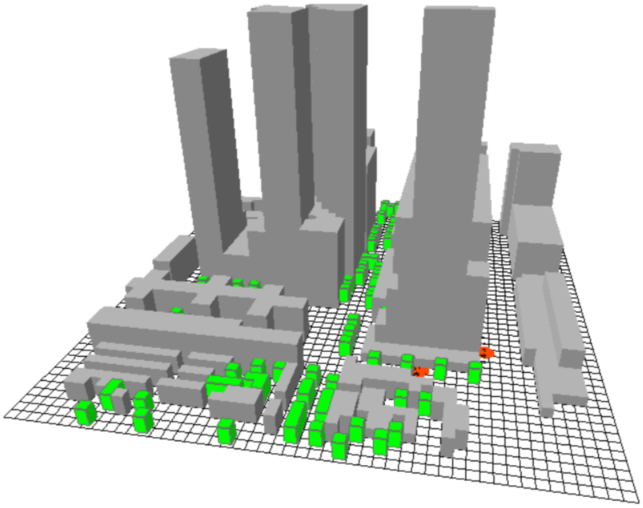


Figure 39: ENVI-met model

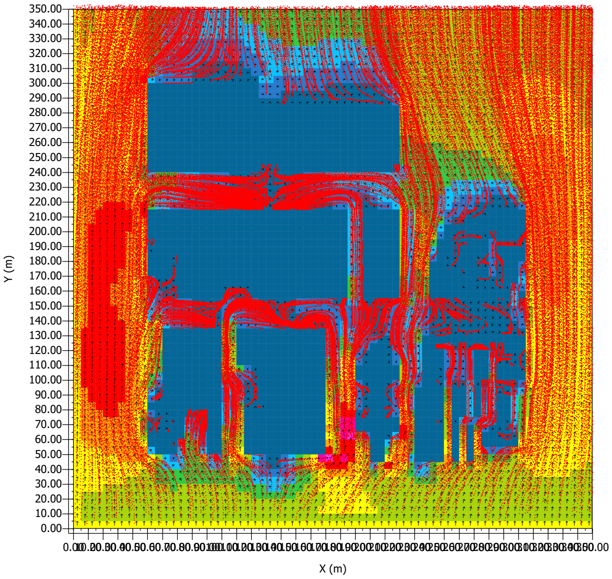


Figure 40: Airflow around the design

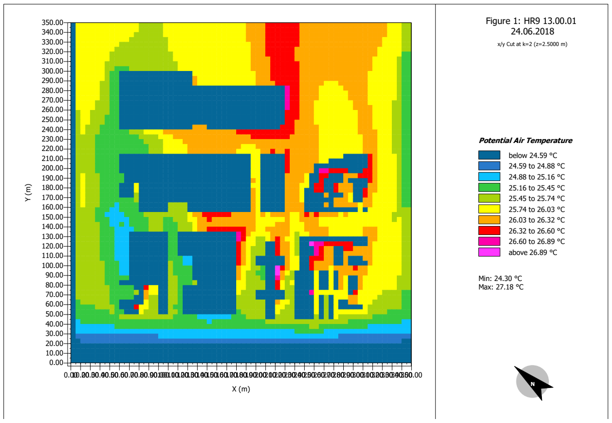


Figure 41: Potential air temperature 13:00 Showing the hotter area’s and the effect of the UHI

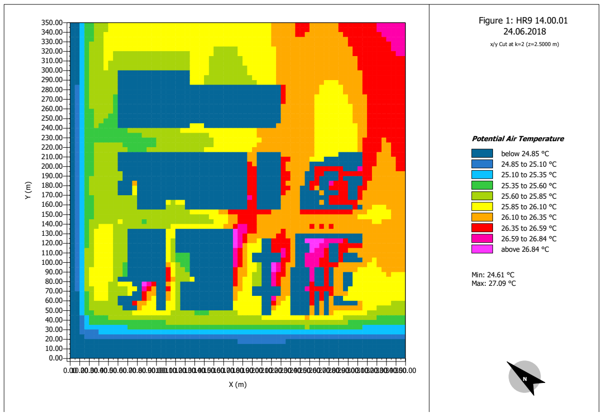


Figure 42: Potential air temperature 14:00 Showing the hotter area’s and the hourly change

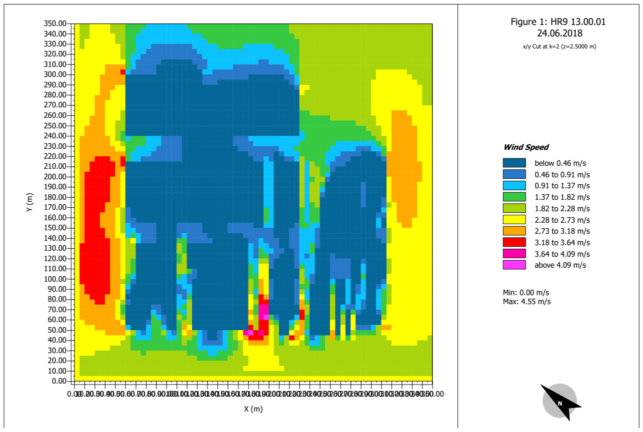


Figure 43: wind speed 13:00 showing areas with increased wind speed

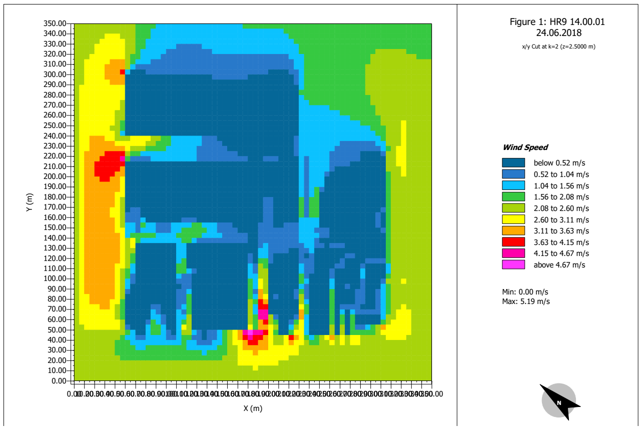


Figure 44: wind speed 14:00 showing areas with increased wind speed

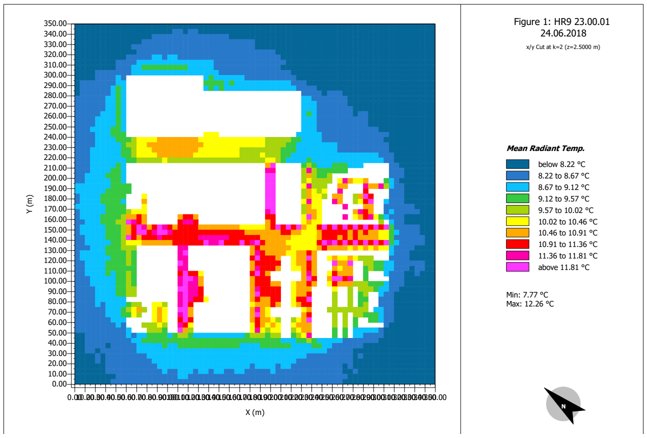


Figure 45: Radiant temperature at 23:00 showing which surfaces get hot and still glow after sundown

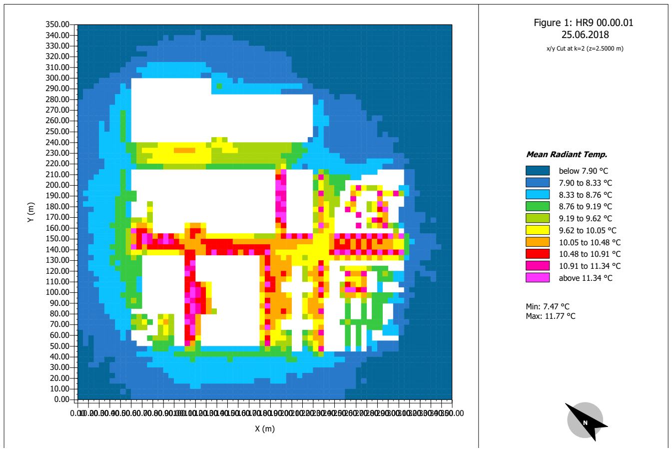


Figure 45: Radiant temperature at 24:00 showing which surfaces get hot and still glow after sundown

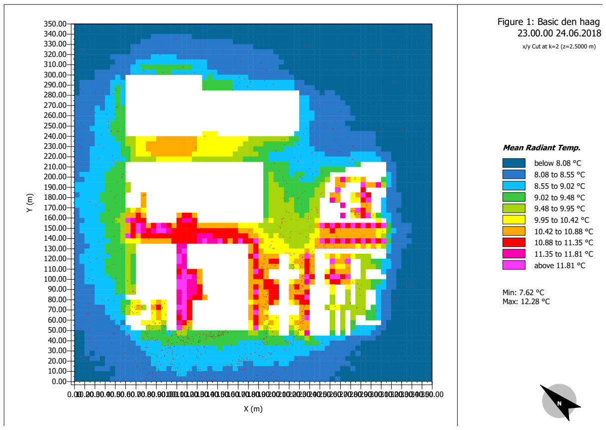


Figure 46: Radiant temperature at 23:00 without case study building showing difference in radiant temperatures

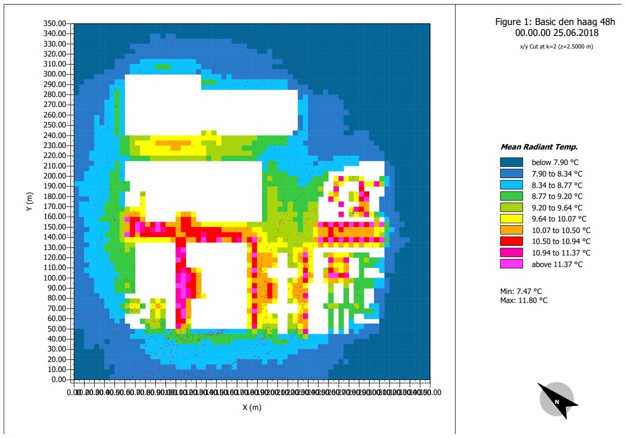


Figure 46: Radiant temperature at 23:00 showing which surfaces get hot and still glow after sundown

These problem areas are even further confirmed when looking at the radiant temperature during the night. The radiant temperature during the night gives an indication of surfaces that are still radiating heat when sun is no longer a factor. In the images above it becomes clear that some urban canyons with a low sky view factor are present around the building site. This highlights another aspect of the UHI-effect caused by the new design especially when comparing it to the ENVI-met images of the current situation without the design present. The difference is even played down with this analyses because in the ENVI-met model includes rows of trees around the building whereas the model of the current situation exists of an empty area with a hard surface. After these ENVI-met analyses a second shading analyzing is done to look at the shading situating on the plot. This model is also used to test shading on possible building shapes of the alternatives.

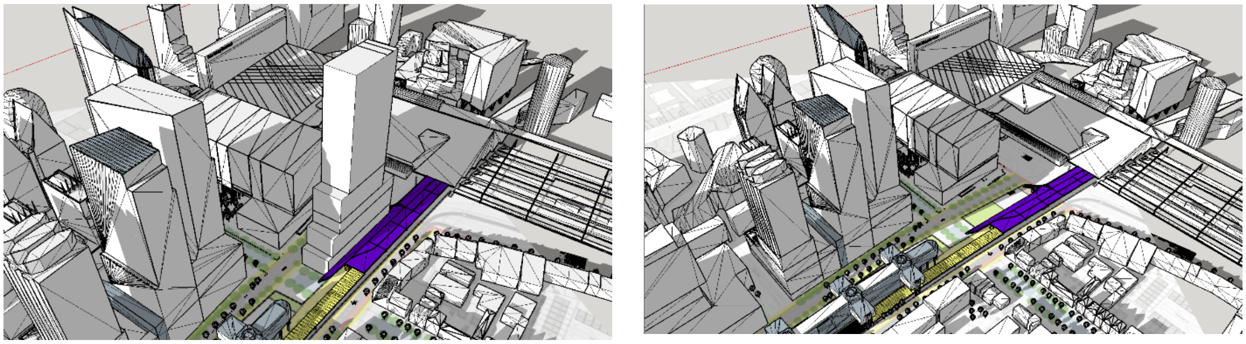


Figure 48: Shade analysis of the current design and empty plot

Looking at the summer months the plot receives shading only in the late afternoon/early evening starting from around 17:30. This means that when taking full advantage of the shaded side of the plot the façade at those points can start cooling off earlier then if they were situated at the other side of the plot. The shade casted by the building shape is a bit harder to determine. However with the right shading it can be possible to shade the areas that suffered from a low sky view factor that were identified in the ENVI-met analysis. This can be done by taking full advantage of the entire width of the plot and creating mass on the southwest side.

In order to test these shapes three different simulations have been set up. The only difference between each of them is the building shape. The environment, climate and receptors are all exactly the same, the basic template of the surroundings of the case study has been tested extensively so only the different shapes of the buildings are newly introduced to the 3D model.

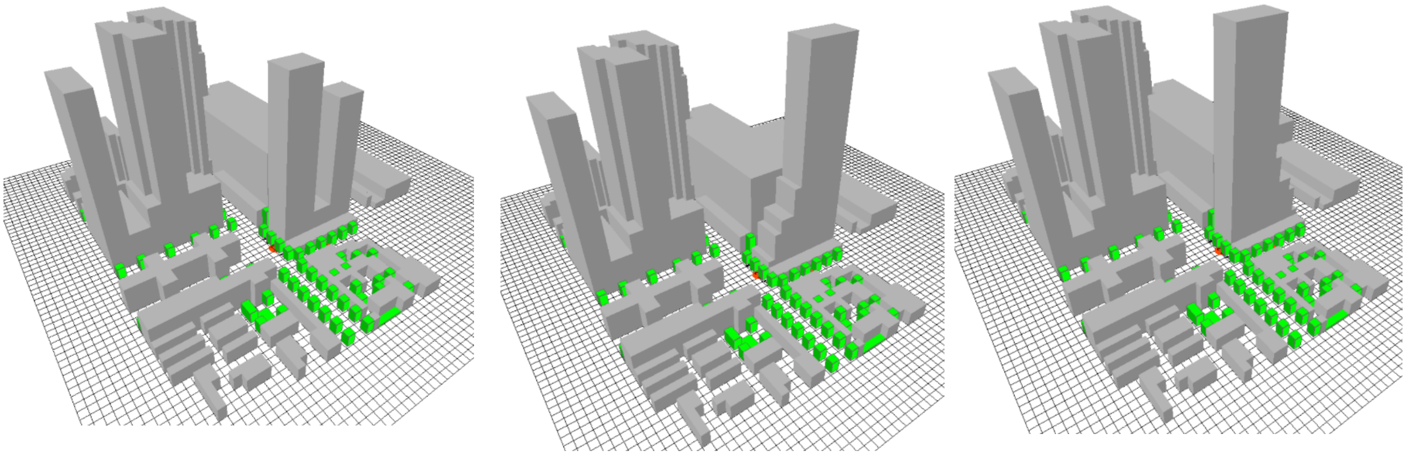


Figure 49: Different shape options modelled in ENVI-met

The general weather settings have been discussed previously and the precise setup can be found in appendix 1. The chosen week was around the high peak of 5th of august: 2-9 august of the climate year. The visual results can be compared using Leonardo from the ENVI-met software suite, however the numerical data from the receptors need to be exported to Excel in order to be analyzed. The initial structure of the data export is based on the work of Zhang et al. (2017)

Analyzing the receptor data from ENVI-met can be done in multiple ways. A receptor in ENVI-met measures all data from wind speed to temperature on a given coordinate in the simulated model. This data is measured every meter from 0,5m up until 347,5 per every ten minutes (simulation time). The created template has four receptors placed around the plot of the design. Combining the data from these receptors is done by first calculating the hourly temperature for every receptor, followed by creating an average hourly temperature of all the receptors combined. However by doing this the effect of the UHI-effect on the temperature gets diluted because the air temperature increase due to the UHI-effect fades away at higher altitudes. It can still be used as a tool to compare different urban geometries and building shapes but the differences will be a lot smaller.

Another option is to select the altitude of the dwelling that is to be designed in the following step and only use data from around that height. By using this method the resulting microclimate becomes much more accurate for the simulation of the single dwelling unit. However a downside of using this method is that comparing the impact on the microclimate of the different shapes of the design becomes more inaccurate. This is because only a small slice of the microclimate is taken around the building ignoring the rest. However both methods could be used in the application they are best for. These methods are further illustrated on page 54.

5.2 results shape

The results of the ENVI-met tests are relatively similar. All three shapes show differences below 0,02 degrees Celsius on an hourly basis. The average hourly temperature over 168 hours between HR11 and HR13 does not differ. The average hourly temperature over 168 hours from simulation HR12 is 0,01 degree Celsius higher. Although this is a result, the average values are too close together to really differentiate between them and choose the shape that is performing the best. Therefore further analysis of the data is needed. Luckily ENVI-met provides a lot of data pertaining to orientations based on receptors and altitude based on measurement heights.

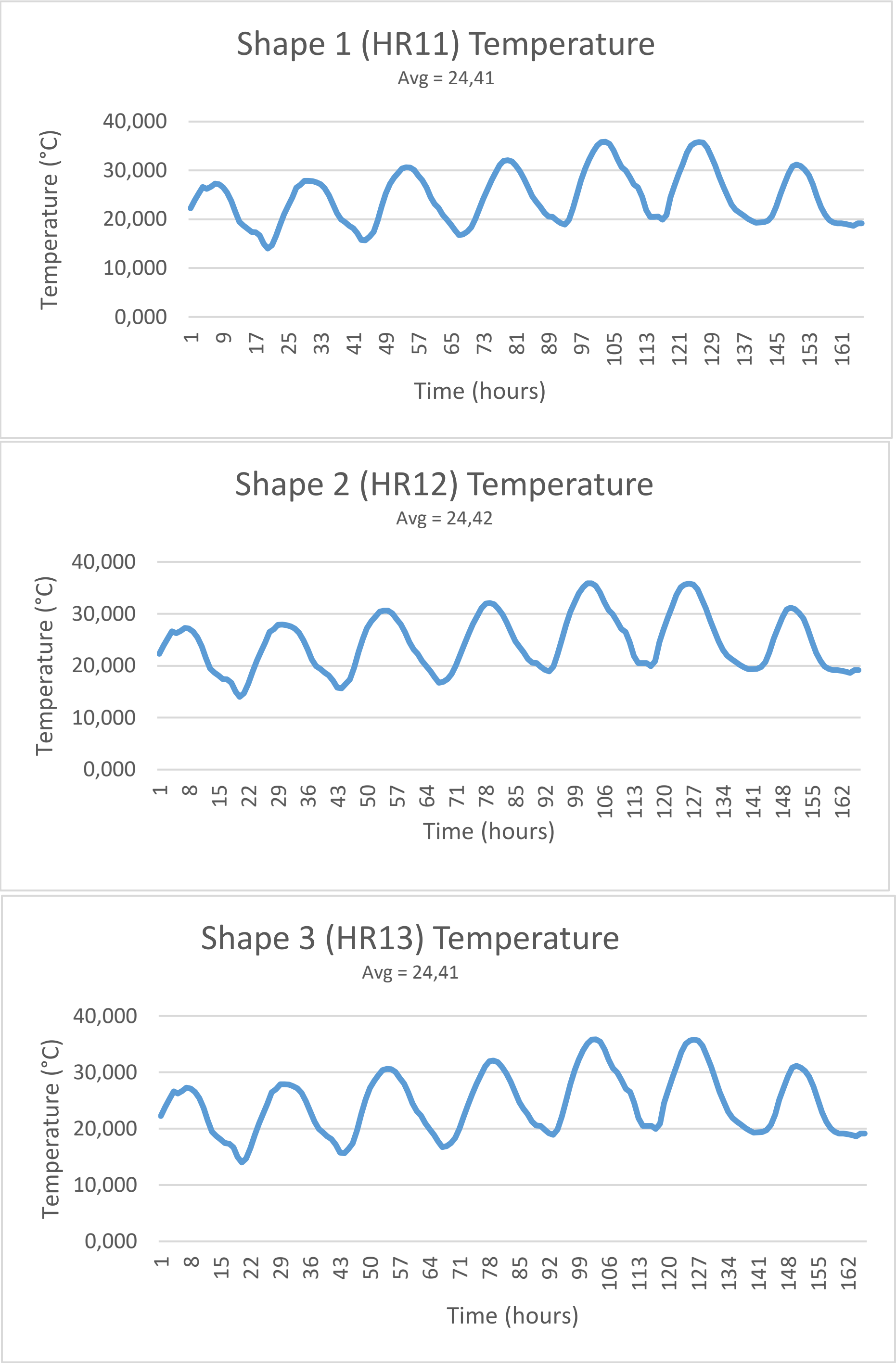
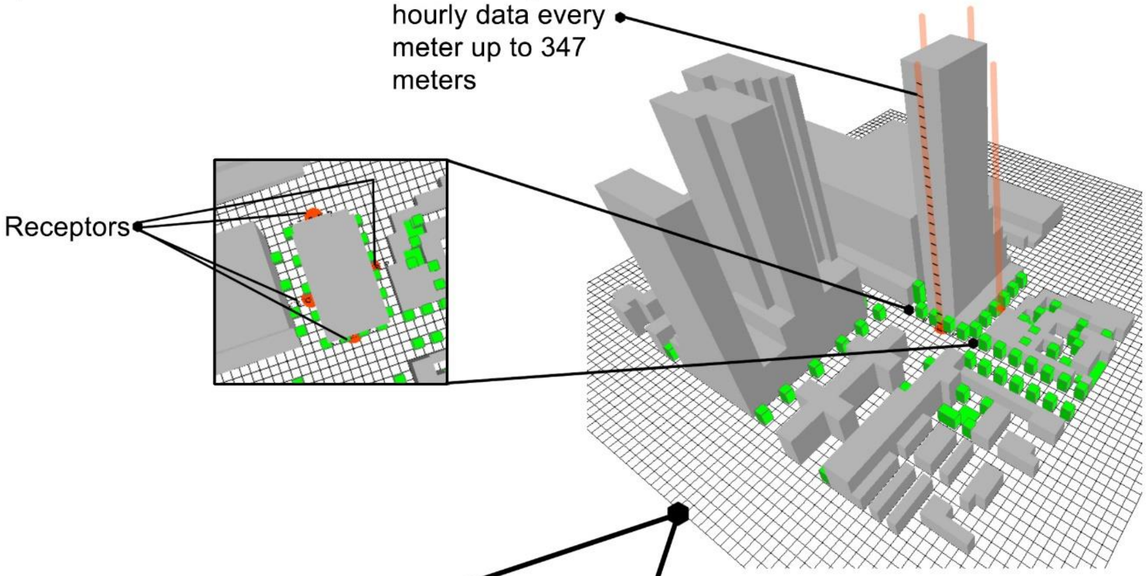


Figure 50: Temperature distribution of different microclimates around the analyzed shapes)

In order to analyze the microclimates from the different shapes more in depth different parameters have to be taken into account. The averages of the temperature of the climate tell only part of the story and because these averages lie so closely together further investigation is necessary. Every microclimate is therefore analyzed on orientation and altitude to see the impact the building shape has on these individual parameters. Orientation is done via receptor point and altitude based on creating smaller zones within the measured microclimate. These microclimate zones are based on air temperature sections from the ENVI-met simulations and are divided into low (0,5m-22,5m) and high (52,5m-77,5m) altitude this is further elaborated on the next page.

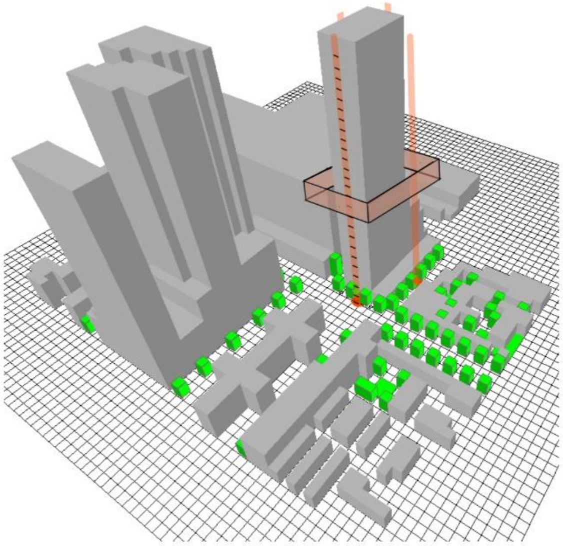
Interpretation of receptor data

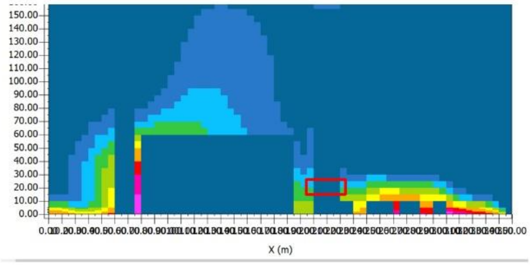


Receptors give hourly data every meter up to 347 meters

Receptors

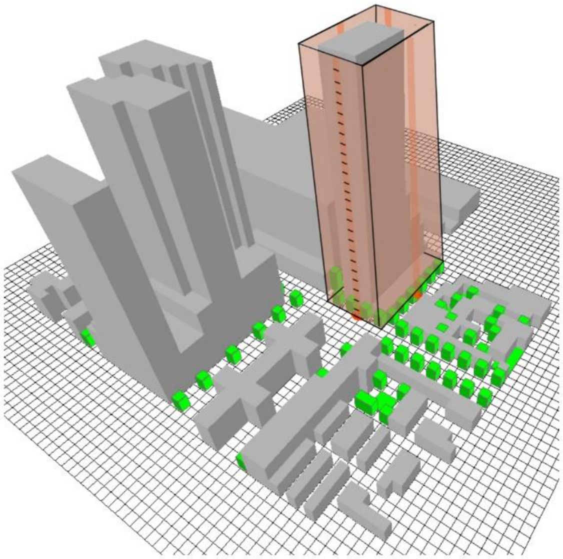
Option 1: Use only receptor data around the floor level of the chosen dwelling creating a highly specific micro climate data file

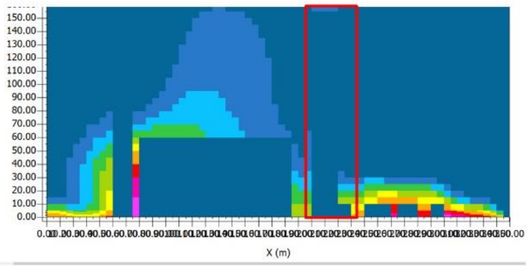




☐ Range of microclimate

Option 2: Use all receptor data creating a more generalized micro climate file





☐ Range of microclimate

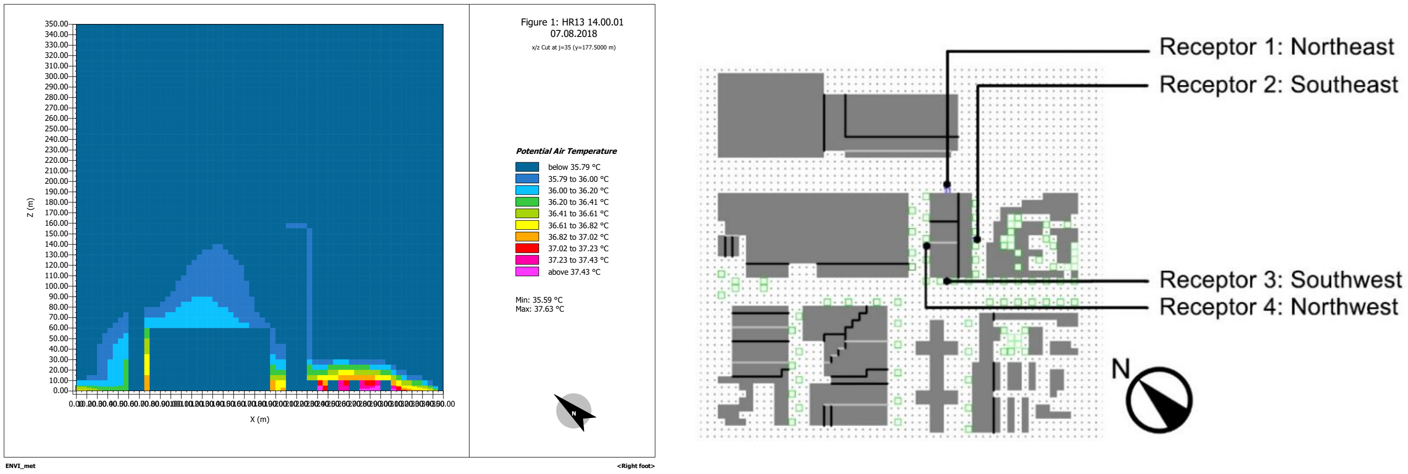


Figure 51: UHI-effect vs height and receptor distribution

The individual results and their analysis can be viewed in appendix 7. It showed that orientation has an impact on temperature however the largest difference in temperature between orientations takes place during peak temperature hours of the day. Furthermore the temperature difference between orientations gets larger with an increased UHI-effect. Altitude has a huge impact on the temperatures, where the high altitude measurements are comparable to that of the total microclimate the low altitude measurements are much higher. The orientations R1 and R2 were on average also higher than R3 and R4. However the difference between shapes is negligible. The peak temperature differences between these shapes are also negligible as the differences are quite small. In the end these peak temperatures are what would really motivate a choice for one of the shapes.

