SUSTAINABLE DESIGN SOLUTIONS

FOR THE MIDDLE CLASS IN THE CENTRE OF PRETORIA, SOUTH AFRICA

an analysis of current housing in Pretoria and a new and different housing concept

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Sustainable design solutions

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by

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Preface

During most of the time of my master's I worked at ''VDNDP bouwingenieurs'', an office with architects and engineers working on Dutch projects but also on African projects. This was the first time I got to know South Africa and the South African architecture. I found out that there were a lot of places in South Africa that needed some development and innovation. For this reason I really wanted to work on a project which was connected to South Africa because I really thought it would be a challenge to do something completely different compared to Dutch projects and also because I thought it would be interesting to learn a lot about other cultures and climates.

At the presentation about the possible research subjects, I heard that the TU delft has connections with the university in Pretoria, South Africa and that is was an option to work on a project at this location. For me, it was a logical decision to choose a project at this location.

The result of the research is not completely different or new or innovative, but it is different for the current South African (Pretoria) apartment buildings. Also it is analysed how these design changes will work within the climate of Pretoria, which is what makes it interesting.

Now my project is finished, I can definitely conclude that these months were the most interesting and challenging months of my studies. It was really interesting and amazing to visit the project location and climate and learn about it and the people who live there. This reminded me that every project has its own identity and challenges. I really enjoyed the whole process and I was glad that Andy and Marcel wanted to guide me during the process.

I would like to thank some people who have been very important to me in this project. First, I would like to thank Andy van den Dobbelsteen and Marcel Bilow for guiding me during the whole process and giving me feedback to improve my research. Second, I would like to thank Robert van Kats from Butterfly Housing to advise me about South Africa and my research. Furthermore, I would like to thank Nicholas Clarke, Dirk Conradie, Jan Hugo, Johan Swart, Llewellyn van Wyk, Carin Combrinck, Abre Crafford and Yeast City Housing for welcoming me in Pretoria and for broadening my knowledge.

Also, I want to thank ''VDNDP bouwingenieurs'' for supporting me with my research and for sponsoring me for my trip to Pretoria, South Africa.

Last, but most important, thanks to my parents and my love Marc, who have always been there for me and give me all the joy and support I could wish for.

Contents

Abstract

The population of South Africa is still growing, where around 60% of the population is urban. According to the data booklet ''The World's Cities in 2016'' by the United Nations, the city population of Pretoria will grow by 27% between 2016 and 2030. Despite the grow of the city population, the housing sector is not able to deliver enough housing solutions at the rate and scale needed. Next to that it is not able to deliver housing solutions for the varying social classes and the affordability for these classes. According to a report by Blok (2017) housing solutions have been provided at the lowest and uppermost ends of the market, which leaves the households in the lower middle class without an entrace in the urban market.

Furthermore, it is expected that the climate in South Africa will change and become drier with higher temperatures. For this reason it's important to provide sustainable housing solutions which enable climate change adaptation and mitigation.

By analysing and simulating an existing apartment building in the centre of Pretoria and a new development in housing for South Africa, new design solutions where found, focused on comfort, energy use and material costs.

By simulating improved versions of the apartment buildings, it was found that the use of: insulated walls, glass on the north facade, HR ++ glass in windows and doors and overhangs above the windows would improve the comfort significantly.

As an result the new version of Thembelihle village saves 48628,70 ZAR (3241,91 euro), which means a **payback time of 6 years.**

The newer version of Butterfly saves in total 15576,32 ZAR (1038,42), which means a **payback time of 17,76 years**.

Interesting is that the payback time of Thembelihle is a lot shorter. This can be explained by the fact that the comfort of the current Butterfly building was better compared to Thembelihle. The differences with the improvements were for this reason bigger for Thembelihle and smaller for Butterfly.

Altogether, simple design solutions will easily improve the comfort of the user . Furthermore it is economically interesting because it can save a lot of energy.

Chapter I - Research plan

1.1 Introduction

The population of South Africa is still growing, where around 60% of the population is urban. According to the data booklet ''The World's Cities in 2016'' by the United Nations, Johannesburg will become one of the megacities of the world between 2016 and 2030. Furthermore, the report states that the city population of Pretoria will grow by 27% between 2016 and 2030.

Despite the grow of the city population, the housing sector is not able to deliver enough housing solutions at the rate and scale needed. Next to that it is not able to deliver housing solutions for the varying social classes and the affordability for these classes. According to a report by Blok (2017) housing solutions have been provided at the lowest and uppermost ends of the market, which leaves the households in the lower middle class without an entrace in the urban market.

NIDS (National Income Dynamics Study) identifies five main social classes: the elite, the stable middle class, the vulnerable middle class, the transitory poor and the chronic poor. Only one in four South Africans are part of either the secure middle class or the elite, which means that the rest is part of the vulnerable middle class, the transitory poor or the chronic poor.

''With global warming and climate change becoming more and more of a reality, South Africa is also experiencing a gradual, yet steady, change in climate. '' (Climate System Emergency Institute, 2012)

Climate models anticipate that the air temperature over South Africa will rise 2°C over the next century. Animals and plants may not be able to immediate adapt to the results of climate change and therefore the whole ecosystem is in danger. According to climate data from the South African Weather Service, between 1960 and 2004 there have been eight summer-rainfall seasons where rainfall for the relevant area has been less than 80% of normal. As a result, there will be crop and water shortage followed by economic and social problems. The higher temperatures will influece the rainfall, but it is hard to predict how the rainfall will change. It could increase in some parts of the country, and decrease in other parts.

1.2 Problem statement

There are not enough sustainable design solutions for the middle class housing and most of the existing solutions are not resisted against the extreme weather conditions and the climate change.

Research shows us that climate change results in more extreme weather conditions which is resulting in floods, heat and drought. For this reason it's important to provide sustainable housing solutions which enable climate change adaptation and mitigation.

According to the article *"South Africa urgently needs to rethink its approach to housing"* by Osman (Associate Professor in Architecture, University of Johannesburg), the supply of houses has not been able to keep up with the rise in demand in urban areas. Osman (2017) concludes that the government's approach has given a lot of "one-size-fits all" houses, located far from work opportunities and services. Furthermore, Osman (2017) concludes that models of delivery can't pursue with relying on the government but focus on approach with the involvement of many role players. which will result in differtent types of housing. *"There has been surprisingly little innovation in the field of housing. It's time for that to change, before it's too late." (Osman, A., 2017)*

Satterthwaite (1999) suggests that the goal of urban sustainability is not to "sustain cities or urbanization, but to meet human needs in settlements of all sizes without depleting environmental capital". Sustainability therefore intents to accomplish two things: improve human well-being and the quality of life, and protect the natural systems that support and enable this quality of life.

To focus the research on sustainable solutions and strategies for climate change adaptation and mitigation, an existing social housing project is used as input for this research. This housing project is located near Church Square in Pretoria and is called "Thembelihle Village". The project is chosen because it's one of the newer housing projects in Pretoria for the middle class (lower and higher middle class). This project will then be compared with a new development in housing for the middle class: 'butterfly housing' which is designed by Robert van Kats. This concept is chosen because it's comletely different with the current building methods in Pretoria, and it would be interesting to analyse if a new development like this would work in this area.

1.3 Objectives

The general objective of this research is to provide sustainable design solutions for the middle class of the centre of Pretoria, South Africa, which enable climate change adaptation and mitigation.

The sub objectives of this research are formulated below. The sub objectives are divided under two categories: context and technology.

The subjectives focused on the <u>context</u> are:

- Improve human well-being and quality of life

- Protect the natural systems that support and enable this quality of life

- Design sustainable design solutions for the middle class in the centre of Pretoria

- Design sustainable design solutions which (at least) fit to the current cultures, habits and standards of the middle class

- Design sustainable design solutions which fit in the centre of Pretoria, South Africa and its climate conditions

- Learn about the (geographical) history of Pretoria

The subjectives focused on <u>technology</u> are:

- Use local materials, prodcution techniques and resources in the new design where possible

- Learn about current building methods of South Africa

- Learn about current developments for middle class homes

- Integrate strategies for climate change mitigation and adaptation in the design

Fig. 01 Concept Butterfly by Butterfly Housing BV, for this project the multilevel version of this concept will be used

Fig. 02 Thembelihle Village

This paper will result in guidelines with the elements of new sustainable housing solutions for the middle class of Pretoria, South Africa. Sustainability includes three different aspects: a social aspect, a economic aspect and a environmental aspect. In order to find a solution for the problem, all three aspects need to be included in the solution. The goal is to find design strategies which improve costs, comfort and energy usage.

1.4 Research questions

As a result of the general objective, the research question can be formulated. The general research question is: ''What are the sustainable design solutions for the middle class of Pretoria, South Africa, which enable climate change adaptation and mitigation?''

As a result of the sub objectives, the sub research questions can be formulated. The sub research questions are divided under two categories, context and technology:

<u>Context:</u>

What is the definition of the middle class in Pretoria?

What are important, location related, circumstances for middle class homes in the centre of Pretoria?

What is the (geographical) history of Pretoria?

What are the climate conditions in Pretoria?

<u>Technology:</u>

What materials, resources and production techniques are locally available?

What are the current building methods used in middle class homes?

What are the current developments for middle class homes?

What are the solutions for climate change adaptation and mitigation for this location?

Background questions which are needed to validate the sustainable solutions are listed below:

What are the costs of the sustainable design solutions (compared to the current building methods)?

What are the energy costs that will be saved by applying the sustainable design solutions?

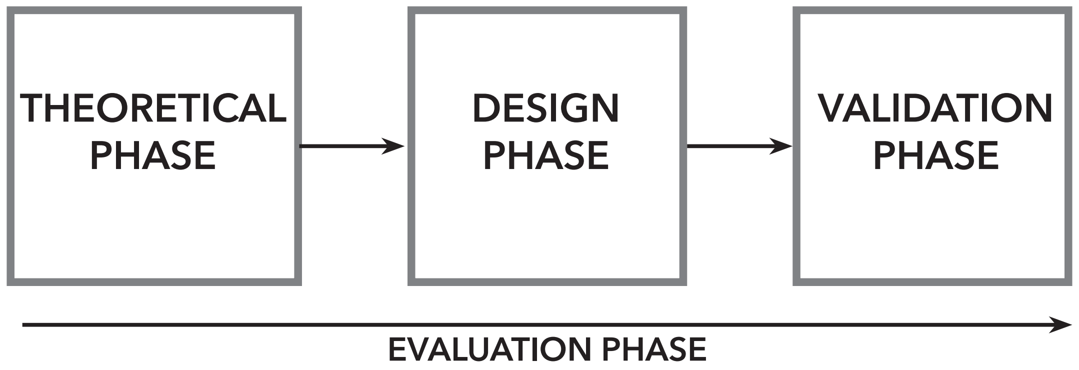


Fig. 03 Research proces in steps

1.5 Approach and methodology

The research is divided in four phases which are all connected. The basic scheme in Fig. 03 shows the relation between the four phases:

1. THEORETICAL PHASE

This phase is mainly focused on the literature study. There will be a site visit where the results of the literature study will be validated. The site visit is important to really get to know and understand the environment and the cultures. The theoretical phase is mostly based on literature study, meetings with professionals (most of them in Pretoria, South Africa), the site analysis during the visit and conversations with the middle class households in Pretoria, South Africa.

2. DESIGN PHASE

The results of the theoretical phase will be used as starting point in this phase. At the beginning of this phase the design requirements will be formulated. The final product of the design phase will be guidelines and drawings of the sustainable housing solutions. The guidelines will be focused on comfort, energy use and material costs.

3. VALIDATION PHASE

When the theoretical phase is finished and there's an result from the design phase, it's time to validate or test these results. First the results will be tested on the costs of the solutions.
In order to simulate the South African weather and climate, software such as ClimateConsultant and VABI elements will be used to validate the results. In addition, a physical model will be created which gives a visualisation of the results.

When this validation is not successful, the design needs to be adjusted in order to change or further develop the result. After that, the result can be validated again.

4. EVALUATION PHASE

The evaluation of the research will be described in the report. All of the previous steps will be described in the report.

In Fig. 04 the total research process with approach and methodology is shown.

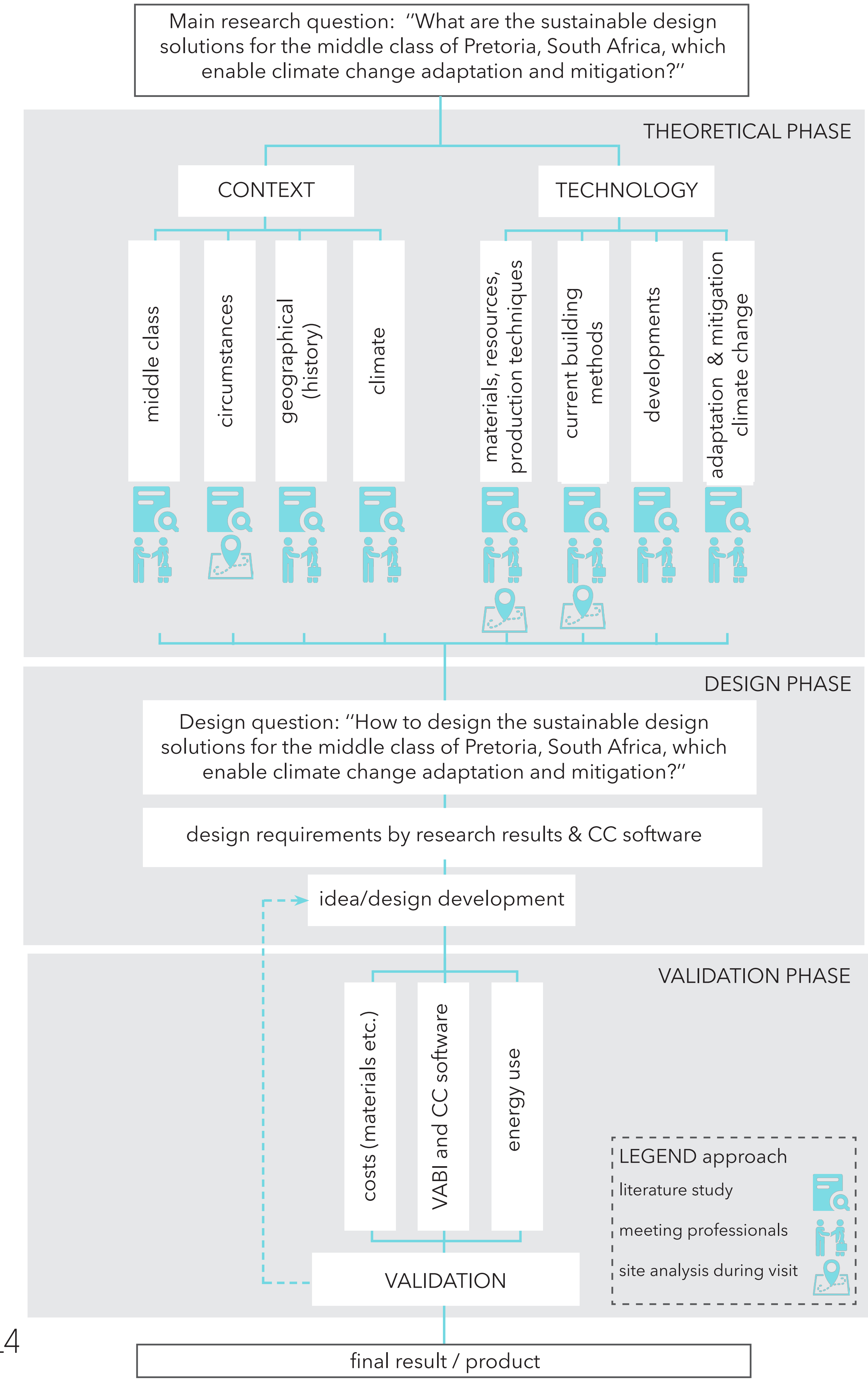
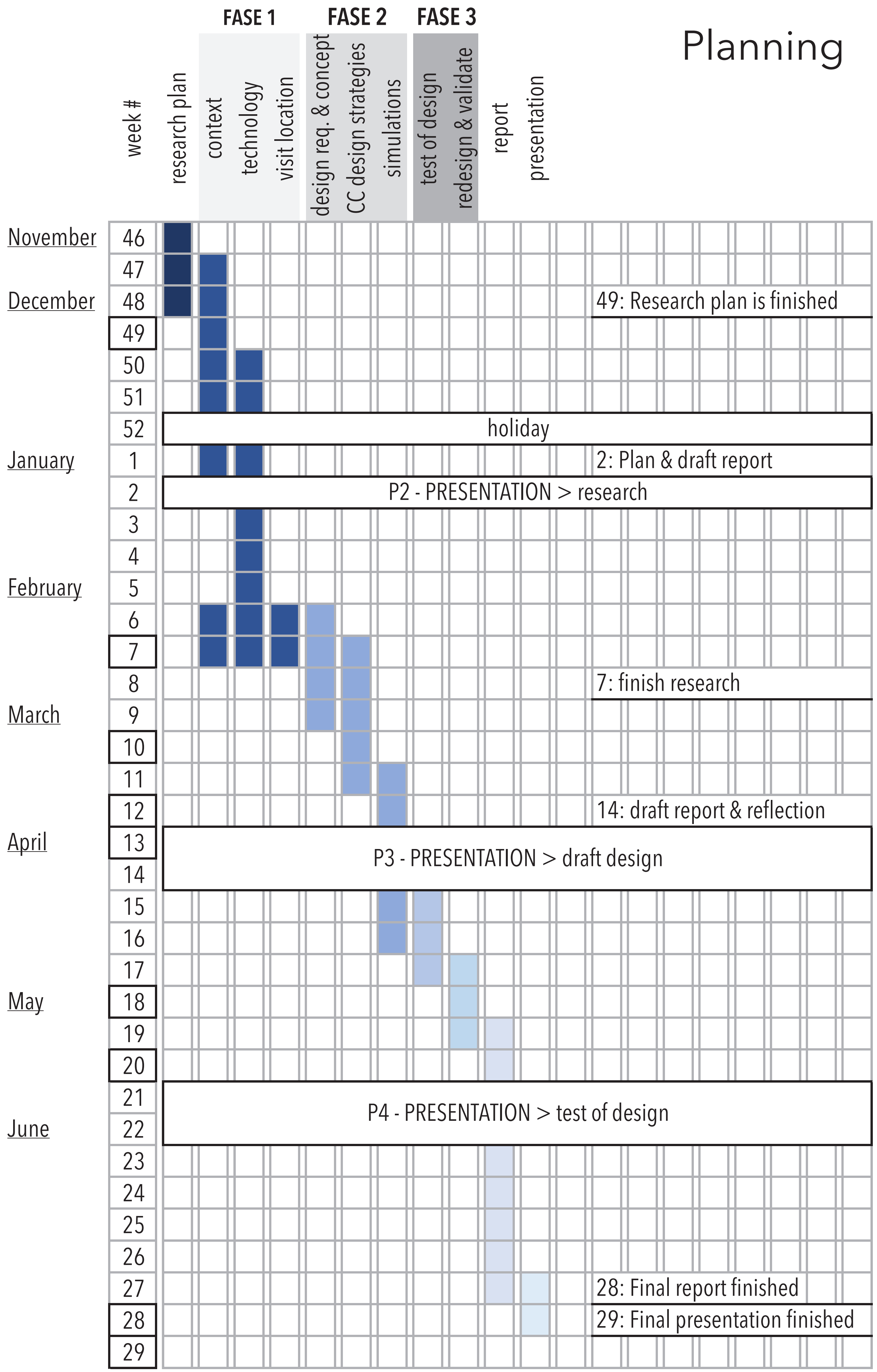


Fig. 04 Total research process: approach and methodology

Planning



Chapter II – Geography and people

2.1 Introduction

This chapter is about the geography of Pretoria and the middle class who live in Pretoria. To be able to work on a design project which is located in an unfamiliar location, it’s important to understand the context. In this chapter background information about the history, the geography and the middle class in Pretoria will be described. Three research questions will be answered in this chapter:

- *What is the (geographical) history of Pretoria?*

- *What is the definition of the middle class in Pretoria?*

- *What are important, location related, circumstances for middle class homes in the centre of Pretoria?*

2.2 History and geography

South Africa is the most southern country of the continent Africa with a population of 55.6 million people (statistics south africa). Gauteng, the province where Pretoria is located, is the smallest province of South Africa. However, it is also the province with the highest population because two of the three largest cities of South Africa are located in this Province (Johannesburg and Pretoria).

Pretoria has always been involved with major political changes in South Africa, with the inauguration of President Nelson Mandela at the Union Buildings In 1994 as high point. Building a church in August 1854 was the beginning of the town.

The city is still one of the most important cities for the government. Furthermore the city is headquarters of the defence forces and the University of South Africa, with over 125,000 students throughout the world, is based in the city.

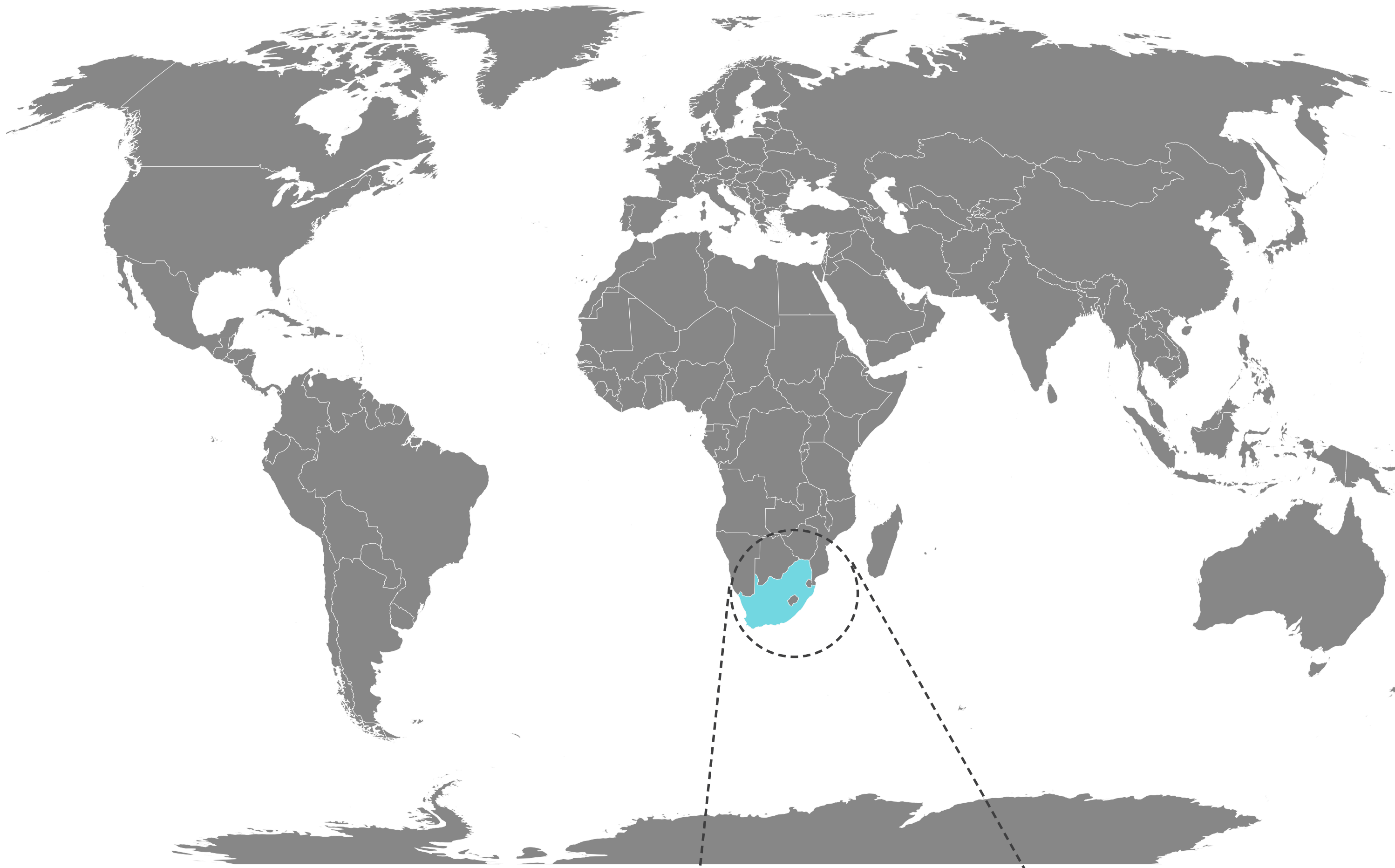


Fig. 05 World map with South-Africa pointed out, autors figure

Pretoria is located in the north east of South Africa, in the Province of Gauteng.

Pretoria is with an area of 687,5 km² more than three times larger as Amsterdam.