Avg ^{0}C under 22,5m					
		R1	R2	R3	R4
	HR13	24,75	24,74	24,60	24,63
	HR12	24,79	24,78	24,69	24,68
	HR11	24,78	24,75	24,61	24,64

Avg ^{0}C total					
		R1	R2	R3	R4
	HR13	24,44	24,41	24,40	24,41
	HR12	24,46	24,42	24,40	24,41
	HR11	24,45	24,41	24,40	24,41

Avg ^{0}C 52,5-77,5m					
		R1	R2	R3	R4
	HR13	24,43	24,37	24,38	24,39
	HR12	24,48	24,37	24,38	24,39
	HR11	24,48	24,37	24,38	24,39

Maximum ^{0}C under 22,5m					
		R1	R2	R3	R4
	HR13	36,76	37,07	36,49	36,70
	HR12	36,78	37,06	36,68	36,77
	HR11	36,74	36,99	36,49	36,65

Maximum ^{0}C 52,5-77,5m					
		R1	R2	R3	R4
	HR13	35,91	35,72	35,77	35,82
	HR12	36,04	35,71	35,70	35,82
	HR11	36,00	35,72	35,77	35,82

Figure 52: Air temperature data of different microclimates

For the next phase in this research it means that impact the shape has a negligible effect on its surrounding microclimate. Therefor HR13 will be used as the shape to continue but any shape would have sufficed. However this does not mean that the shape research will not be used to learn from.

The orientation analysis showed that the east orientation tends to become warmer than the others especially at hotter hours during the day so these facades might need extra attention in terms of heat rejection.

The higher altitudes measurements of all of the different shapes are very close to that of their respective whole microclimate combined. This shows that altitude really does have an impact on the temperature and the effectiveness of the UHI-effect. In terms of the facade design this means that most measurements to mitigate and adapt to the UHI-effect should be focused on the lower parts of the building. Measurements to keep the heat outside however can be a bit more minimal above the range of the UHI-effect as it does not get as warm as the lower regions that are affected by the UHI-effect.

HR11 was focused on lowering the profile of the building maximizing the sky view factor of the areas around it and creating shade by having two different towers. However it shows that either the sky view factor does not have a big enough impact on the microclimate or the tower does not maximize the sky view factor enough. The shading via the larger tower also did not have the expected result. This may come from the fact that the parts of the building that shade the lower parts of the microclimate are present in all of the shapes. The larger tower mostly shades larger parts around the building. Finally the northeast side is by far warmer than HR13 and a little bit colder than HR12. Both HR11 and 12 have large flat facades on this orientation which could account for the difference.

HR12 is in every receptor category the warmest from the total average temperature to the lower altitude average temperature and the higher altitude average temperature. This could be attributed that the entire mass of the shape that is situated towards the warmest orientations. Another reason is that the maximum exposure to wind is not as effective as planned or does not work as intended. This becomes apparent when looking at receptor 3 which is a lot hotter than in other shapes. This could be a cause of the downdraught effect.

HR13’s shape produces the coldest climate in all of the different categories. This could be due to previously mentioned downdraft effect because the main mass of the building is orientated towards the main wind orientation cooling down R3 and R2/R4 around the corners. Another reason could be the staggered masses towards the warmest receptors allowing the solar radiation not to focus on a single large surface.

However all of these shape changes did not have a large impact on the resulting microclimate temperatures and require further research to analyze if more drastic shape changes would have a different effect. These shapes are still relatively similar due to their set volume sizes and other requirements. If more freedom would be used in choosing a shape the resulting microclimate could show more changes.

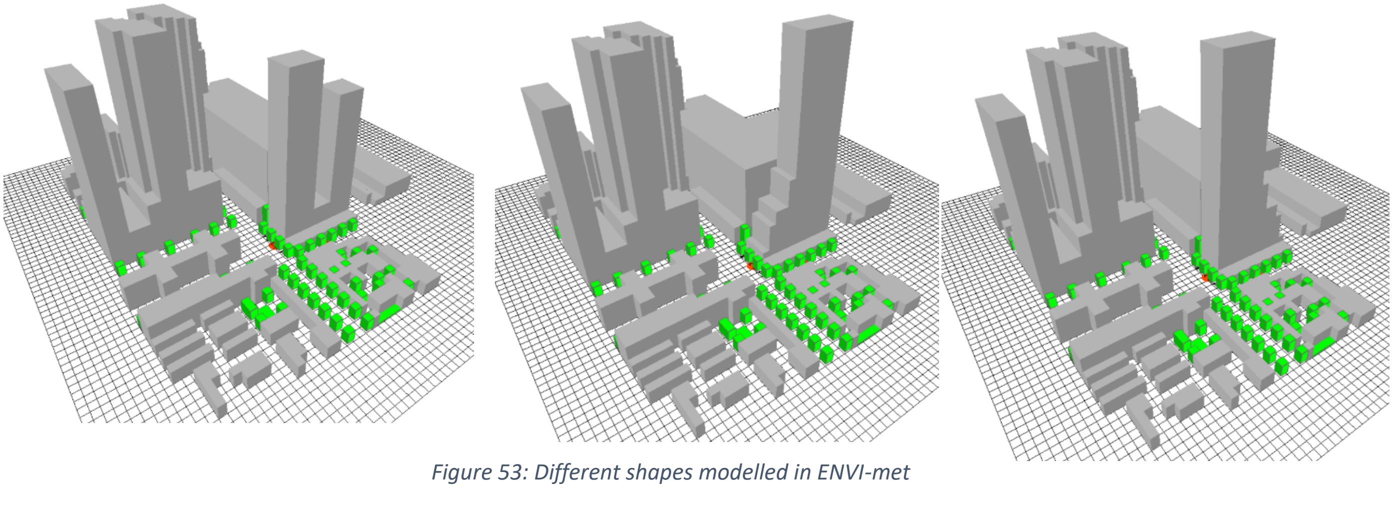


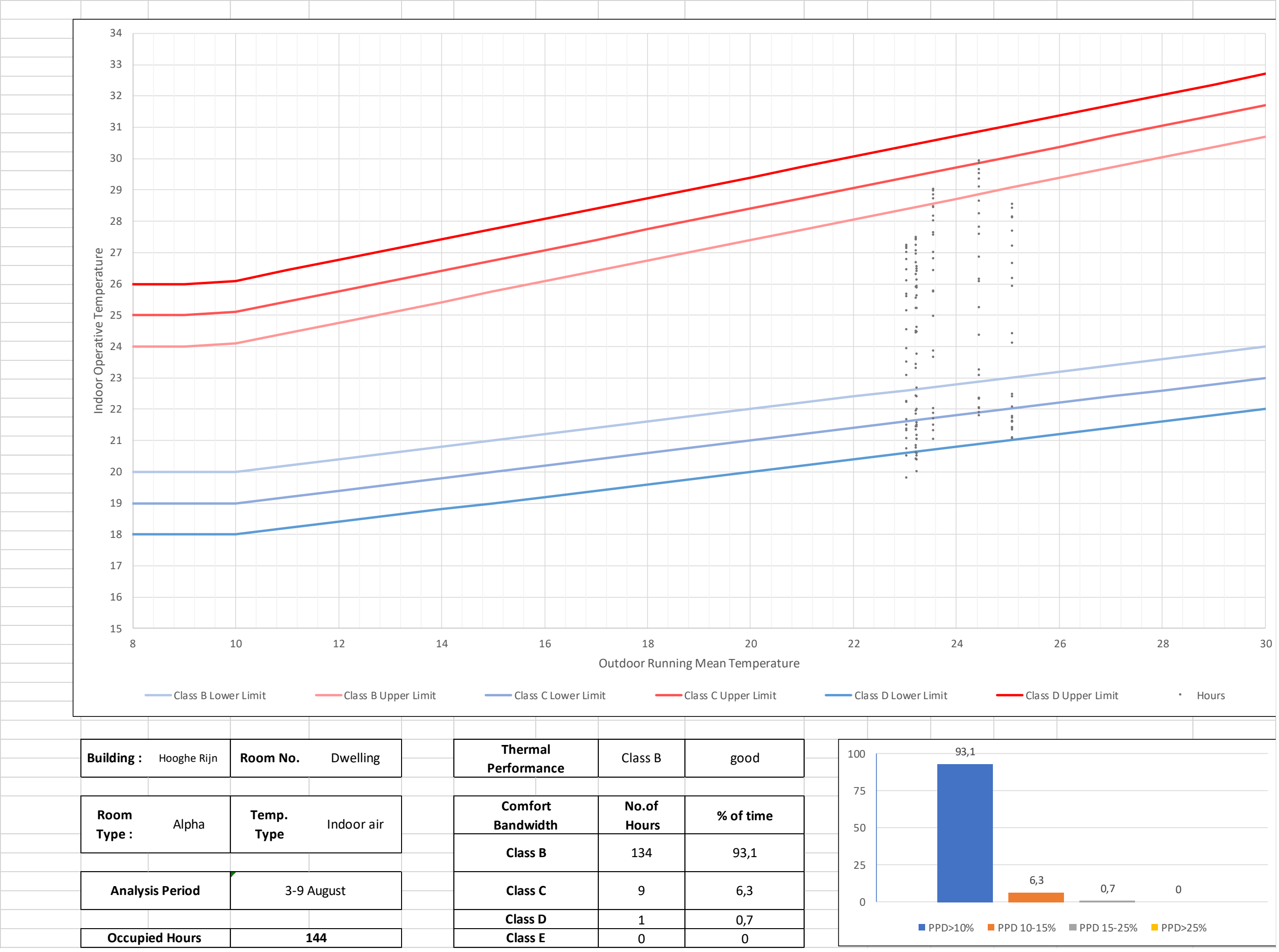
Figure 53: Different shapes modelled in ENVI-met

5.3 Results facade

Every facade option has two separate ATG analyses: the first being the analysis of thermal comfort in the low altitude dwellings with their respective facade variant and climate data and the second being the higher altitude dwellings and their respective inputs. In the graph below the results of facade option 3 with the low altitude variant can be seen. The ATG graphs of all the facades can be viewed in Appendix 9. The resulting data of these graphs has been combined and can be viewed in the table on the next page.

As this research is focused on overheating only the hours going over the ATG limits are counted towards the total comfort hours percentage. A total of 144 hours of occupancy are used in the evaluation.

From these results a few things can be seen, the first being that all of the facades are relatively close in terms of comfort hours and all of the facades at least have a PPD of 90% meaning they all classify for class B at a minimum. The lower level facade variants are especially close together when looking at the class B hours. This is especially interesting in the context of their differences regarding window to wall ratio and thermal conductance. The exact impact each parameter is hard to determine and out of the scope of this research.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Indoor air
Analysis Period	3-9 August		
Occupied Hours	**144**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	134	93,1
Class C	9	6,3
Class D	1	0,7
Class E	0	0

Figure 54: ATG analysis results of facade option 3 low altitude

	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Facade 1 low alt	132,0	91,7	9,1	6,3	3,0	2,1		
Facade 1 high alt	130,0	90,3	9,9	6,9	4,0	2,8		
Facade 2 low alt	132,0	91,7	8,1	5,6	4,0	2,8		
Facade 2 high alt	138,0	95,8	6,0	4,2	0,0			
Facade 3 low alt	134,1	93,1	9,1	6,3	1,0	0,7		
Facade 3 high alt	130,0	90,3	9,9	6,9	4,0	2,8		

Figure 55: ATG analysis results of all of the different facade options on the west southwest orientation

Furthermore this analysis shows that at the lower altitude facade 3 is a little bit more comfortable than facades 1&2. However when looking at the impact the facades can have on their microclimates ,which is important at these lower altitudes where the UHI-effect is at its most intense, facade 3 is at the bottom with 30% opaque parts then facade 1 at 50% and finally facade 2 at 70%. This part is fairly important because the facade will be tested on the effect it has on its microclimate and thereby also its own indoor thermal comfort.

The upper facades are quite a different story compared to their lower altitude counterparts. The main difference is that the microclimate is relatively stable and will not be heavily interfered by facade design choices. This is because at higher altitudes the UHI-effect is negligible and thereby the effect of the facade on its microclimate as well.

In term of thermal comfort all of these facades are relatively well performing. Looking at the higher altitudes facade 2 is the best performing thermal comfort wise by quite a margin. Combining this with the fact that the running mean outdoor temperature will change minimally by any facade at this altitude and therefore have a similar results at the final ATG analysis makes the choice for this variant at a higher altitude quite clear.

However at a lower altitude the choice of facade is not immediately apparent when solely focusing on the indoor thermal comfort hours. Facade 3 is the best performing, but with its high glazing % in the facade it does not have a lot of potential of impacting the microclimate compared to the other two facades. Changing the microclimate at these lower altitudes can improve indoor thermal comfort by lowering the outside air temperature. Especially because the difference in the ATG analysis are so close between facades it could prove more beneficial to choose a facade with more potential to impact its microclimate.

	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Facade 1 low alt	121,0	84,0	10,9	7,6	9,1	6,3	3,0	2,1
Facade 1 high alt	122,0	84,7	9,9	6,9	9,1	6,3	3,0	2,1
Facade 2 low alt	136,0	94,4	8,1	5,6	0,0	0,0	0,0	
Facade 2 high alt	136,9	95,1	7,1	4,9	0,0	0,0	0,0	
Facade 3 low alt	130,0	90,3	10,9	7,6	3,0	2,1	0,0	
Facade 3 high alt	129,0	89,6	10,9	7,6	4,0	2,8	0,0	

Figure 56: ATG analysis results of all of the different facade options south-southeast

The south-southeast orientation has more sun hours and this can be seen in the resulting ATG percentages, facade 1 is significantly less comfortable on this orientation. Facade 2 is slightly more comfortable and facade 3 is slightly less comfortable. This show that facade 2 performs better than the other facades and even better than the previous orientation. This is probably due to the radiation activated solar shading which could get activated for more hours compared to the previous orientation.

In the end the decision is made to implement facade 2 and test its impact on the urban microclimate. The reason being its performance at higher altitudes and its potential to impact the microclimate at lower altitude combined with close results of the ATG analysis compared to the other facades at low altitude.

5.4 Microclimate results

The microclimate analysis is done in the same way as the previous microclimate analysis of the different building shapes. This entails analyzing both the lower and upper microclimate and looking at the peak temperatures, the average temperatures and the individual receptors to see the difference and possible patterns

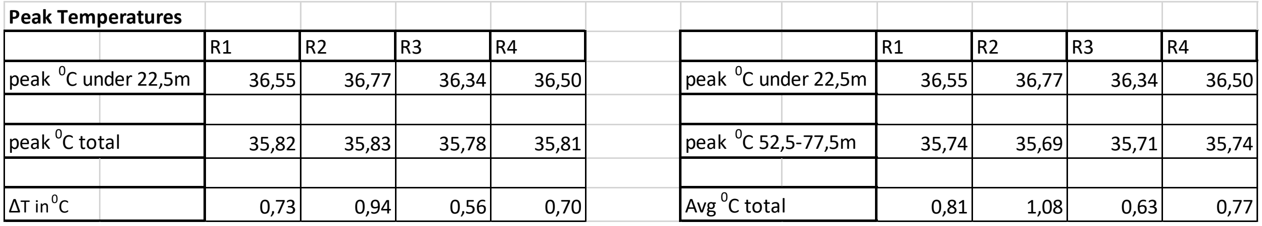
Average Temperatures

	R1	R2	R3	R4
Avg ^{0}C under 22,5m	24,64	24,67	24,54	24,54
Avg ^{0}C total	24,40	24,40	24,38	24,39
ΔT in ^{0}C	0,24	0,26	0,15	0,15

	R1	R2	R3	R4
Avg ^{0}C under 22,5m	24,64	24,67	24,54	24,54
Avg ^{0}C 52,5-77,5m	24,39	24,36	24,36	24,37
ΔT in ^{0}C	0,26	0,30	0,18	0,17

Figure 57: Comparison of average temperatures between altitudes

In the table above the average temperatures of the microclimate around the new case study design can be found. It seems that the microclimate behaves somewhat similar to that of the microclimate of a building without passive measures (see HR13 microclimate analysis) with regards to the differences between altitudes and receptors. This is mainly referring to the fact that lower altitude microclimate is on average much warmer than the total microclimate or the 52,5-77,5m altitude microclimate. The same can be said for the difference between receptors where R1 and R2 are among the warmest.



Peak Temperatures

	R1	R2	R3	R4
peak ^{0}C under 22,5m	36,55	36,77	36,34	36,50
peak ^{0}C total	35,82	35,83	35,78	35,81
ΔT in ^{0}C	0,73	0,94	0,56	0,70

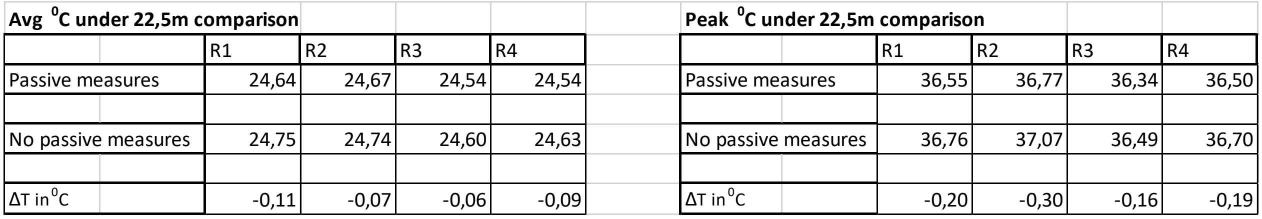
	R1	R2	R3	R4
peak ^{0}C under 22,5m	36,55	36,77	36,34	36,50
peak ^{0}C 52,5-77,5m	35,74	35,69	35,71	35,74
Avg ^{0}C total	0,81	1,08	0,63	0,77

Figure 58: Comparison of peak temperatures between altitudes

A more important metric to look at however would be the peak temperatures since these can negatively impact the indoor thermal comfort the most. In figure 58 all of these peak temperatures can be found and their differences. It shows that in this microclimate the peak temperatures can differ quite a lot. Especially the difference between the lower and higher altitude can go up to more than 1 ^{o}C.

In order to assess the performance of the passive measures on the building it is compared with the same measurements from a different microclimate that did not incorporate any passive measures (HR13) but does have the same building shape. The average temperatures show some small differences in temperatures. These are the biggest under 22,5m probably because that is where most of the passive measurements are located. However peak temperature is a much more telling metric. The peak temperature shows a larger difference between the two going as far as 0,3 ^{o}C. So these passive measurements definitely help with lowering peak temperatures although not by that much. The peak temperature difference at higher altitudes is a bit lower, this could be because of the decreased passive measurements or the absence of the urban heat island effect.

These results show that the measurements to mitigate the effects of the urban heat island effect are effective to certain extent. The peak temperatures get lowered allowing the building to ensure indoor thermal comfort more easily. A lowering of 0,16 ^{o}C-0,3 ^{o}C does not seem that large but these results are just from incorporating these measurements on a single building.



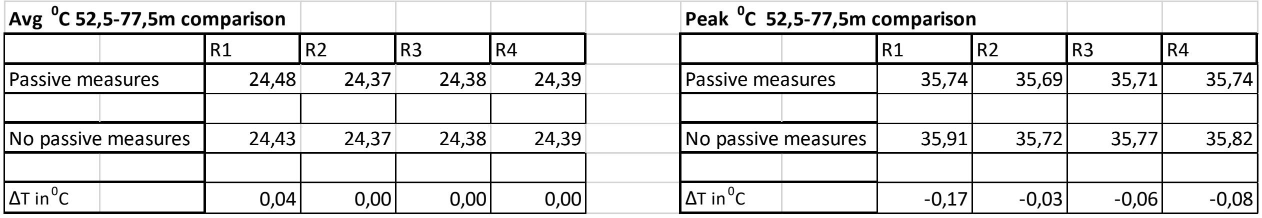
Avg ^{0}C under 22,5m comparison

	R1	R2	R3	R4
Passive measures	24,64	24,67	24,54	24,54
No passive measures	24,75	24,74	24,60	24,63
ΔT in ^{0}C	-0,11	-0,07	-0,06	-0,09

Peak ^{0}C under 22,5m comparison

	R1	R2	R3	R4
Passive measures	36,55	36,77	36,34	36,50
No passive measures	36,76	37,07	36,49	36,70
ΔT in ^{0}C	-0,20	-0,30	-0,16	-0,19

Figure 59: Comparison of average and peak temperatures between microclimates under 22,5



Avg ^{0}C 52,5-77,5m comparison

	R1	R2	R3	R4
Passive measures	24,48	24,37	24,38	24,39
No passive measures	24,43	24,37	24,38	24,39
ΔT in ^{0}C	0,04	0,00	0,00	0,00

Peak ^{0}C 52,5-77,5m comparison

	R1	R2	R3	R4
Passive measures	35,74	35,69	35,71	35,74
No passive measures	35,91	35,72	35,77	35,82
ΔT in ^{0}C	-0,17	-0,03	-0,06	-0,08

Figure 60: Comparison of average and peak temperatures between microclimates 52,5-77,5

5.5 Thermal comfort results

Now the climate file from the previous step will be used to recalculate the thermal comfort. The case study dwellings and its facade will also be assessed on its thermal comfort under present time climate circumstances. This is to ensure the building design is comfortable not only in the future but also in its current circumstances.

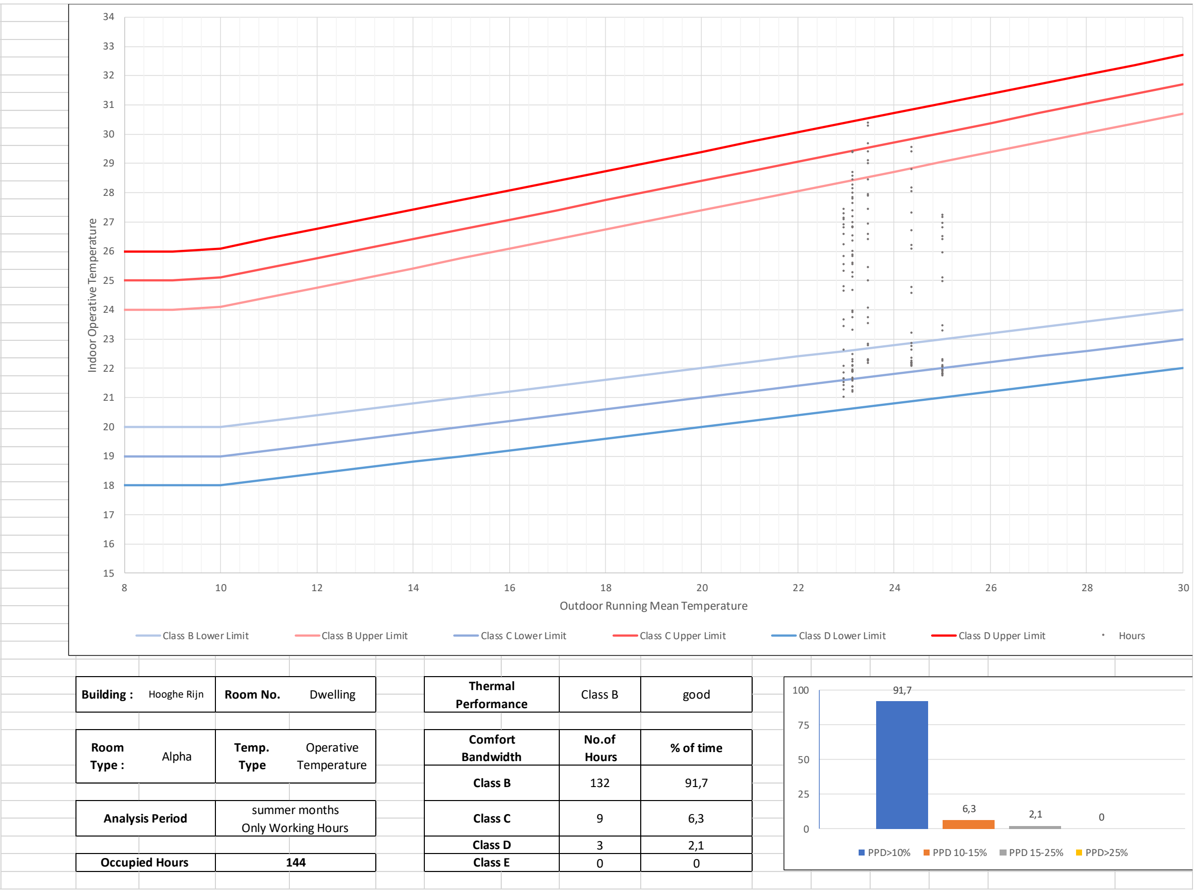
ATG Future climate scenario

In important distinction for the ATG analysis is how the temperature dataset to calculate the running mean outdoor temperature is determined. The ISSO74 states that a close by weather station should be used to determine these daily temperatures. However in this research the dataset of the temperature directly around the building was created specifically to have a better image of the microclimate around the building so this dataset is used to determine the running mean outdoor temperatures. Now the situation arises where the building exerts its influence on this microclimate and lowers it, thereby lowering its indoor temperatures making it more comfortable. However it also lowers the running mean outdoor temperature and thus making the limits in the ATG method more strict. So by improving the microclimate the goalposts of the ATG method move with it. This phenomenon is quite small in this situation and does not really have a large impact however it is an interesting discussion point and something to keep in mind when viewing the results.

The dataset problem encountered in the previous ATG analysis is also present in this dataset as only a single week was simulated. The same solution is used here to solve it, by looking at the difference in temperature on a daily basis and applying that difference to the ENVI-met dataset week that is before the actual measurement, this ensures a realistic running mean outdoor temperature.