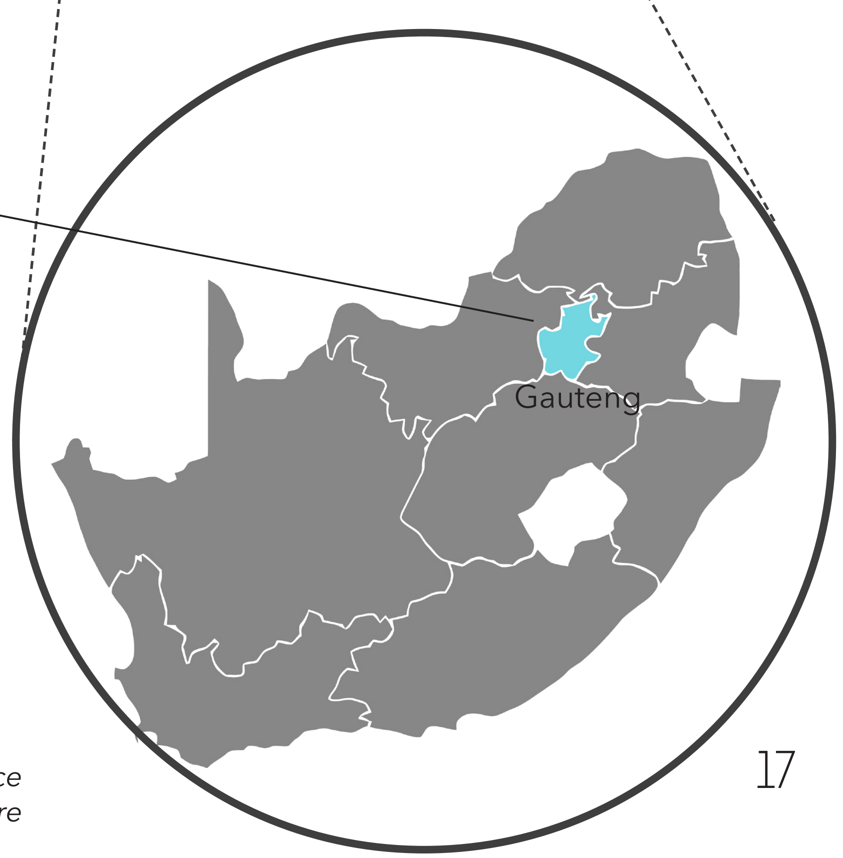


Fig. 06 Map of South-Africa with province Gauteng and Pretoria pointed out, autors figure

THE NETHERLANDS

Population	17.1 million
Area	41.540 km²
Density	411 pers./km²
Female	49,6%
Male	50,4%
Formal housing	99-100%
Access to water	100%
Access to electricity	100%
Access sanitation facilities	100%

Data: cbs

SOUTH AFRICA

Population	55.6 million
Area	1.220.000 km²
Density	45 pers./km²
Female	51%
Male	49%
Formal housing	79,2%
Access to water	89,9%
Access to electricity	91,1%
Access sanitation facilities	97,6
Households experienced crime	7,5%
Feelings safety during day	79,4%
Feelings safety during night	34,3%

Data: Statistics South Africa

GAUTENG

Population	12.2 million
Area	18.176 km²
Density	671 pers./km²
Female	50,7%
Male	49,3%
Formal housing	81,4%
Access to water	97,5%
Access to electricity	90,4%
Access sanitation facilities	98,5%
Households experienced crime	9,1%
Feelings safety during day	78,7%
Feelings safety during night	32,8%

CITY OF TSHWANE

Population	2.9 million
Area	6368 km²
Density	455 pers./km²
Female	50.2%
Male	49.8%
Formal housing	75,0%
Access to water	98,7%
Access to electricity	98,9%
Access sanitation facilities	99,0%

Fig. 07 Union Buildings in Pretoria

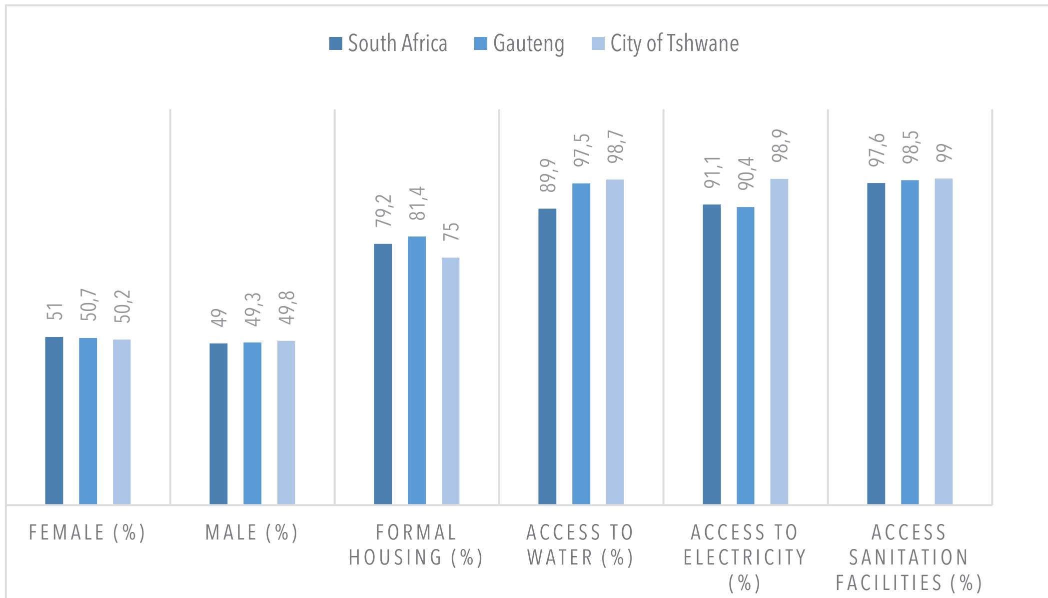


Fig. 08 Comparison graph of data, data: Statistics South Africa autors figure

In the mid-2000s it was decided that the name of Pretoria should be changed to Tshwane, which stands for "we are the same". Many South Africans felt that the name needed to change because of the history of Apartheid and others thought that the name "Pretoria" was of historical significance. Despite the disagreement, the name was changed to Tshwane in 2005. Even though the name was changed, switching from the name Pretoria to Tshwane has been challenging for many local and international businesses and institutions. This is why the city is still called "Pretoria".

In Fig. 10 the dot maps of Pretoria and its surrounding are displayed. The first map shows the household income, the second one the languages spoken and the third one the difference in race. In all maps there are three areas which stand out: the centre of Pretoria, the large area northeast of Pretoria and the area at the west side of Pretoria.

In the centre of Pretoria the household income is very varying as shown in Fig. 12. However, in the other two areas the household income seems to be lower because of the orange color. This can be explained by the fact that there are two large townships at these locations: Mamelodi and Atteridgeville. Most of the black africans live at these three areas.

Fig. 09 Old centre of Pretoria, church square

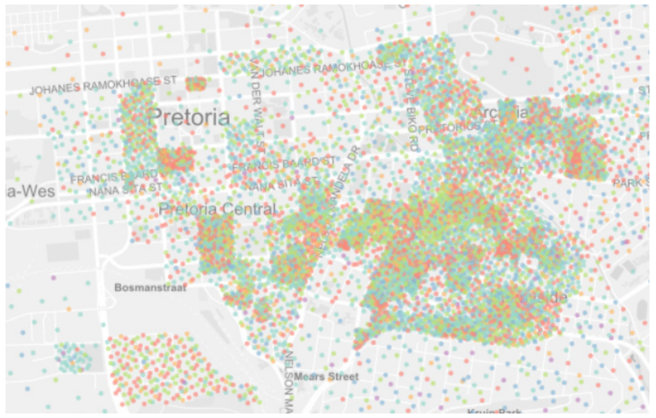


Fig. 10 Dot maps of household income in Pretoria, https://dotmap.adrianfrith.com/ data: Statistics South Africa

Fig. 11 Old centre of Pretoria

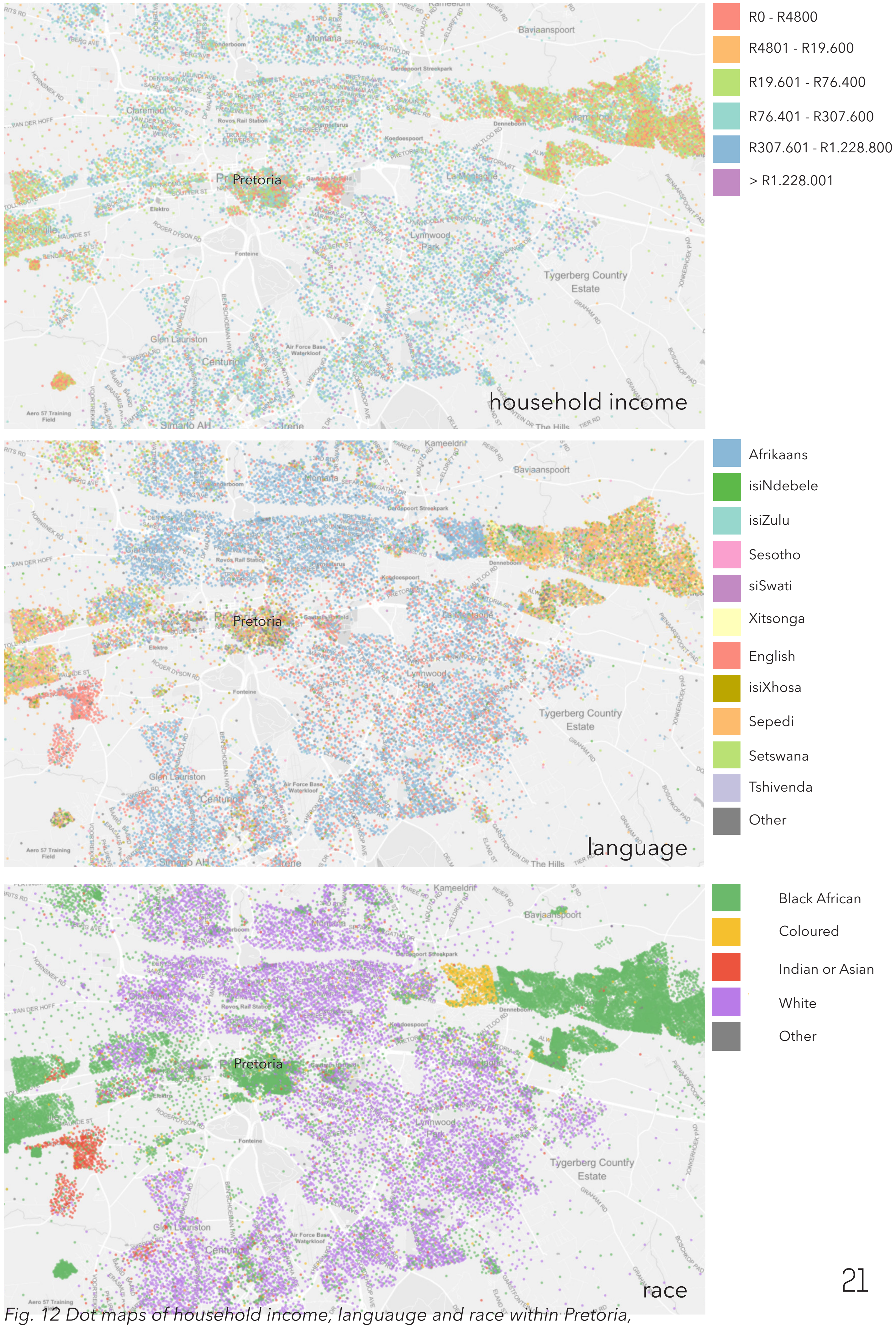


Fig. 12 Dot maps of household income, languauge and race within Pretoria, https://dotmap.adrianfrith.com/ data: Statistics South Africa

2.3 Thembelihle Village

The project is located in the City's Inner City and part of the West Capital Precinct Development Programme. The Thembelihle Village Project, meaning 'good hope', is located close to government departments, other places of work, shops, social amenities and public transport, which is very interesting for people with a lower income because of the high transport costs.

The Thembelihle site is accessible due to its location along two mobility spines viz. Kgosi Mampuru Street/Sophie de Bruyn (north-south linkage) and Struben Street/Johannes Ramokhoase (east-west linkage). The Belle Ombre plaza and transport hub is located approximately 500 meter north of the proposed development. Belle Ombre transport hub (Railway station, bus depot and taxi rank) serves as the northern gateway into the City and provide linkages to areas such as Mabopane, Soshanguve and Garankuwa. The hub caters for long distance bus and taxi commuters and the Metrorail connects with the Tshwane Ring

Fig. 13 (YEAST city housing)

Rail network which links with the eastern areas.

The project consists of eleven 3 to 4 storey walk-up blocks and six tower blocks of 10 to 11 storeys. The ground floors facing the streets will cater for retail space and services.

On-site landscaping includes walkways, grassed areas with trees and shrubs. Provision will be made for on-site parking as well as picnic areas, swimming-pool and playgrounds.

There are 238 bachelor apartments, 140 1-bedroom apartments, 303 2-bedroom apartments and 52 3-bedroom apartments. In addition, there's 1300 m2 of commercial/office space, 188 on-site parking ays and social amenities.

Hot water is used from heat pumps to reduce electricity costs for tenants. A smart metering system is used for municipal services.

The start date of construction was 24 June 2014 and the end date of construction was 31 December 2017.

The income range of the tenants is R2200 - R7500 and the rent starts from R750 - R2250.

Fig. 14 (YEAST city housing)

Fig. 15 Area Thembelihle Village

Fig. 16 (YEAST city housing)

Fig. 17 Project site with surrounding buildings (Source: google maps)

In Fig. 17 the projec site is visualized. Because of the size of the project, the project was realized in four different phases. In Fig. 18 the four different phases are visualized. The constructor started with the smaller apartment buildings (the green and yellow buildings in Fig. 18) in Phase 1 and Phase 2. After that they realized the larger apartment buildings (the blue and red buildings in Fig. 18) in Phase 3 and Phase 4.

In Fig. 19 the floorplan of one of the larger buildings (Phase 3) is visualized. The different apartment types are visualized in this floorplan by using different colors. Interesting is that the types are all mixed.

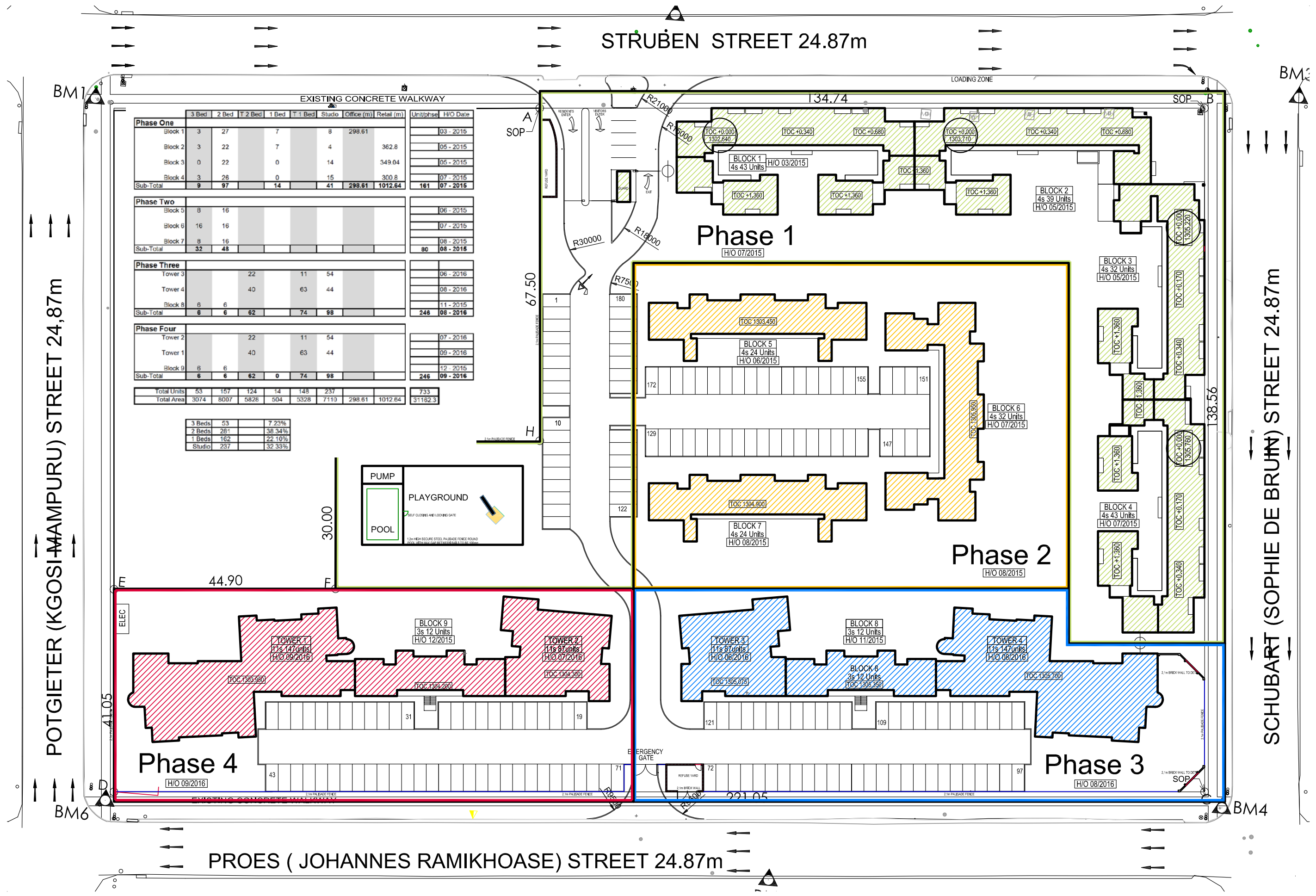


Fig. 18 Phases of construction Thembelihle Village (Source: YEAST city housing)

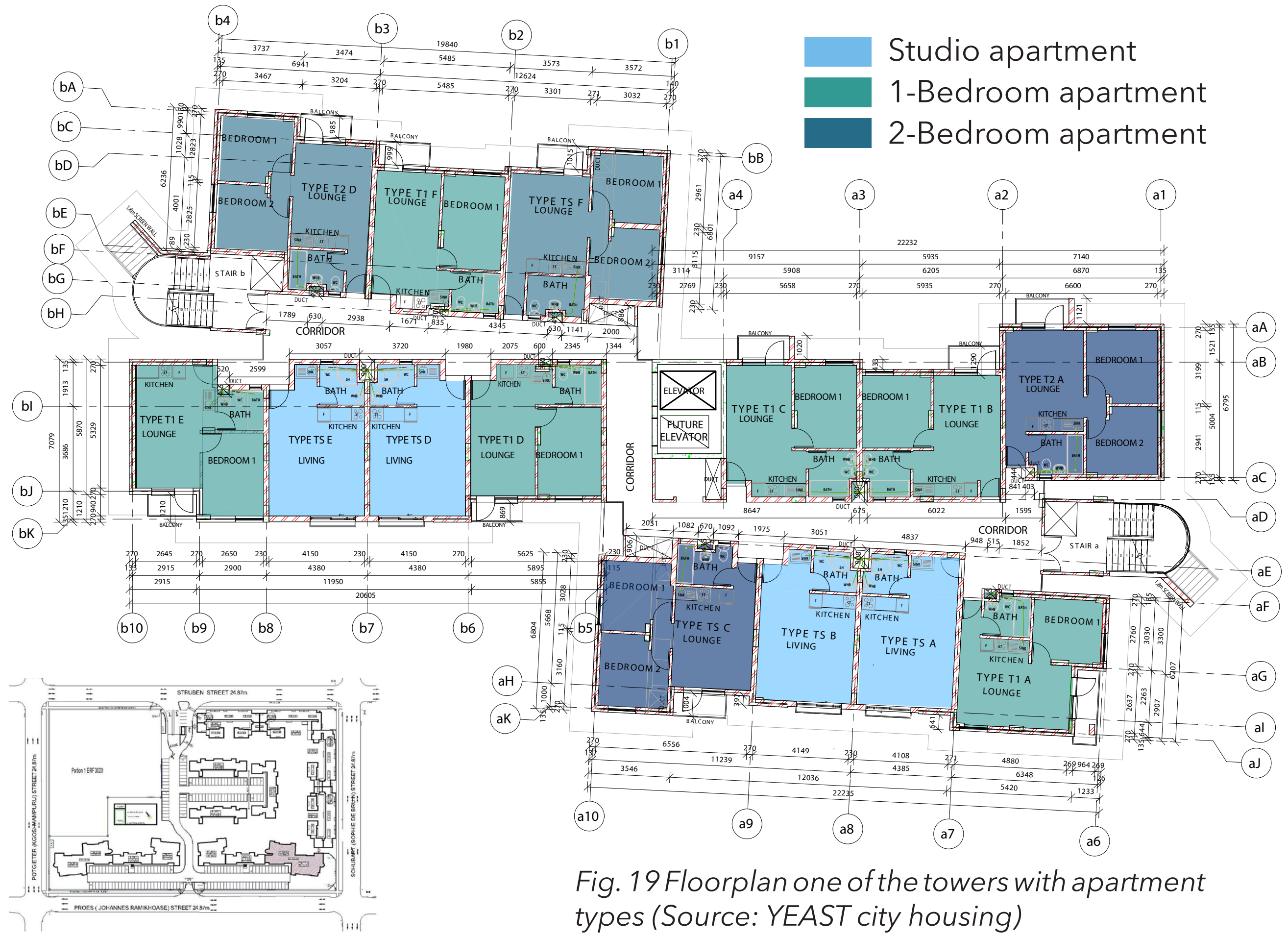


Fig. 19 Floorplan one of the towers with apartment types (Source: YEAST city housing)

Fig. 20 Thembeligke Village, photo by: Dippenaar and Lapage

Fig. 21 Thembeligke Village, photo by: Dippenaar and Lapage

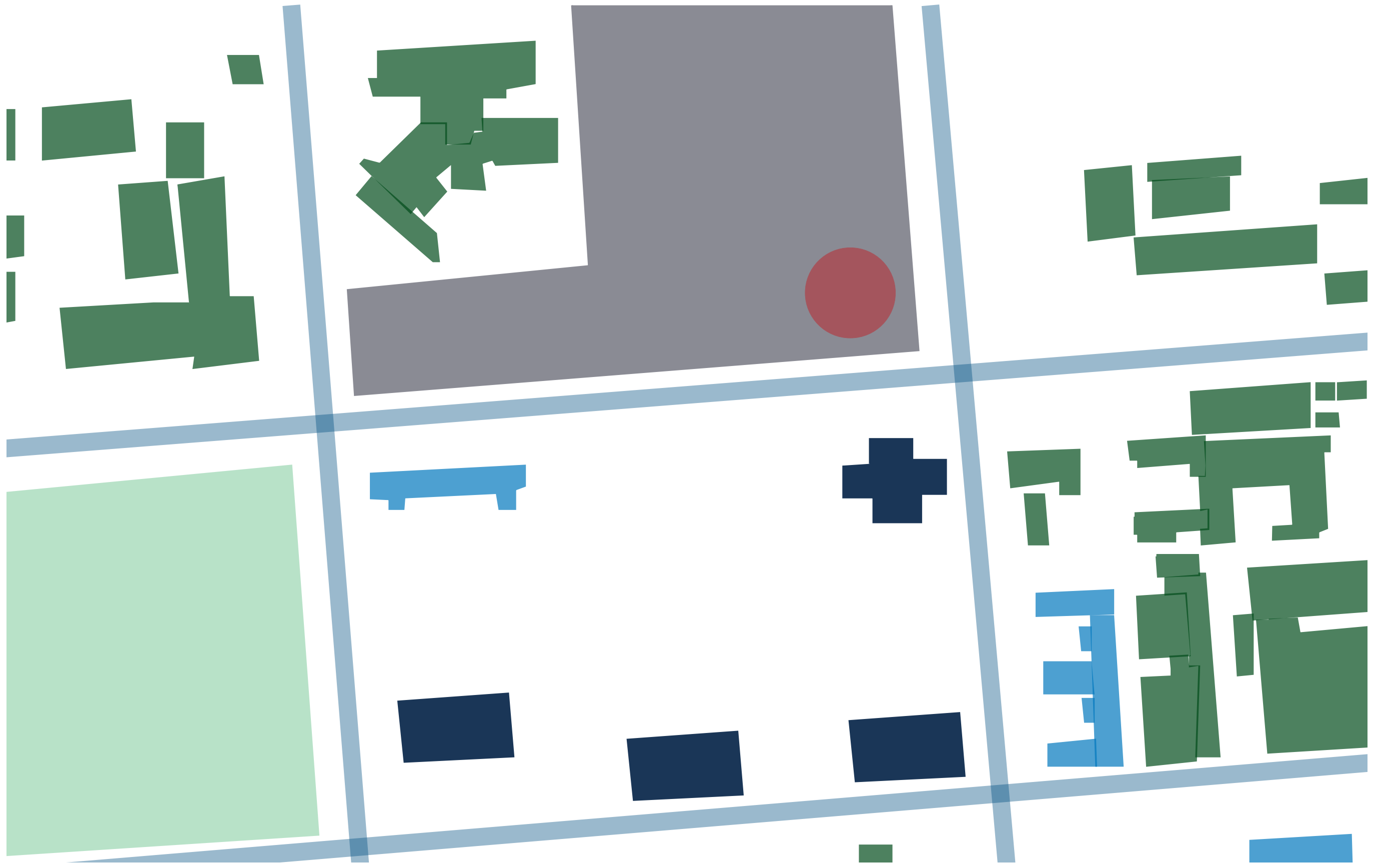


Fig. 22 Site and area

Fig. 23 Site and area with google maps underlay

The test location of the project/the site is located at an intersection between two streets: Schubart Street and Johannes Ramokhoase Street.

On the entire project lot they have build eleven buildings which are called: Thembelihle Village.

Most of the buildings in the area are schools, commercial buildings and government buildings which is shown on the map in Fig. 22. Interesting is that there are four abandoned buildings in the area which have no function. There's is no money to finish or restart the construction of those buildings.

LEGEND:

- housing
- other funtions: schools, government- and commercial buildings
- no function
- the entire project plot
- the test location of the project
- green area
- roads

1

Fig. 24 Photo of Thembelihle Village

2

Fig. 25 Photo of housing near the project site

3

Fig. 26 Photo of the abandoned buildings near the project site

Fig. 24 shows the intersection between two streets: Schubart Street and Johannes Ramokhoase Street and the first building of Thembelihle Village. This will also be the test location for this research.

Fig. 25 shows the housing on the other side of the road. which is most likely housing for the middle class.

Fig. 26 shows one of the abandoned buildings near the project location. There's is no money to finish or restart the construction of those buildings.

2.4 Defining the middle class

The middle class in South Africa is very complicated to define because of the wide range of income levels. Research has shown that the middle class influences the political stability and the economic growth, which is why the middle group of households is of interest.

Visagie (2013) suggests there are two ways to define the "middle class": the literal middle and the relatively affluent middle as shown in Fig 28 and Fig 29. The total income is calculated for a household size of four persons. The figures show how low the literal middle actually lies and how this differs with the relatively affluent middle, which starts at a much higher income. It can be concluded that the actual middle is not in the middle of the household income distribution (where the actual "middle" is as understood in everyday usage).

For this reason it is very difficult to define the middle class with just the three categories (lower group, middle group and elite).

In a NIDS discussion paper about vulnerability and the middle class in South Africa, Zizzamia, et al. (2016) stated that a monthly per capita household expenditure of R3,104 (in January 2015 prices) is the minimum requirement for a reasonably economically stable and secure middle class. The upper bound that separates the middle class from the elite is set at R10,387 (in January 2015 prices). According to this data Zizzamia, et al. (2016) described a four layerd class system following a vulnerability based approach as shown in Fig. 30.

Zizzamia, et al. (2016) from NIDS analysed data of the growth of the four social classes as shown in Fig. 27. Interesting is that the rates at the bottom are still very high and that the middle class has not changed much. Finn et al., 2013a stated that the high rates at the bottom of the distribution can mainly be connected to rearranged income support through supplying of social grants. The social grants signify a drop in the depth of poverty, but were not able to lift those households in an economically stable situation.

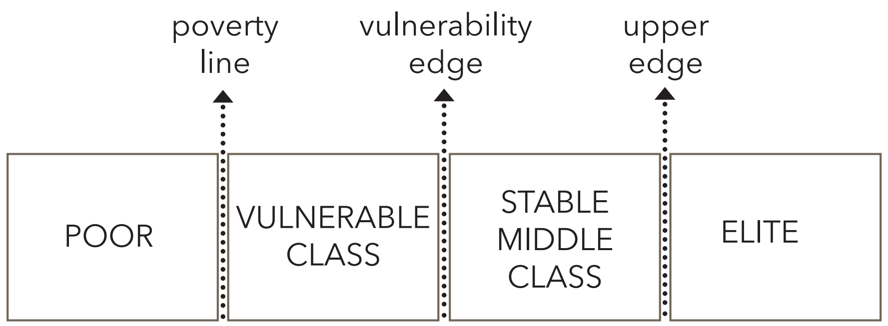


Fig. 27 Four classes, data: Zizzamia, et al. *(2016), autors figure*

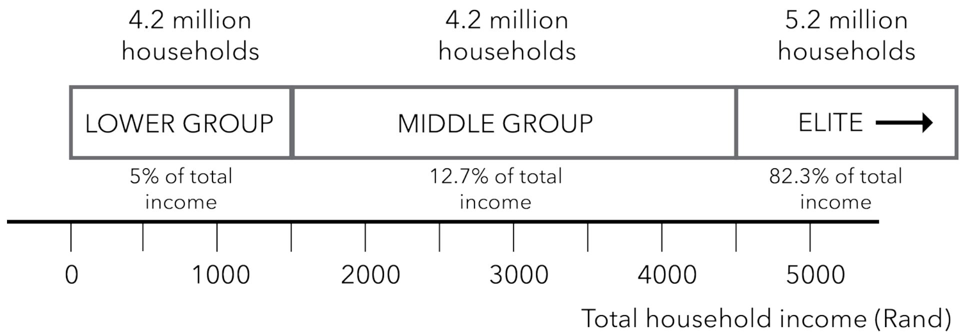


Fig. 28 Literal middle, data: Visagie (2013), autors figure

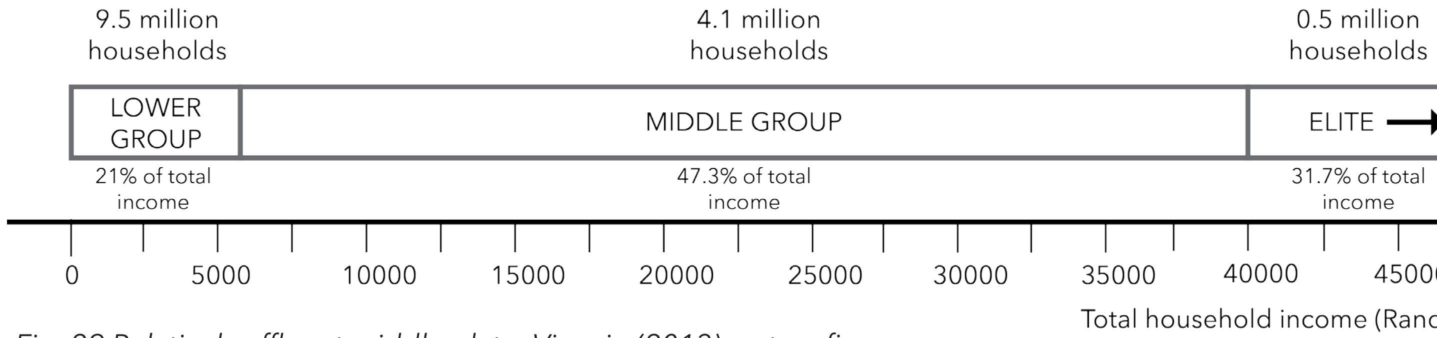


Fig. 29 Relatively affluent middle, data: Visagie (2013), autors figure

	1993	**2008**	**2010/11**	**2012**	**2014/15**
Poor	71.65	67.37	71.34	68.84	65.02
Vulnerable class	15.77	15.85	13.32	17.02	17.99
Stable middle class	11.69	13.15	11.79	10.92	13.53
Elite	0.9	3.62	3.55	3.22	3.46

Fig. 30 Growth social classes 1993 to 2014/15, data: NIDS (2016)

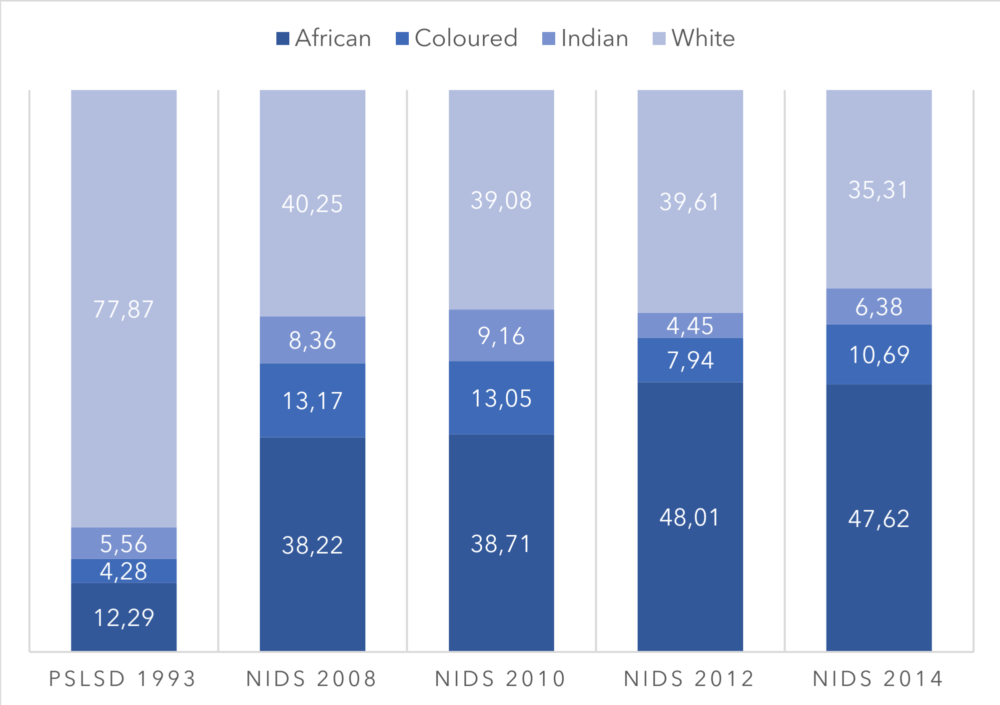


Fig. 31 Racial composition middle (%), data: Zizzamia, et al. *(2016), autors figure*

However, the number of Africans in the middle class has risen steadily. as shown in Fig. 31. This means that the composition of the middle class has changed, while the size of the middle class has relatively stayed the same.

In Fig. 32 Zizzamia, et al. (2016) collected data of different aspects of the four social classes. The table shows that most of the South Africans are poor (65,02%). Interesting is that the income range of the stable middle class is very wide, with a median of R5,031. The vulnerable class has a higer population share as the stable middle class, but the expenditure share of the stable middle class is more than twice as high.

Furthermore, the table shows that the percentage of Africans drops when the social class becomes higher. The opposite applies to the percentage of White. Also the poor have the largest unemployment rate. Interesting that the unemployment rate of the stable middle class (6.31%) is less than a half of the unemployment rate of the vulnerable middle class (13.02%).

In an article about the average house price in South Africa with data of FNB, the average house price of 2017 for the different income areas are published. The average house price 2017 for the upper income areas is set to R2.892.000 and for the middle income areas is set to R1.517.000. The average house price for the lower middle income areas is set to R952.964 and for the low income areas is set to R503.305.

	POOR	VULNERABLE CLASS	STABLE MIDDLE CLASS	ELITE
Population share (%)	65.02	17.99	13.53	3.46
Income range	R0-R1,283	R1,283 - R3,104	R3,104 - R10,387	>R10,387
Median expenditure	R476	R1,890	R5,031	R14,727
Expenditure share (%)	16.9	16.8	35.2	31.1
African (%)	90.46	79.99	47.62	23.94
White (%)	0.82	5.31	35.31	57.39
Years of education	8.3	10.3	12	13.3
Educated (tertiary qualifications) (%)*	7.63	22.90	42.87	61.93
Employed** (%)	48.47	73.42	82.54	83.68
Unemployed*** (%)	22.98	13.02	6.31	1.29

Fig. 32 Aspects of the four social classes data and figure: Zizzamia, et al. *(2016)*
** Employment statistics for individuals between the ages of 15 and 62.*
*** 'Unemployed' includes both the 'strict' and 'discouraged' unemployed.*
**** 'Educated' limited to adults above the age of 23.*

Fig. 33 Social housing project: Thembelihle Village

According to Yeast City Housing, the developer of Thembelihle village, there are three types of apartments in the building. The income of the households start from R2200 till R7500 (2014). The rent differs from R750 till R2250 (2014), based on unit type and size. When comparing the data in Fig. 32, both the vulnerable middle class (the lower middle class and the stable middle class are living in this building. However, it is not known how much the rent is increased every year.

The rental prices in the same area have been raising according to Private Property South Africa (march, 2018): a one bedroom apartment (one bedroom with communal bathroom and kitchen facilities) costs around R2000-R2500. Still these numbers fit in the income range of the lower middle class and the stable middle class.

In addition to the general aspects of the four social classes, Zizzamia, et al. (2016) collected the NIDS data about the income composition by class. In Fig. 35 the data is collected. Interesting is that 24,4% of the income of the poor consists of grants. Furthermore, 65% of the income of the poor is by labour. While it is around 82% in the middle class and the elite.

To be able to understand which profession fits to the different incomes it's important to know more about the salarys. According to Payscale (2018) security guards in Pretoria earn +/- R47.000 a year, cleaners in Pretoria earn +/- R30.000 a year, office assistants in Pretoria earn +/- R68.000 a year, delivery drivers in Pretoria earn +/- R67.000 a year, receptionists in Pretoria earn +/- R70.000 a year and handymen in Pretoria earn +/- R75.000 a year. By comparing these numbers with the income range of the people who live in Thembelihle Village, these kind of professions could fit to the people who live in Thembelihle Village.

The Statistics South Africa (2014/15) analysed the expenditures of the different population groups. Interesting is that the black africans spend most of their income on food and clothing as shown in Fig. 36. But it is important to take the size of the income into account, since the "Black Africans" have a much lower average expenditure in comparison with the "White" which is shown in Fig. 34.

While most of the poor are Black Africans (90,46%), there is also a group of White in this social class. According to Fig. 31 there is a percentage of 47,62 of Africans and a percentage of 35,31 in the stable middle class. For this reason it is not possible to completely link this data to the four social classes.

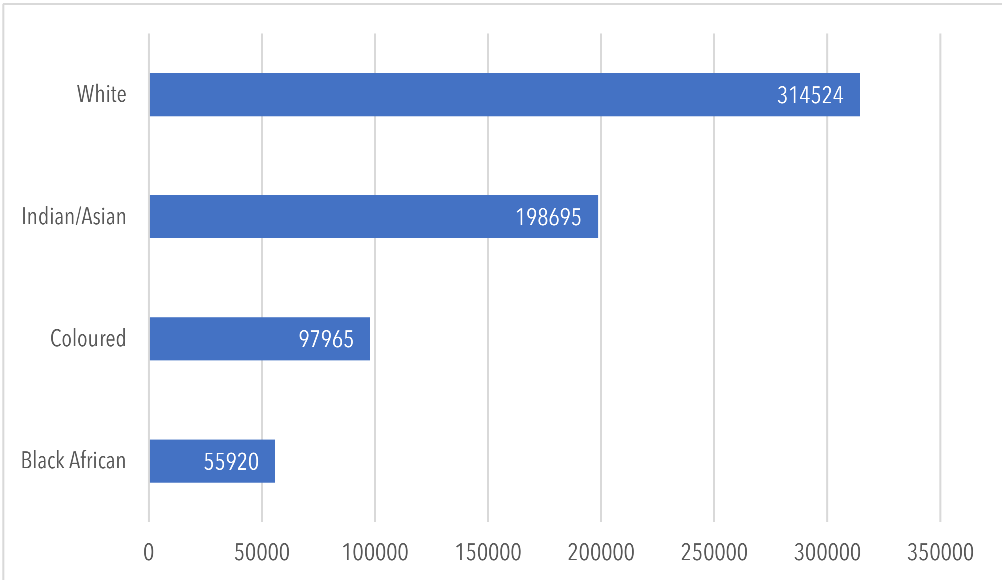


Fig. 34 Average expenditures per household in Rand by population group data: SAS (2010/11), authors figure

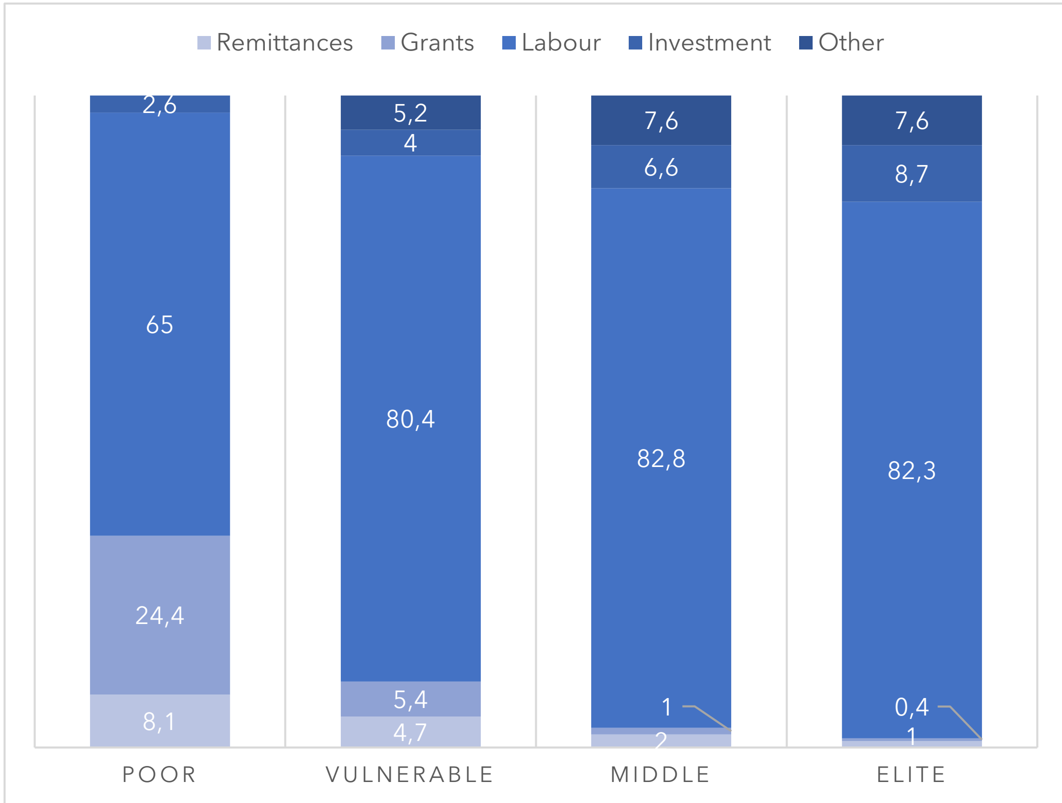


Fig. 35 Income by class (%), data: Zizzamia, et al. *(2016), authors figure*

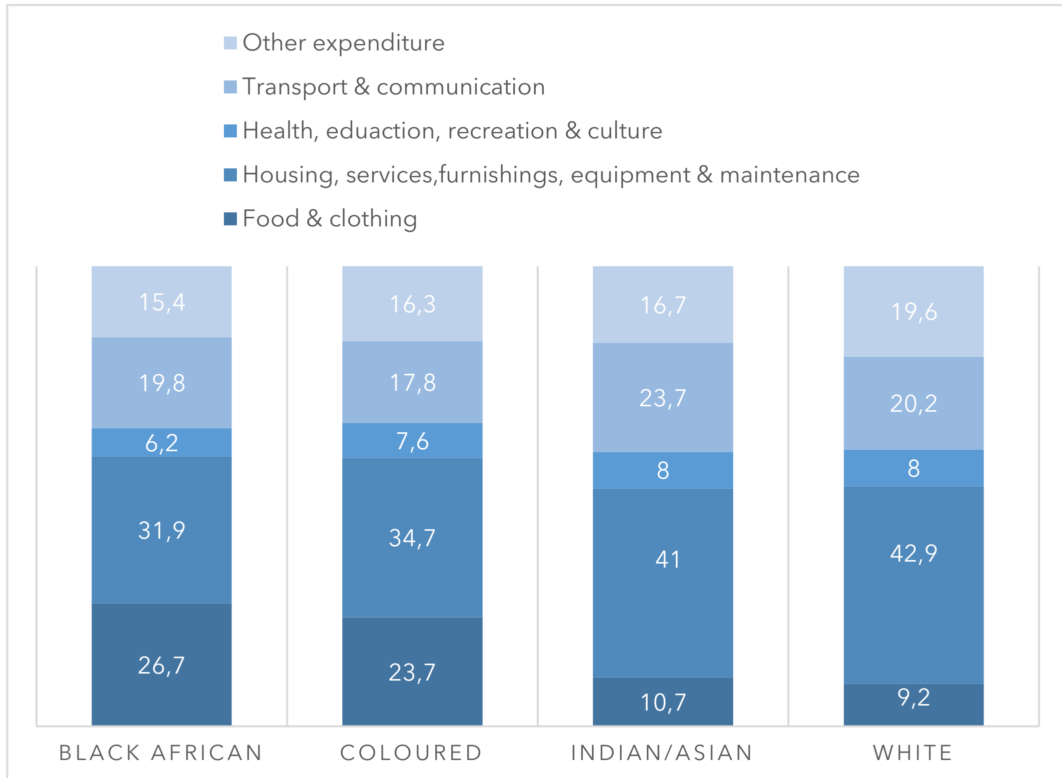


Fig. 36 Expenditures by population group (%), data: SAS (2010/11), *authors figure*

Fig. 37 Middle class housing: Thembelihle village in the centre of Pretoria

Fig. 39 Middle class housing in the centre of Pretoria

Fig. 38 Middle class housing just outside Pretoria

Fig. 40 Middle class housing in the centre of Pretoria

Although it is difficult to define the middle class in South Africa, a definition is formulated for this research by combining the theoretical approach with the photos of the location (Pretoria) and the information of the project developer (Yeast City Housing).

Zizzamia, et al. (2016) described a four layerd class system with a vulnerable middle class and a stable middle class because it is too complicated to define the middle class with just three categories (lower group, middle and elite).

According to Zizzamia, et al. (2016) the vulnerable middle class has a population share of 17.99%, an income range of R1283-R3104, an expenditure share of 16,8% and 73,4% is employed. The stable middle class has a population share of 13,53%, an income range of R3104-R10,387, an expenditure share of 35,2% and 82,5% is employed.

According to Yeast City Housing, the developer of Thembelihle village, the income of the households start from R2200 till R7500 (2014). Which means that both the vulnerable middle class as the stable middle class should live in this type of building. If we compare the numbers and the appearance of Thembelihle village, the expectation is that the middle class also lives in buildings as shown in Fig. 38, Fig. 3 and Fig, 40.

The middle class of the centre of Pretoria, South Africa has an income range of R1283 - R10,387 and lives in multilevel apartment buildings as shown in Fig. 37, Fig. 38, Fig, 39 and Fig. 40. The profession of the people who live in these buildings could be for example: security guard, cleaner, receptionist, delivery driver, handyman or office assistant.

2.5 Energy use households Pretoria

There's not a lot of information available about the energy use of the households in Pretoria. However, Statistics South Africa wrote a report about a household survey of energy data from 2002-2012.

The report shows that 50% of the South African households spent less than 5% on electricity and +/- 75% spent below 10% on electricity.

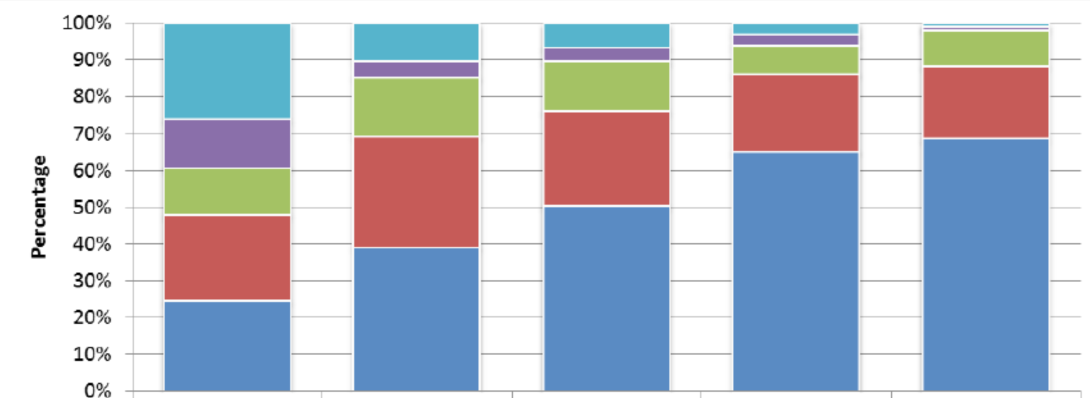
As shown in Fig. 41, 50,4% of Gauteng households spent 0-5% on electricity. Only 4% spents 15-19% of their income on electricity. However, 11,4% spents more than 19% of their income on electricity. Because we don't know the relation between the numbers and the income, it is not clear what the middle class spents on electricity.

In Fig. 42 the income guintile is added to the percentage of household income spent on elctricity. The figure shows that 39,2% of quintile 2, 50,4% of quintile 3 and 65,2% of quintile 4 spents 0-5% of their income on electricity. Quintile 2 spents the highest percentage of their income on electricity, but the income of this quintile is lower compared to the other two quintiles.

Quintile 1: R0 - R390
Quintile 2: R391 - R764
Quintile 3: R765 - R1499
Quintile 4: R1500 - R3997
Quintile 5: Larger than R3997

	0-5%	5-9%	10-14%	15-19%	>19%
Western Cape	50,3	23,4	12,1	4,7	9,5
Eastern Cape	53,3	25,1	11,1	4,7	5,9
Northern Cape	51,0	20,2	14,4	5,8	8,6
Free State	46,1	27,3	13,1	5,9	7,7
KwaZulu-Natal	47,1	26,8	11,8	5,5	8,8
North West	48,1	23,5	13,2	5,7	9,4
Gauteng	50,4	21,4	12,7	4,0	11,4
Mpumalanga	56,6	22,5	11,1	4,4	5,4
Limpopo	53,3	25,1	8,9	5,3	7,5
South Africa	**50,5**	**24,0**	**11,9**	**4,9**	**8,8**

Fig. 41 Percentage of household income spent on electricity by province, 2012 Figure: Statistics South Africa



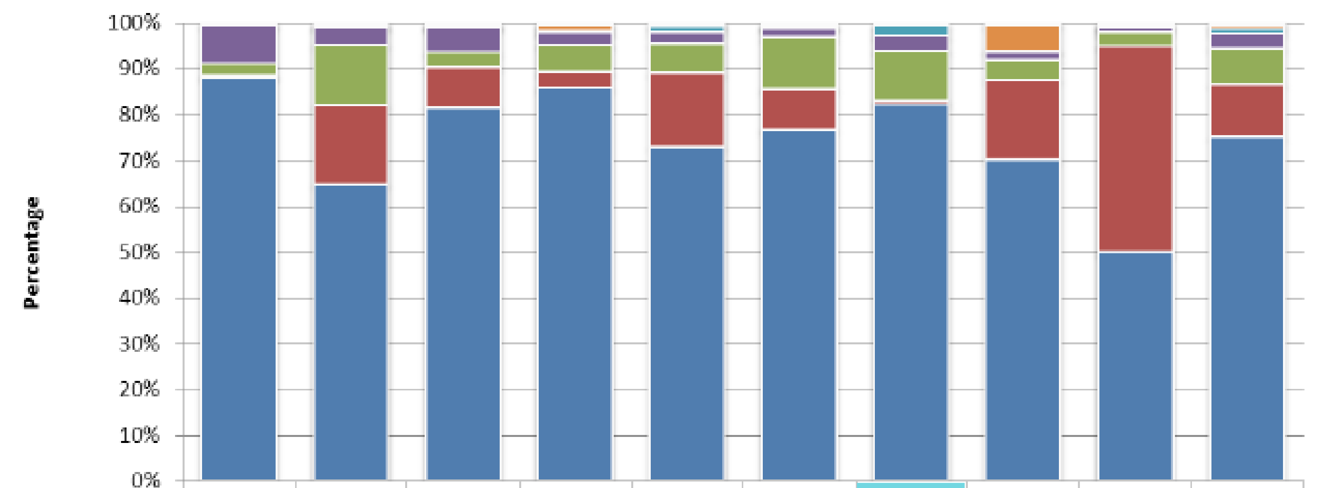
	Poorest quintile	Quintile 2	Quintile 3	Quintile 4	Wealthiest quintile
>19%	26,1	10,2	6,5	3,0	0,7
15-19%	13,2	4,5	3,8	3,0	1,1
10-14%	12,7	16,1	13,5	7,8	9,7
5-9%	23,4	30,1	25,8	21,0	19,9
0-5%	24,6	39,2	50,4	65,2	68,6

Fig. 42 Percentage of household income spent on electricity by households with access to electricity by income quintile, 2012 Figure: Statistics South Africa

In Fig. 43 the main sources of energy for cooking by province are presented. In Gauteng 82,2% of the households use electricity for cooking, 10,9% of the households use paraffin for cooking and 3,1% of the households use gas for cooking.