However because this new dataset from a microclimate with passive measures is different than the data set used in the previous ATG analysis a new temperature transformation Δ is needed. To find this number the same steps have been taken to that of the previous ATG analysis and can be found in Appendix 9. The outcome is a ΔT of 0,9 ^{o}C for the low altitude transformation and 1,2 ^{o}C for the high altitude transformation.

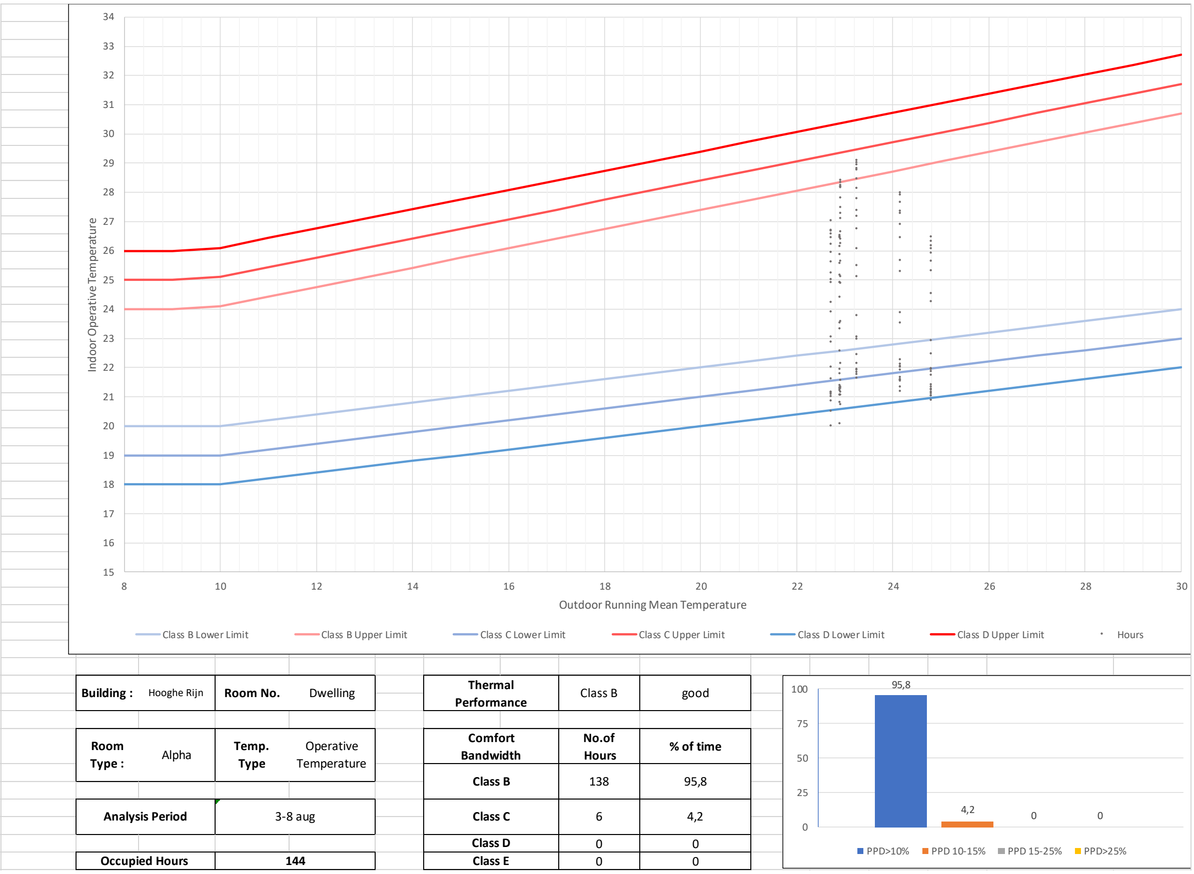
The resulting ATG graphs can be found on the next page. The first thing to notice is that both altitude variations fall within class B of the ATG method and the high altitude variation even in class A. When looking at the difference between the ATG results of this microclimate and the microclimate of the building without passive measurements there is little improvement on the thermal comfort numbers when improving the microclimate. This is because when changing the microclimate it also changes the running mean outdoor temperature and that influences the limits of the indoor thermal comfort and thereby limiting thermal comfort improvement. Nevertheless this new variant of the case study design is thermally comfortable in future climate scenarios while being passively cooled.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	132	91,7
Class C	9	6,3
Class D	3	2,1
Class E	0	0

Figure 61: ATG graph of under 22,5m



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	3-8 aug		
Occupied Hours	**144**		

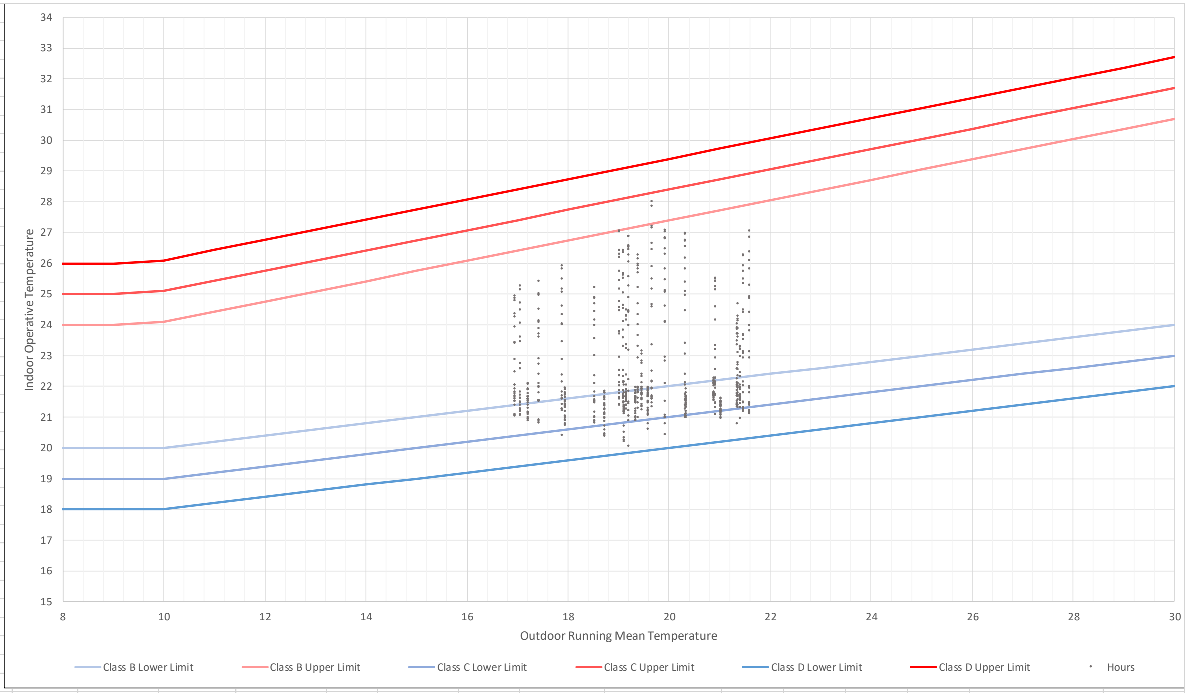
Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0

Figure 62: ATG graph of 52,5-77,5m

ATG present time

It is important to not only take future scenarios into account. The whole premise of designing a building in this way is making it resilient to a changing climate. Although it may seem doubtful that a building is comfortable in futuristic hot weather scenarios but not in a current day climate it is still important to check and simulate if it is true.

Here the design is tested under current day climate circumstances and analyzed via the ATG adaptive comfort method. This is done for both the lower altitude dwelling and the higher altitude dwelling. For this current climate data the NEN5060 thermal comfort 5% exceedance chance temperature data is used in combination with climate data identical to that of the previous data files, this way only the temperatures change. Because this analysis is not bound by a certain simulated week more hourly data can be used check its indoor thermal comfort validity. However it is still good to include the same week that is in the ATG future analysis. Therefore the month of 09-07 until 09-08 is used.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Indoor air
Analysis Period	3-9 August		
Occupied Hours	**696**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	694	99,7
Class C	2	0,3
Class D	0	0
Class E	0	0

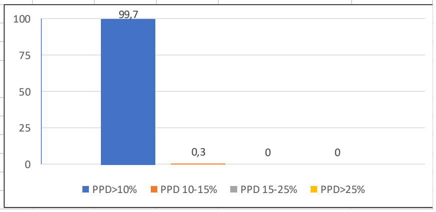
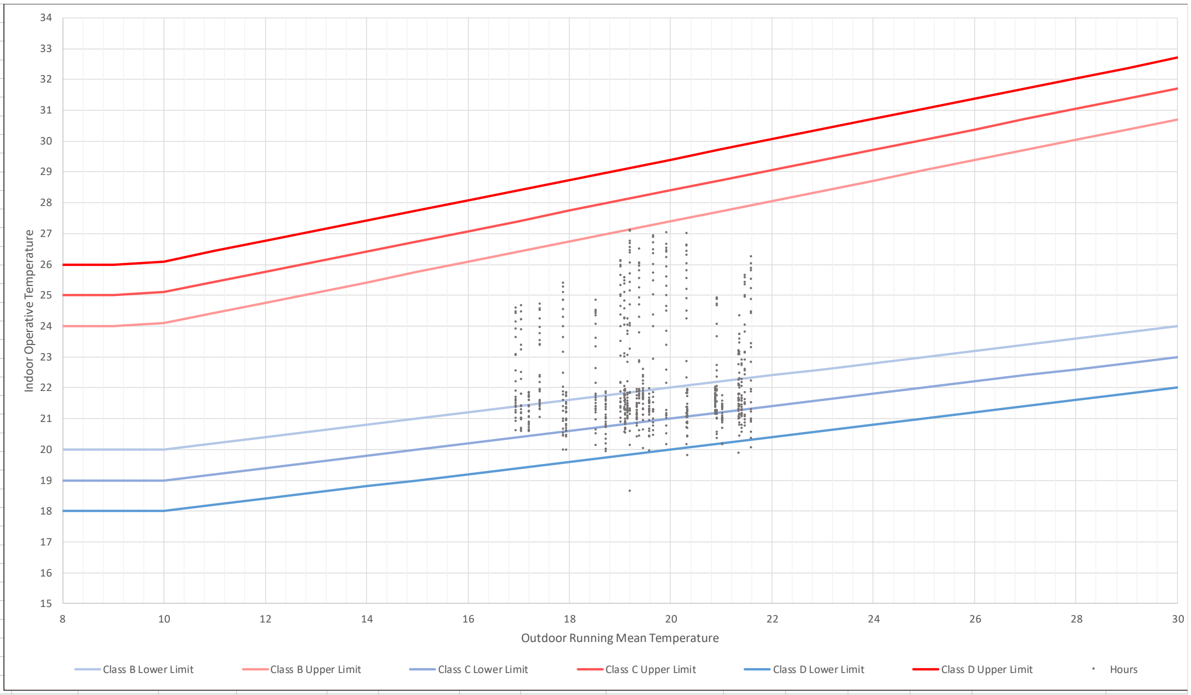


Figure 63: Thermal comfort hours in NEN5060 5% climate in the lower altitude dwelling



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Indoor air
Analysis Period	9 July-9 August		
Occupied Hours	696		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	696	100
Class C	0	0
Class D	0	0
Class E	0	0

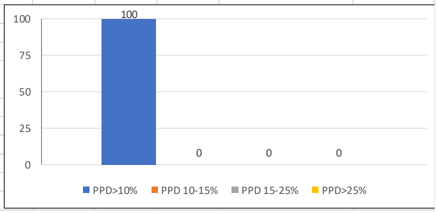


Figure 64: Thermal comfort hours in NEN5060 5% climate in the higher altitude dwelling

In these two graphs it can be seen that the alternative design functions really well with regard to indoor thermal comfort under current day summer scenarios. It is important to keep in mind that these calculations only take summer overheating into account, more research is needed to see if this building is comfortable year round.

After these analyses it can be said that this alternative design to the case study is thermally comfortable both in future and present scenarios with both of the facade variations. Although it is important to note that only a single week has been simulated out of an entire year. But this simulation week was picked for its extreme temperatures and the ATG method is percentage based so even if this weather was projected over the entire week the comfortable hour percentage would not change that much.

Another thing to keep in mind is the way these energy plus simulations are done regarding natural ventilation cooling. As it will have the windows controlled “perfectly” where the windows will only be fully opened when the outside air temperature is lower and not when it is hotter. This can be done in a real life situation with a heat sensor controlled system however users are still able to override them. So these calculations are based on a perfect handling of the system without user interference.

6. Final design

The next step consists out of designing and detailing a facade from the different requirements that meet the standards of thermal comfort and the effect on the urban micro-microclimate.

Requirements

The concept facade was designed and tested with an R_c of 6 ($U=1/6= 0{,}167\ W/m^2K$) while this requirement is not set in stone it is proven to work in the Designbuilder simulation and provides a thermally comfortable building throughout the year.

The window to wall ratio of 30% below 20 meters and 70% above was used in ENVI-met to determine the microclimate and should be kept the same as much as possible in the final facade design.

The current shading solution works well enough to maintain a comfortable indoor air temperature however this external reflective screen solution is vulnerable to wind and can be prone to malfunctions due to its moving parts. Shading solutions can be freely designed as long as it ensure an indoor comfort in accordance with the ATG method.

The glazing type fulfills a similar role to that of the shading solution: the current choices work however this is just an option other configurations could work much butter are could be much cheaper. Shading and glass type should be looked at simultaneously as they perform similar roles and have an effect on each other.

The external layer of the facade (I.e. Cladding/green facade) is also one of the elements that influenced the simulated ENVI-met model therefore it should be kept relatively similar. This means the opaque parts under 20 meters should have a form of vegetation on the facade and the opaque parts above that have a light reflective color.

The difference in requirements between the facade on the upper side and the lower side comes from the difference in external factors. The most important factor of this the intensity of the UHI-effect which is lower on the upper side of the facade. Despite these different requirements the facades should still have a relative similar look.

Challenges

The basic requirements can be accomplished using standard facade products however some aspects still need to be analyzed and filled in. The combination of sun shading and glazing requires further analysis especially in the case of the higher altitude façade. The external sun shading screen is not the best option and a lot of maintenance and costs can be avoided by designing a better more fitting solution.

The green facade is another aspect that needs attention in this phase, this facade layer is quite important for the impact on the urban microclimate and therefore the entire design. It is vital the green façade remains coverage throughout the summer and the right plants are chosen for the right orientations. The maintenance of this façade is also very important as it can become quit extensive and expensive when designed in a bad way.

Green Facade

The detailing of a green facade starts with a decision about the type of green façade is needed for the project. In the images below some of these options can be seen. The first option is made out of self-climbing plants, which climb using tendrils, twining stems or suckers; a cheap option but full coverage takes time and is not guaranteed. The second option is climbing plants that need a construction placed in front of the wall along which they can grow and climb, similar issues arise as the previous option as well as issues with heavy wind. The third option is a green facade garden, whereby plants grow upwards from pots fastened to the facade or from a substrate attached to it. This is a sturdier option that ensures full coverage but can be more expensive. (Urban Green-Blue Grids, N.D.)

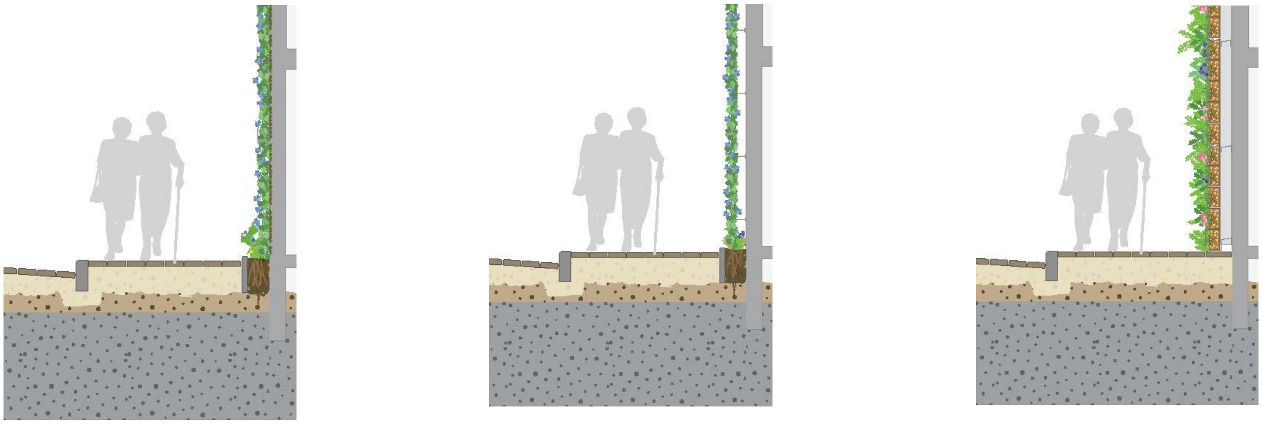


Figure 65: Three green facade options Urban Green-Blue Grids (N.D.) Green facades Retrieved 19-05-2020 from: https://www.urbangreenbluegrids.com/measures/green-facades/#cite-0

The green facade garden seems like the best possibility, especially because these are proven systems and come with guarantees from established manufacturers. The detailing in this design is based on a system from Gsky (Gsky, N.D), this system incorporates a tubing system between the planters that regulates irrigation with minimal waterlines. In addition to this it is also easily assembled into a modular system which can be vital in a small urban construction site. These planters also make sure coverage is complete from installation this is also done by plant selection making sure that all orientations have fitting plants that grow throughout the year.

Figure 66: Installation of the green façade and opening day Gsky (N.D.) Westfield mall retrieved at 18-05-2020 from: https://gsky.com/portfolio/westfield-mall-london/

Solar shading

In order to properly asses the shading needs of the façade a separate analysis has been made using Design builder to test different shading options and their effect on the indoor thermal comfort. A baseline façade with no shading has been used as a comparison, three different shading options and finally two combined options. These have all been tested on the two southern apartments with a high altitude façade variant (70% glazing). All of the shading solutions use triple glass with a g-value of 0,6 , the variant with high value glazing uses a g-value of 0,3.

	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	87,0	60,4	10,9	7,6	6,0	4,2	40,0	27,8
Balconies 2m	104,0	72,2	13,0	9,0	12,0	8,3	15,0	10,4
Low g-value	108,7	75,5	15,0	10,4	9,1	6,3	10,9	7,6
Sidefins 1m	99,1	68,8	14,0	9,7	10,9	7,6	20,0	13,9
balconies/g-value	131,0	91,0	9,9	6,9	3,0	2,1	0,0	0
sidefines/g-value	127,0	88,2	11,0	7,6	6,0	4,2	0,0	0

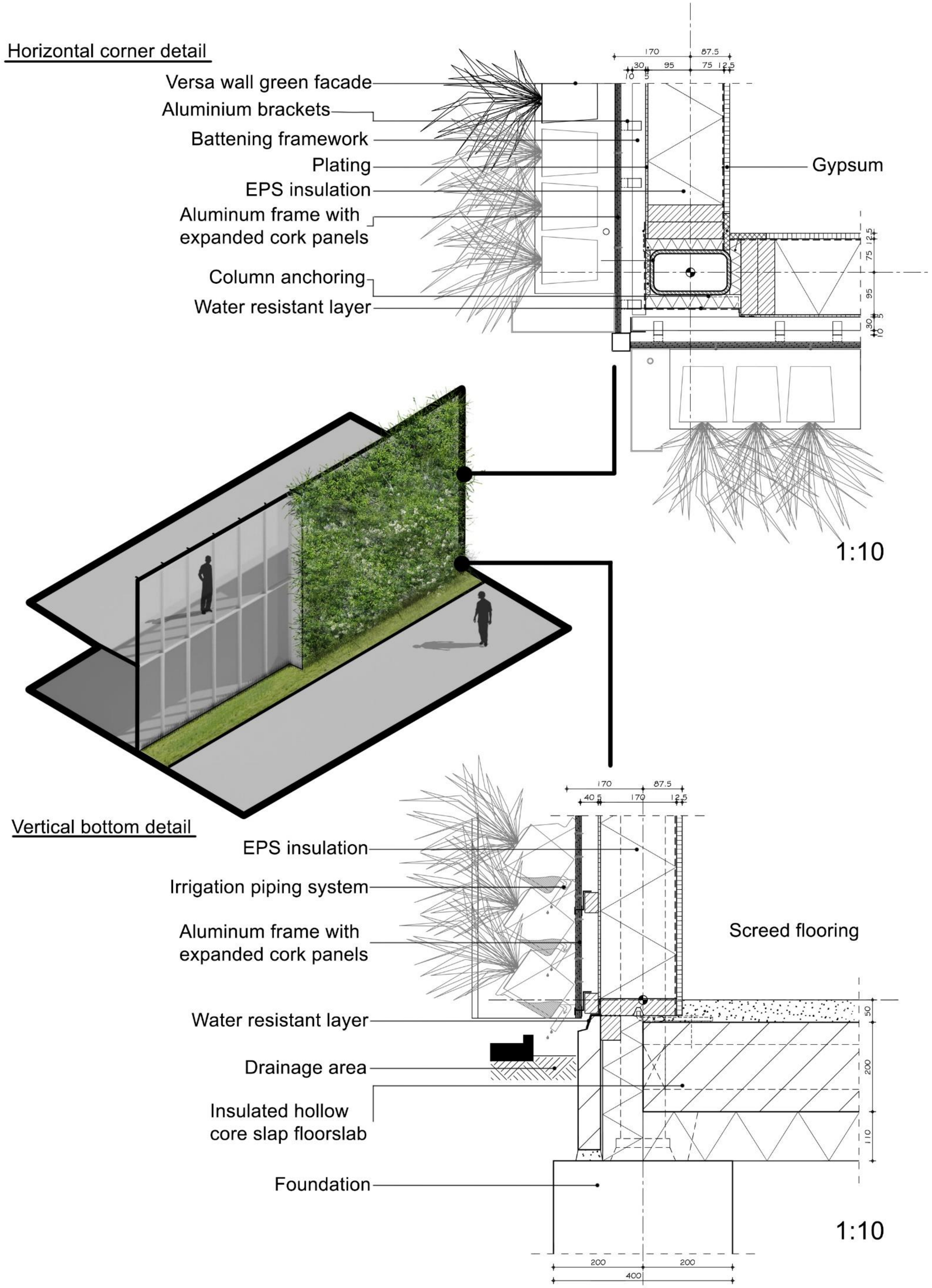
Figure 67: Indoor thermal comfort of different shading solutions for the south southwest facade

	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	108,0	75,0	9,9	6,9	8,1	5,6	18,0	12,5
Balconies 2m	128,0	88,9	6,0	4,2	7,1	4,9	3,0	2,1
Low g-value	131,0	91,0	9,1	6,3	3,0	2,1	1,0	0,7
Sidefins 1m	120,0	83,3	8,1	5,6	8,1	5,6	8,1	5,6
balconies/g-value	144,0	100,0	0,0	0,0	0,0	0,0	0,0	0
sidefines/g-value	141,0	97,9	11,0	2,1	0,0	0,0	0,0	0

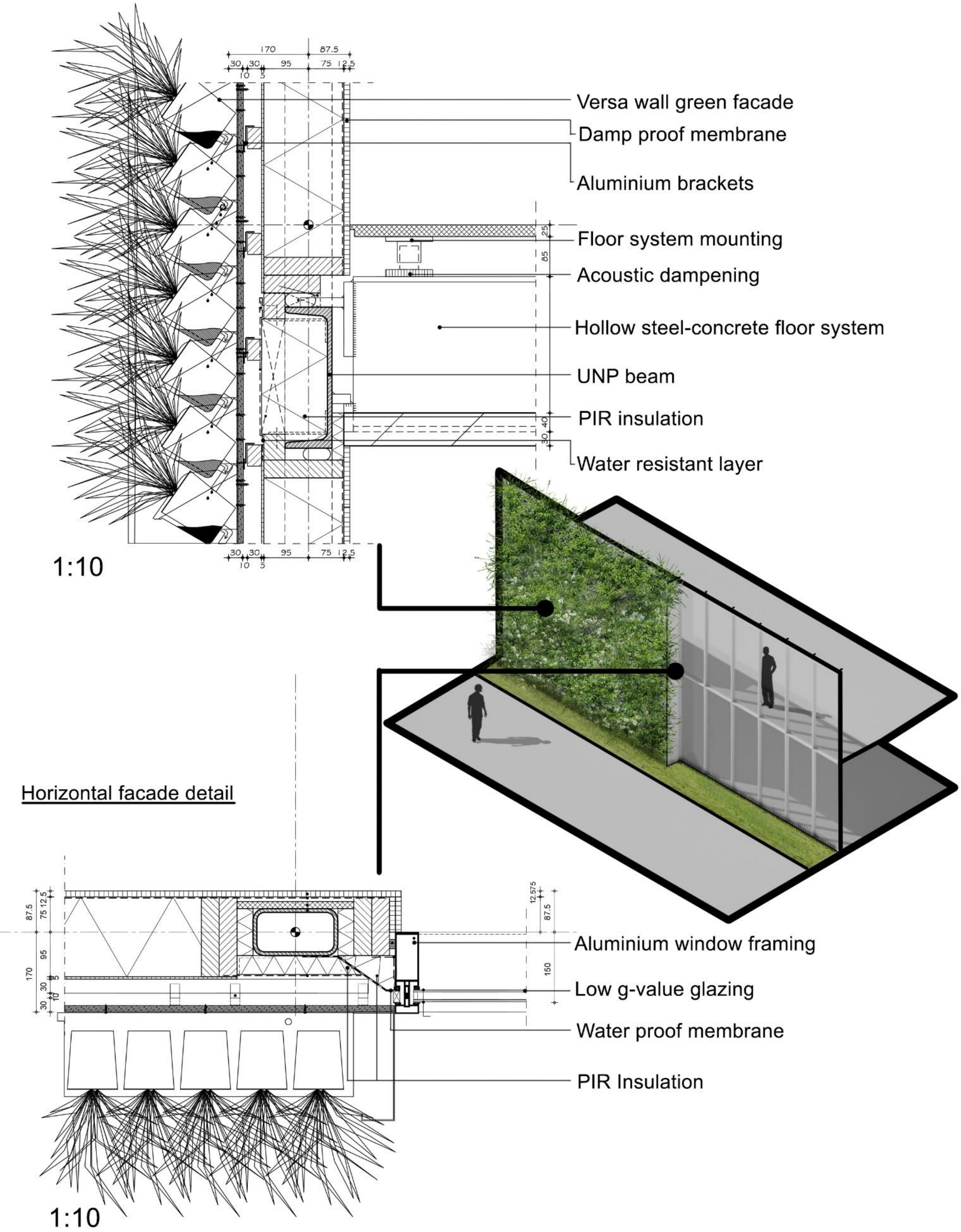
Figure 68: Indoor thermal comfort of different shading solutions for the east southeast facade

The analysis shows that the south southwest facade requires a combination of different methods as any single method does not suffice the indoor thermal comfort requirements. Either balconies or side fins would work. The east south east facade already realizes a relatively comfortable indoor temperature with either balconies or low g-value glazing so extra measures do help but are not necessary.

These measures show that low g-value glazing is necessary on all parts of the building to avoid using sunscreens. In addition to these balconies and side fins are needed on the southern two facades. The two northern facades can implement balconies but this would be for architectural reasons. The details of both these facades can be found on the next four pages.