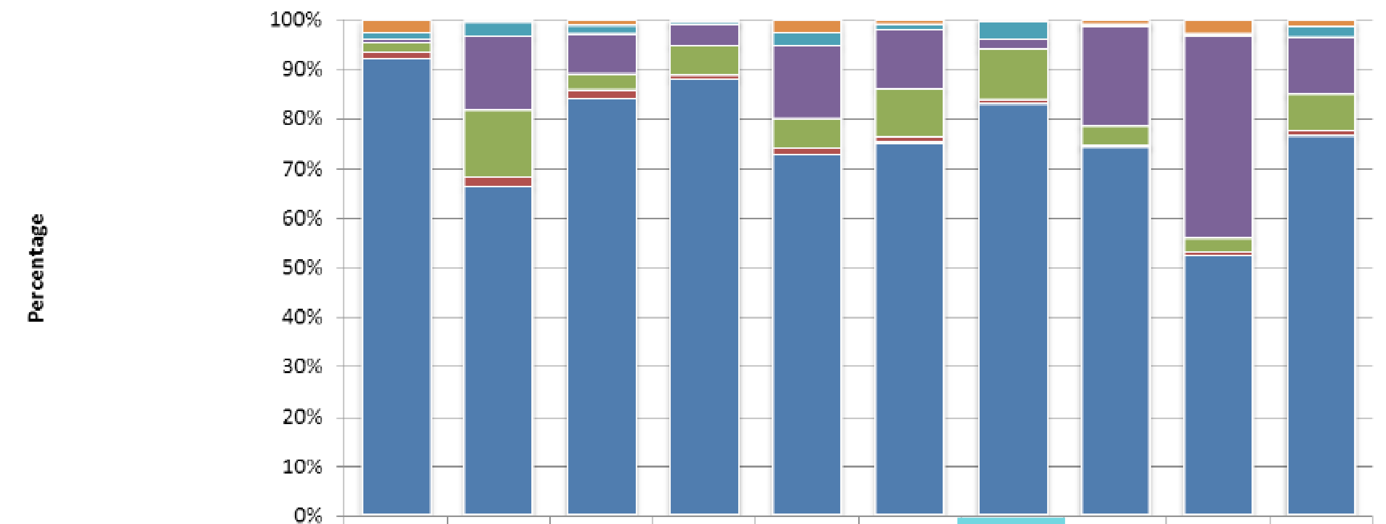
In Fig. 44 the main sources of energy for heating by province are presented. 83,2% Of the households use electricity for heating water and 10,2% of the households use paraffin for heating water.

Fig. 45 shows the main sources of energy for lighting by province. In Gauteng 86,2% of the households use electricity, 9,8% of the households use candles and 1,5% of the households use paraffin.



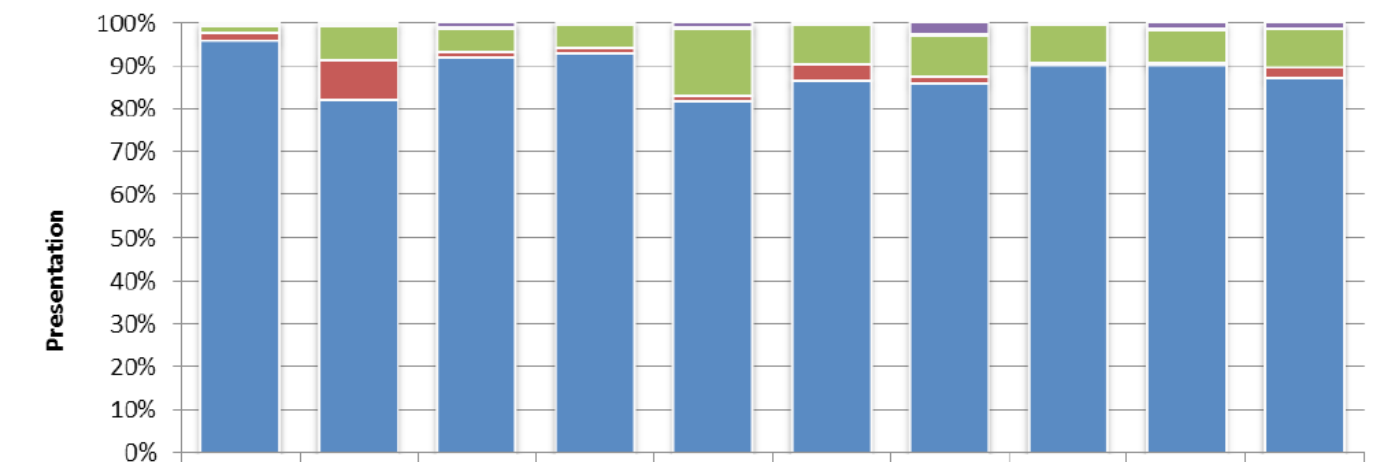
	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma-langa	Limpopo	South Africa
None	0,2	0,2	0,5	0,3	0,1	0,5	0,0	0,2	0,5	0,2
Animal dung	0,0	0,6	0,1	0,2	0,3	0,2	0,0	0,2	0,0	0,2
Coal	0,0	0,0	0,1	1,3	0,4	0,3	0,5	5,7	0,3	0,8
Other	0,3	0,2	0,4	0,3	1,1	0,2	2,4	0,1	0,2	1,0
Gas	8,4	3,8	5,3	2,6	2,7	1,9	3,1	1,8	1,1	3,3
Paraffin	2,4	13,1	3,3	6,0	6,4	11,3	10,9	4,3	3,0	7,8
Wood	0,6	17,3	8,7	3,5	16,0	8,8	0,9	17,6	45,1	11,6
Electricity	88,1	64,9	81,7	85,9	73,1	76,8	82,2	70,1	49,8	75,2

Fig. 43 Main sources of energy for cooking by province, 2012 Figure: Statistics South Africa



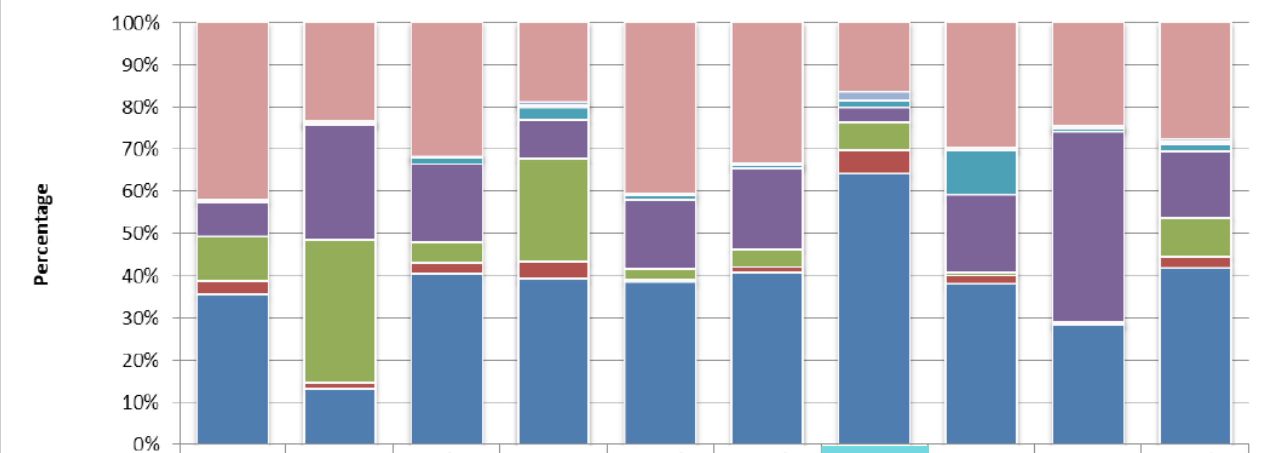
	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma-langa	Limpopo	South Africa
None	2,5	0,4	1,0	0,2	2,6	0,9	0,2	0,8	2,8	1,2
Other	1,4	2,8	1,8	0,7	2,5	1,0	3,8	0,5	0,4	2,2
Solid fuels (wood, coal, dung)	0,7	15,1	8,0	4,2	14,9	12,0	1,8	20,1	40,9	11,6
Paraffin	1,9	13,4	3,2	5,9	5,7	9,8	10,2	3,8	2,8	7,3
Gas	1,4	1,8	1,8	1,0	1,3	1,1	0,8	0,3	0,6	1,1
Electricity	92,1	66,5	84,3	88,0	73,0	75,3	83,2	74,5	52,6	76,7

Fig. 44 Main sources of energy for heating water by province, 2012 Figure: Statistics South Africa



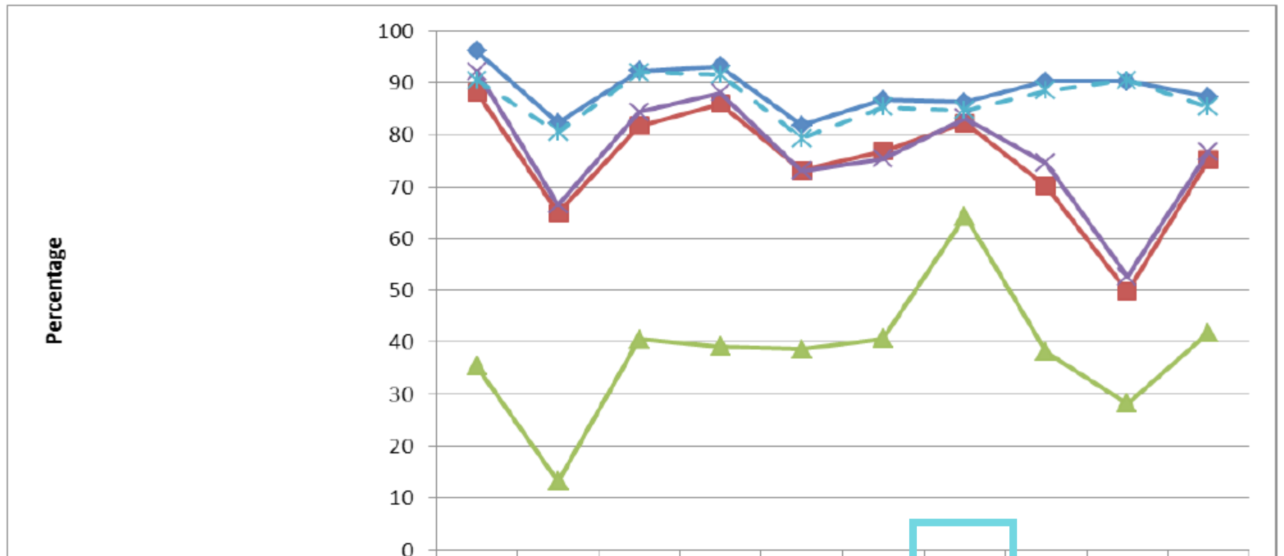
	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma-langa	Limpopo	South Africa
Other	0,6	0,6	1,1	0,2	1,1	0,3	2,6	0,2	1,4	1,3
Candles	1,6	7,8	5,6	5,4	15,8	9,2	9,8	8,7	7,6	9,0
Paraffin	1,7	9,4	1,0	1,2	1,3	3,8	1,5	0,9	0,8	2,4
Electricity	96,1	82,2	92,3	93,1	81,8	86,7	86,2	90,2	90,3	87,3

Fig. 45 Main sources of energy for lighting by province, 2012 Figure: Statistics South Africa



	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma-langa	Limpopo	South Africa
None	42,0	23,5	31,9	18,9	40,5	33,3	16,4	29,7	24,6	27,7
Other	0,5	0,1	0,1	0,8	0,2	0,3	2,0	0,5	0,5	0,8
Animal dung	0,0	0,5	0,2	0,4	0,5	0,3	0,2	0,2	0,1	0,3
Coal	0,0	0,2	1,3	3,0	0,9	0,8	1,7	10,5	0,6	1,8
Wood	8,3	27,3	18,6	9,3	16,5	19,0	3,4	18,5	45,1	15,8
Paraffin	10,4	33,7	5,0	24,3	2,5	4,2	6,7	0,7	0,5	9,2
Gas	3,3	1,4	2,3	4,1	0,4	1,4	5,5	1,9	0,3	2,7
Electricity	35,4	13,2	40,6	39,2	38,6	40,7	64,2	38,1	28,2	41,8

Fig. 46 Main sources of energy for space heating by province, 2012 Figure: Statistics South Africa



	WC	EC	NC	FS	KZN	NW	GP	MP	LP	SA
Used for lighting	96,1	82,2	92,3	93,1	81,8	86,7	86,2	90,2	90,3	87,3
Used for cooking	88,1	64,9	81,7	85,9	73,1	76,8	82,2	70,1	49,8	75,2
Used for space heating	35,4	13,2	40,6	39,2	38,6	40,7	64,2	38,1	28,2	41,8
Used for water heating	92,1	66,5	84,3	88,0	73,0	75,3	83,2	74,5	52,6	76,7
Connected to mains electricity	90,5	80,4	91,9	91,5	79,3	85,3	84,6	88,4	90,5	85,3

Fig. 47 Percentage of households with access to mains electricity compared to percentage of households that used electricity for cooking, lighting, heating water and heating space by province, 2012 Figure: Statistics South Africa

Fig. 46 shows the main sources of energy for space heating by province. In Gauteng 64,2% of the households use electrictiy, 16,4% use nothing, 6,7% use paraffin and 5,5% use gas for space heating.

In Fig. 47 the relation between electricity used for lighting, cooking, space heating, water heating and access to mains electricity is visualised. The dotted line shows the households connected to mains electrictiy, which shows directly a relation with the other numbers. Gauting is the province which uses the highest percentage of electricity for space heating.

2.6 Housing policies

In a housing white paper (1994) by the department of housing, providing housing was seen as one of the biggest challenges for the government. The estimation was that the housing backlog was about 1.5 million at that moment and was growing with 178,000 a year. In 2011 the number of informal housing was about 1.9 million, which was around 13 percent of all households.

To respond to South Africa's housing problems, the government has set up housing policies and programmes. The housing policy is divided in three broad programmes: the Incremental Housing Programme, the Social and Rental Housing Programme and the Rural Housing Programme. The housing policies had different improvements on the standards, norms and models. These improvements are described in this paragraph.

2.4.1 White paper on Housing and Housing Act (no. 107, 1997)

The white paper on Housing and Housing Act was created for seven reasons: stabilisation of the housing environment, mobilising housing credit, providing subsidy assistance, rationalising institutional capacities, facilitating the speedy release and servicing of land, and coordinating government investment development. The main goal was to create as many houses as possible (subsidised) with an target of 1 million houses in five years, which was achieved in seven years. Between 1992 and 2003 there were a lot of complaints by the citizens, because of the quality and the size of the houses. Furthermore, the contractors had complaints about the expected standard compared to the subsidy. As a result, national minimum standards were developed and the amount of subsidy was changed over time. By the year 1999 the amount of units completed was over 200.000.

2.4.2 Breaking New Ground (BNG) in 2004

The BNG focused on the delivery of sustainable housing and the process of this delivery, the importance of integrated development and the improvement of informal housing. The programme ensured that quality was more important than quantity. Besides the BNG, there were other developments including, the FLISP in 2005, the Social Housing Policy in 2005, a Rental Housing Amendment Act (No. 43 of 2007) and the Social Housing Act (No. 16 of 2008). The housing delivery increased until 2006 (just over 150.000 units per year in 2008 and 2009) because of higher delivery norms, the global financial crisis and the raise in construction costs.

2.4.3 National Housing Code

The Housing Code in 2009 consists of the principles, guidelines and norms and standards to the housing programmes. The programme supports a secondary housing market and providing subsidies within integrated areas. Next to the Housing Code, there was a development called "Outcome 8". With this programme the government devoted itself to improve 400.000 informal houses starting in 2010. In 2012 the government announced a fund to promote households to buy a house.

2.7 Summary

Gauteng, the province where Pretoria is located, is the smallest province of South Africa. However, it is also the province with the highest population because two of the three largest cities of South Africa are located in this Province (Johannesburg and Pretoria). The city is still one of the most important cities for the government and most overseas civil servants are based there.

Although it is difficult to define the middle class in South Africa, a definition is formulated for this research by combining the theoretical approach with the photos of the location (Pretoria).

Zizzamia, et al. (2016) described a four layerd class system with a vulnerable middle class and a stable middle class because it is too complicated to define the middle class with just three categories (lower group, middle and elite).

According to Zizzamia, et al. (2016) the vulnerable middle class has a population share of 17.99%, an income range of R1283-R3104 (per month). The stable middle class has a population share of 13,53%, an income range of R3104-R10,387 (per month).

The middle class of the centre of Pretoria, South Africa has an income range of R1283 - R10,387 (per month) and lives in multilevel appartment buildings. One of the projects with multilevel buildings is Thembelihle Village which is located close to government departments, work, shops, social amenities and public transport, which is very interesting for people with a lower income because of the high transport costs.

The profession of the people who live in these buildings could be for example: security guard, cleaner, receptionist, delivery driver, handyman or office assistant.

In Gauteng 82,2% of the households use electricity for cooking, 10,9% of the households use paraffin for cooking and 3,1% of the households use gas for cooking. 83,2% Of the households use electricity for heating water and 10,2% of the households use paraffin for heating water. 86,2% Of the households use electricity, 9,8% of the households use candles and 1,5% of the households use paraffin for lighting. n Gauteng 64,2% of the households use electrictiy, 16,4% use nothing, 6,7% use paraffin and 5,5% use gas for space heating.

Chapter III – Climate

3.1 Introduction

This chapter is about the Climate of Pretoria. To be able to work on a design project which is located in an unfamiliar location, it's important to understand the climate and it's conditions. In this chapter background information about the current climate conditions and the future climate of Pretoria will be described. One research question will be answered in this chapter:

- What are the climate conditions in Pretoria?

3.2 Current climate conditions

One of the ways to analyse current climate conditions is by using the Köppen-Geiger classification. This classification is based on five zones:

Type A: Equatorial climates
Type B: Arid climates
Type C: Warm temperature climates
Type D: Snow climates
Type E: Polar climates

As shown in Fig. 49 CSIR has made a map of South Africa with all the different zones, which are all subdivided under the main five zones. In this map is also visible that

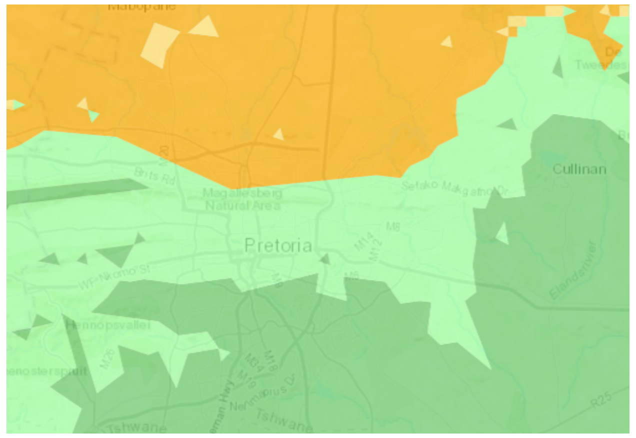


Fig. 48 Dirk Conradie (CSIR) Köppen-Geiger map Pretoria, data: 1985-2005 South African Weather Services

Pretoria is located in multiple zones. The different zones are visualized in Fig. 48. The figure shows the three colors of the climate zones, which are: BSh (Arid steppe, hot arid), Cwa (Warm temperature, dry winter, hot summer) and Cwb (Warm temperature, Dry winter, Warm summer).

<u>Rainfall</u>

In Fig. 50 the rainfall in four different months are visible. The maps show that most of the rain is falling in the summer (December till February) which is the winter in the Netherlands. The winter (June till August) is the driest period in Pretoria.

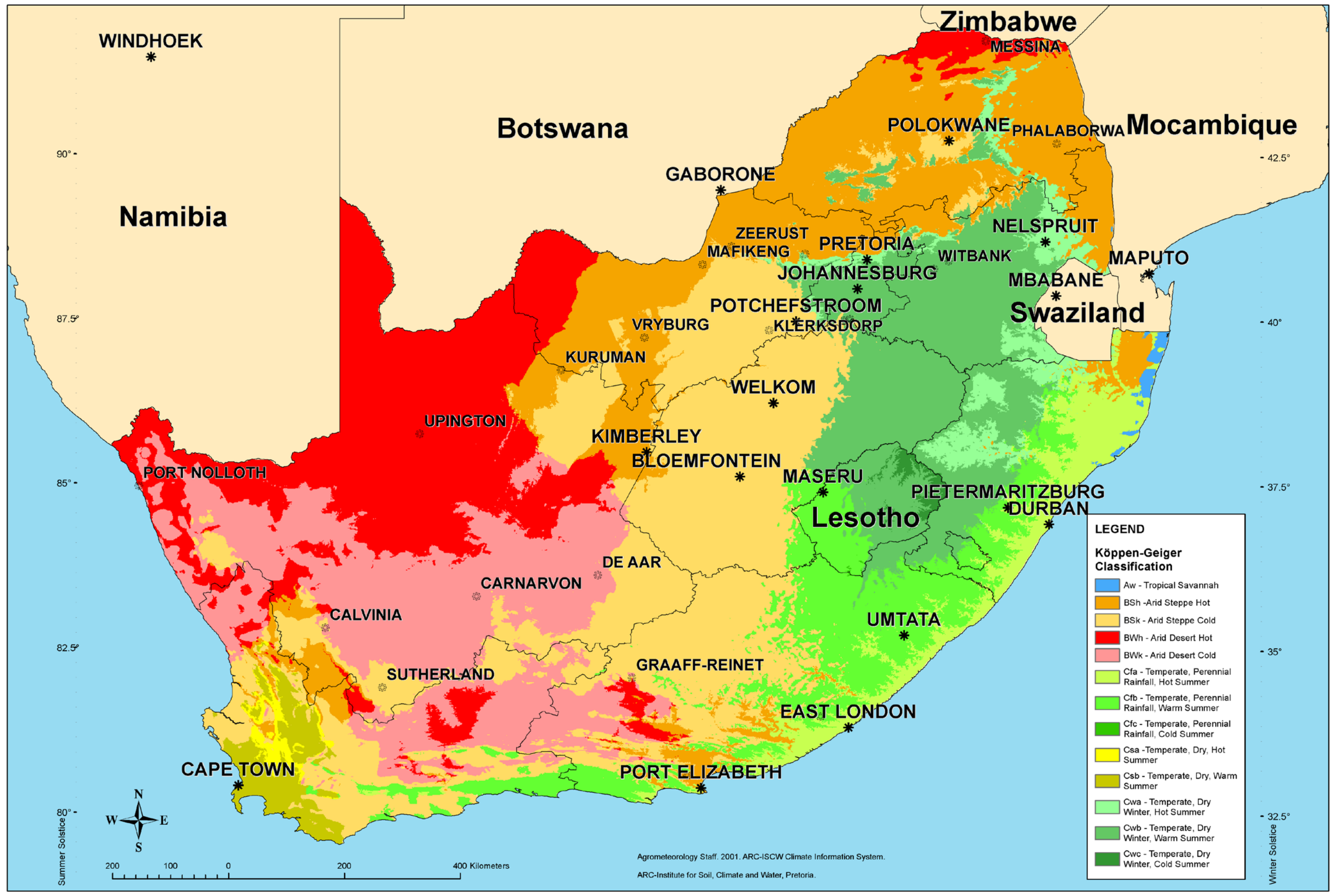


Fig. 49 CSIR Köppen-Geiger map based on 1985 to 2005 South African Weather Services data on a very fine 1 km x 1 km grid (Conradie)

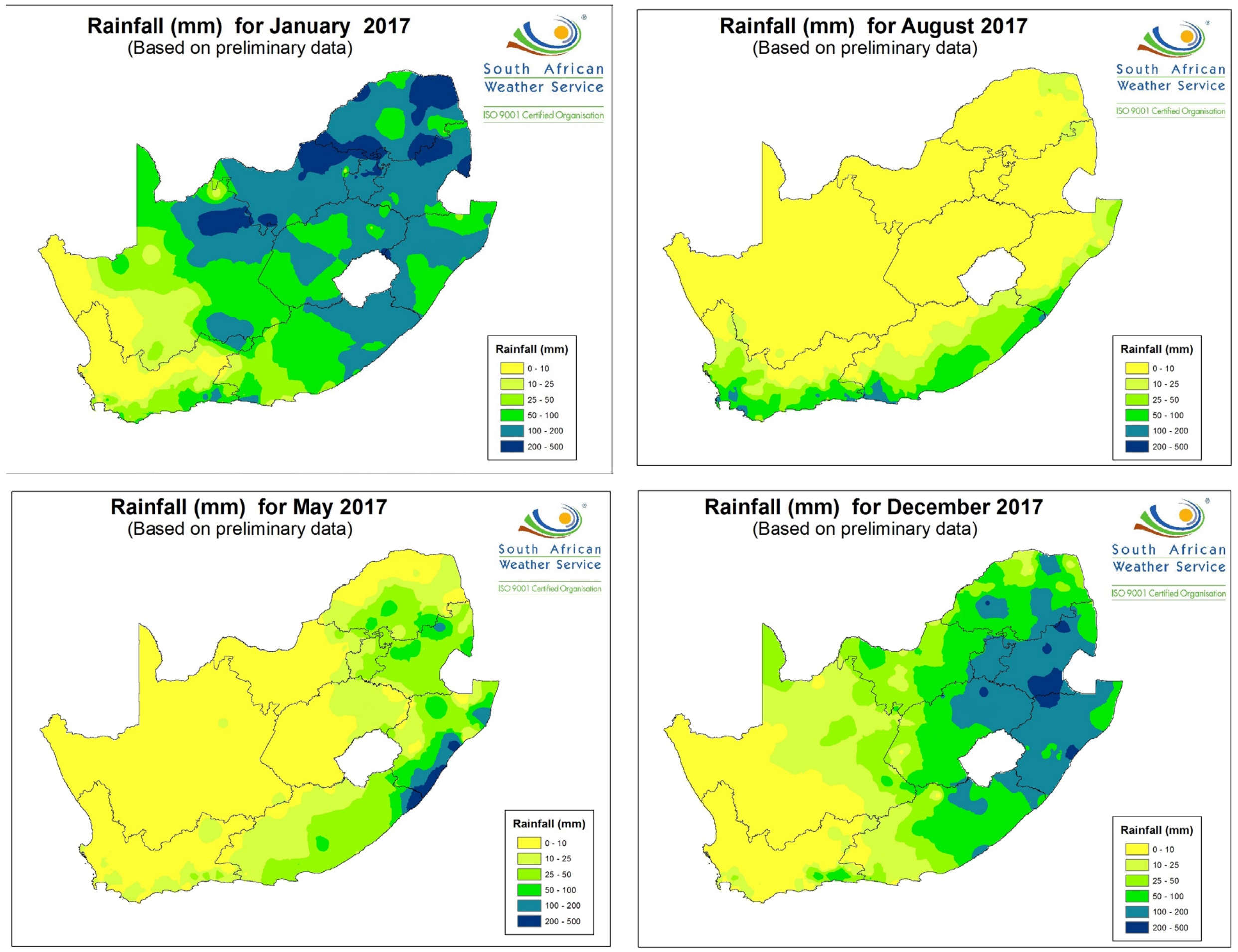


Fig. 50 Rainfall maps (South African weather service

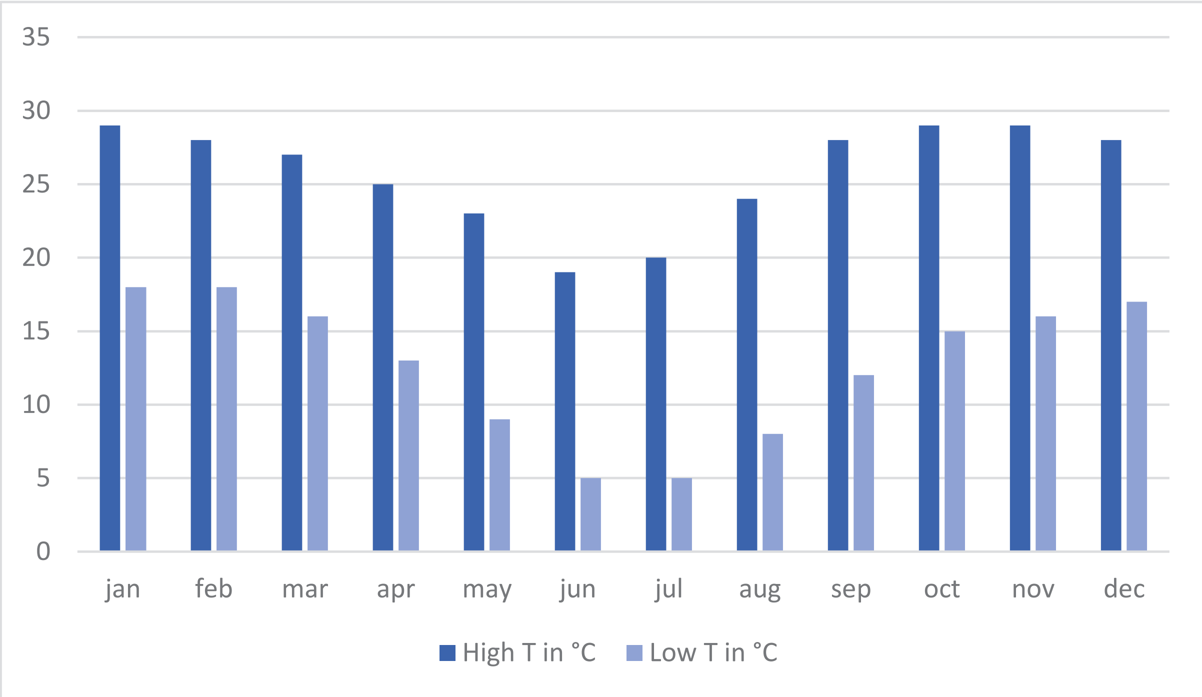


Fig. 51 Average maximum and minimum temperatures during the year in Pretoria. Data: Klimaatinfo

Date	Sunrise	Sunset	Length	Change	Dawn	Dusk	Length	Change
Today	05:23	19:03	13:40		04:58	19:29	14:31	
+1 day	05:24	19:03	13:39	00:01 shorter	04:58	19:29	14:31	00:00 equal length
+1 week	05:29	19:03	13:34	00:06 shorter	05:03	19:29	14:26	00:05 shorter
+2 weeks	05:34	19:02	13:28	00:12 shorter	05:09	19:28	14:19	00:12 shorter
+1 month	05:46	18:56	13:10	00:30 shorter	05:22	19:20	13:58	00:33 shorter
+2 months	06:05	18:31	12:26	01:14 shorter	05:42	18:54	13:12	01:19 shorter
+3 months	06:19	17:59	11:40	02:00 shorter	05:56	18:22	12:26	02:05 shorter
+6 months	06:54	17:30	10:36	03:04 shorter	06:29	17:55	11:26	03:05 shorte

Fig. 52 Sunrise and sunset information starting from 07 January 2017. Data: Geisma

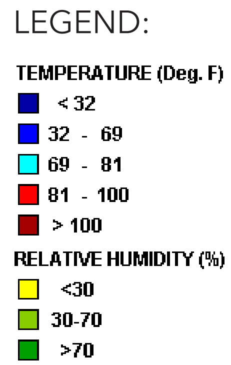
Sun

Fig. 51 shows the average maximum and minimum temperatures during the year. In June and July the temperatures are the lowest (winter time) and in November till January the temperatures are the highest (summer time).

Fig. 52 shows the sunrise ans sunset information starting from 7 January 2017.

Wind directions

Fig. 53 shows the average winddirection in Pretoria over the year, which is mostly east and northwest wind.



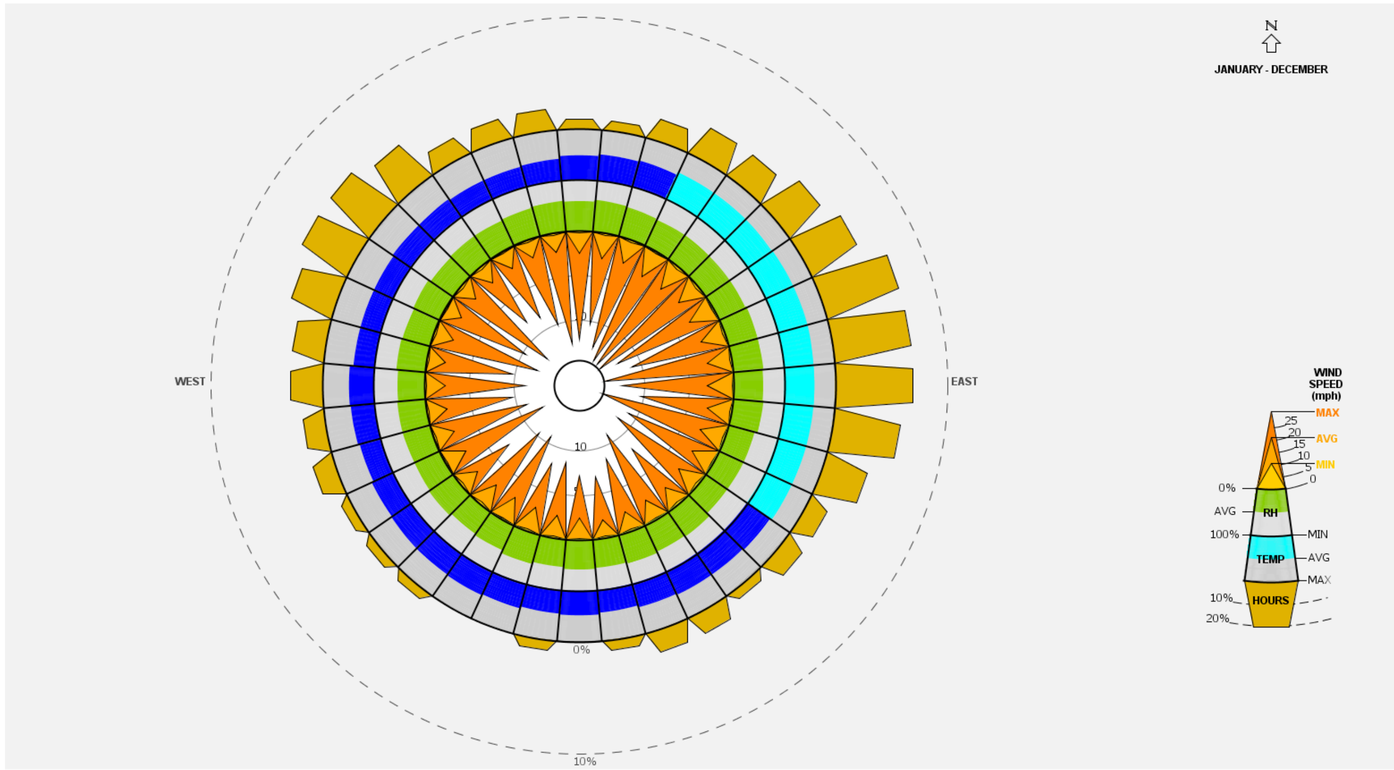


Fig. 53 Wind wheel with weather data of Pretoria from Climate Consultant software

3.3 Future climate

As explained in paragraph 3.2, Pretoria is located in multiple climate zones. The different zones are visualized in Fig. 54, which is the world map of Köppen-Geiger Climate Classification over the period: 1901 - 1925. The figure shows the three colors of the climate zones, which are: BSh (Arid steppe, hot arid), Cwa (Warm temperature, dry winter, hot summer) and Cwb (Warm temperature, Dry winter, Warm summer).

In Fig. 55 the world map of Köppen-Geiger Climate Classification over the period 2076-2100 is presented. The map shows that Pretoria will be located in just one climate zone in the future: BSh (Arid steppe, hot arid).

The climate will then be a lot drier with less rain which is very important to include in the design.

3.4 Summary

Pretoria is located in multiple climate zones, which are: BSh (Arid steppe, hot arid), Cwa (Warm temperature, dry winter, hot summer) and Cwb (Warm temperature, Dry winter, Warm summer).

Most of the rain in Pretoria is falling in the summer (December till February) which is the winter in the Netherlands. The winter (June till August) is the driest period in Pretoria.

In June and July the temperatures are the lowest (winter time) and in November till January the temperatures are the highest (summer time).

According to the Köppen-Geiger climate change analysis, Pretoria will be located in just one climate zone in the future: BSh (Arid steppe, hot arid). The climate will then be a lot drier with less rain which is very important to include in the design.

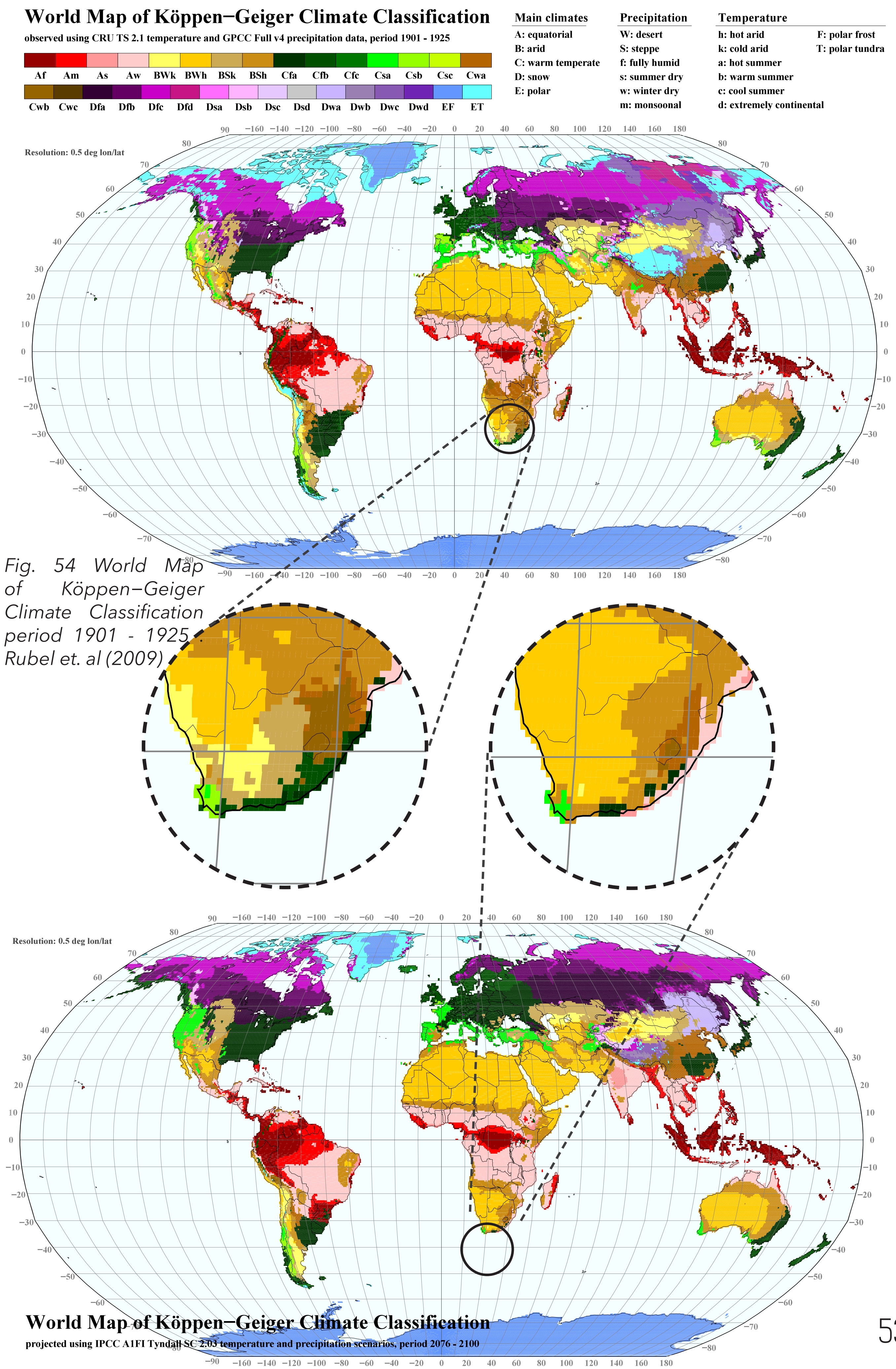


Fig. 54 World Map of Köppen−Geiger Climate Classification period 1901 - 1925 Rubel et. al (2009)

Fig. 55 World Map of Köppen−Geiger Climate Classification period 2076 - 2100. Rubel et. al (2009)

Chapter IV – Technology

4.1 Introduction

This chapter is about the building methods for this specific location and climate. To be able to work on a design project which is located in an area with other building methods and materials as used in the Netherlands, it is important to analyze those other building methods. In this chapter the current building methods and a new building method for this area will be described. Two existing housing projects will be used to describe the current building methods in Pretoria, South Africa. The following research questions will be answered in this chapter:

What are the current building methods used in middle class homes?

What are the current developments for middle class homes?

4.2 Current building methods

To be able to understand the current building methods in Gauteng, South Africa two, quite new, social housing projects will be described. The first project is "Germiston Fire Station" and the second project is "Thembelihle Village".

<u>Germiston Fire Station (Germiston Fire Station & Delville Ext 9)</u>

The social housing project: Germiston Fire Station is located at President Street and Linton Jones Street in Germiston South (near Johannesburg). The project consists of four storey apartment buildings.

The units in the buildings range from one to two bedroom units or bachelor flats. All have their own living room, kitchen and bathroom. The apartments will also be suitable for people with disabilities.

Interesting is that there is only shading by the balconys.

Fig. 56 Example project : Germiston Fire Station

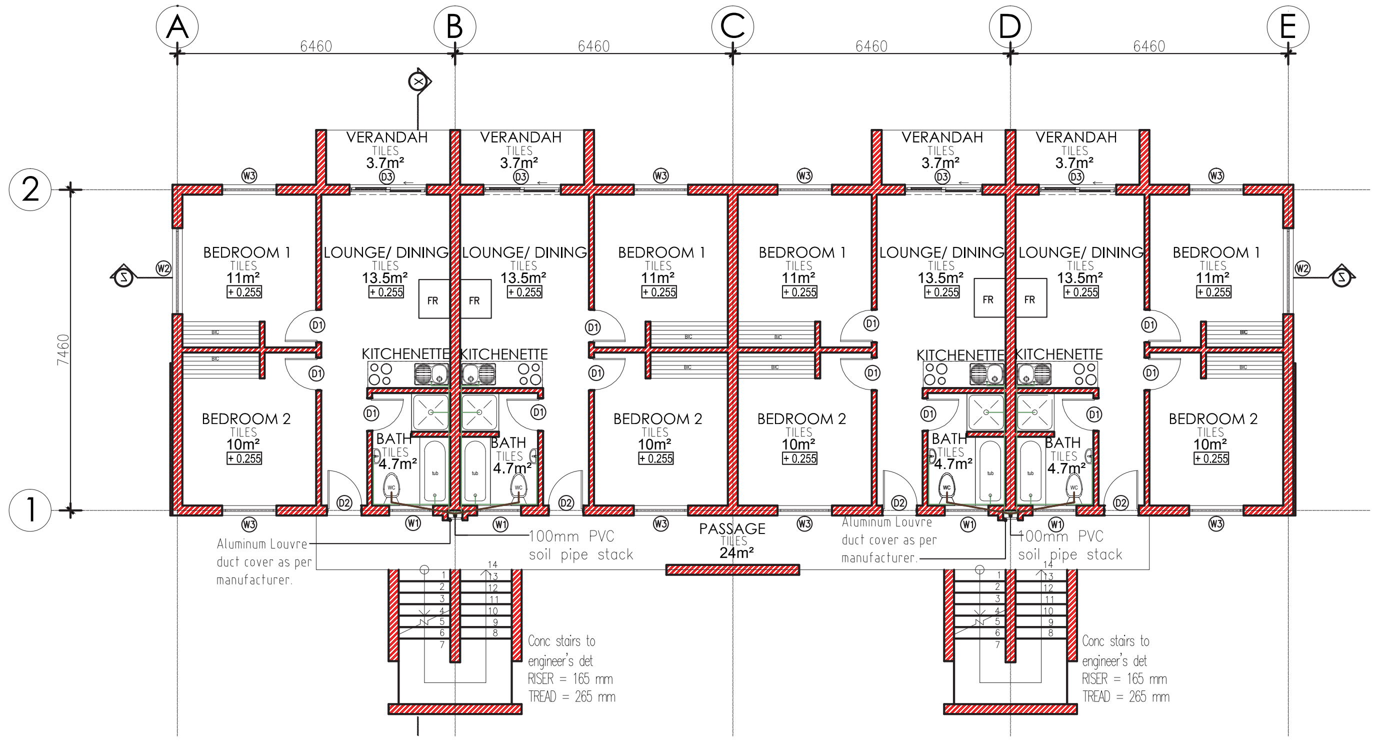


Fig. 57 Example project : Germiston Fire Station

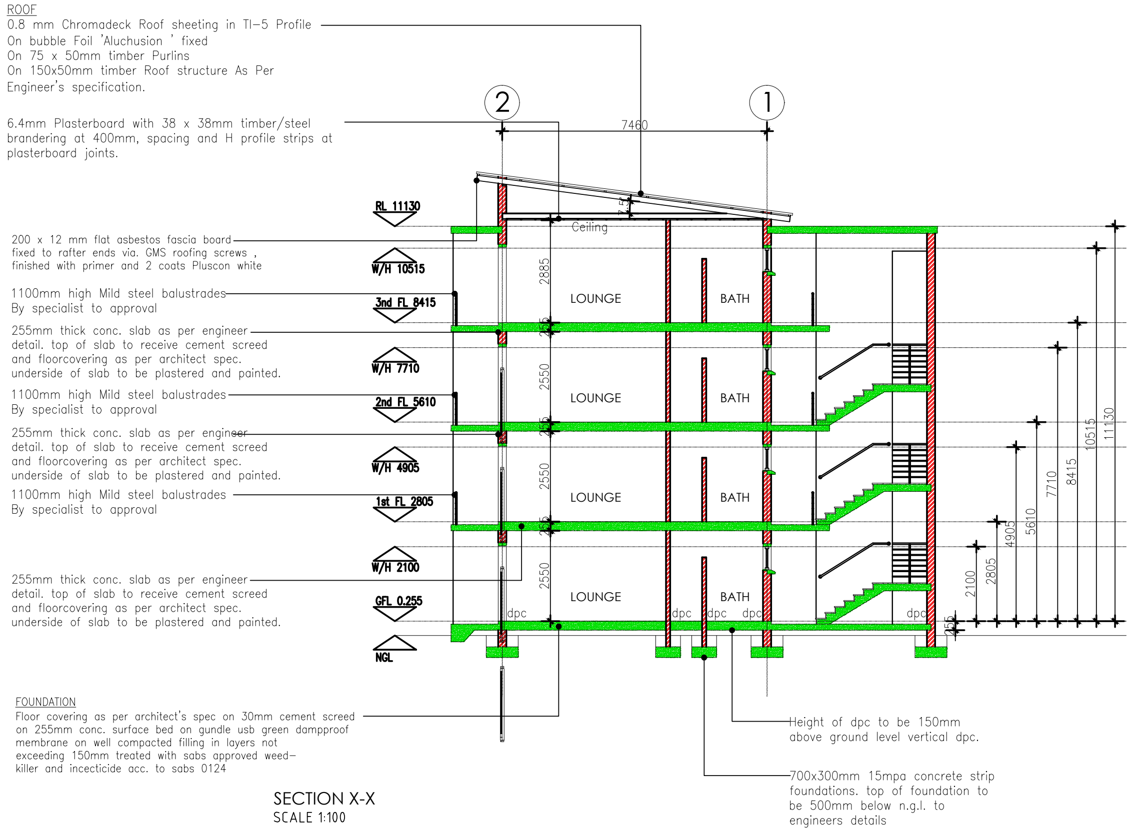


Fig. 58 Example project : Germiston Fire Station

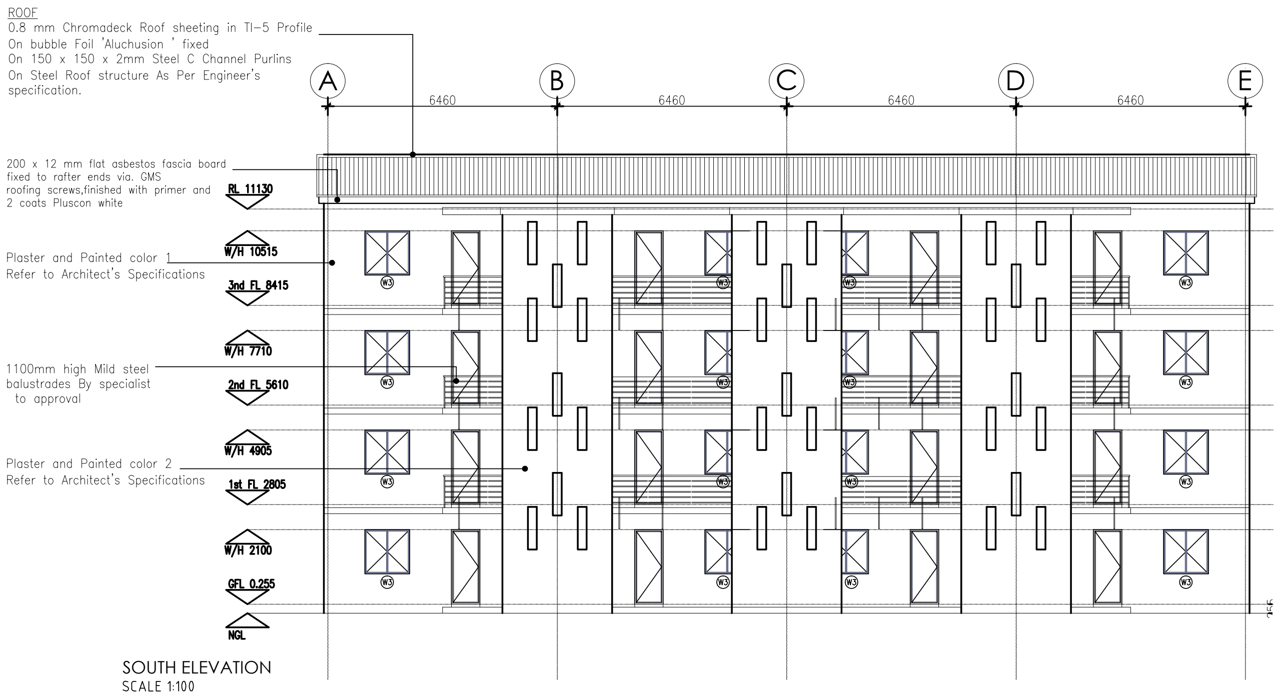


Fig. 59 Example project : Germiston Fire Station

Fig. 60 Construction of Germiston Fire Station
By:

As shown in the drawings, the roof consists of the following layers:
- 0.8 mm Chromadeck Roof sheeting in TI-5 Profile
- On bubble foil 'Aluchusion' fixed
- On 75 x 50 mm timber Purlins
- On 150 x 50 mm timber Roof structure

The floors are 255 mm thick concrete slabs. The top of the floor is covered with a 30 mm cement layer.