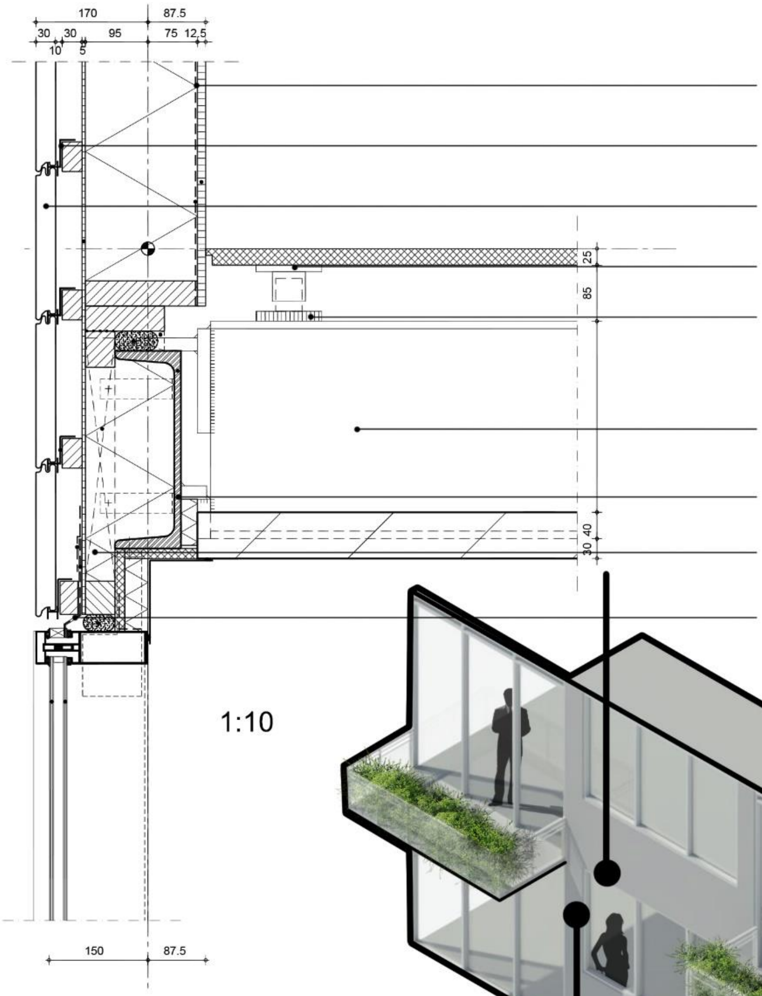

Horizontal corner detail
Versa wall green facade
Aluminium brackets
Battening framework
Plating
EPS insulation
Aluminum frame with expanded cork panels
Column anchoring
Water resistant layer
Gypsum
170
87.5
30
95
75
12.5
10
5
12.5
75
95
30
5
10
1:10
Vertical bottom detail
EPS insulation
Irrigation piping system
Aluminum frame with expanded cork panels
Water resistant layer
Drainage area
Insulated hollow core slap floorslab
Foundation
Screed flooring
170
87.5
40
5
170
12.5
50
200
110
200
200
400
1:10

Vertical floor-facade detail

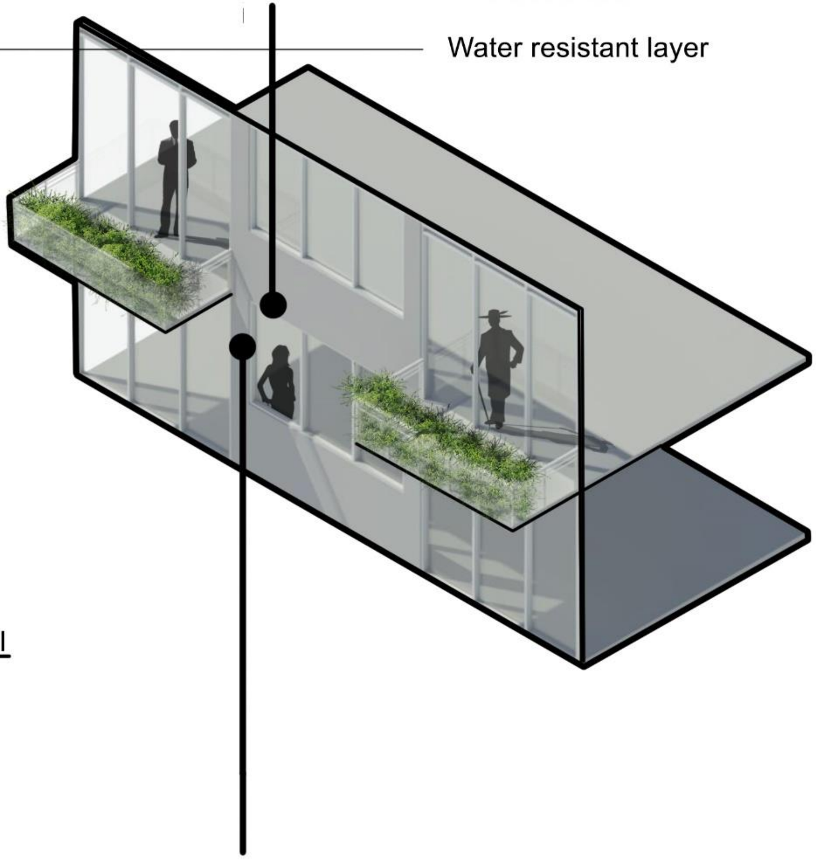


Horizontal facade detail

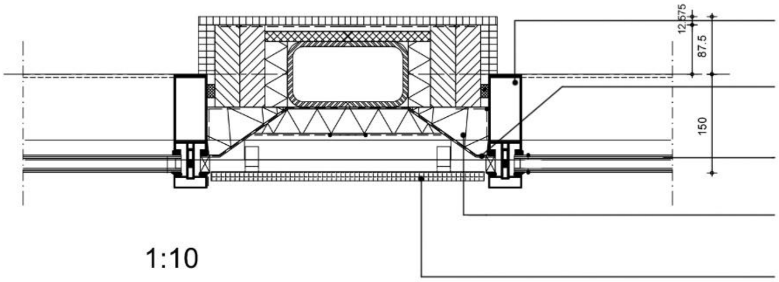
Vertical floor-facade detail



1:10

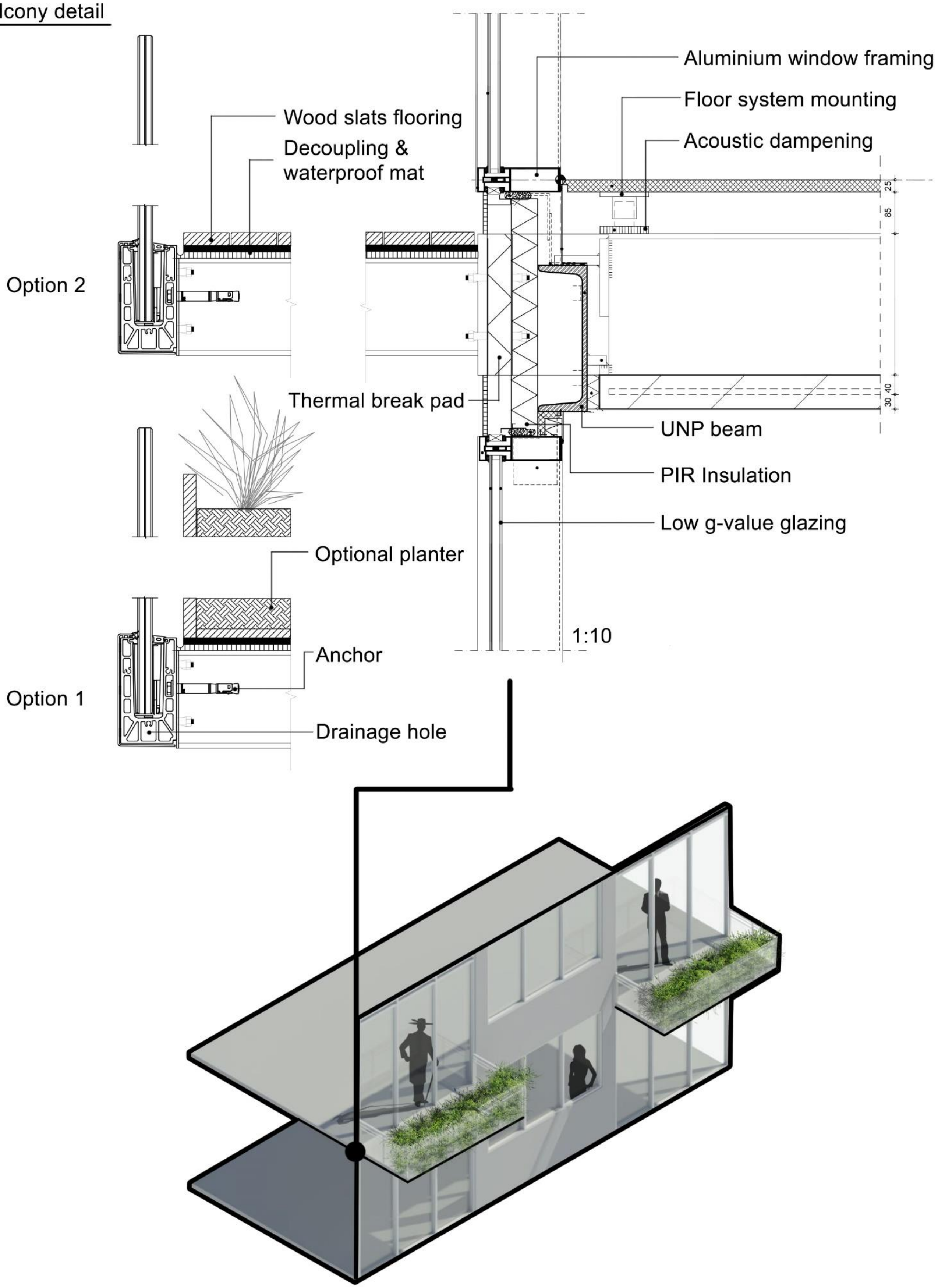


Horizontal facade detail



1:10

Balcony detail



Lower facade Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Cork	0,02	0,04	0,5
Cavity	0,04	0,22	0,1818182
Plywood	0,005	0,18	0,0277778
EPS Insulation	0,17	0,031	5,483871
Gypsum	0,0125	0,13	0,0961538
Total			6,2896208

Figure 69: Thermal transmittance lower facade

Lower facade thermal bridge Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Cork	0,02	0,04	0,5
cavity	0,04	0,22	0,18181818
plywood	0,005	0,18	0,02777778
Wood block	0,17	0,13	1,30769231
Gypsum	0,0125	0,13	0,09615385
Total			2,11344211

Figure 70: Thermal transmittance lower facade thermal bridge

Upper facade Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Trespa	0,02	0,3	0,0666667
Cavity	0,04	0,22	0,1818182
Plywood	0,005	0,18	0,0277778
PIR Insulation	0,17	0,029	5,862069
Gypsum	0,0125	0,13	0,0961538
Total			6,2344854

Figure 71: Thermal transmittance upper facade

Figure 72: Heating need from: OVO Energy (N.D.) How Much Energy Do You Use To Heat Your Home? Retrieved 18-05-2020 from: https://www.ovoenergy.com/guides/energy-guides/how-much-heating-energy-do-you-use.html

Insulation value facades

Additionally a thermal transmittance check is performed for both facades to test if they adhere to simulation parameters of $R_C = 6$ m^2 x K/W or higher. Both facades meet the requirements, however some thermal bridging occurs which is inevitable this calculation can be seen in the figures above.

Energy usage

For this calculation the same Design builder file is used to simulate a NEN5060 5% year. The corner apartment with an upper facade (70% window to wall ratio) and a surface area of 65 m^2 is used. The apartment is heated via full electric heat pump. The yearly energy usage for heating this apartment is 2685,9 kWh per year which is 41,3 kWh/m^2. Compared to other housing it would fall between the low (50 kWh/m^2) and passive (15 kWh/m^2) category (OVO Energy, N.D.).

Comparing this energy usage to that of similar dwellings that use natural gas can be done by using CBS (Central Statistics Bureau) statistics (2018). A similar older apartment uses 1090 m^3 of natural gas annually for heating according to these CBS statistics, which comes down to around €887,26 when using the CBS (2018) pricing of 81,4 cents per m^3. Compared to the simulated apartment which comes down to €604,3 with a pricing of 22,5 cents per kWh. In the graphs below the daily usage throughout the year can be seen together with the use of additional natural ventilation.

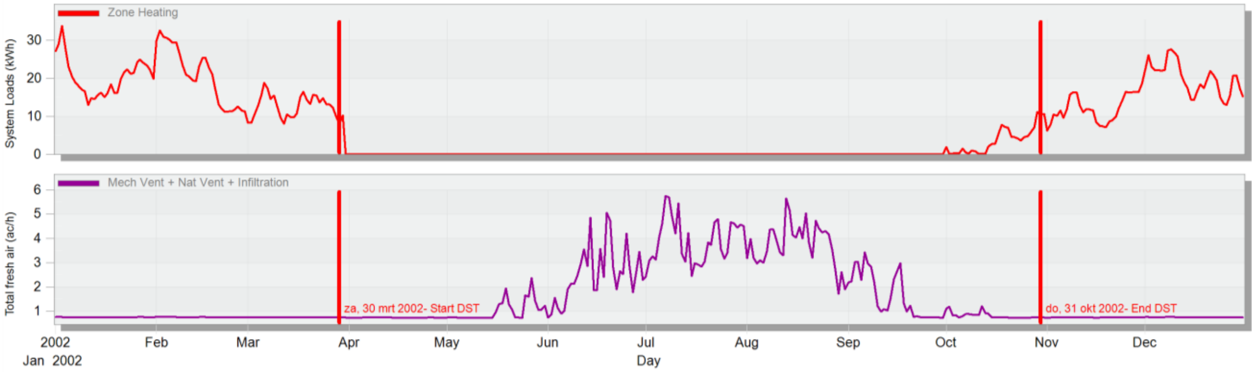


Figure 73: Energy usage & ventilation throughout the year

7. Discussion

Further research into this topic and its various subtopics is definitely necessary. In this chapter various recommendations will be provided based on the experiences from this research to help future research avoid certain problems or focus on the right parts of these topics.

This research was focused specifically on the relation between urban microclimate, passive design measures and the indoor thermal comfort. However this completely disregards outdoor thermal comfort. This is important specifically for dense urban environments where the UHI-effect is at its most intense and where the surroundings of a building are heavily used. The outdoor thermal comfort can be seen as another positive aspect of improving the microclimate. ENVI-met which is also used in this research even has a separate software module to look into thermal comfort in outdoor spaces.

Another aspect of this topic which was not a part of this research is the relation between wind speed and the UHI-effect. Due to simulation time the real hourly wind speed could not be used in the simulations. Instead a standard low wind speed was used. However this wind speed still has an effect on the temperature and the way the microclimate behaves with regards to its surroundings. A separate research setup could test a similar urban environment with different wind speeds and analyze the effect it has on the urban microclimate.

Legislation of measures against the effects of the UHI-effect is also something that could be a very interesting and useful follow up research topic. At this moment there is no legislation regarding the effect a building has on its microclimate surroundings however there have been discussion on implementing it. The research could be based on applying certain legislative measures on all of the buildings in a certain urban environment and seeing what legislative action would be the most effective. This would also address the question if it is better to have some buildings incorporating a lot of measures or a lot of buildings incorporating some measures.

There is also the fact that in the current ATG method to determine indoor thermal comfort the standard is set to use data from the closest weather station as the running mean outdoor temperature. However when a climate simulation is run on an urban center it shows that the actual outside air temperature can differ quite a lot. This is probably because this the data of the urban microclimate around the building is not available. Research into this phenomenon could be very interesting especially because when taking the urban microclimate as a passive design tool it could also influence the running mean outdoor temperature and therefor also the ATG indoor thermal comfort limits.

Further research into this topic is not only extremely interesting it is also vital for our future cities. The urban areas of the future are predicted to become larger and larger while the population in these areas continue to grow as well. Combined with the rising temperatures due the climate change makes this a real threat for the livability of our urban areas. However with ample research and swift action in the right areas it should be achievable.

8. Conclusion

"How can a high-rise residential building in a Dutch urban center integrate passive design measures to ensure indoor thermal comfort without negatively impacting the temperature of its surrounding microclimate in future climate scenarios"

-How will the temperature of the future urban Dutch microclimate change due to climate change and the UHI-effect?

The exact changes the Dutch urban microclimate will undergo are hard to determine. Climate change will increase the temperatures of Dutch climate, the amount however depends on how the world reacts to climate change in the coming decades but an average increase of 1-2 ^{o}C is predicted. The microclimate changes due to the UHI-effect will differ per urban zone as the intensity of the UHI-effect is linked to population size and urban density. However these are both projected to increase in Dutch urban centers. Finally these two changes will influence each other as well worsening the effects of both. The temperatures of future urban Dutch microclimates will rise however due to the UHI-effect, climate change and the combination of the two affecting each other, how much will depend on location and climate change scenario. In the scenario and location of this research the daily average increase was around 1,9-3 ^{o}C, this is an extreme summer in 2050 scenario however.

-How to determine the indoor thermal quality under changing outdoor temperatures due to climate change & UHI-effect?

Determining indoor thermal comfort can be done in a number of ways. In this context the outdoor temperature is the most important parameter and used as a tool to test the indoor thermal comfort levels. The adaptive comfort method takes the outdoor temperature of several days into account and uses it as translation to indoor thermal comfort boundaries. This method also includes other important factors such as psychological and behavioral aspects and it has a separate model for passively cooled (Alpha) buildings. The indoor thermal quality can be determined in a number of ways, in this research the ATG method is used for its adaptive approach, inclusion of psychological and behavioral factors and a separate model for passively cooled buildings. This method was specifically chosen because it links the outside temperature to indoor thermal comfort range. Using this method in this research resulted in barely changed indoor thermal comfort hours when using the urban microclimate as a tool to improve thermal comfort during overheating. This is because when lowering the urban microclimate with passive measures it also lowers the acceptable ranges of the indoor thermal climate.

-What passive design measures could be used to ensure indoor thermal comfort in buildings in the Dutch urban areas?

In order to ensure thermal comfort in buildings in Dutch urban areas a number of different passive design measures can be used. Before this however it is vital to research and analyze what measures are effective at what places. This research shows that some measures were not effective at all while others were extremely effective. An analysis of the different possible passive measures should result in a requirement list that can be filled in with different forms of these passive measures. In this case study design it was a combination of low g-value glazing, shading trough balconies, Low U-value facades, green facades, white metal facade cladding, etc. But these requirements could have also been reached with a combination of different passive measures. Therefor it is imperative to choose the measures that not only fulfill the requirements but also fit the design and budget of their project.

-What design solutions can be used to minimize the negative temperature effects of a building on the urban micro climate?

The design solutions found in this case study mostly pertain to the direct design of the building because of its already established surroundings. The design solutions used to minimize the negative temperature effects in the case study are the implementation of a green facade system, white facade cladding and passive cooling (instead of mechanical). It is important for these measures to be focused on the lower parts of the building (below 20m) because the intensity of the UHI-effect is much higher in these areas.

The integration of passive design measures starts in the early design phase with a thorough analysis of the buildings surroundings, design parameters, wind direction, shading, plot size and floor space are important. Now an overall passive cooling strategy can be determined. This passive cooling strategy should combine different passive measures, optimize their individual strengths and be catered to the specific demands of the building and its surroundings. These passive cooling concepts can be assessed on their thermal comfort performance and microclimate impact by different computer simulations, this way the best overall strategy can be found. The second step, when the broad passive cooling strategy has been defined, tested and accepted is using the test data of the new urban microclimate to re-assess the different passive cooling strategies allowing the design to optimize its passive cooling solutions to its changing microclimate. This process can be repeated until the results of the indoor thermal comfort are satisfactory. This not only ensures a resilient building that is thermally comfortable for the coming future it also minimizes the effect of the urban heat island effect resulting in a more comfortable outdoor environment for the city.

Reflection

General

Looking back at these past few months made me truly appreciate the entire process and the changes this research went through. After many ups and downs I can look back and be very content with the end product.

Approach

I can say so far that my approached has largely worked although with many adaptions along the way. The initial approach I had envisioned at my P2 was much more simple and straightforward however in that approach a lot of important details had not been addressed yet and exactly those details made the whole approach more complex. However by realizing what impact those smaller details had on the entire project you realize how important they are.

Understanding on the “how and why”

The how and why on the entire topic improved every week during this research. Some of the most interesting parts are encountered when things learned in the literature study were seen in the results of some of the simulations. This obviously makes sense, however for me it was really giving me a better understanding of the topic as a whole. This topic is not very new but lately has becoming more and more relevant, so the relevance (or why) of this topic has become more and more clear over the last few years. The methods used in my research were really challenging and not always in a good way. Working with different software packages simultaneously allowed me to take the strengths of each software and combine the results of each of them into an analysis. The downside of this was that all of these software packages were relatively new to me could be frustrating at times. Especially the combination of long simulation times and frequent crashes caused me re-evaluate my choices sometimes.

Feedback from mentors

The most important feedback from my mentors was input on structuring my research. Especially in the beginning phase when I was struggling to find the right niche in the different topics for my research and how to structure this research. In addition a lot of good feedback has also been given in terms knowledge of the field: from different literature sources to validation methods and of course how to simplify and streamline some parts of the process. Finally in the last few weeks some parts of the research did not go as planned here my mentors helped me to make decisions on how to proceed despite some setbacks.

Translating feedback into the project

Translating feedback into the research was initially done via changing the structure, setup, methodology or scope of the research. In the beginning this happened a lot as I was still searching for the right direction to go in. After gaining my footing and having started the research process the incorporation of feedback changed with it. This feedback now went into more detail and pointed me towards certain directions I would not have looked myself or how to best interpret the data from simulations. An example would be from a microclimate analysis where I compared them using average temperatures, however after getting feedback about this the analysis was changed to include peak temperatures as well. I tried to incorporate feedback as best as possible even though sometimes it meant going back to a certain point in the research and doing it again in a different way. This can be difficult however in the end it ensured a better research project.

Learned from my own work

First and foremost is the knowledge I gathered on this topic and its various niche subtopics. These subtopics provided some of the more surprising lessons, things like manipulating climate data files, CFD simulation troubleshooting, software license management, etc. Other things that might be less obvious are things like managing large datasets, every week long ENVI-met simulation took up around 60GB of data. Extracting the right data, making it readable and finally drawing conclusions from this data was something that I was quite new at and had some trouble with initially. However practice makes perfect and by improving my excel knowledge simultaneously I was able to manage these large datasets. The software I used were also a learning experience from me not only be directly learning the software but also the approach to mastering and troubleshooting new software. Especially ENVI-met in that regard had a very steep learning curve and tested my patience often, but by using a structured trial and error approach to my simulations and making full use of the three simulation computers I had at my disposal it was possible to end up with a useful research tool. Finally I also learned a lot about myself and how to structure my work. A thesis looks like an overwhelming task in the first few weeks and I found it hard to really get a grip on the whole process. Sometimes it was hard to stay motivated or to keep believing in your own work, especially during the lockdown weeks when human interaction was minimal. However in the end it all turned out all right and although I could keep working on this for while I am quite content with the results.

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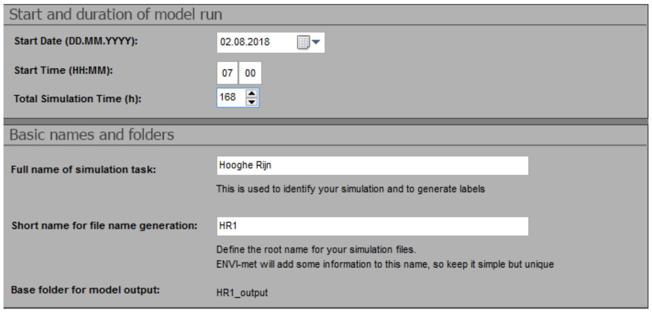
Appendix 1: ENVI-setup

Step 1 date and duration: here a specific period of simulation can be filled in. In this research a week is selected around the temperature peak of august the 5th. The time slot can be selected per hour.



Start and duration of model run

Start Date (DD.MM.YYYY): 02.08.2018

Start Time (HH:MM): 07 00

Total Simulation Time (h): 168

Basic names and folders

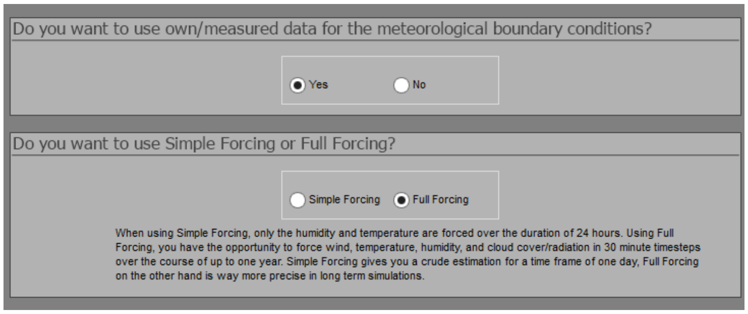
Full name of simulation task: Hooghe Rijn

This is used to identify your simulation and to generate labels

Short name for file name generation: HR1

Define the root name for your simulation files.
ENVI-met will add some information to this name, so keep it simple but unique

Base folder for model output: HR1_output



Do you want to use own/measured data for the meteorological boundary conditions?

● Yes ○ No

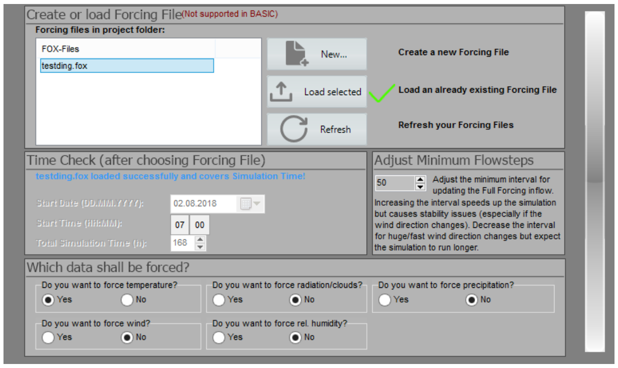
Do you want to use Simple Forcing or Full Forcing?

○ Simple Forcing ● Full Forcing

When using Simple Forcing, only the humidity and temperature are forced over the duration of 24 hours. Using Full Forcing, you have the opportunity to force wind, temperature, humidity, and cloud cover/radiation in 30 minute timesteps over the course of up to one year. Simple Forcing gives you a crude estimation for a time frame of one day, Full Forcing on the other hand is way more precise in long term simulations.

Step 2 climate data selection: selection weather ENVI-met can use generic weather data or self-measured and making a selection between full and simple forcing. In order to use custom climate data full forcing is needed.

Step 3 full forcing options: in this menu options can be chosen on what data from the climate file needs to be full forced. After selecting and loading the custom created weather file for the case study only temperature is selected. This is one of the simplifying measures implemented to cut down on calculation time. When things like wind are not full forced they will be based on the initial meteorological settings and keep repeating these initial steps. So for something like wind speed which is low during these hot days it can be substituted for a general low speed from the dominant wind direction. This cuts the calculation time in half. After some analysis on historical weather data it shows that there is a correlation between low wind speed and hotter temperatures, this is also concluded in the literature part of this research.



Create or load Forcing File(Not supported in BASIC)

Forcing files in project folder:

FOX-Files
testding.fox

Create a new Forcing File

Load an already existing Forcing File ✓

Refresh your Forcing Files

Time Check (after choosing Forcing File)

testding.fox loaded successfully and covers Simulation Time!

Start Date (DD.MM.YYYY): 02.08.2018

Start Time (HH:MM): 07 00

Total Simulation Time (h): 168

Adjust Minimum Flowsteps

50 Adjust the minimum interval for updating the Full Forcing inflow. Increasing the interval speeds up the simulation but causes stability issues (especially if the wind direction changes). Decrease the interval for huge/fast wind direction changes but expect the simulation to run longer.