The foundation consitst of 700 x 300 mm concrete strips.

The outdoor walls are masonry and are plastered and painted afterwards.

The ground floor, the first floor and the second floor have a ceiling height of 2550 mm and the fourth floor has a ceiling height of 2885 mm.

Thembelihle Village

The social housing project Thembelihle Village is located at Schubart Street and Johannes Ramokhoase Street.

As written in chapter 2, the project consists of eleven 3 to 4 storey walk-up blocks and six tower blocks of 10 to 11 storeys. The ground floors facing the streets will cater for retail space and services.

There are 238 bachelor apartments, 140 1-bedroom apartments, 303 2-bedroom apartments and 52 3-bedroom apartments. In addition, there's 1300 m2 of commercial/ office space, 188 on-site parking ays and social amenities.

Hot water is used from heat pumps to reduce electricity costs for tenants. A smart metering system is used for municipal services.

As shown in Fig. 62 the structure of the buildings consists of concrete elements (floors, walls and columns).

All of the walls are masonry, where some parts of the facades are plastered and painted, as shown in Fig. 63. This has also been noticed during the visit to Pretoria.

The roofs are similar to the Germiston Fire Station project, with a timber roof structure and steel roof sheeting.

Just as the other social housing project in this report, there is only shading by some of the balconys. Dirk Conradie and Llewellyn van Wyk from CSIR concluded that more shading would definitely improve the current social housing.

Fig. 61 Construction Thembelihle Village

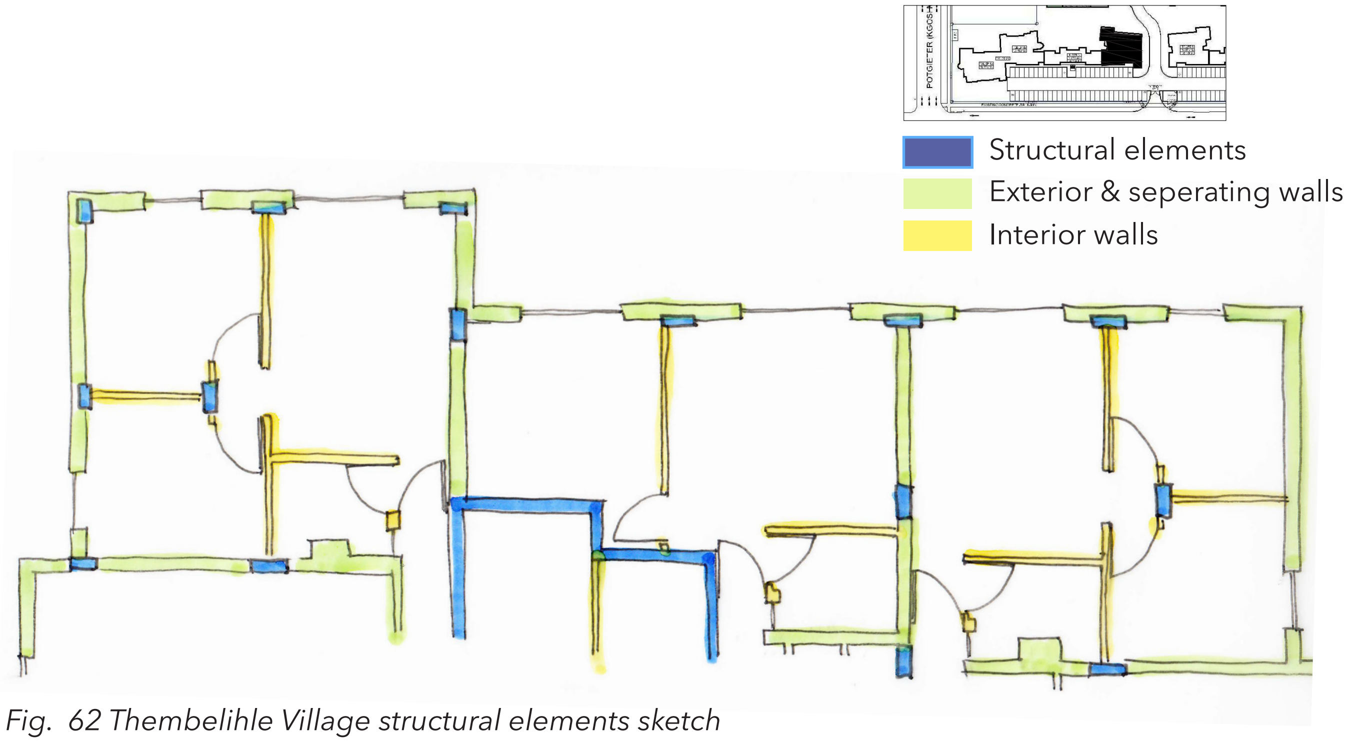


Fig. 62 Thembelihle Village structural elements sketch

Fig. 63 Thembelihle Village Facades

4.3 New concept and building method

Next to the current building methods, there are also some developments in housing for Africa. One of those developments is Butterfly Housing. This concept is designed by Robert van Kats and is completely different compared to the current building methods. This is also why it is interesting to include this project in this research.

Butterfly housing is a concept which is designed as a product. The product is a house based on a hybrid construction sytem with passive climate control. It consists of a steel structure/skeleton (columns and floors) with a finish of different infill materials such as earth blocks or insulated panels. The roof has a steel structure with steel sheeting.

The product is designed in a way that it's easy and fast to build. Depending on the location, local materials are used as much as possible.

The concept is designed as a singe house which can be easily adjusted in size because of the flexible modular building method. Because of this building method, Butterfly Housing also designed a multilevel version of this concept as shown in Fig. 65 and Fig. 66. The roof is designed in a way that it can easily catch water. Furthermore, there is a large balcony between the apartments.

Fig. 64 Butterfly housing concept Image: Butterfly housing BV

4.6 Summary

Thembelihle village and Germiston Fire station were used to analyse the current building methods in Gauteng.

Both of the buildings have concrete structures which consist of concrete floors, concrete columns and concrete walls. The walls are masonry and some parts are plastered and painted. Furthermore, the roofs are made of a timber structure with steel roof sheeting.

During the visit to Pretoria it was noticed that most of the buildings have masonry walls which are (partly) plastered and painted.

One of the new housing concepts for South Africa is Butterfly Housing. This concept is designed as a product which is completely different from the current building methods. The building/concept consists of a steel structure (columns, roof and floors) with a finish of different infill materials


Fig. 65 Butterfly housing apartment building Visual by: Butterfly Housing

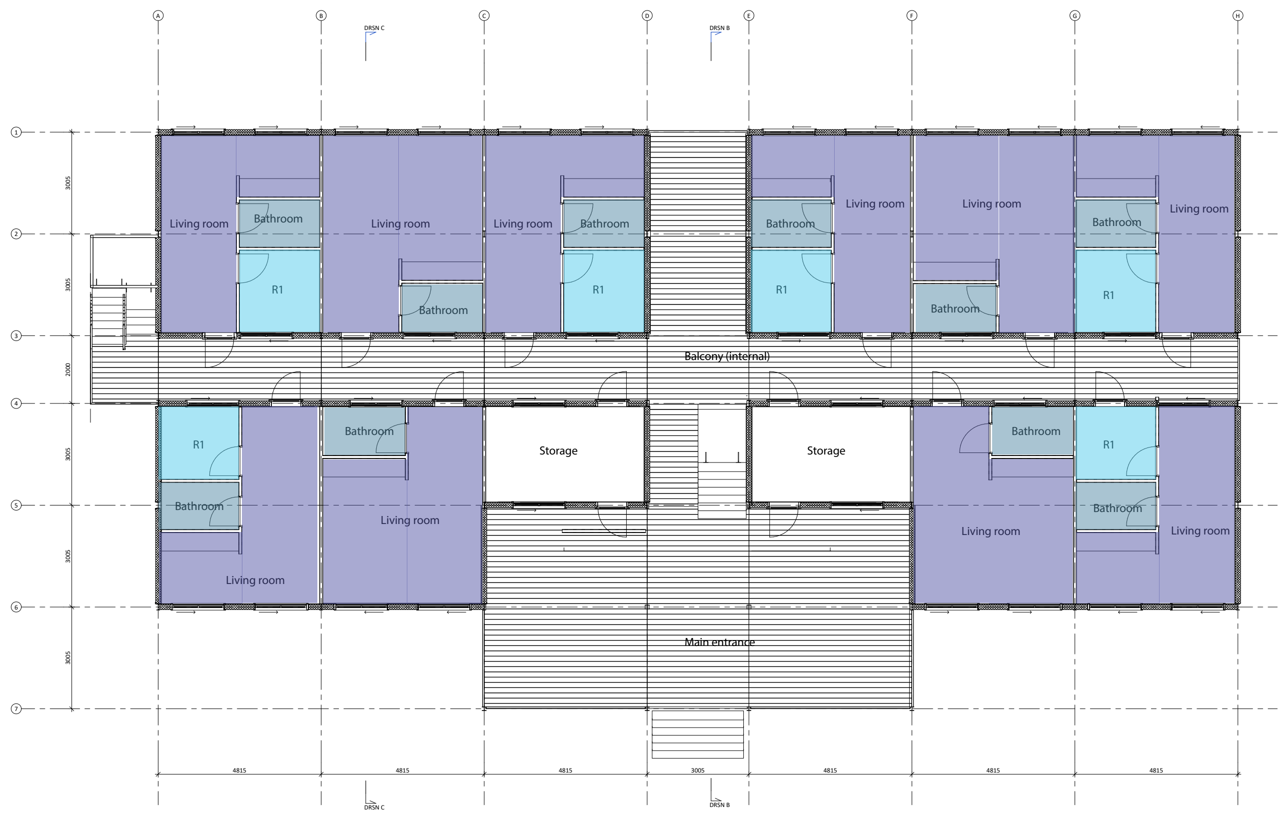


Fig. 66 Butterfly housing apartment building ground floor with rooms

Chapter V – Draft design

5.1 Introduction

In this chapter the first steps of the design process will be described. Furthermore, the first simulations of Butterfly Housing and Thembelihle Village will be shown.

The design goal is to design a solution with:
- more comfort
- less energy use
- costs are more or less the same as current design

The research questions that will be partly answered in this chapter are:

What are the solutions for climate change adaptation and mitigation for this location?

5.2 Reserach results & programme of requirements

In this paragraph the research results which are important for the design and the first programme of requirements will be presented. The requirements are divided in two categories: Context and Technology. The programme of requirements can be found on the following pages.

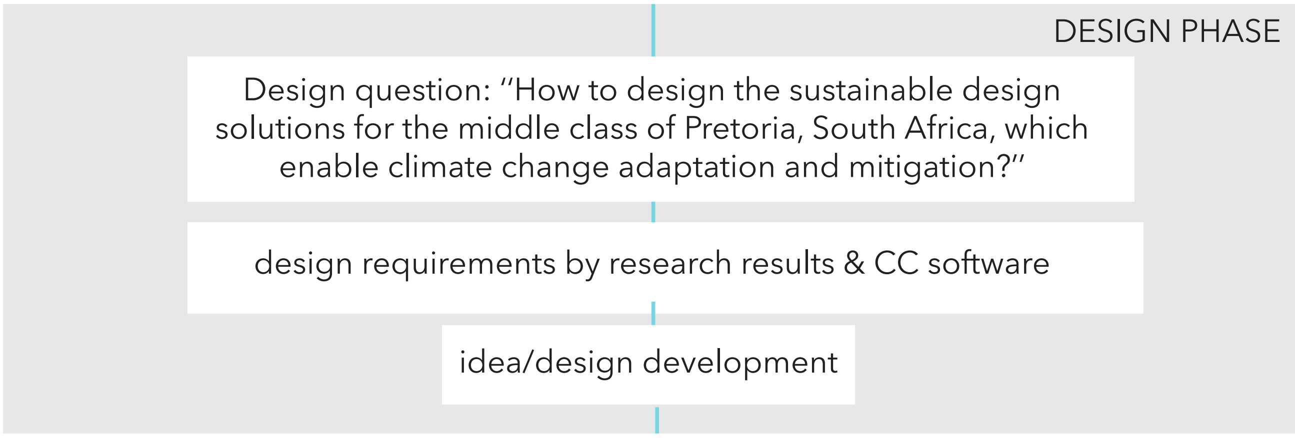


Fig. 67 Design phase from scheme graduation plan

CONTEXT

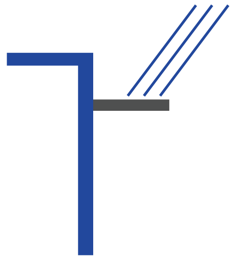
For both the vulnerable as the stable middle class, with an income range of R2200 - R7500

Take into account that building is located in the centre of Pretoria, South Africa

82,2 Of the households use electricity for cooking, 83,2% use electricity for heating water, 86,2% use electricity for lighting and 64,2% use electricity for space heating. Goal is to using less electricity (and overall less energy) by using passive design strategies

Pretoria is located in three climate zones, but from 2030 it will probably be located in only one climate zone: Bsh (arid steppe). The climate will be drier, with less rain and higher temperatures. For this reason more shading and catching rain water would be usefull.

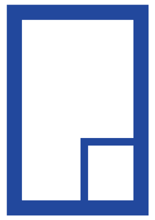
TECHNOLOGY



Current housing has not a lot of shading, more shading would probably improve the comfort and less energy would be needed to cool the apartments

Current housing has single glass windows, insulated glass (in combination with insulated walls) will probably keep the high temperatures outside

Current housing has masonry walls (one layer walls) with no insulation, insulation or high mass walls will keep the high temperatures outside



Take into account that the apartments types are studio's, 1-bedroom, 2-bedroom and 3-bedroom apartments

The construction costs should be the same or lower than current housing, also include possible improvements in energy use

5.3 Design strategies

During my visit to Pretoria I spoke with Dirk Conradie from CSIR. We spoke a lot about the climate in Pretoria and the value of the software Climate Consultant. Climate Consultant uses existing climate data as input and shows passive design strategies specifically for that climate.

By using the file with climate data from Dirk Conradie (CSIR) in Climate Consultant I found the passive design strategies for the climate in the centre of Pretoria.

In Fig. 68 the psychrometic chart with the results is shown. The psychrometic chart shows which building design strategies to use within a specific climate but also shows how effective each strategy will be. The temperature (bottom scale) and absolute humidity (right scale) are plotted for every hour of the year. All of the 13 different building design strategies are shown in the graph as different colored zones.

The list with the 13 design strategies also shows the percentage of hours that fall into each of these 13 zones. The best design strategies for this climate have the highest percentages. In Fig. 69 (on the next two pages) a table with the percentages per month are shown. In the colder months (June and July) no sun shading and more heating is needed. While it is the opposite in warmer months.

In Appendix I the use of Climate Consultant and de steps in Climate Consultant will be further described.

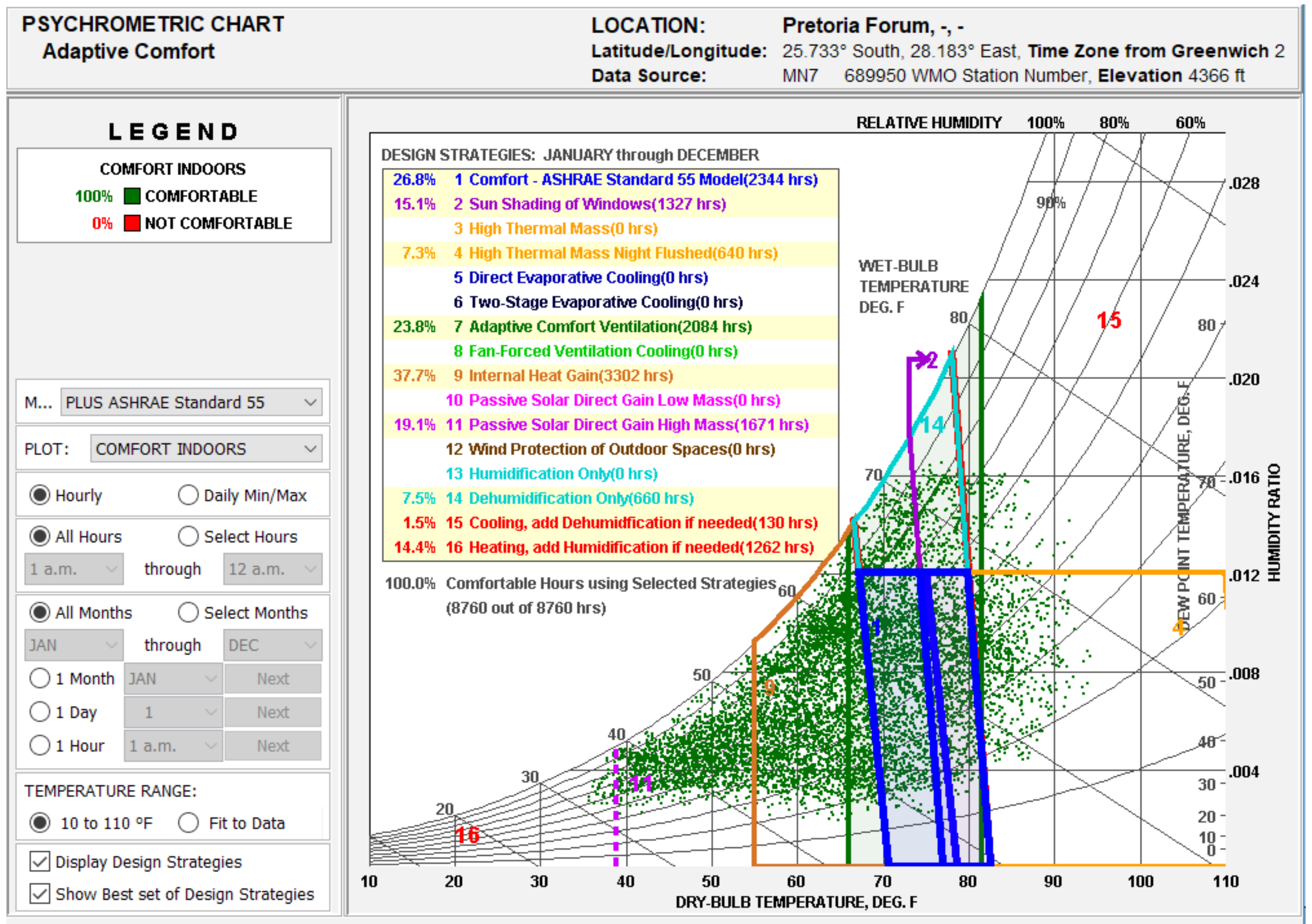


Fig. 68 Psychrometic chart from Climate Consultant file Pretoria Forum (File from Dirk Conradie (CSIR))

DESIGN STRATEGY	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	All months
relative humidity (avg monthly)	66	66	65	65	58	61	49	45	40	50	59	62	
1 Comfort – ASHRAE standard 55 model	30.8%	30.8%	39,7%	32.1%	14.1%	3.3%	6.2%	19.8%	32.5%	37.1%	36.3%	38.8%	26.8%
2 Sun shading of windows	27.3%	22.0%	20.4%	12.2%	3.2%			5.0%	16.0%	23.7%	24.2%	28.2%	15.1%
3 High thermal mass					0.4%			1.1%	7.5%				
4 High thermal mass night	12.1%	13.4%	9.3%	3.5%							11.4%	12.5%	7.3%
5 Direct evaporative cooling													
6 Two-stage evaporative cooling										17.2%			
7 Adaptive comfort ventilation	32.9%	33.6%	31.7%	21.8%	14.7%	9.9%	10.5%	19.0%	22.5%	25.9%	28.9%	34.7%	23.8%
8 Fan-forced ventilation													
9 Internal heat gain	28.4%	29.8%	34.5%	54.2%	44.4%	40.7%	34.9%	43.7%	44.2%	37.1%	34.9%	25.8%	37.7%
10 Passive solar direct gain low mass													
11 Passive solar direct gain high mass	14.5%	15.9%	19.6%	20.3%	19.9%	13.5%	15.2%	27.3%	25.6%	20.3%	18.9%	17.7%	19.1%
12 Wind protection of outdoor spaces													
13 Humidification only													
14 Dehumidification only	21.0%	22.5%	14.0%							6.0%	11.0%	16.8%	7.5%
15 Cooling, add dehumidification if needed	6.2%	3.4%	1.1%							0.3%	2.9%	3.8%	1.5%
16 Heating, add humidification if needed			0.7%	9.0%	30.9%	45.7%	47.8%	24.1%	10.7%	0.9%	1.9%		14.4%

Fig. 69 Table with data per month from Psychrometic charts in Climate Consultant

Assuming only the Design Strategies that were selected on the Psychrometic chart, 100% of the hours will be comfortable. Climate consultant created a list of Residential Design guidelines which applies specifically to this particular climate. The most important ones are the first on the list.