Which data shall be forced?

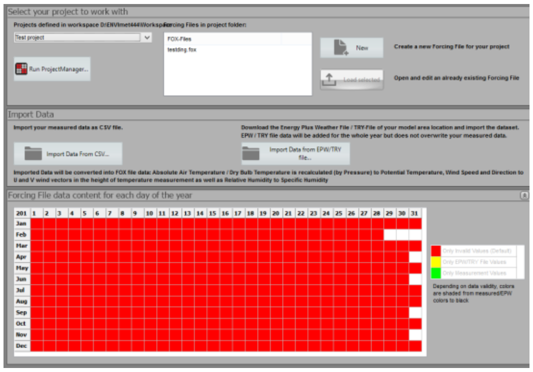
Do you want to force temperature? ● Yes ○ No

Do you want to force radiation/clouds? ○ Yes ● No

Do you want to force precipitation? ○ Yes ● No

Do you want to force wind? ○ Yes ● No

Do you want to force rel. humidity? ○ Yes ● No



Select your project to work with

Projects defined in workspace D:\ENVImet444\Workspace Test project

Forcing Files in project folder: FOX-Files testding.fox

Create a new Forcing File for your project

Open and edit an already existing Forcing File

Import Data

Import your measured data as CSV file.

Download the Energy Plus Weather File / TRY-File of your model area location and import the dataset. EPW / TRY file data will be added for the whole year but does not overwrite your measured data.

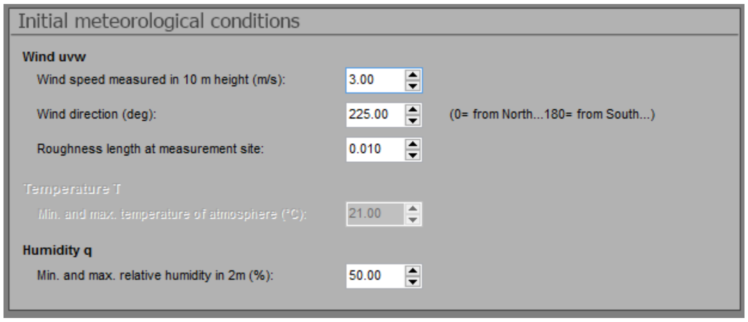
Imported Data will be converted into FOX file data: Absolute Air Temperature / Dry Bulb Temperature is recalculated (by Pressure) to Potential Temperature, Wind Speed and Direction to U and V wind vectors in the height of temperature measurement as well as Relative Humidity to Specific Humidity

Forcing File data content for each day of the year

🟥 Only Invalid Values (Default)
🟨 Only EPW/TRY File Values
🟩 Only Measurement Values

Depending on data validity, colors are shaded from measured/EPW colors to black

Step 4: In this step the initial meteorological conditions can be stated. The scatter plot is a combination of the temperatures and wind speed of historical measured data at the case study site. So for the wind speed a low 3m/s was chosen from the south west orientation.



Initial meteorological conditions

Wind uvw

Wind speed measured in 10 m height (m/s): 3.00

Wind direction (deg): 225.00 (0= from North...180= from South...)

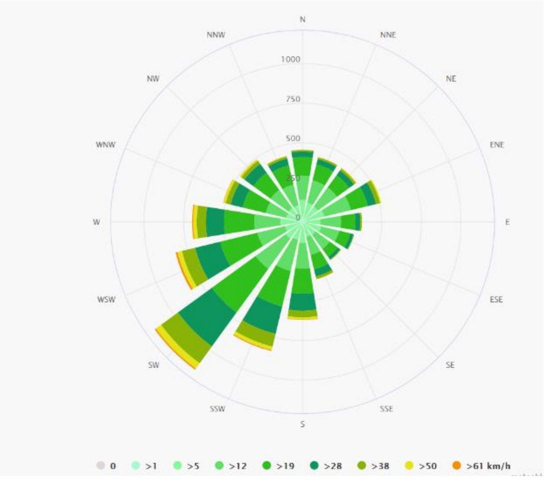
Roughness length at measurement site: 0.010

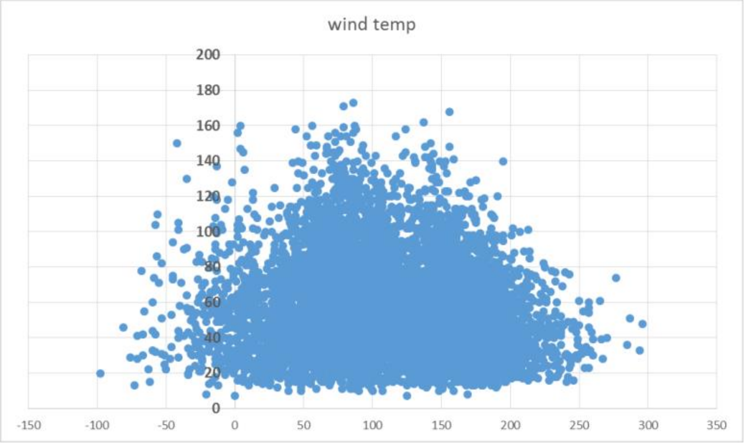
Temperature T

Min. and max. temperature of atmosphere (°C): 21.00

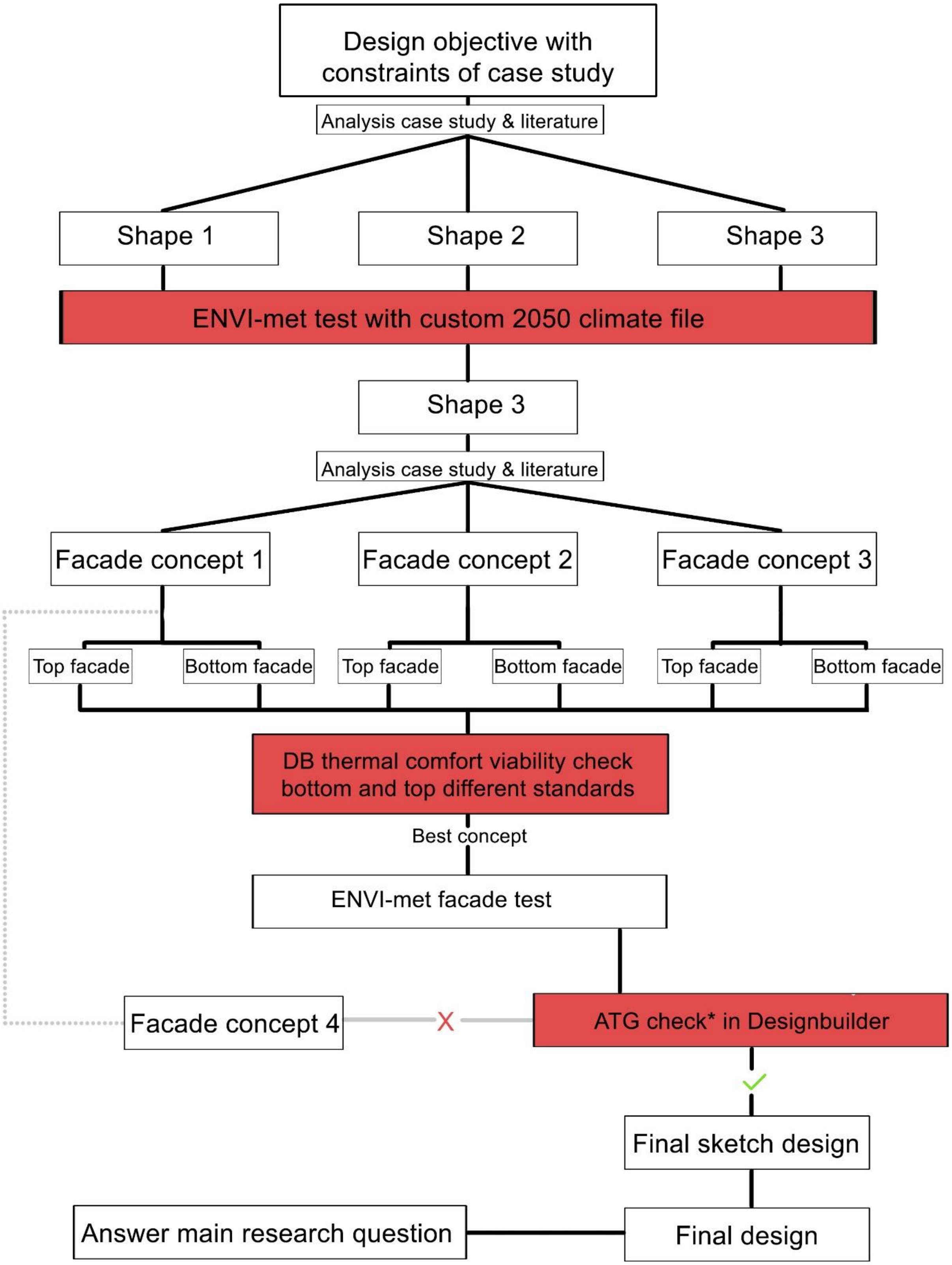
Humidity q

Min. and max. relative humidity in 2m (%): 50.00



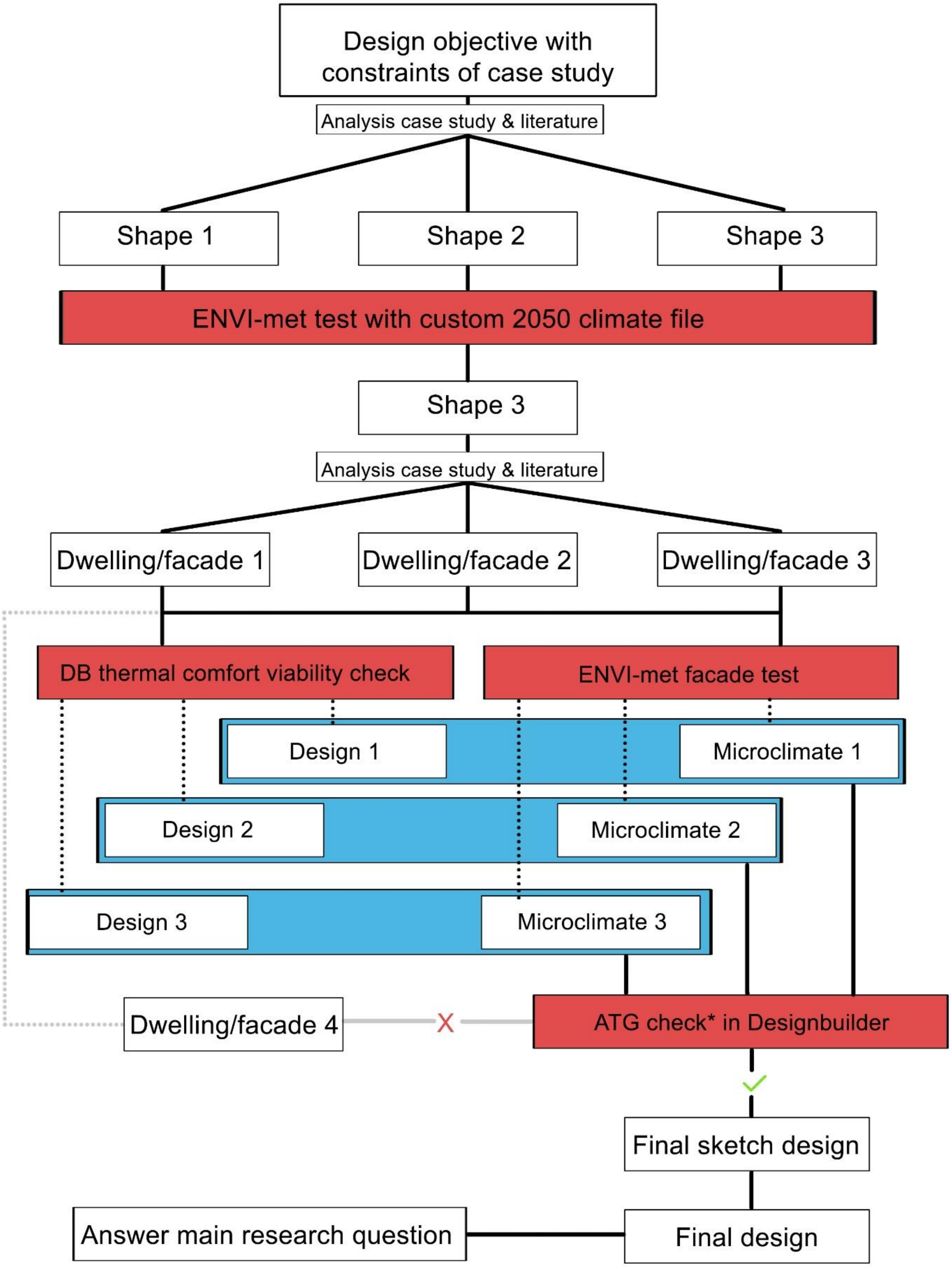


Appendix 2: Research frameworks



*For current and future climate

Old framework variant

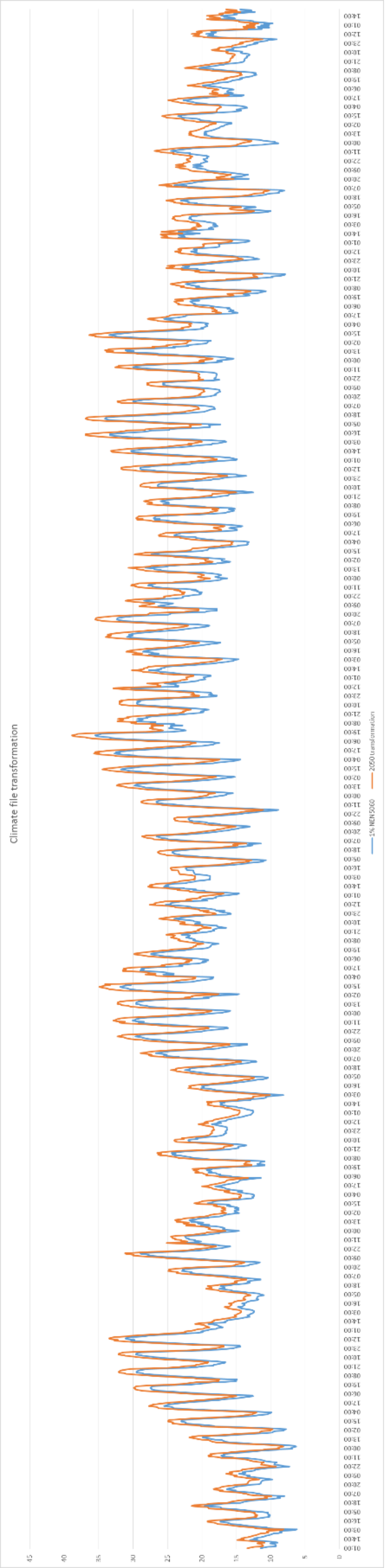


*For current and future climate

Appendix 3: weather files

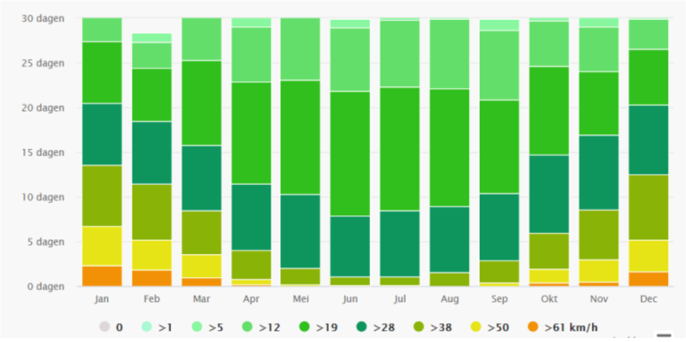
Here the data transformation of the climate files can be seen.

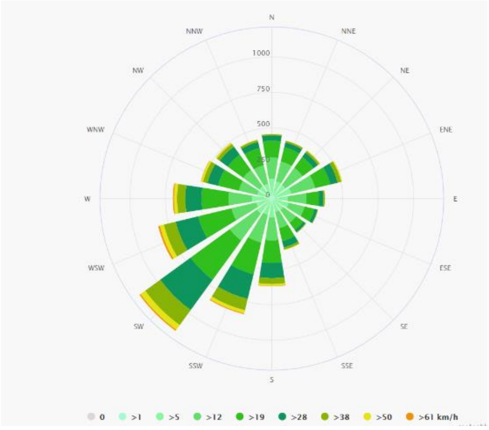
	June	July	Aug
Date	ΔT	ΔT	ΔT
1	1,9	2,5	2,5
2	1,9	2,4	2,4
3	1,9	2,5	2,5
4	1,9	2,7	2,7
5	1,9	2,9	2,9
6	1,9	3,5	3,5
7	1,9	2,8	2,8
8	1,9	2,3	2,3
9	2,2	2,3	2,3
10	2,4	2,6	2,6
11	2,6	3	3
12	2,5	2,9	2,9
13	2,4	2,4	2,4
14	1,9	2,3	2,3
15	1,9	2,2	2,2
16	1,9	2,2	2,2
17	2	2,3	2,3
18	2,2	2,5	2,5
19	2,2	2,4	2,4
20	2,1	2,1	2,1
21	1,9	2,2	2,2
22	1,9	2,5	2,5
23	1,9	2,4	2,4
24	2,1	2,2	2,2
25	2	2,3	2,3
26	1,9	2,2	2,2
27	1,9	2,2	2,2
28	1,9	2,1	2,1
29	2	2,1	2,1
30	2,2	2,1	2,1
31		2,1	2,1



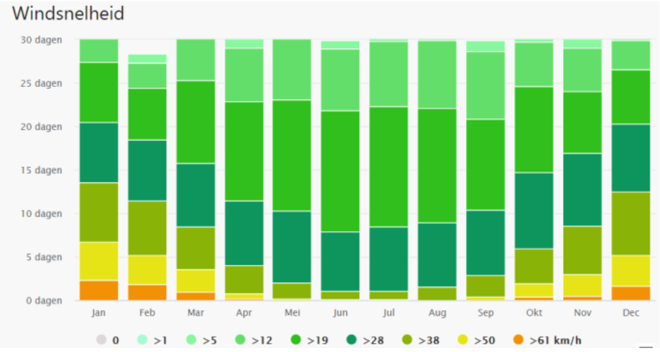
Appendix: 4 Comparing weather stations around the Hague area

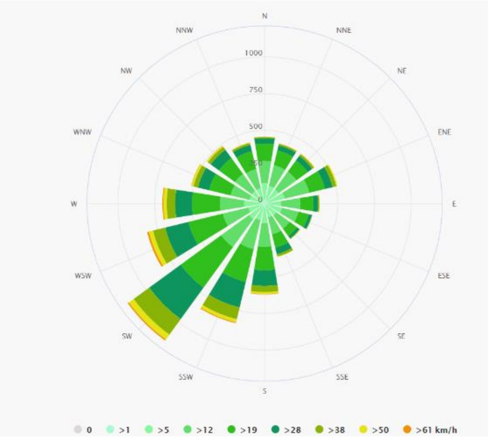
The Hague



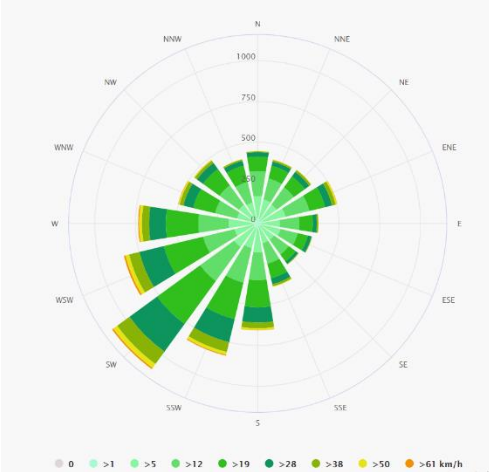


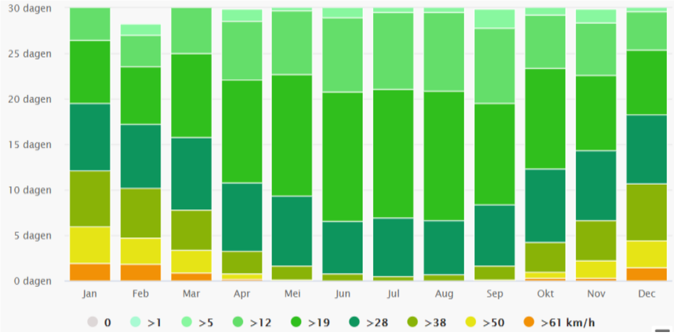
Hoek van Holland





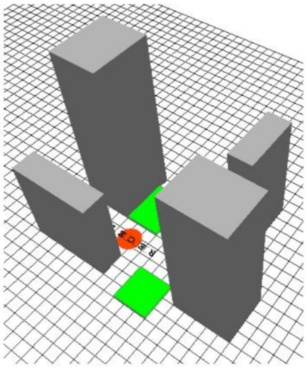
Rotterdam





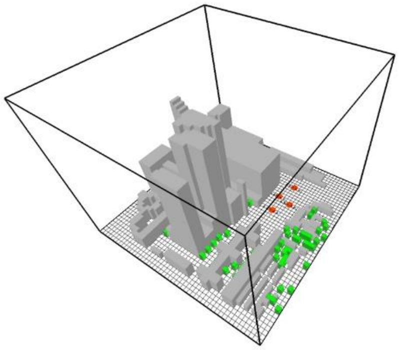
Appendix 5: ENVI-met testing

ENVI-met tests



Round 1: Testing session
First round of testing was done to practice with geometry in a simple setup and try different options, these tests were done in serie instead of simultaneously in order to improve every step. Short duration were chosen just to check if the simulation would crash, once stable longer duration and custom weather options would be possible.

TS_1	**TS_2**	**TS_3**	**TS_4**	**TS_5**
2 hour simple forcing	2 hour simple forcing buildings same height	2 hour simple forcing Buildings same height Adding extra cells at vertical and horizontal border	2 hour simple forcing more complex geometry Adding extra cells at vertical and horizontal border	10 hour placeholder weather file Adding extra cells at vertical and horizontal border
✗ Crashed	✗ Crashed	✓ Succeeded but no output	✓ Succeeded but no output	✓✓ Succeeded with output



Round 2: Creating a base template
Testing different options in order to produce a single template of the surroundings of the case study. In this template four receptors are placed aswell that need to record the hourly air temperature.

BT_1	**BT_2**	**BT_3**	**BT_4**	**BT_5**
8 hour simple forcing complex geometry	2 hour simple forcing buildings same height	2 hour simple forcing Buildings same height Adding extra cells at vertical and horizontal border	2 hour simple forcing more complex geometry Adding extra cells at vertical and horizontal border	10 hour placeholder weather file Adding extra cells at vertical and horizontal border
✗ Crashed	✗ Crashed	✓ Succeeded but no output	✓ Succeeded but no output	✓✓ Succeeded with output

Round 3: Weather file wind force testing. In order to test the wind settings and the added calculation times that go with with simulation different setups were used. Already the modelled case study building was used in this setup to get a realistic sense of the calculation times

HR_1	**HR_2**	**HR_3**	**HR_4**
48hour No building Full forcing wind	48hour HR building Simple forcing wind	48 hour No building Simple forcing wind	48 hour HR building Full forcing wind
✓ Succeeded but with 80hours sim time	✓✓ Succeeded with 40 hours sim tim	✓✓ Succeeded with 40 hours sim time	✓ Succeeded but with 80hours in sim time

Appendix 6: Eyeline skyline document

The document outlines four distinct parts of a skyscraper In the Hague: “plint” (Ground floor level), “stedelijke laag” (city layer), “toren” (tower) and “kroon” (crown).

Stedelijke laag:

-minimum of 9 maximum of 25 meters

-Recognizable part in design shape

-Wind nuisance minimized, solar acces for outside spaces optimized

Plint:

-Part of stedelijke laag

-Atleast 50% of facade transparent

Toren

-Tower can only take 50% of the space of the stedelijke laag.

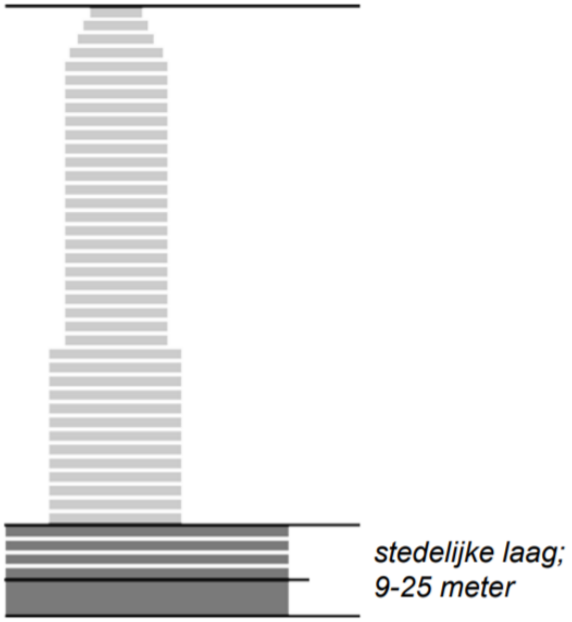
-The first 70 meters the tower can have a maximum circumference of 56 meters

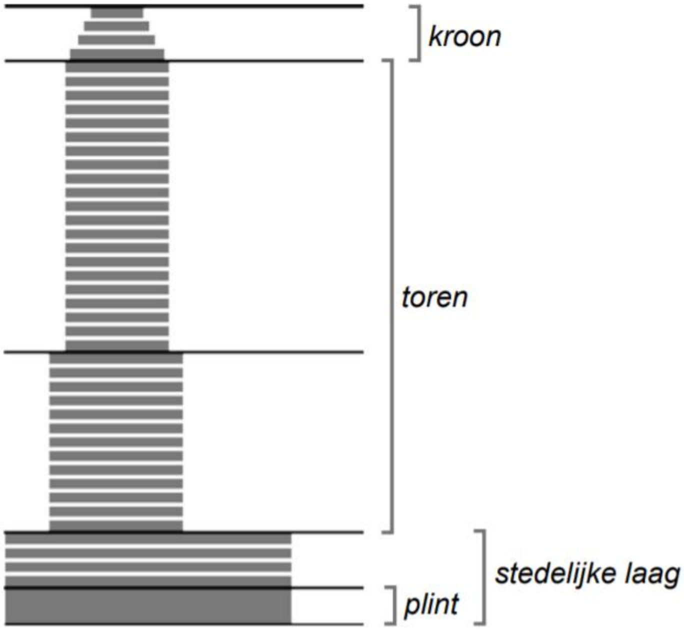
-from 70 meters the maximum circumference changes to 45 meters

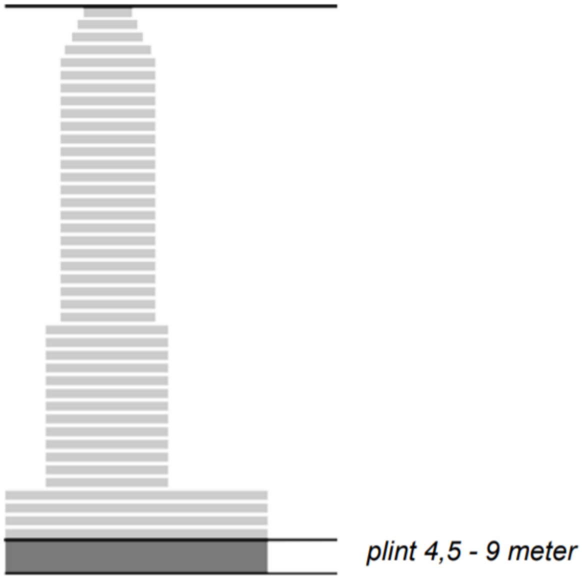
Kroon

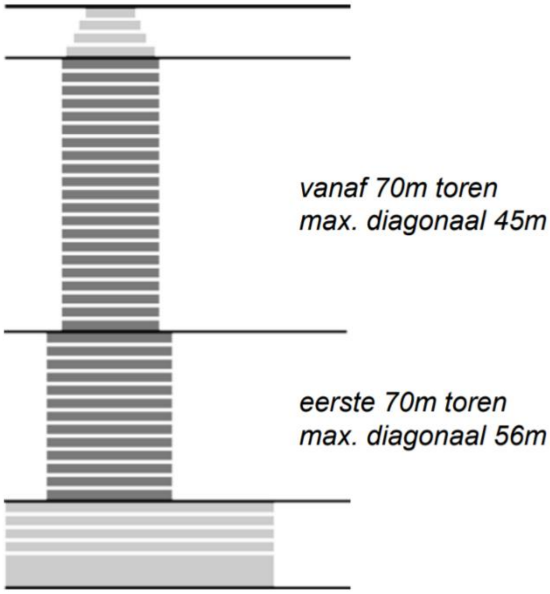
-Own signature design

-day and night design

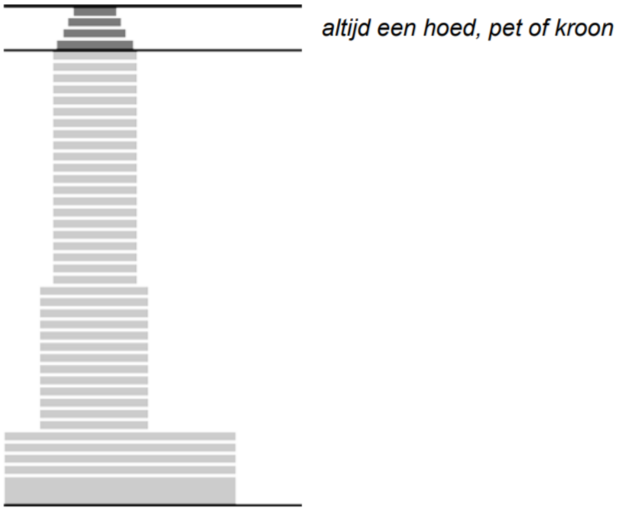








toren hoger dan 70m



Appendix 7: In depth microclimate analysis per shape: HR11

Due to small differences in temperature measurement per receptor there is not much to be seen by plotting them all in the same graph. However when doing this and zooming in on the daily maximum and minimum temperatures some interesting things come to light. This graph can be seen on the next page.

The difference in receptors only becomes noticeable when focusing on the daily temperature peaks Therefore a maximum average ΔT per hour of all four receptors graph is used and confirmed this finding. The largest differences between receptors are at the hottest times of the day. The difference during these peak hours can get up to 0,15 ^{0}C while during the nighttime the difference can fall to around 0,01 ^{0}C.

Looking at the peaks of a of a graph with all of the receptors average hourly temperature plotted against each other the difference become noticeable. Here it also show the difference per receptor which reflects the average of the receptors. R1 is consistently the highest during these peak hours, while the other three receptors register lower temperatures close to each other. The averages come down to R1=24,45^{0}C R2=24,41^{0}C R3=24,40^{0}C R4=24,41^{0}C.

However when looking at a cross section air temperature heat map it can be seen that the urban heat island effect on the temperature is most noticeable closer to the ground. Therefore further analysis is needed. For this two datasets are researched on the edges of the effects of the UHI-effect. Where the bottom edge data set will be made up of measurements from 0,5-22,5m and the upper edge data set will be taken from measurements of 52,5m-67,5m.

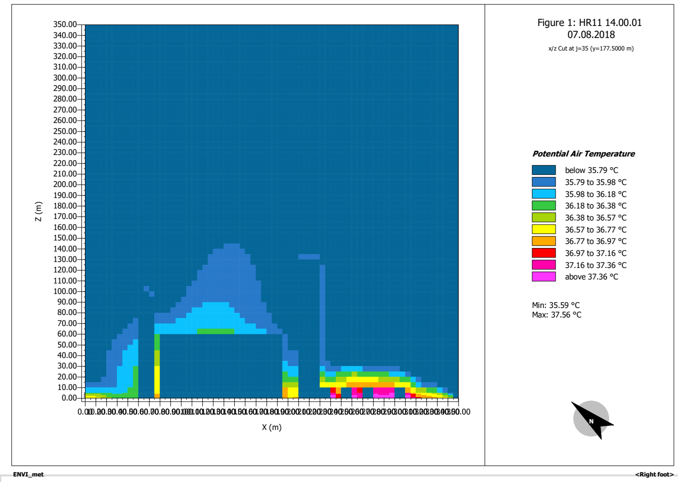
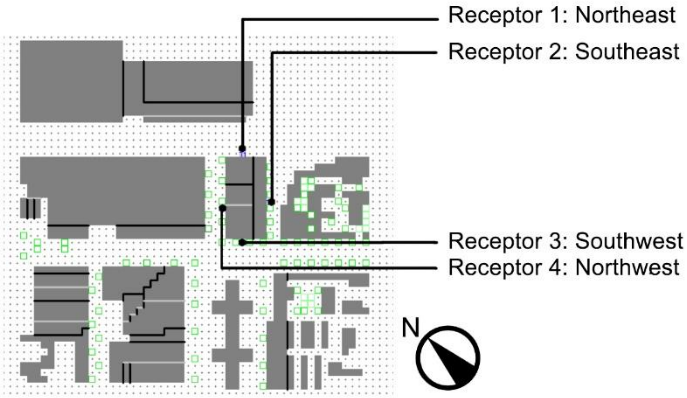
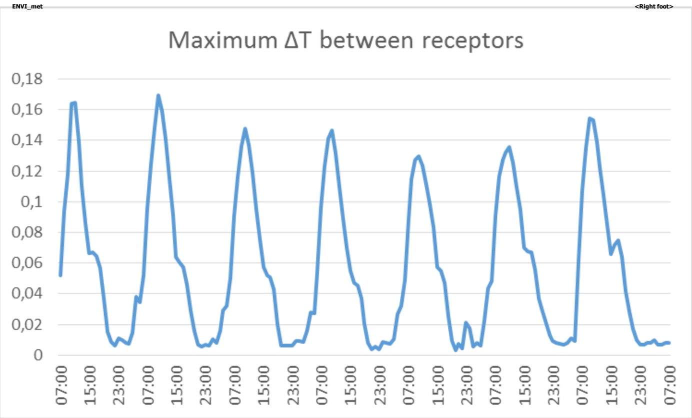
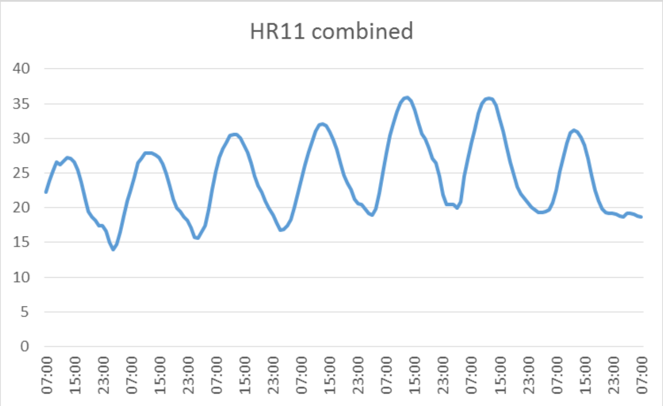
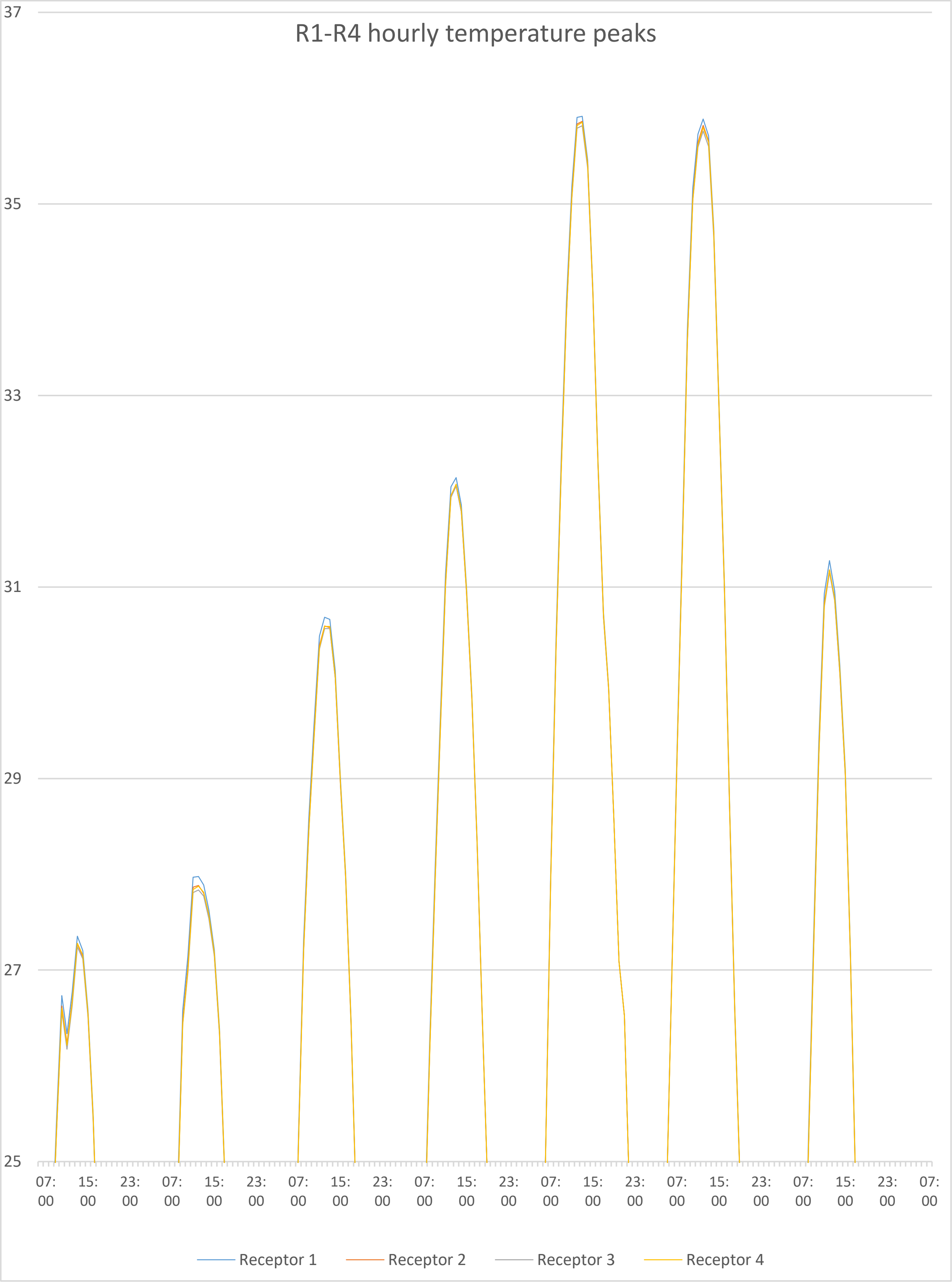


Figure 1: HR11 14.00.01
07.08.2018
x/z Cut at j=35 (y=177.5000 m)








R1-R4 hourly temperature peaks
37
35
33
31
29
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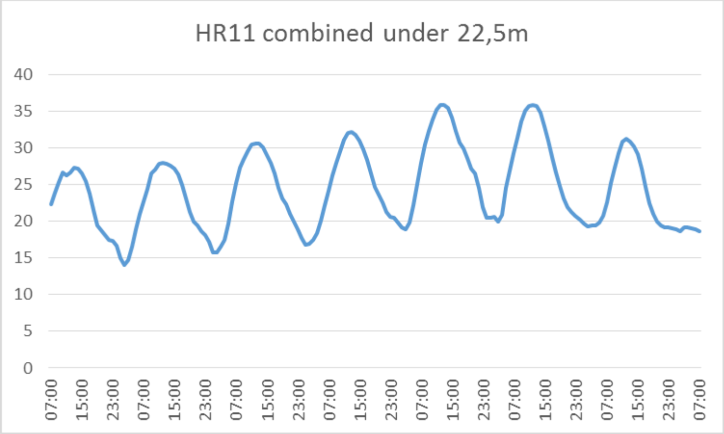
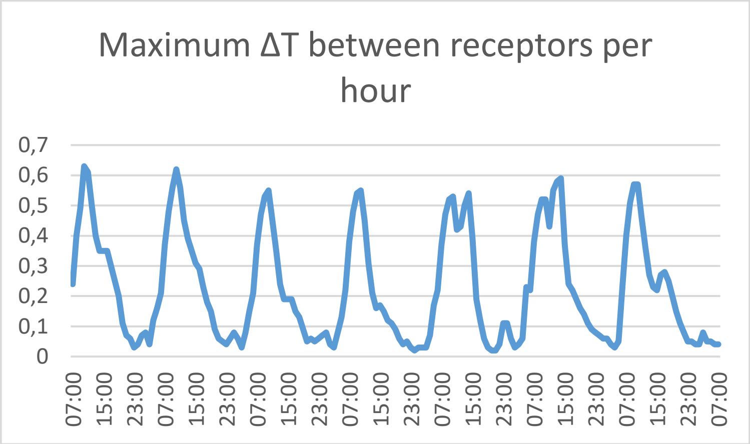
07:00
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR11 - height – low altitude

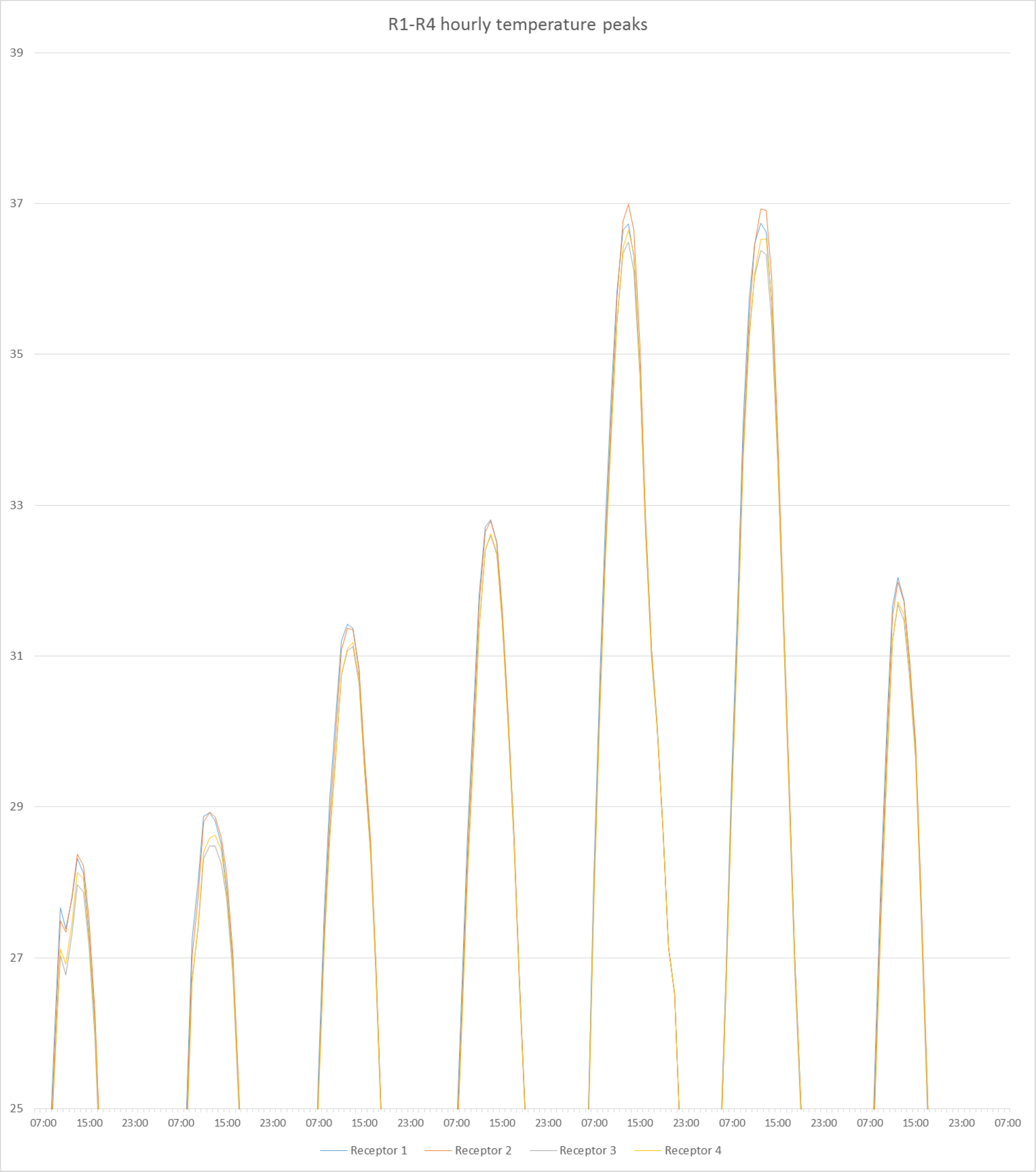
In this analysis the dataset for HR11 will be used but only the data measured under 22,5m.
When looking at the average temperature difference per receptor under 22,5 meter it shows that R1 and R2 increase a similar amount the same can be said about R3 and R4 only the increase is smaller than the other two receptors. When looking at the maximum difference between the receptors the patterns is similar to that of the total height receptors. However the difference between these receptors is a lot bigger: up to 0,6 ^{0}C in contrast to the 0,15 ^{0}C from the receptors of the total height. When looking at the graph where all the receptor hourly temperature data is plotted against each other similar differences can be found such as R1/R2 and R3/R4 being similar and R1/R2 measuring higher temperatures during the hottest hours of the day compared to their counterparts. Only on the two hottest days R1 measures a little bit higher temperatures than R2. Also when looking at the lows of this graph there is a single receptor that measures a little bit lower temperatures compared to the others. R3 is consistently a little bit colder than the rest of the receptors at the lows of the graph. However this difference between receptors at the bottom of the hourly temperature graph is very small.

The receptor data gives an idea of the temperature in the microclimate based on orientation. Where Northeast and Southeast are relatively hotter compared to the southwest/northwest part.





		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,78	24,75	24,61	24,64
Avg ^{0}C total		24,45	24,41	24,40	24,41
ΔT in ^{0}C		0,33	0,34	0,22	0,23


R1-R4 hourly temperature peaks
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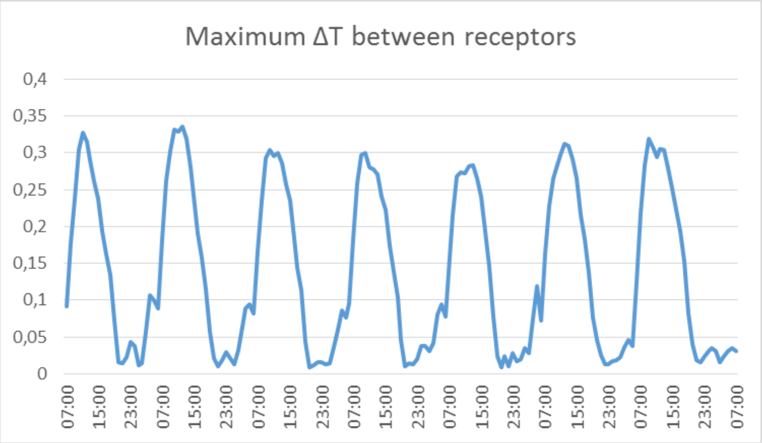
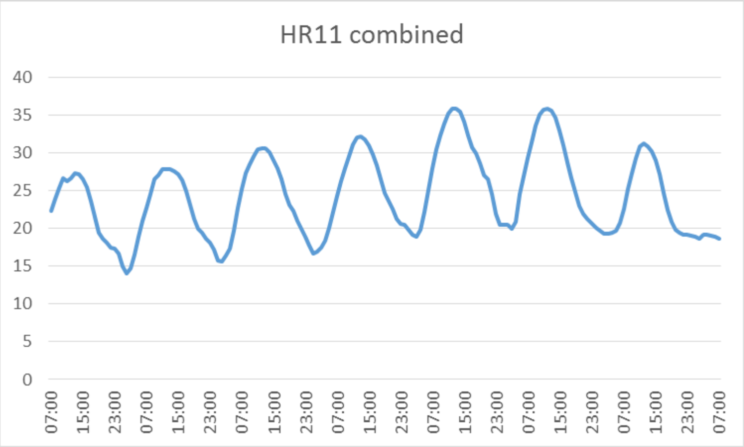
07:00
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR11 - height – high altitude

Here the upper edge of the microclimate that is effected by the UHI-effect will be analyzed. This upper part consists out of measurement taken from 52,5m-77,5m. Comparing the average measurements of the higher altitude with the total average of the microclimate around the entire building show that the difference per receptor is almost negligible and that in the case of R2/R3/R4 the higher altitude measurements are actually lower than the average of the entire microclimate. This same difference becomes apparent when comparing the average lower altitude data with the average higher altitude data. However when looking at the maximum ΔT data between receptor of the higher altitude dataset it can be seen that at peak temperatures the maximum ΔT exceeds 0,3 ^{0}C, double that of the total dataset. This difference does not matter for the average hourly temperature per receptor however which follows the hourly average temperature closely. This means that in those peak hours the receptors differ in such a way that they compensate each other's temperature difference and end up at a similar average to that of the total dataset. This can also be seen in the graph on the next page where all of the receptors hourly average temperatures are plotted against each other. The difference in peak temperature could explain the difference in average temperatures.

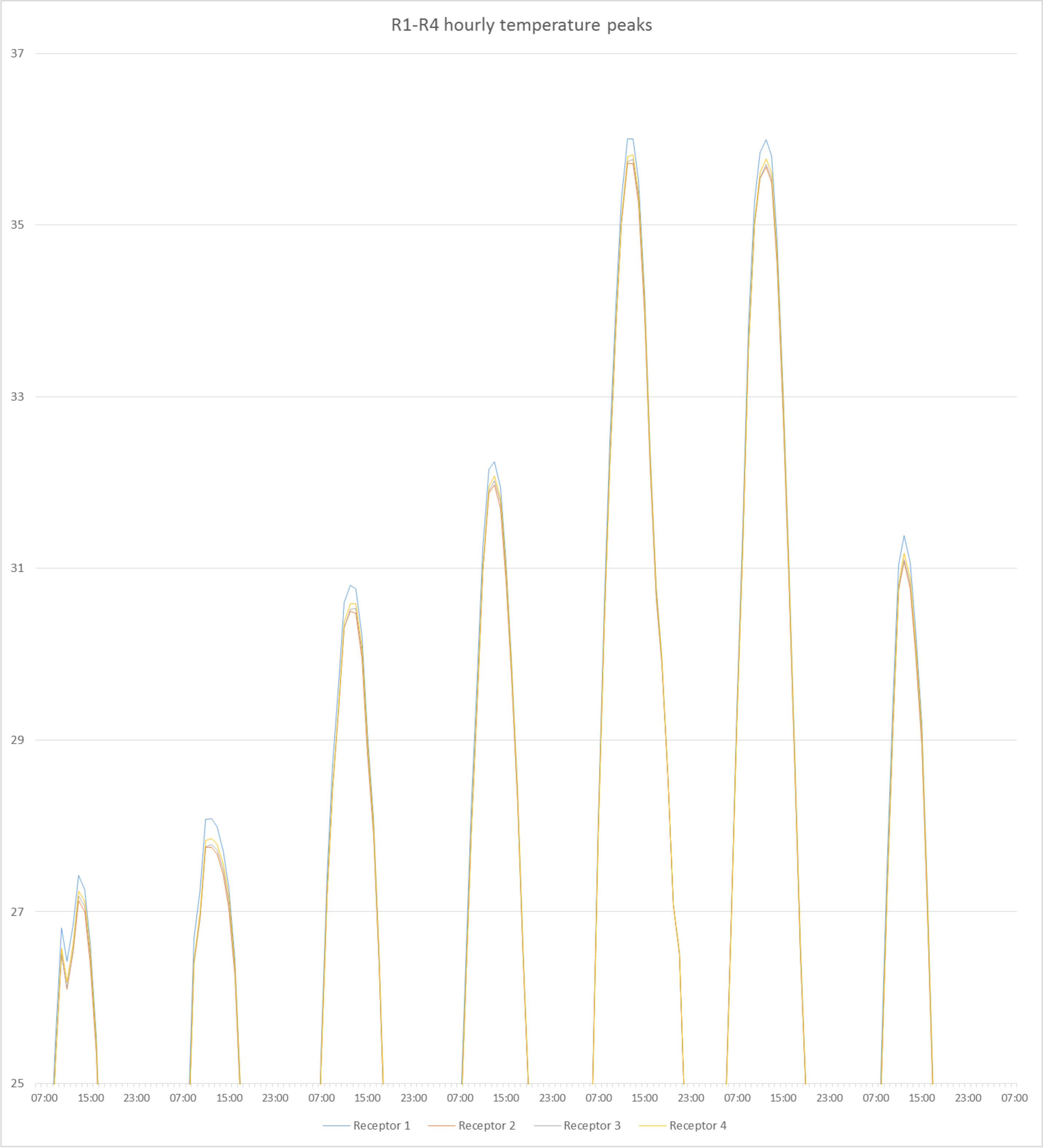
This hourly average temperature graph per receptor also gives an indication of the differences per orientation of the microclimate around the building at a height of 55,2m-77,5m. Where Northeast is the warmest at peak temperatures followed by Northwest, Southeast and finally Southwest.