#62: Traditional passive homes in temperate climates used light weight construction with slab on grade and operable walls and shaded outdoor spaces

#58: This is one of the more comfortable climates, so shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter

#35: Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes

#33: Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates

#56: Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems

#11: Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well insulated (to lower Balance Point temperature)

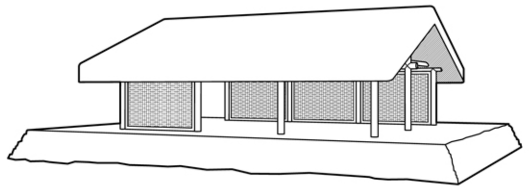


Fig. 70 #62 (Image by ClimateConsultant)

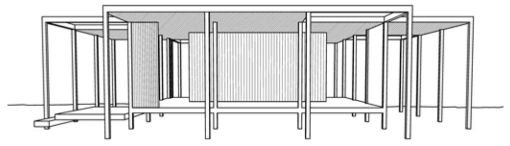


Fig. 71 #58 (Image by ClimateConsultant)

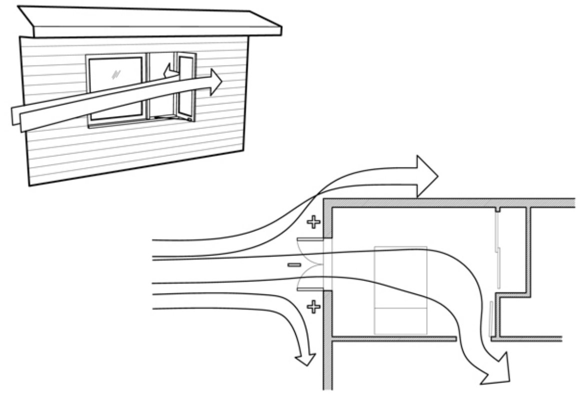


Fig. 72 #35 (Image by ClimateConsultant)

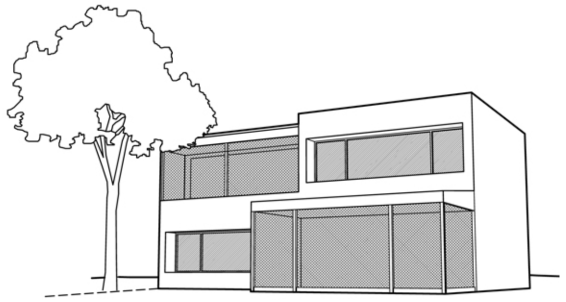


Fig. 73 #56 (Image by ClimateConsultant)

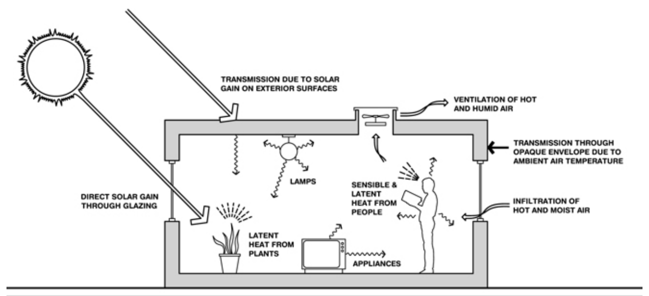


Fig. 74 #11 (Image by ClimateConsultant)

#55: Low pitched roofs with wide overhangs works well in temperate climates

#19: For passive solar heating face most of the glass area north to maximize winter sun exposure, but design overhangs to fully shade in summer

#36: To facilitate cross ventilation, locate door and window openings on opposite sides of building with larger openings facing up-wind if possible

#20: Provide double pane high performance glazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain

#34: To capture natural ventilation, wind direction can be changed up to 45 degrees toward the building by exterior wingwalls and planting

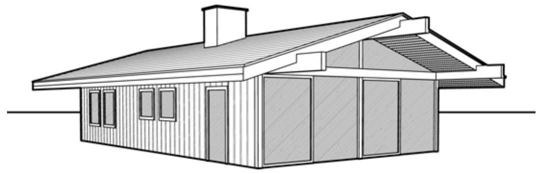


Fig. 75 #55 (Image by ClimateConsultant)

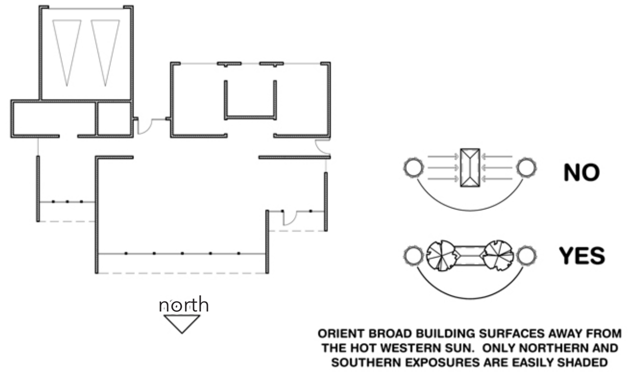


Fig. 76 #19 (Image by ClimateConsultant)

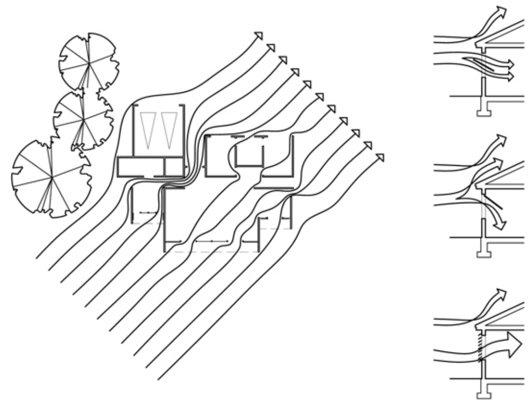


Fig. 77 #36 (Image by ClimateConsultant)

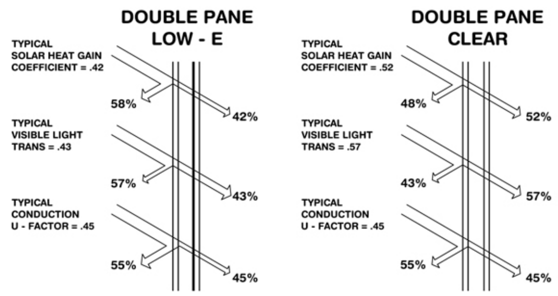


Fig. 78 #20 (Image by ClimateConsultant)

#3: Lower the indoor comfort temperature at night to reduce heating energy consumption (lower thermostat heating setback)

#42: On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8 degrees Celsius) or more, thus less air conditioning is needed

#39: A whole-house fan or natural ventilation can store nighttime 'coolth' in high mass interior surfaces (night flushing), to reduce or eliminate air conditioning

#37: Window overhangs (designed for this lattitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning

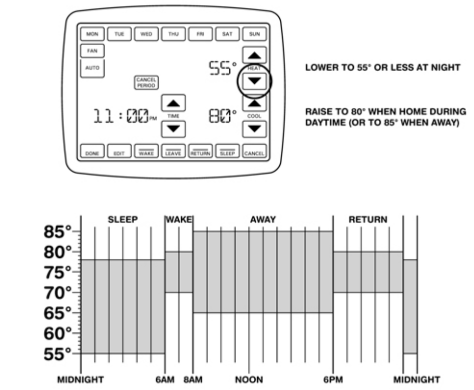


Fig. 79 #3 (Image by ClimateConsultant)

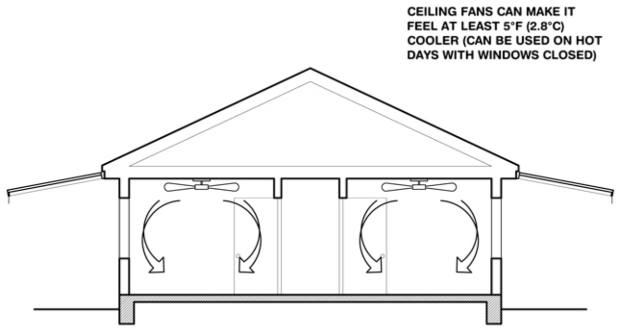


Fig. 80 #42 (Image by ClimateConsultant)

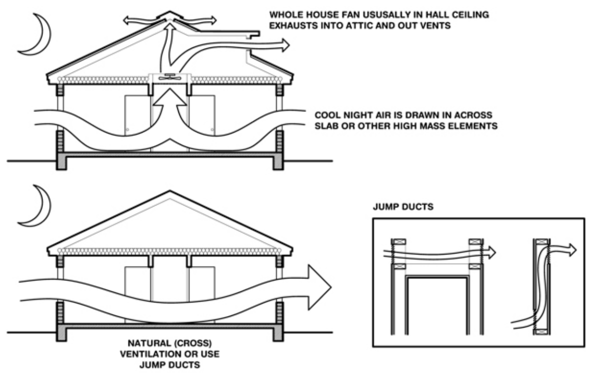


Fig. 81 #39 (Image by ClimateConsultant)

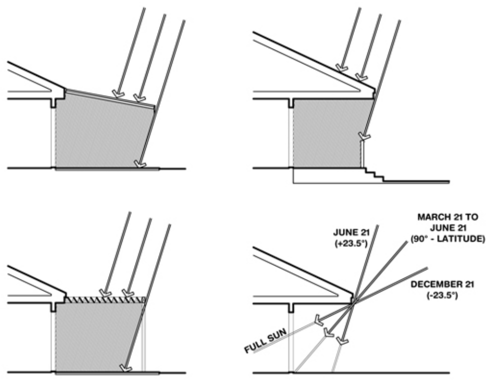


Fig. 82 #37 (Image by ClimateConsultant)

#31: Organize floorplan so winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation

#49: To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and outlet (open stairwells, two story spaces, ..)

#53: Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes can extend living and working areas in warm or humid weather

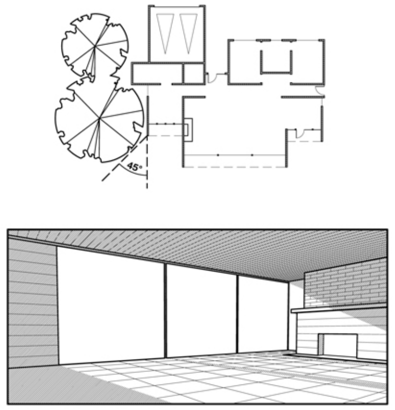


Fig. 83 #31 (Image by ClimateConsultant)

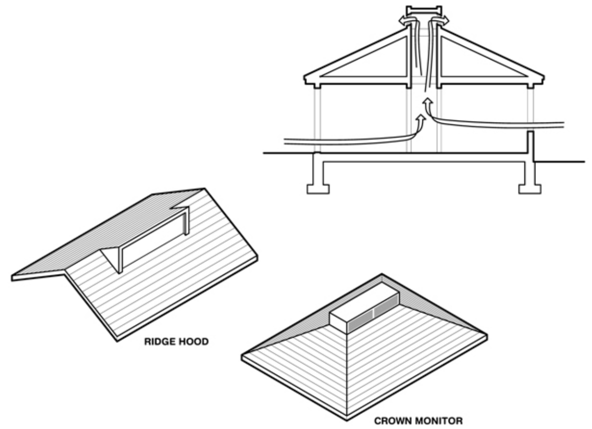


Fig. 84 #49 (Image by ClimateConsultant)

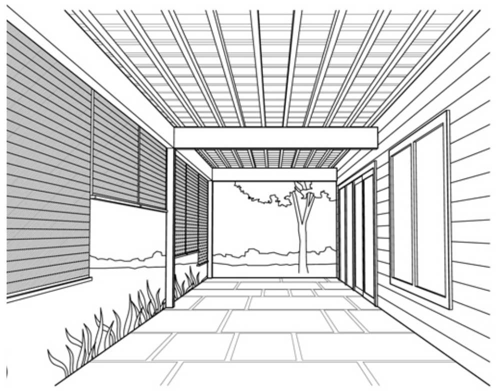


Fig. 85 #53 (Image by ClimateConsultant)

#24: Use high mass interior surfaces like slab floors, high mass walls, and a stone fireplace to store winter passive heat and summer night 'coolth'

#47: Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.

On the next page the design strategies are categorized in four categories: design, materials, behaviour & plot. These four different categories were used to organize all of the design strategies and make it easier to use in the design process.

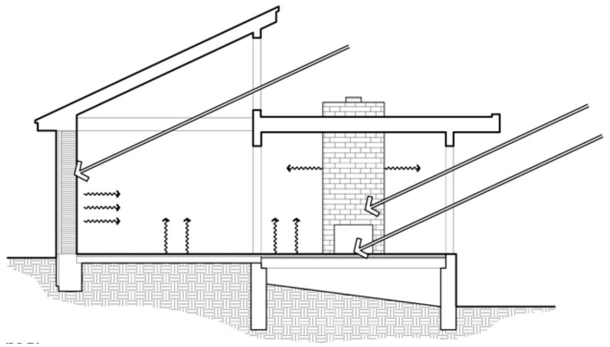


Fig. 86 #37 (Image by ClimateConsultant)

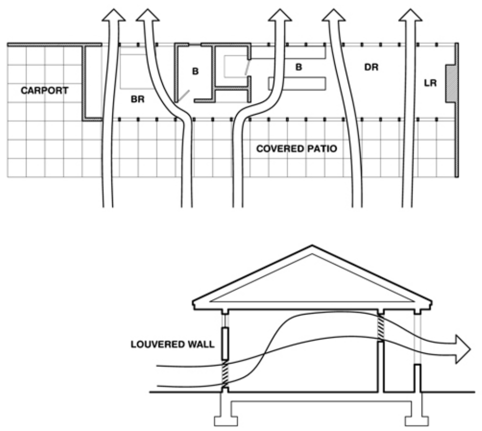
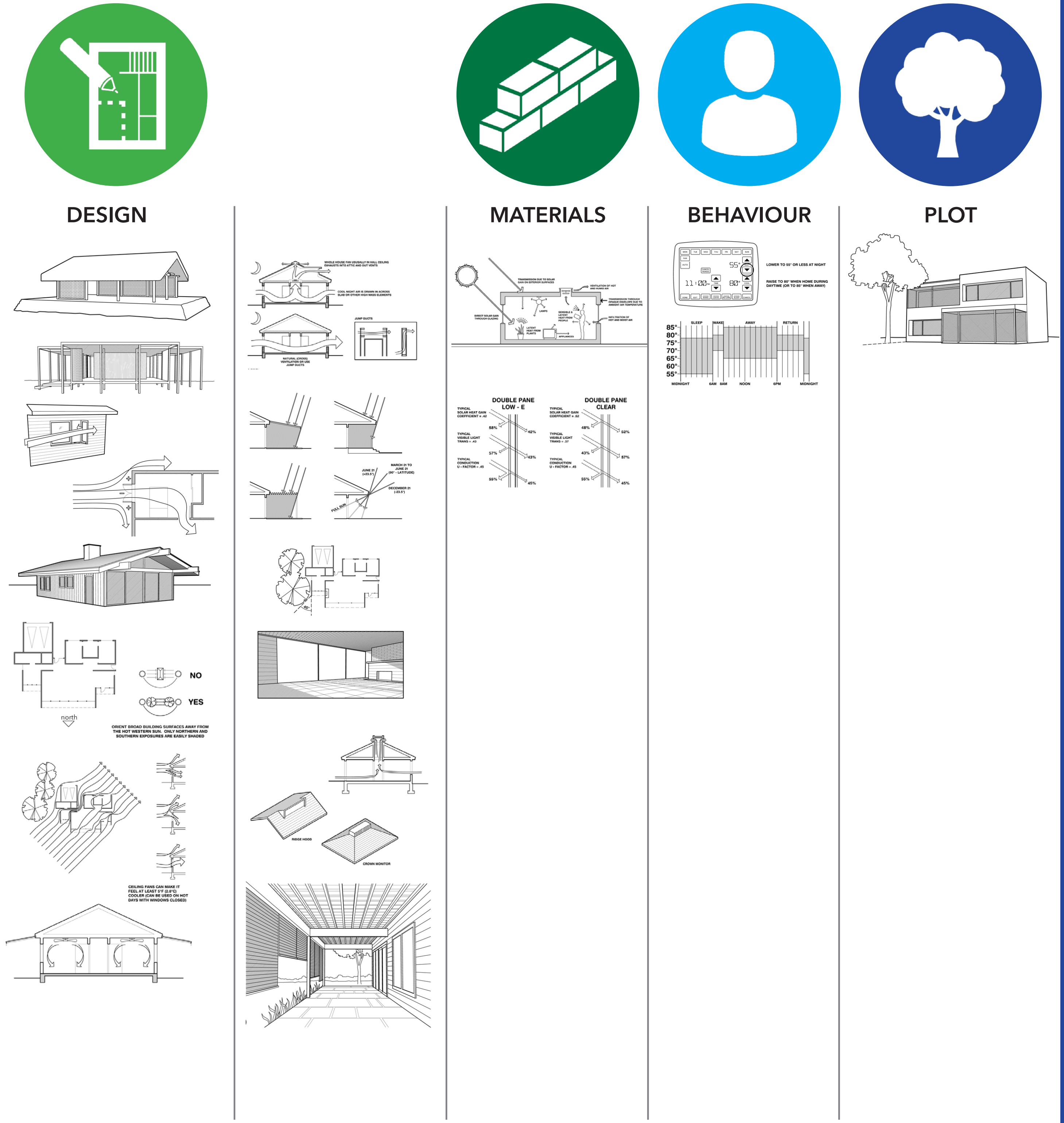


Fig. 87 #24 (Image by ClimateConsultant)



5.4 Design requirements

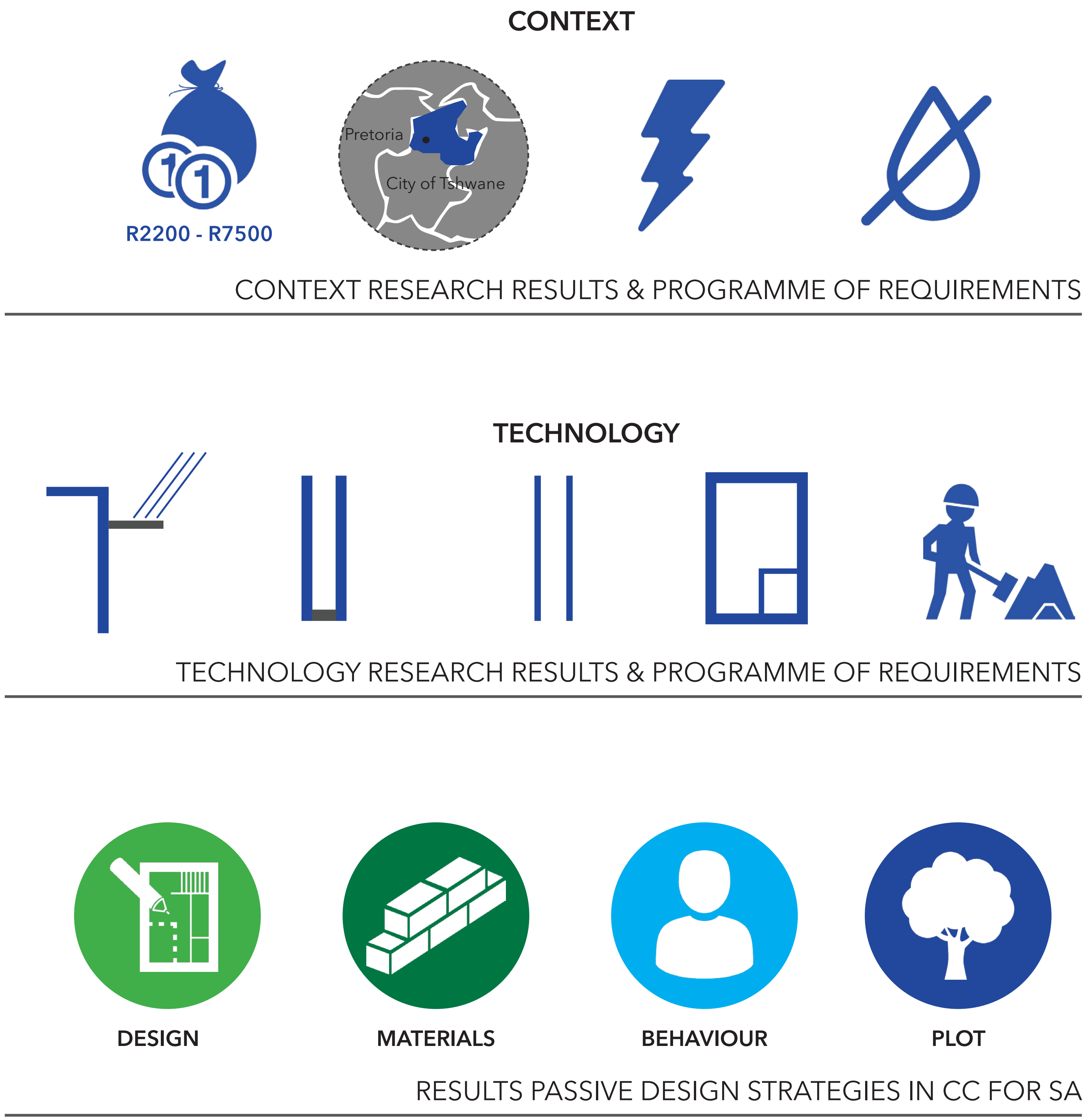
The design requirements are formed by combining the programme of requirements (research results) with the passive design strategies for South Africa (Climate Consultant).

The difference is that first part of the programme of requirements: ''context'' are relevant for all the solutions. The design strategies are a list of passive design strategies that can be used in the design. Some could work in one building, but aren't working in an other building.

In VABI elements, a software which simulates the comfort in a room or building, the design strategies will be tested on Thembelihle Village and the concept of Butterfly Housing. VABI is used for this research because this software combines the climate data, materials and building design with comfort temperature. First the current buildings of Thembelihle Village and Butterfly Housing will be simulated.

Some of the design strategies can be combined and some would work better on their own. This will be explained in the next paragraph.

On the following pages the use of VABI elements will be further explained.



simulate current situation in:
vabi elements

results: what could be improved?

choose design strategies based on what could be improved

simulate new design in:
vabi elements

is the result an improvement and it is expected that it cannot be further improved

yes / no

extra validation on: expected energy use, costs & climate consultant result (progr. req.)

outcome is an improvement according to programme of requirements

yes / no

final design
Thembelihle Village

simulate current situation in:
vabi elements

results: what could be improved?

choose design strategies based on what could be improved

simulate new design in:
vabi elements

is the result an improvement and it is expected that it cannot be further improved

yes / no

extra validation on: expected energy use, costs & climate consultant result (progr. req.)

outcome is an improvement according to programme of requirements

yes / no

final design
Butterfly Housing

The first simulations were setup by applying some of the design requirements. Not all of the requirements could be simulated because some of them are too general (some of the requirements about ''context'') and it was chosen to not change te building and apartments too much to keep it realistic (the goal is to look for improvements and not to design a totally different building).

A selection of the design requirements was made to see how and if these changes would improve the comfort. The first simulation will be a basic simulation of Butterfly Housing and Thembelihle with the current situation. By doing this, it is possible to see if the other simulations improve the comfort by comparing the simulations with the basic version. This means that there will be a basic simulation for both of the buildings. The changes will also be simulated for both of the buildings. The combinations were advised by climate consultant.

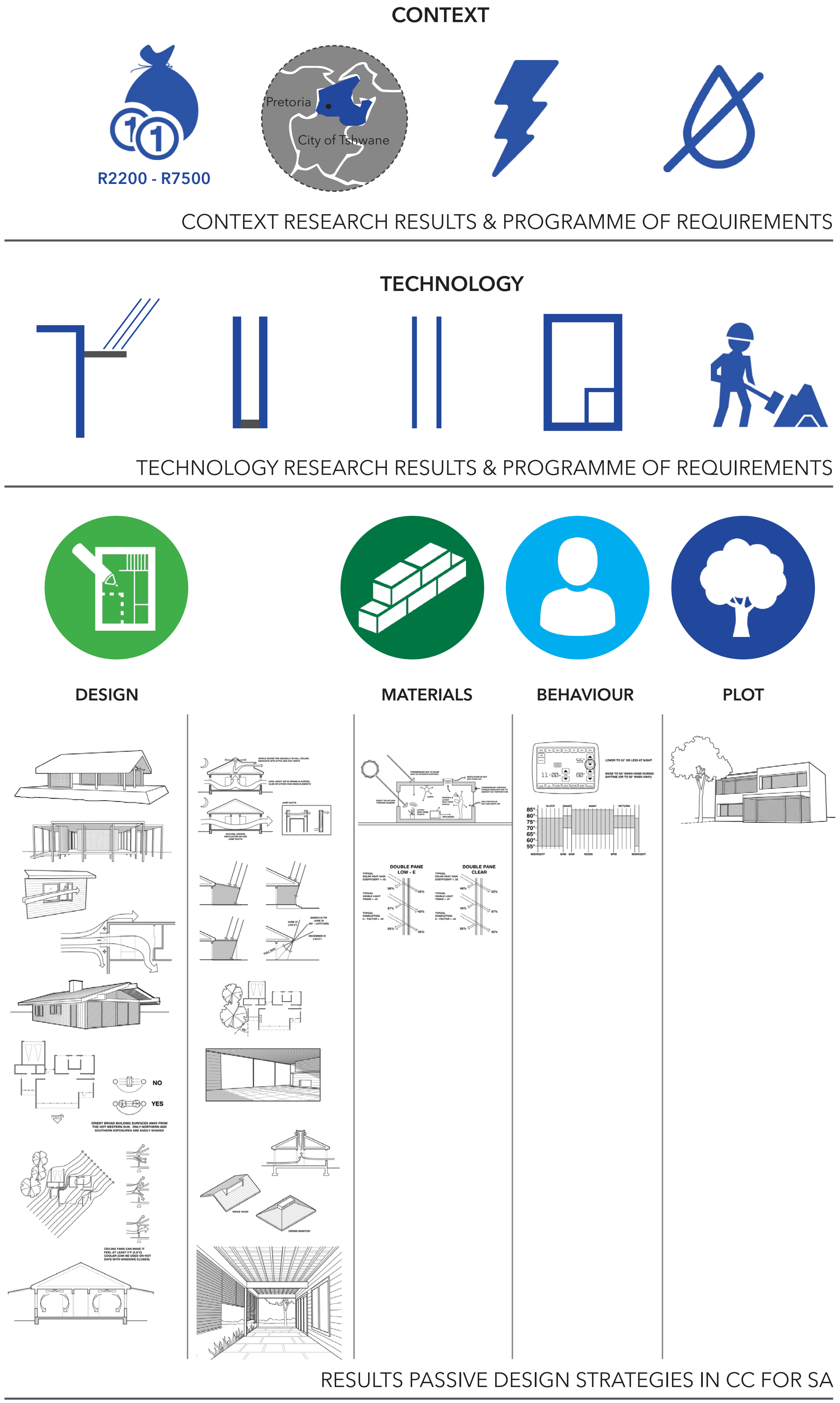
The second simulation includes:
- a lightweight construction
- overhang by the roof
- operable walls

The third simulation includes:
- shading above the windows
- open windows to breeze
- use of passive solar gain in winter
(glass on north facade)

The fourth simulation includes:
- insulated walls and roofs

The fifth simulation includes:
- singe glass windows and doors changed to e glass

In Appendix - II the different steps in VABI elements will be described, together with all of the results. In the next two paragraphs the most important results will be shown and described.



5.5 Results simulations Thembelihle Village

The first simulation of Thembelihle Village was the basic simulation. This simulation shows the current situation and is used to compare with the other simulations.

Interesting was that results of living room 5 and the results of living room 8 are very close. The expectation was that living room 8 would have less "cold" hours, because it was north oriented. However, only a small part of the living room was at the north facade, because the bathroom is also on the north facade.

Furthermore, it was interesting to see that there are a lot of hours were it is "too cold" during the year. This can be explained by the internal heat gain and the walls which are not insulated. The internal heat gain is quite low because only one or two people are living in this apartment (studio apartment).

Because of the low insulation value and low internal heat gain, the comfort temperature is following the outside temperature, which is shown in Fig. 90. This is also the case when it's cold outside, which is also why there are a lot of "cold" hours shown in Fig. 92 and Fig. 93.