		R1	R2	R3	R4
Avg ^{0}C 52,5-77,5m		24,48	24,37	24,38	24,39
Avg ^{0}C total		24,45	24,41	24,40	24,41
ΔT in ^{0}C		0,03	-0,04	-0,02	-0,01

		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,78	24,75	24,61	24,64
Avg ^{0}C 52,5-77,5m		24,48	24,37	24,38	24,39
ΔT in ^{0}C		0,30	0,38	0,23	0,25


R1-R4 hourly temperature peaks
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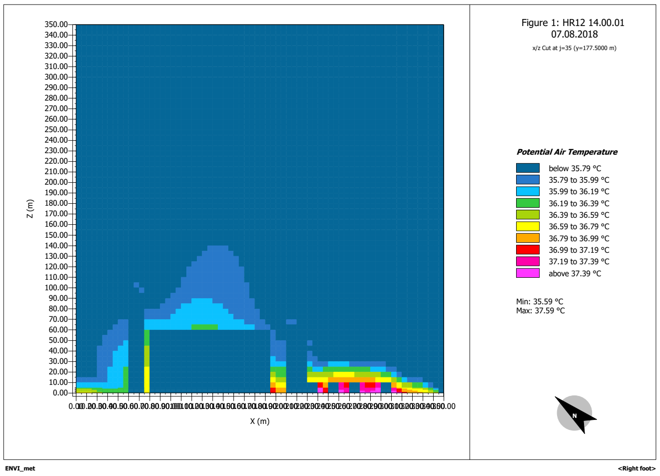
Receptor 1
Receptor 2
Receptor 3
Receptor 4

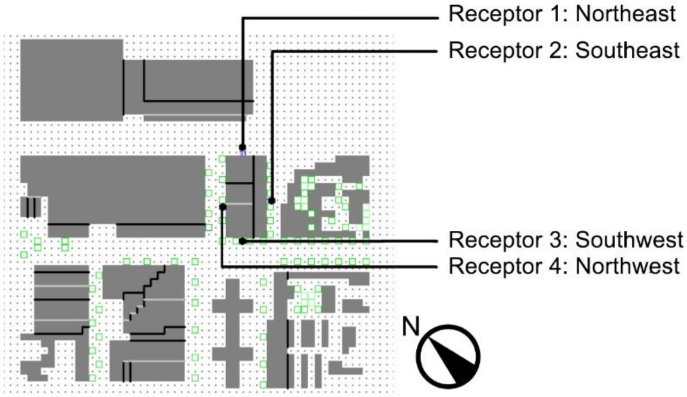
HR12

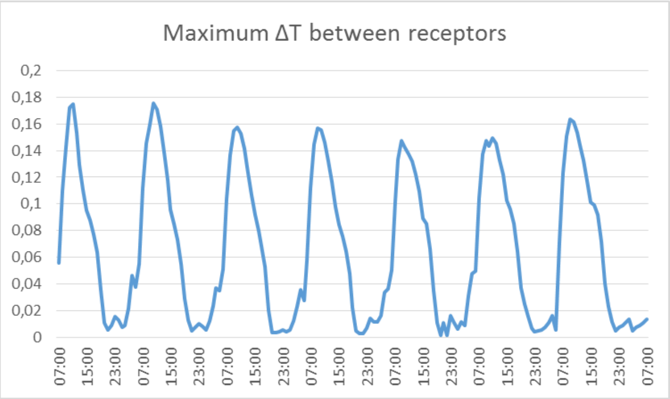
In order to accurately compare the different shapes and their respective microclimates similar analyses will be done on the data of HR12 and HR13. These analyses will use the same altitude bandwidth as the previous analysis of HR11.

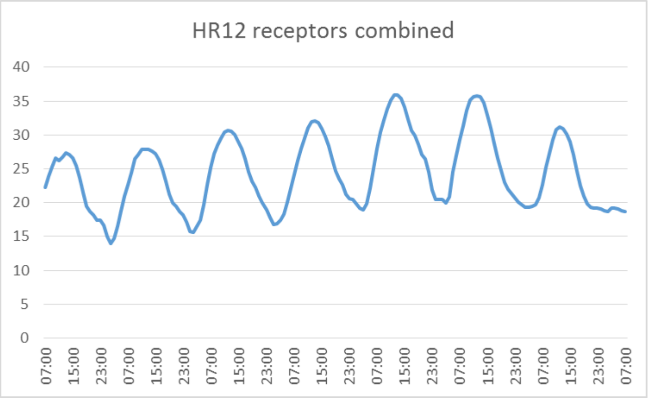
The maximum ΔT of the different receptors is a little bit higher at peak times compared to HR11. However when looking at the graph of the average hourly temperatures per receptor a similar spread can be noticed where R1 measures the highest temperatures with the maximum difference coinciding with the maximum average daily temperature.

		R1	R2	R3	R4
Avg ^{0}C total		24,46	24,42	24,40	24,41










R1-R4 hourly temperature peaks
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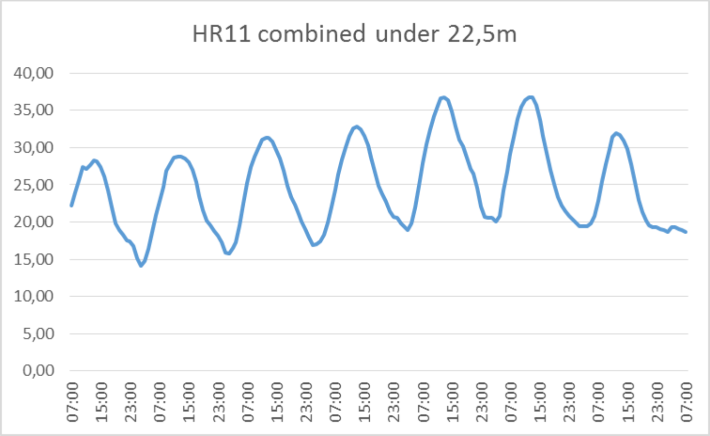
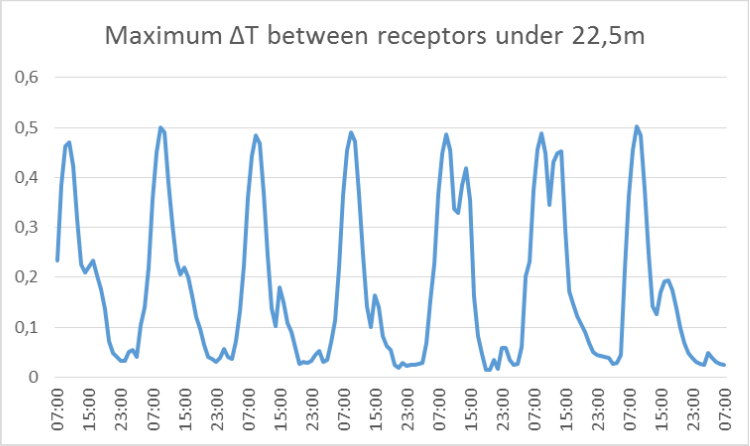
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR12 - height – low altitude

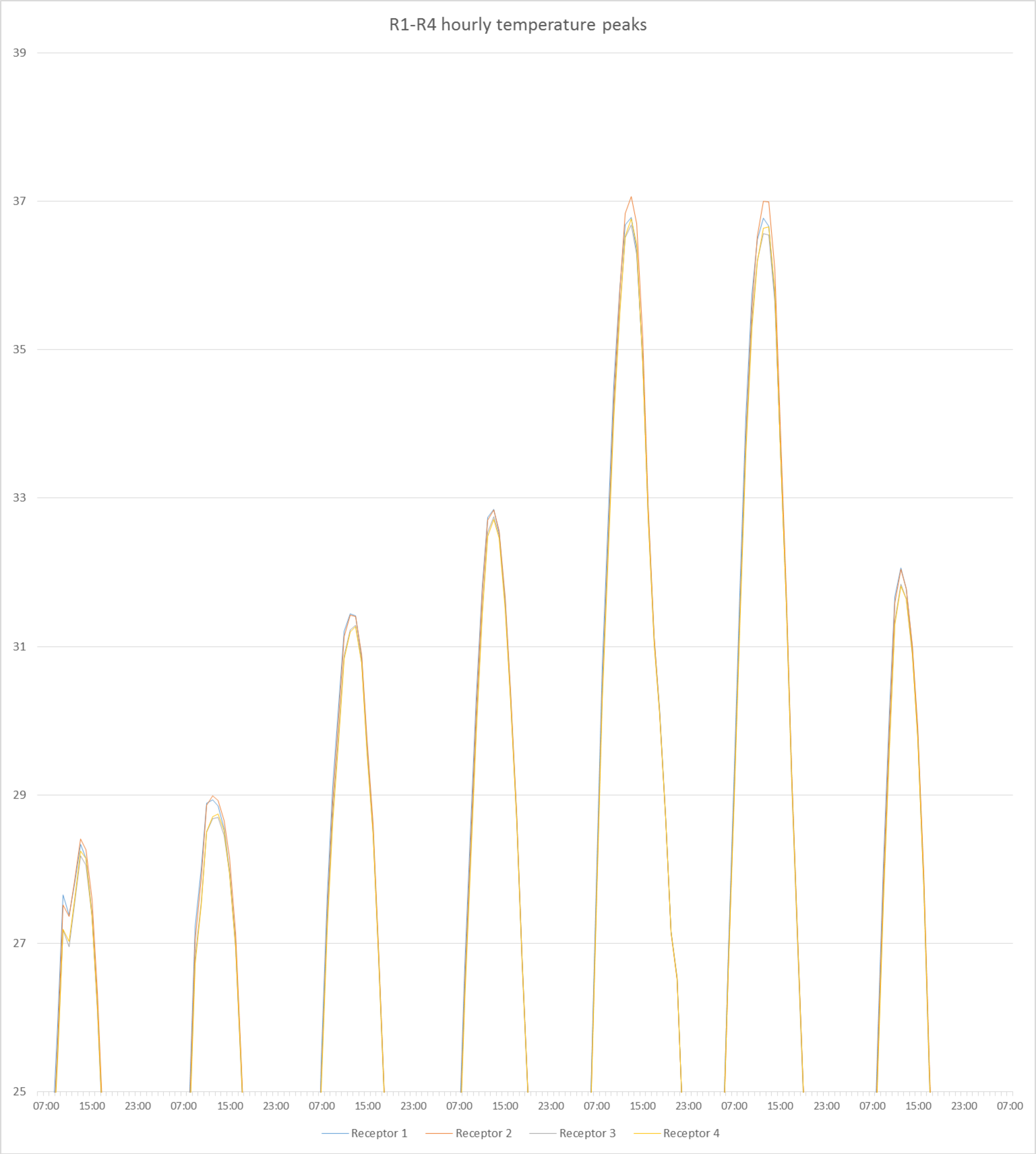
In this analysis the dataset for HR12 will be used but only the data measured under 22,5m.
When looking at the average temperature difference per receptor under 22,5 meter it shows that R1 and R2 increase a similar amount. The same can be said about R3 and R4 only the increase is smaller than the other two receptors. When looking at the maximum difference between the receptors the patterns is similar to that of the total height receptors. However the difference between these receptors is a lot bigger: up to 0,5 ^{0}C in contrast to the 0,17 ^{0}C from the receptors of the total height. When looking at the graph where all the receptor hourly temperature data is plotted against each other similar differences can be found such as R1/R2 and R3/R4 being similar and R1/R2 measuring higher temperatures during the hottest hours of the day compared to their counterparts. Only on the two hottest days R2 measures a little bit higher temperatures than R1. In HR11 in the same range as this microclimate the results of R1 and R2 are mirrored, with the shape of HR11 R1 measures the highest temperatures consistently.

The receptor data gives an idea of the temperature in the microclimate based on orientation. Where Northeast and Southeast are relatively hotter compared to the southwest/northwest part.





		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,79	24,78	24,69	24,68
Avg ^{0}C total		24,46	24,42	24,40	24,41
ΔT in ^{0}C		0,33	0,36	0,28	0,27


R1-R4 hourly temperature peaks
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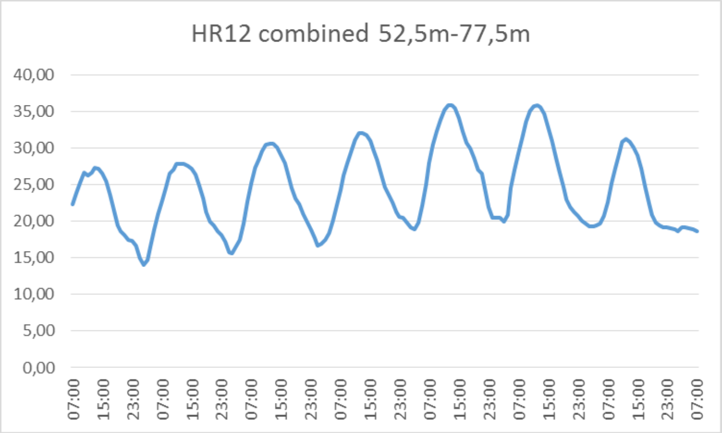
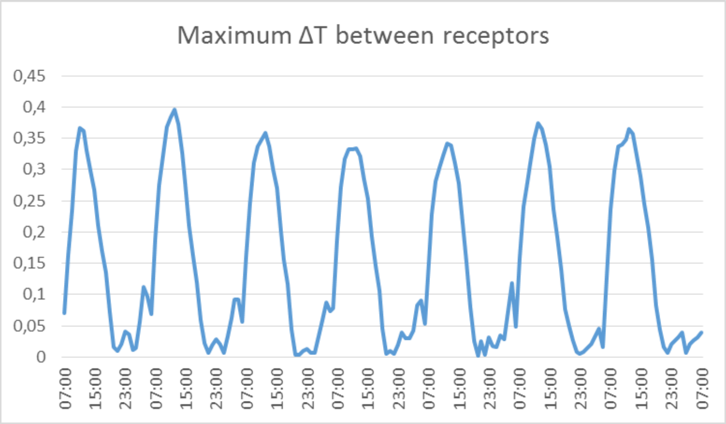
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR12 - height – high altitude

Comparing the average temperature measurements of the higher altitude with the average of the microclimate around the entire building show that the difference per receptor is almost negligible (maximum of 0,05 ^{0}C degrees on average per receptor) and that in the case of R2/R3/R4 the higher altitude temperature measurements are actually lower than the average of the entire microclimate. This same difference becomes apparent when comparing the average lower altitude data with the average higher altitude data. However when looking at the maximum ΔT data between receptor of the higher altitude dataset it can be seen that at peak temperatures the maximum ΔT can go up to 0,4 ^{0}C, more than double that of the total dataset. This difference does not matter for the average hourly temperature per receptor however which follows the hourly average temperature closely. This means that in those peak hours the receptors differ in such a way that they compensate each other's temperature difference and end up at a similar average to that of the total dataset. This can also be seen in the graph on the next page where all of the receptors hourly average temperatures are plotted against each other. The difference in peak temperature could explain the difference in average temperatures.

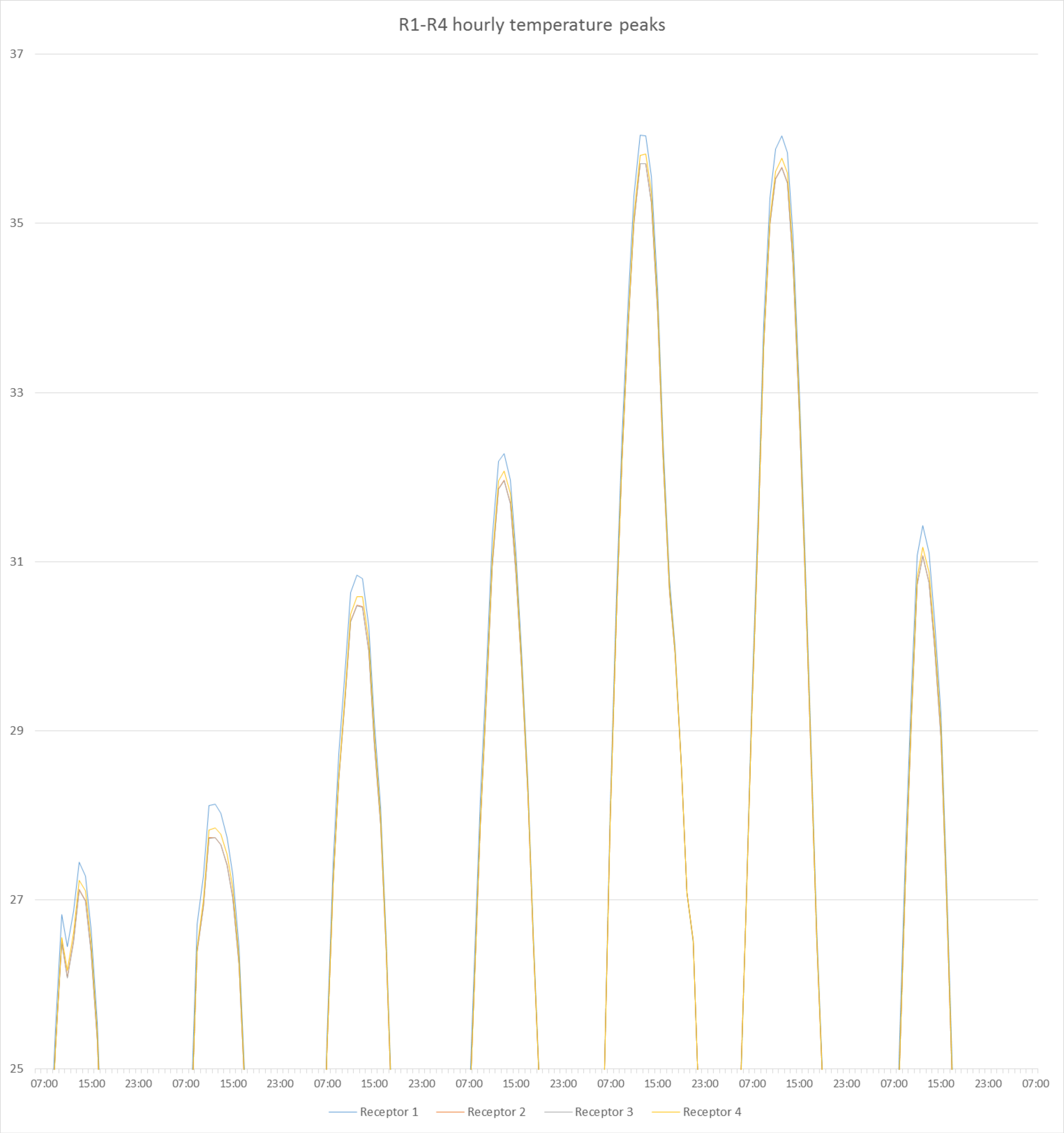
This hourly average temperature graph per receptor also gives an indication of the differences per orientation of the microclimate around the building at a height of 55,2m-77,5m. Where Northeast is the warmest at peak temperatures followed by Northwest, Southeast and finally Southwest.





		R1	R2	R3	R4
Avg ^{0}C 52,5-77,5m		24,49	24,37	24,36	24,39
Avg ^{0}C total		24,45	24,41	24,40	24,41
ΔT in ^{0}C		0,04	-0,05	-0,04	-0,01

		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,78	24,75	24,61	24,64
Avg ^{0}C 52,5-77,5m		24,48	24,37	24,38	24,39
ΔT in ^{0}C		0,30	0,38	0,23	0,25



R1-R4 hourly temperature peaks
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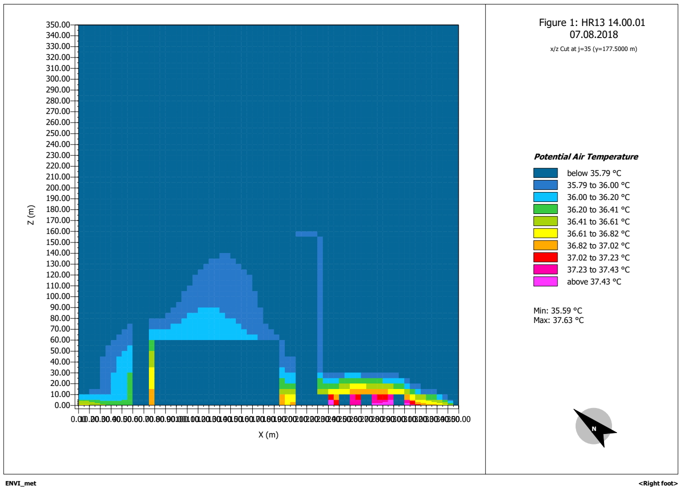
Receptor 1
Receptor 2
Receptor 3
Receptor 4

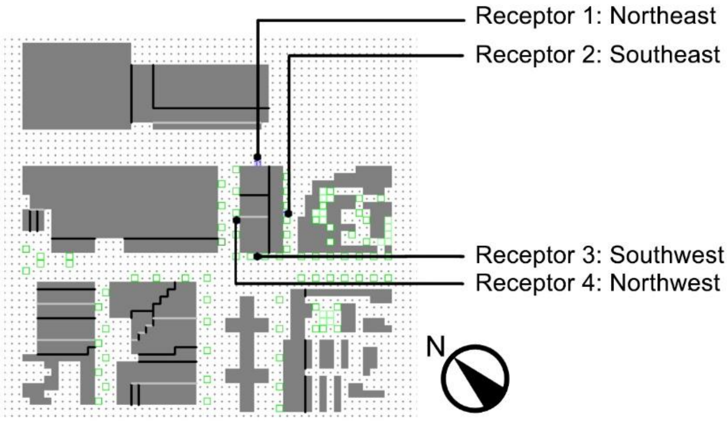
HR13

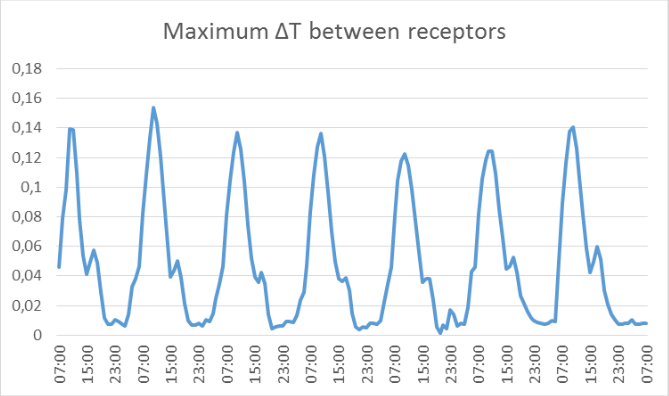
In order to accurately compare the different shapes and their respective microclimates similar analyses will be done on the data of HR11 and HR12. These analyses will use the same altitude bandwidth as the previous analysis of HR11.

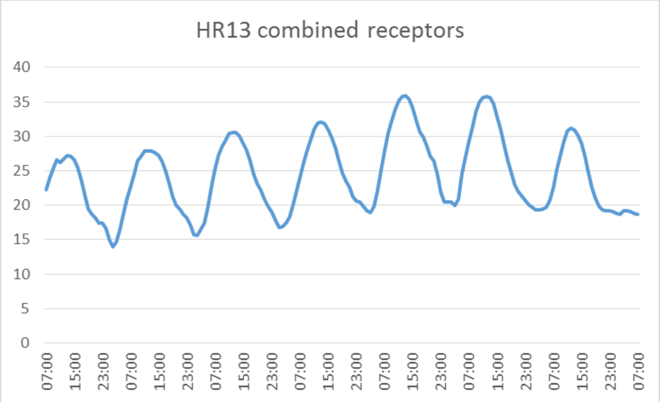
The maximum ΔT of the different receptors is a very similar to that of HR11 and a little bit lower than HR12. However when looking at the graph of the average hourly temperatures per receptor a similar spread can be noticed where R1 measures the highest temperatures with the maximum difference coinciding with the maximum average daily temperature.



		R1	R2	R3	R4
Avg ^{0}C total		24,44	24,41	24,40	24,41








R1-R4 hourly temperature peaks
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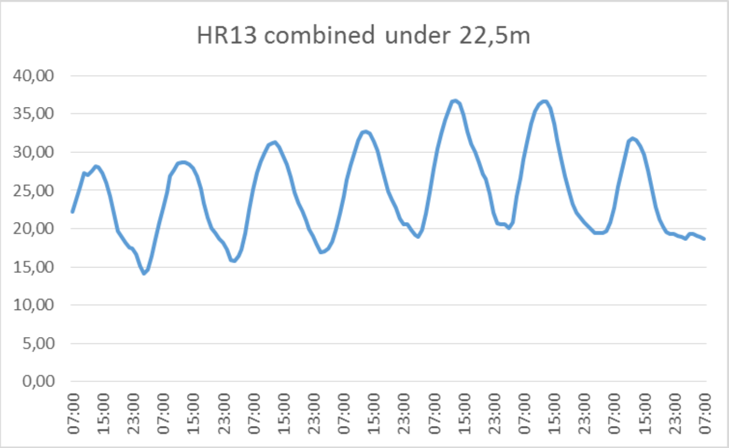
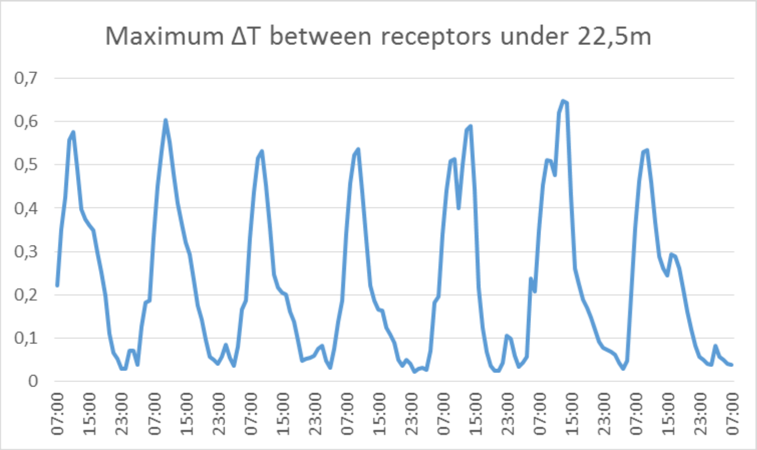
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR13 - height – low altitude

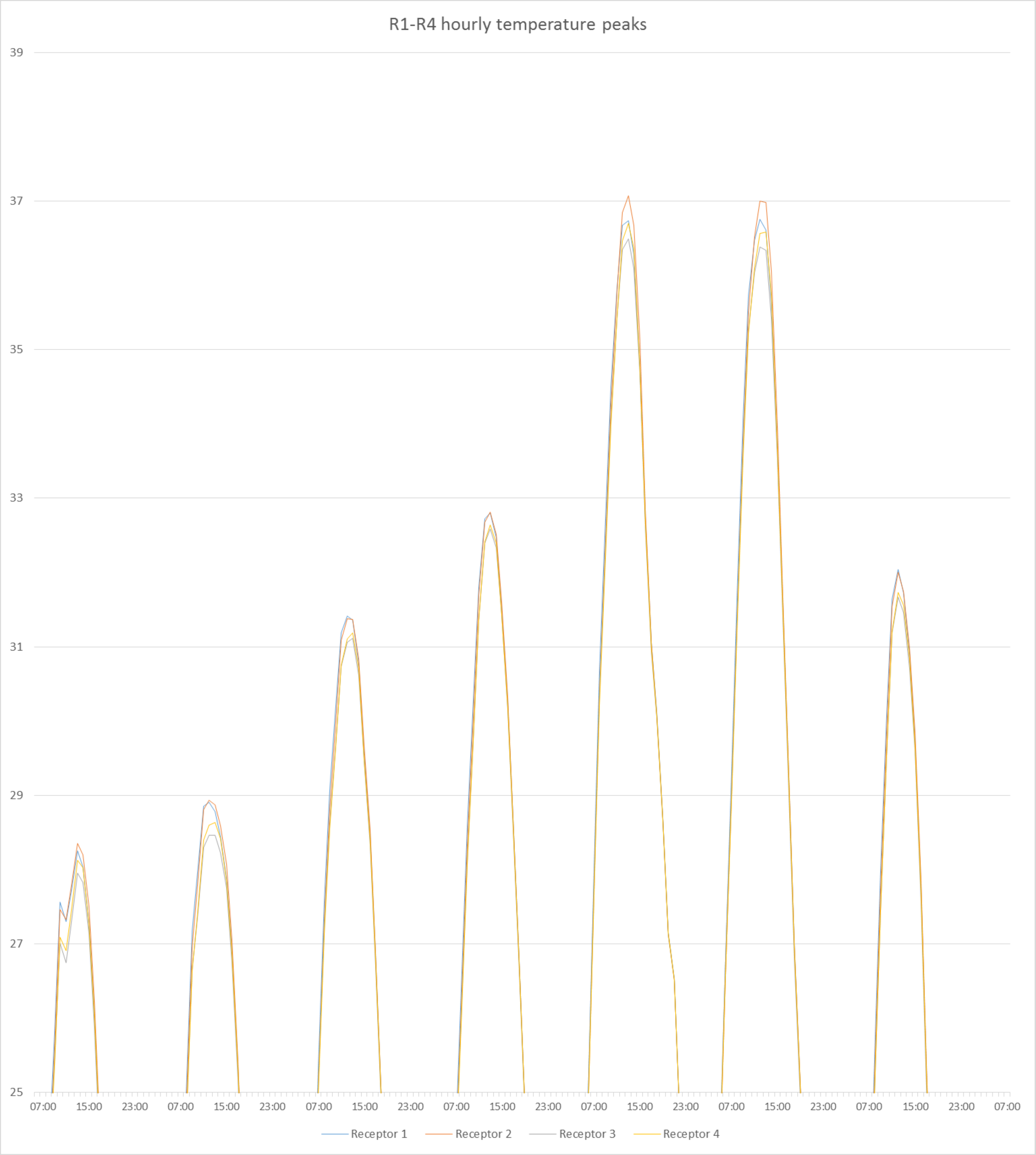
In this analysis the dataset for HR13 will be used but only the data measured under 22,5m.
When looking at the average temperature difference per receptor under 22,5 meter it shows that R1 and R2 increase a similar amount. The same can be said about R3 and R4 only the increase is smaller than the other two receptors. When looking at the maximum difference between the receptors the patterns is similar to that of the total microclimate receptors. However the difference between these receptors is a lot bigger: up to 0,6 ^{0}C in contrast to the 0,14 ^{0}C from the receptors of the total height. When looking at the graph where all the receptor hourly temperature data is plotted against each other similar differences can be found such as R1/R2 and R3/R4 being similar and R1/R2 measuring higher temperatures during the hottest hours of the day compared to their counterparts. Only on the two hottest days R1 measures a little bit higher temperatures than R2. In HR12 in the same range as this microclimate the results of R1 and R2 are mirrored, with the shape of HR12 R1 measures the highest temperatures consistently. This is however comparable to HR11.

The receptor data gives an idea of the temperature in the microclimate based on orientation. Where Northeast and Southeast are relatively hotter compared to the southwest/northwest part.





		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,75	24,74	24,60	24,63
Avg ^{0}C total		24,44	24,41	24,40	24,41
ΔT in ^{0}C		0,33	0,34	0,22	0,23


R1-R4 hourly temperature peaks
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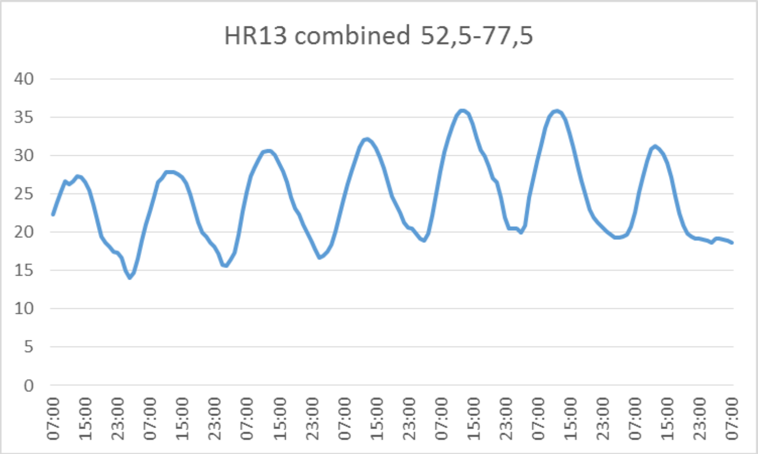
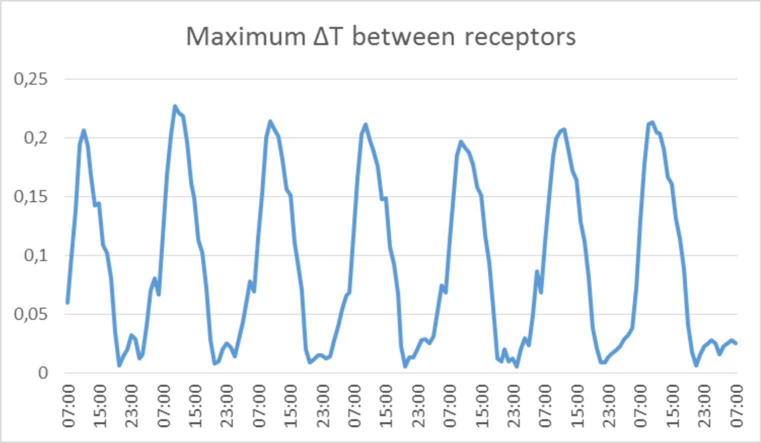
Receptor 1
Receptor 2
Receptor 3
Receptor 4

HR13 - height – high altitude

Comparing the average temperature measurements of the higher altitude with the average of the microclimate around the entire building show that the difference per receptor is almost negligible (maximum of 0,04 ^{0}C degrees on average per receptor) and the higher altitude temperature measurements are actually lower than the average of the entire microclimate. This same difference becomes apparent when comparing the average lower altitude data with the average higher altitude data. However when looking at the maximum ΔT data between receptor of the higher altitude dataset it can be seen that at peak temperatures the maximum ΔT can go up to 0,2 ^{0}C which is very similar to that of the entire microclimate. This can also be seen in the graph on the next page where all of the receptors hourly average temperatures are plotted against each other.

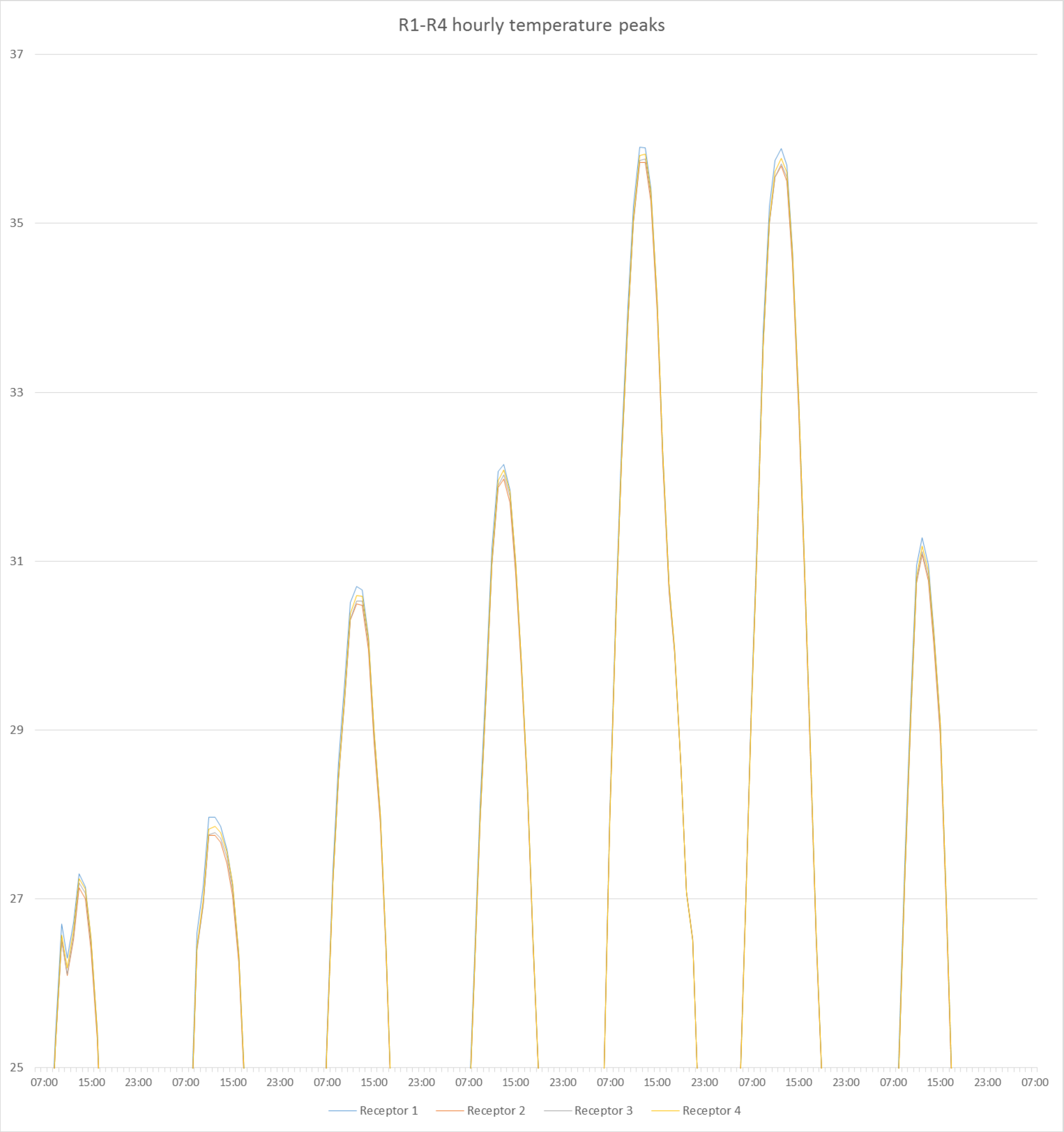
This hourly average temperature graph per receptor also gives an indication of the differences per orientation of the microclimate around the building at a height of 52,2m-77,5m. Where Northeast is the warmest at peak temperatures followed by Northwest, Southeast and finally Southwest. Meaning that higher up the warmest orientation tends to shift.





		R1	R2	R3	R4
Avg ^{0}C 52,5-77,5m		24,43	24,37	24,38	24,39
Avg ^{0}C total		24,45	24,41	24,40	24,41
ΔT in ^{0}C		-0,01	-0,04	-0,02	-0,01

		R1	R2	R3	R4
Avg ^{0}C under 22,5m		24,78	24,75	24,61	24,64
Avg ^{0}C 52,5-77,5m		24,43	24,37	24,38	24,39
ΔT in ^{0}C		0,35	0,38	0,23	0,25


R1-R4 hourly temperature peaks
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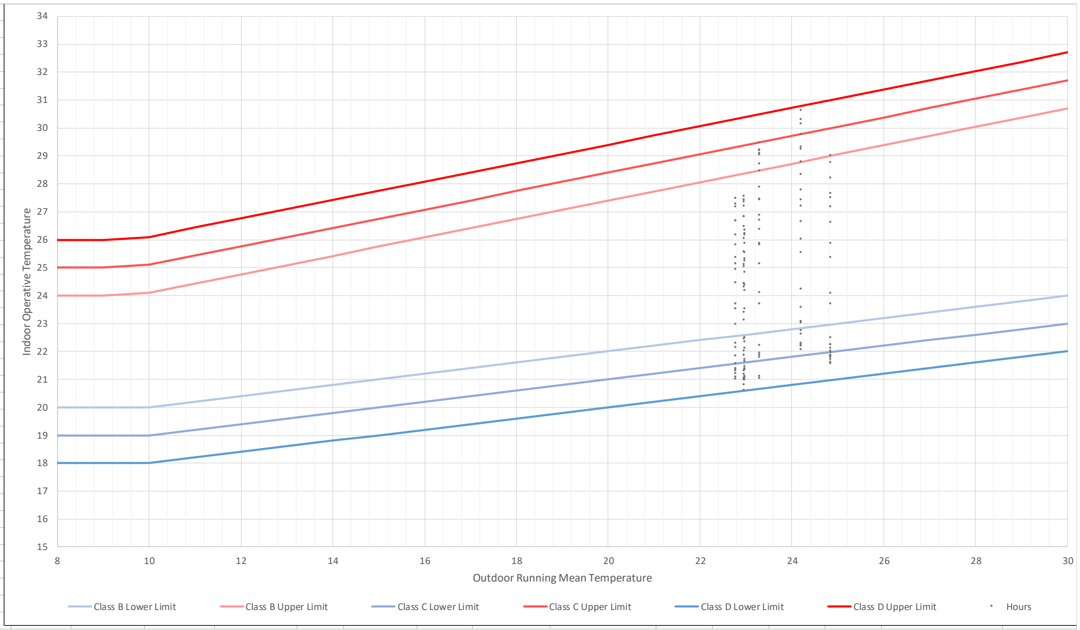
Receptor 1
Receptor 2
Receptor 3
Receptor 4

Appendix 8: Climate data transformation for ATG analysis on facade options

Low altitude							
Daily ΔT low altitude	between ENVI-met input climate data and output climate data						
Date (August)	2	3	4	5	6	7	8
ΔT in °C	1,0	0,8	0,9	0,8	0,9	0,9	0,8
Running mean outdoor average after 0,8 transformation				0,8			
	under 22.5m	No ENVI-met		ΔT			
3-aug	23,23	23,88		0,65			
4-aug	23,03	23,71		0,68			
5-aug	23,22	23,94		0,72			
6-aug	23,55	24,30		0,75			
7-aug	24,44	25,23		0,78			
8-aug	25,08	25,88		0,79			
High altitude							
Daily ΔT high altitude	between ENVI-met input climate data and output climate data						
Date (August)	2	3	4	5	6	7	8
ΔT in °C	1,2	1,0	1,0	1,0	1,0	1,1	1,1
Running mean outdoor average after 1,1 transformation				1,1			
	over 55m	No ENVI-met		ΔT			
3-aug	22,97349227	23,87686		0,903367			
4-aug	22,76795982	23,7117		0,943735			
5-aug	22,95770186	23,93738		0,979676			
6-aug	23,29918148	24,2998		1,000617			
7-aug	24,19944919	25,22536		1,02591			
8-aug	24,84997535	25,87591		1,025936			

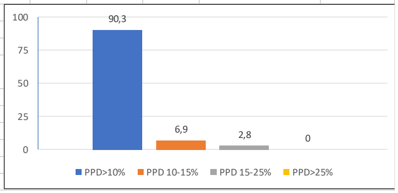
Appendix 9: ATG analysis graphs

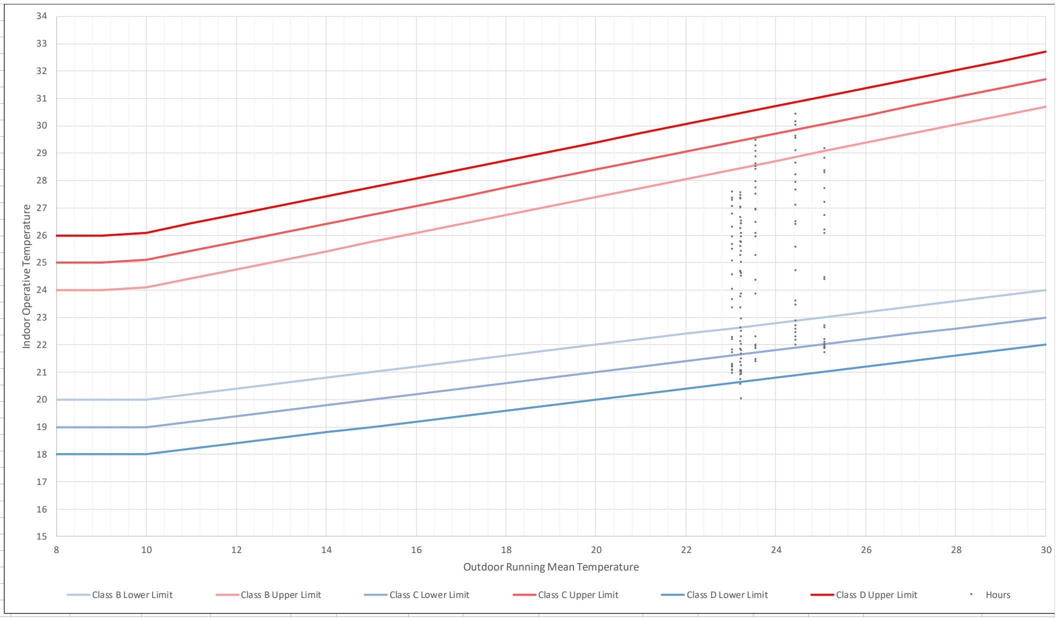
Facade option 1 high altitude (upper graph) and low altitude (lower graph) analysis results.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

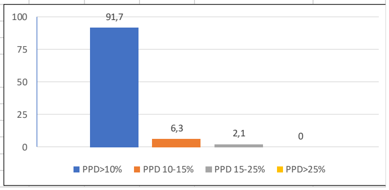
Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	130	90,3
Class C	10	6,9
Class D	4	2,8
Class E	0	0



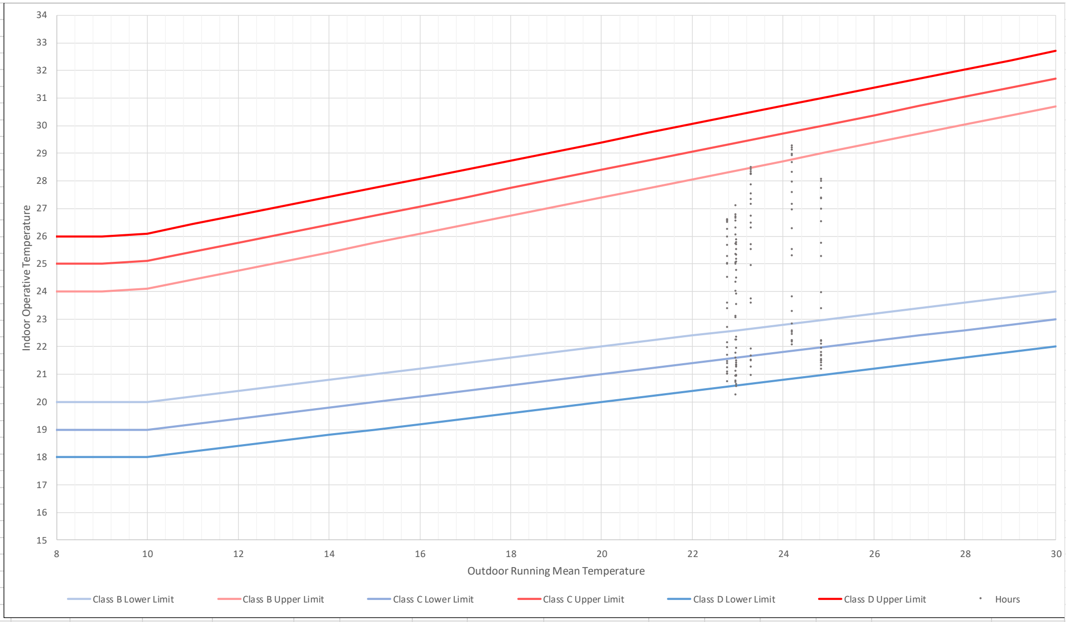


Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	132	91,7
Class C	9	6,3
Class D	3	2,1
Class E	0	0

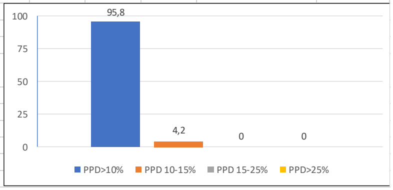


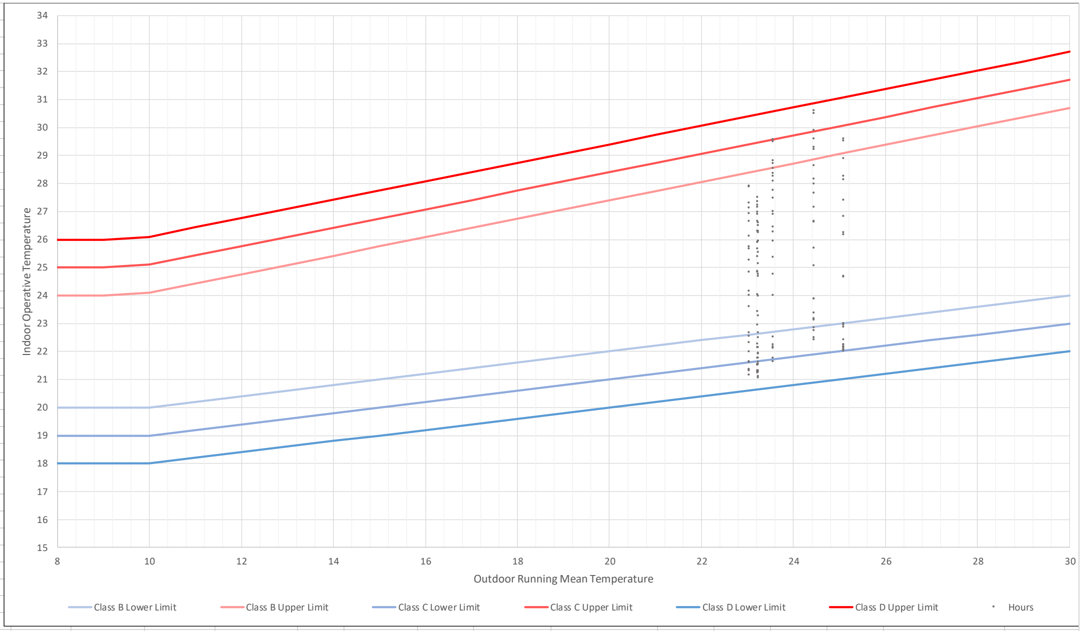
Facade option 2 high altitude (upper graph) and low altitude (lower graph) analysis results.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

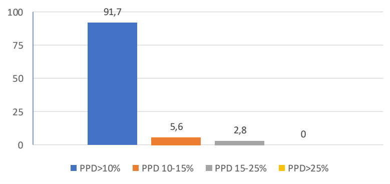
Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0



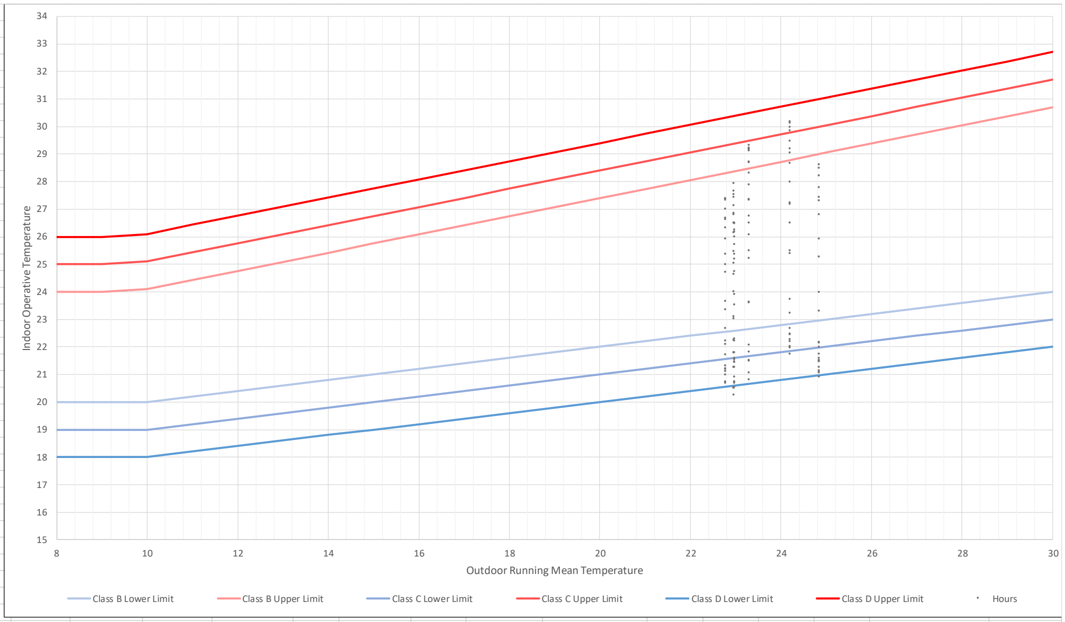


Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	132	91,7
Class C	8	5,6
Class D	4	2,8
Class E	0	0

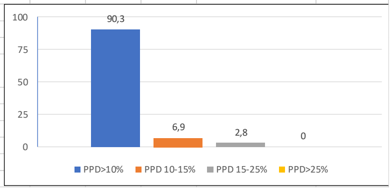


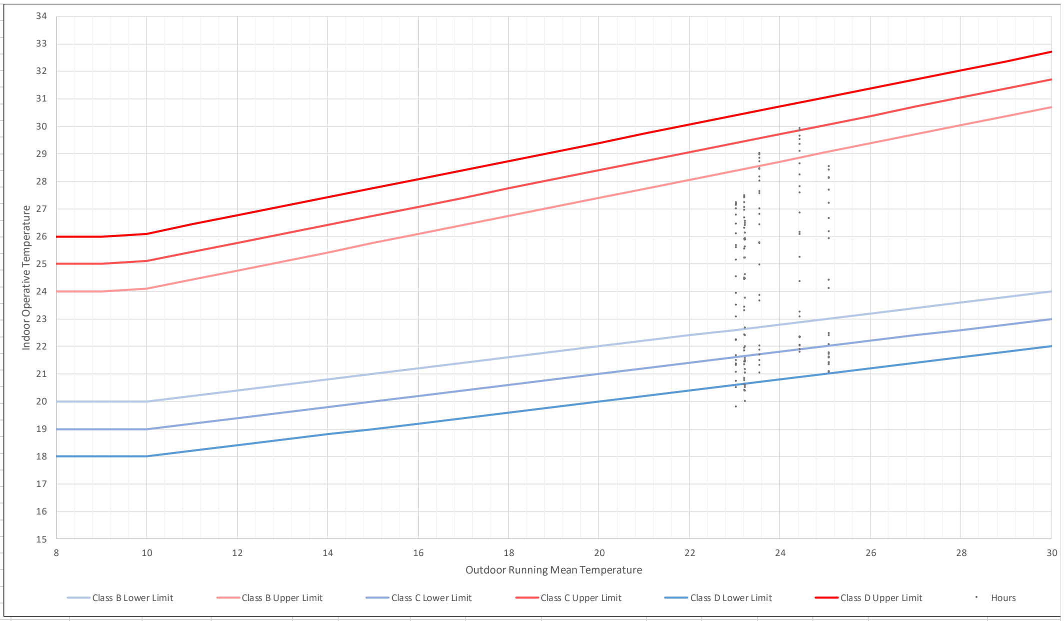
Facade option 3 high altitude (upper graph) and low altitude (lower graph) analysis results.



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period	summer months Only Working Hours		
Occupied Hours	**144**		

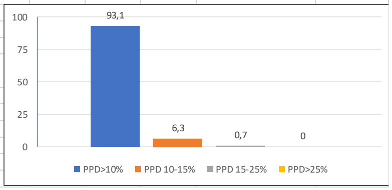
Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	130	90,3
Class C	10	6,9
Class D	4	2,8
Class E	0	0





Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Indoor air
Analysis Period	3-9 August		
Occupied Hours	**144**		

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	134	93,1
Class C	9	6,3
Class D	1	0,7
Class E	0	0



Appendix 10: Climate data transformation for ATG analysis on validity check

Low altitude							
Daily ΔT low altitude	between ENVI-met input climate data and output climate data						
Date (August)	2	3	4	5	6	7	8
ΔT in °C	1,0	0,8	1,0	0,9	1,0	0,9	0,8
Running mean outdoor average after 0,9 transformation							
	under 22.5m	No ENVI-met		ΔT			
3-aug	23,15	23,88		0,73			
4-aug	22,95	23,71		0,76			
5-aug	23,14	23,94		0,80			
6-aug	23,47	24,30		0,83			
7-aug	24,36	25,23		0,86			
8-aug	25,01	25,88		0,87			
High altitude							
Daily ΔT high altitude	between ENVI-met input climate data and output climate data						
Date (August)	2	3	4	5	6	7	8
ΔT in °C	1,3	1,0	1,4	1,1	1,1	1,2	1,1
Running mean outdoor average after 1,2 transformation							
	over 55m	No ENVI-met		ΔT			
3-aug	22,90078949	23,87686		0,976069			
4-aug	22,70594359	23,7117		1,005752			
5-aug	22,90558887	23,93738		1,031789			
6-aug	23,2533251	24,2998		1,046473			
7-aug	24,15693008	25,22536		1,068429			
8-aug	24,80012806	25,87591		1,075783			