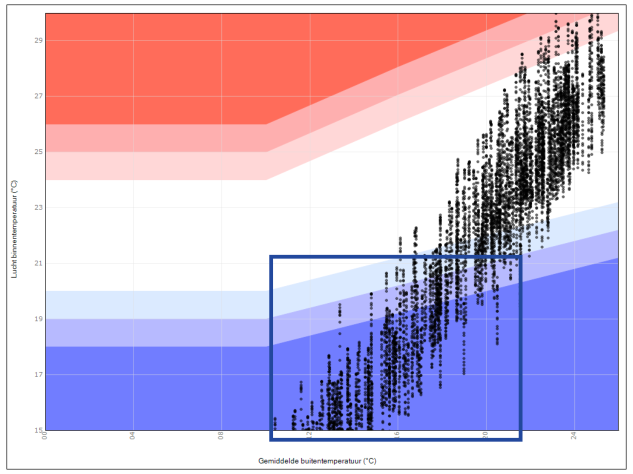


Fig. 88 Basic Thembelihle living room 5 results

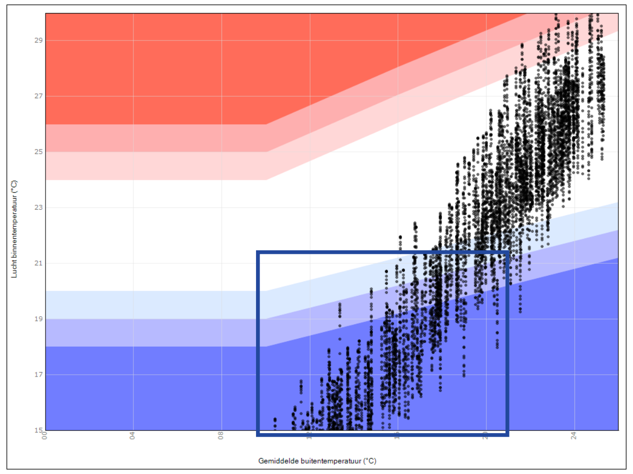


Fig. 89 Basic Thembelihle living room 8 results

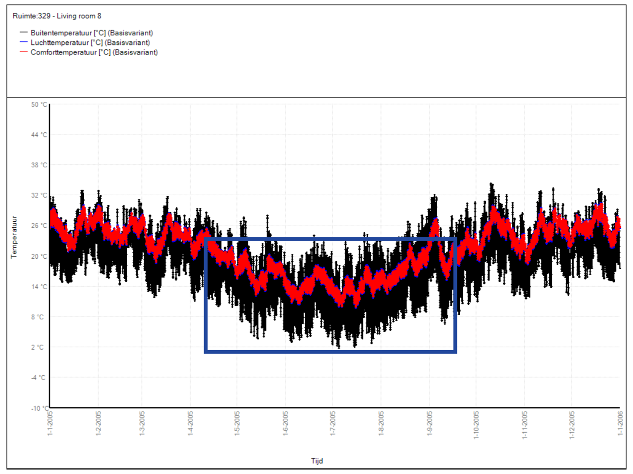


Fig. 90 Basic Thembelihle living room 8 graph

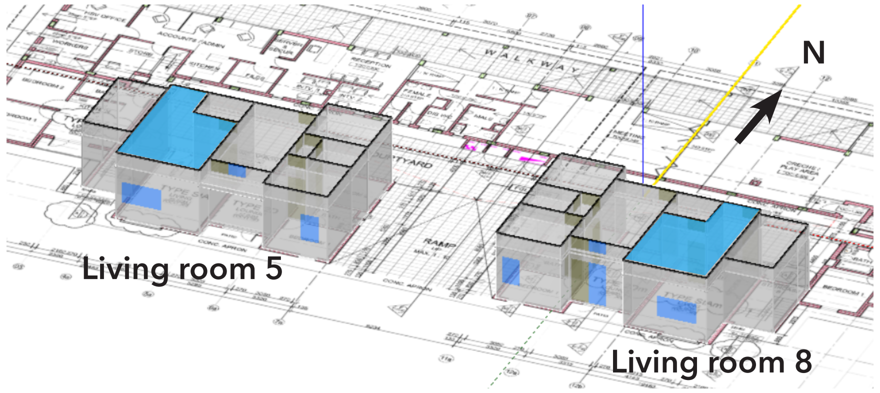


Fig. 91 Basic Thembelihle geometry with the chosen living rooms

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4217	154	4371	50,88
Klasse C	3576	9	3585	41,73
Klasse D	3075	0	3075	35,79

Fig. 92 Basic Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4212	173	4385	51,04
Klasse C	3575	23	3598	41,88
Klasse D	3060	0	3060	35,62

Fig. 93 Basic Thembelihle living room 8 results table

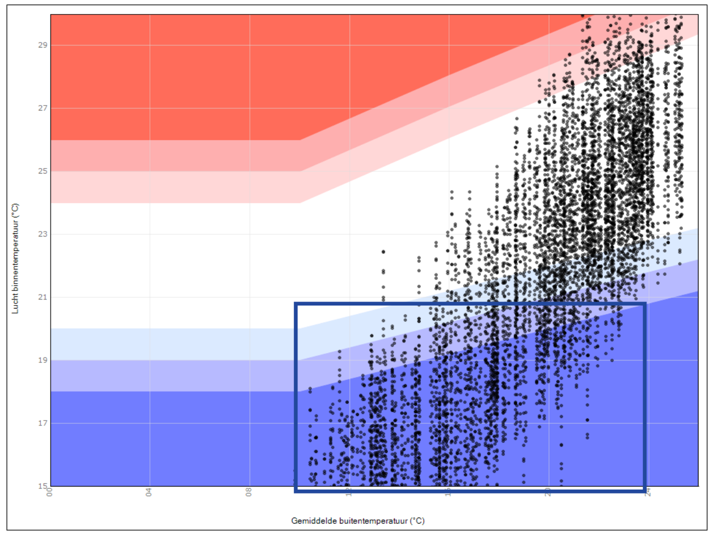


Fig. 94 Second simulation Thembelihle living room 5

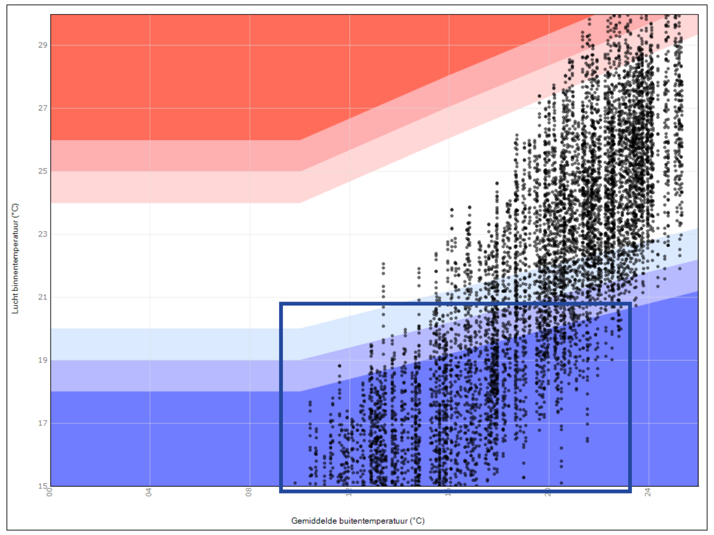


Fig. 95 Second simulation Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4703	325	5028	58,53
Klasse C	3983	119	4102	47,75
Klasse D	3346	41	3387	39,42

Fig. 96 Second simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4672	294	4966	57,80
Klasse C	3949	109	4058	47,24
Klasse D	3339	22	3361	39,12

Fig. 97 Second simulation Thembelihle living room 8 results table

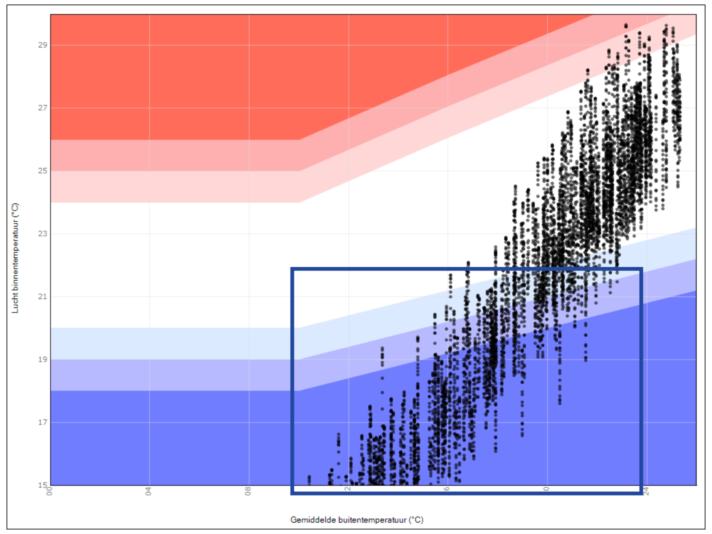


Fig. 98 Third simulation Thembelihle living room 5

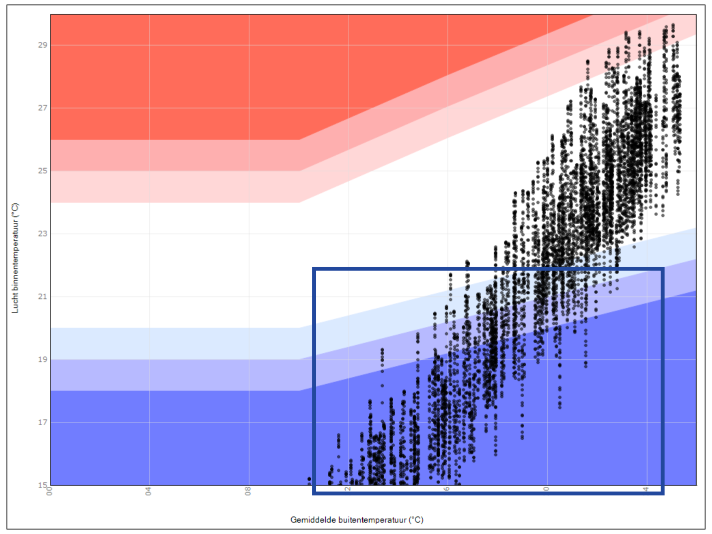


Fig. 99 Third simulation Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4405	86	4536	52,80
Klasse C	3768	4	3772	43,91
Klasse D	3213	0	3213	37,40

Fig. 100 Third simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4472	100	4572	53,22
Klasse C	3773	0	3773	43,92
Klasse D	3230	0	3230	37,60

Fig. 101 Third simulation Thembelihle living room 8 results table

The second simulation was about the operable walls, overhang by the roof and a lightweight construction. Expected was that it would be even cooler because of the overhang and that the comfort temperature would follow the outside temperature because of the operable walls.

In the comfort graphs in Fig. 94 and Fig. 95 it is shown that the points are a lot more spread out compared to the basic simulation. This can be explained by the operable walls, because the comfort temperature is a lot closer to the outside temperature which is also shown in Fig. 102.

In the next simulation overhangs above the windows are added and extra glass on the north facade is added to use passive solar gain in winter. The geometry is shown in Fig. 103.

The expectation was that the extra glass on the north facade would have impact but not too much because of the floorplan design (the bathroom is still on the north facade). The shading works very well, in living room 8 there are 0 hours of a temperature which is "too warm".

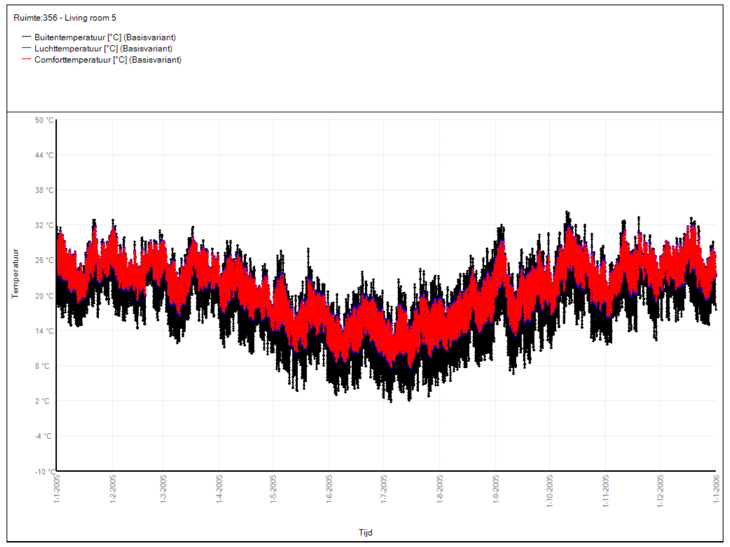


Fig. 102 Second simulation Thembelihle living room 5 graph year

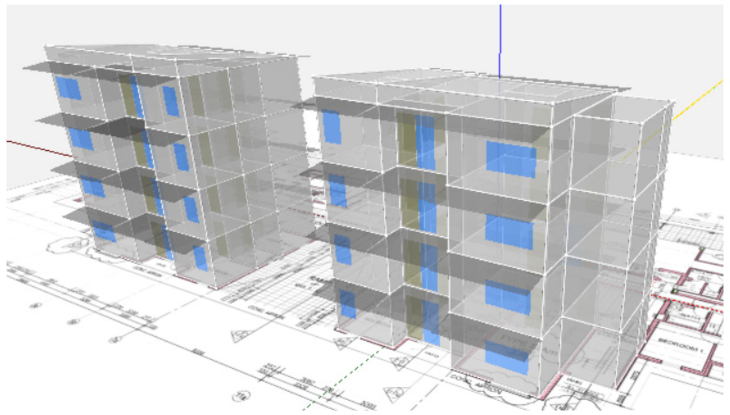


Fig. 103 Third simulation Thembelihle geometry

In the fourth simulation the walls and the roof are insulated. The expectation was that the comfort temperature would be a little bit more stable, because of the insulation layer.

As shown in Fig. 104 and Fig. 105 the points are less spread which means that the temperature is more stable. However, it is still too cold. With the future climate it is expected that the temperatures will be higher, so that should be taken into account. Still the expectation is that it is still too cold if we look at the amount of hours in Fig. 106 and Fig. 107.

In the fifth simulation the single glass windows are replaced by e glass windows. Because only the windows are insulated, the result is less positive as the previous simulation. The points in the comfort graph are more spread and the amount of "cold" hours inreased.

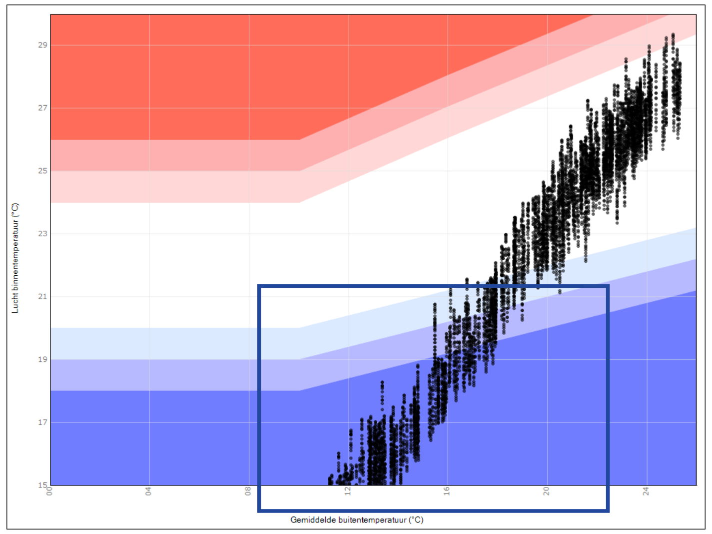


Fig. 104 Fourth simulation Thembelihle living room 5

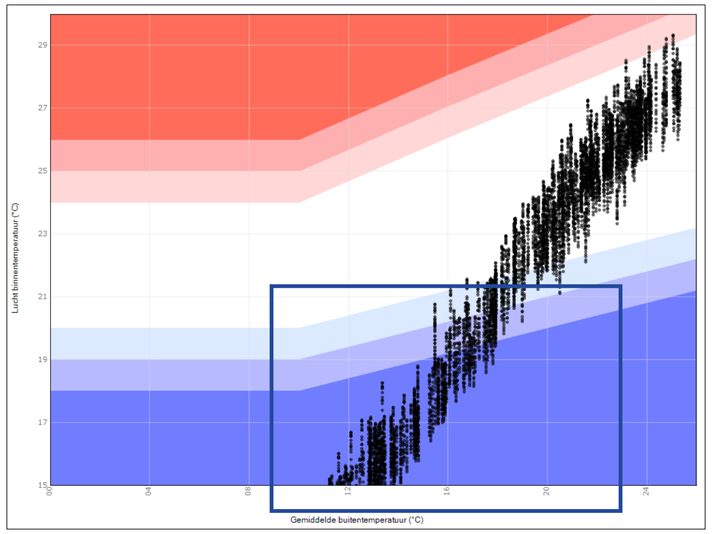


Fig. 105 Fourth simulation Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3656	17	3673	42,75
Klasse C	3149	0	3149	36,65
Klasse D	2704	0	2704	31,47

Fig. 106 Fourth simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3672	15	3687	42,92
Klasse C	3158	0	3158	36,76
Klasse D	2709	0	2709	31,53

Fig. 107 Fourth simulation Thembelihle living room 8 results table

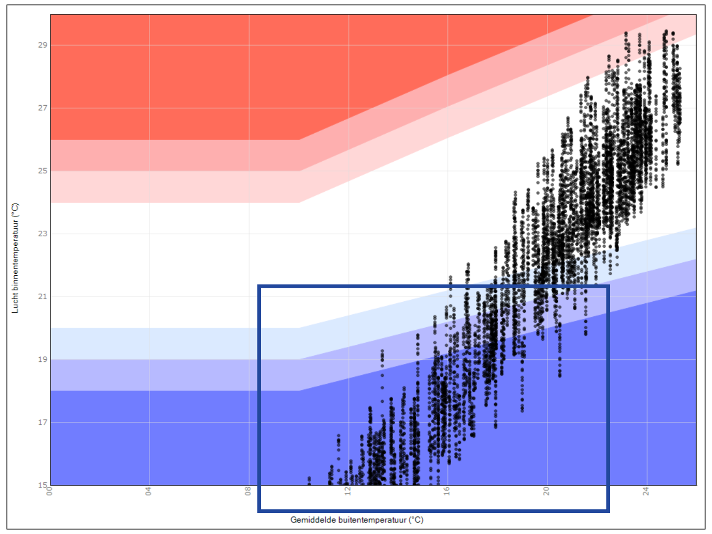


Fig. 108 Fifth simulation Thembelihle living room 5

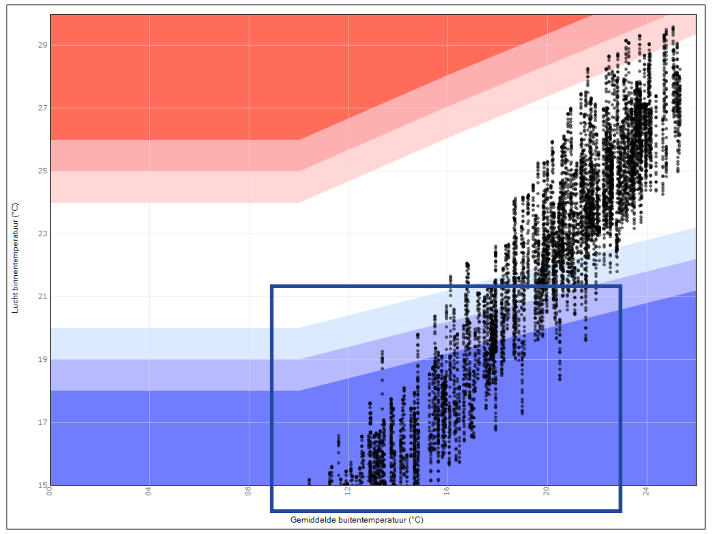


Fig. 109 Fifth simulation Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4310	67	4377	50,95
Klasse C	3616	0	3616	42,09
Klasse D	3089	0	3089	35,96

Fig. 110 Fifth simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4318	82	4400	51,22
Klasse C	3620	0	3620	42,14
Klasse D	3075	0	3075	35,79

Fig. 111 Fifth simulation Thembelihle living room 8 results table

5.6 Results simulations Butterfly Housing

The first simulation of Butterfly Housing was the basic simulation. This simulation shows the current situation and is used to compare with the other simulations.

It was really interesting to see the differences between living room 6 and living room 10. Compared to Thembelihle Village, there is a lot of difference between the two. This can be explained by the larger difference in orientation. Furthermore, has living room 10 the total north facade which has a lot of influence on the "cold" hours as shown in the table in Fig. 118.

The second simulation was about the operable walls, overhang by the roof and a lightweight construction. Expected was that it would be even cooler because of the overhang and that the comfort temperature would follow the outside temperature because of the operable walls, just as the simulations of Thembelihle. In Fig. 119 and Fig. 120 it is visible that the expectations were correct. The differences are smaller compared to the previous simulation, which can be explained by the operable walls.

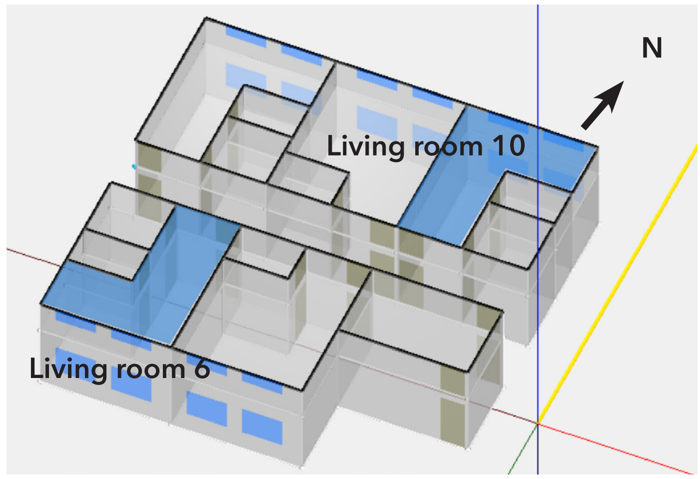


Fig. 112 Geometry Butterfly Housing with chosen living rooms

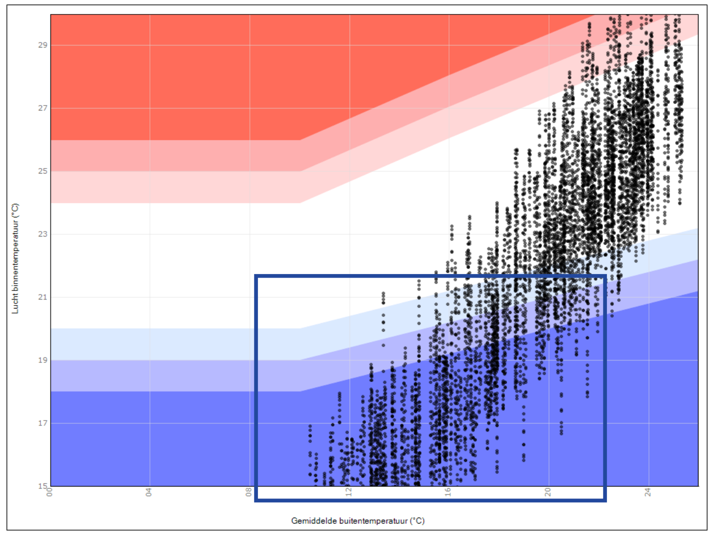


Fig. 113 Second simulation Butterfly living room 6 results

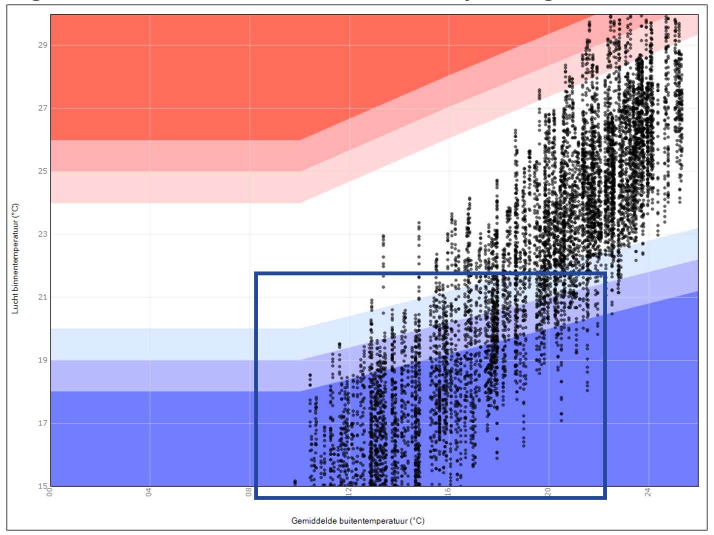


Fig. 114 Second simulation Butterfly living room 10 results

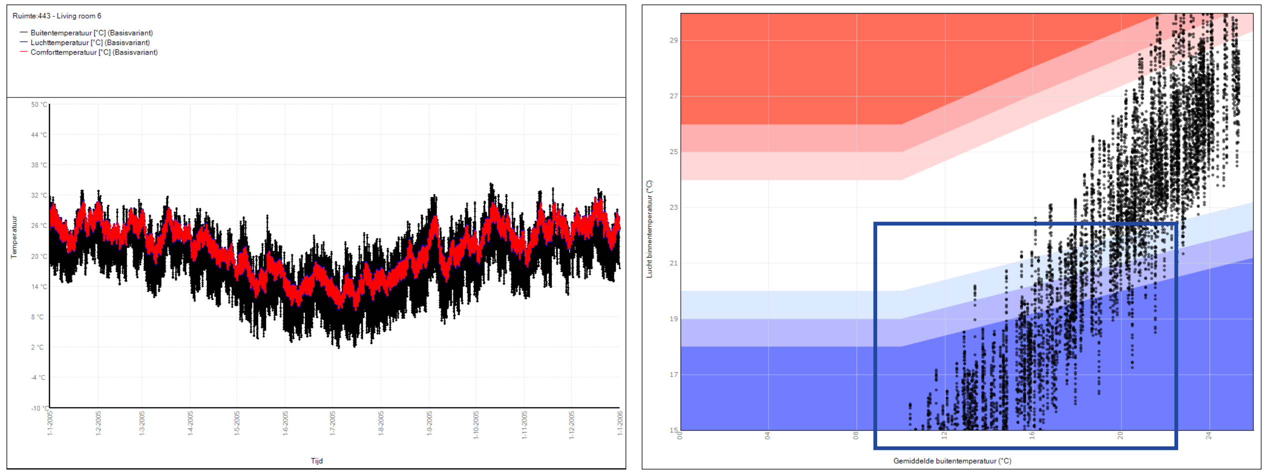


Fig. 115 Basic Butterfly living room 6 results

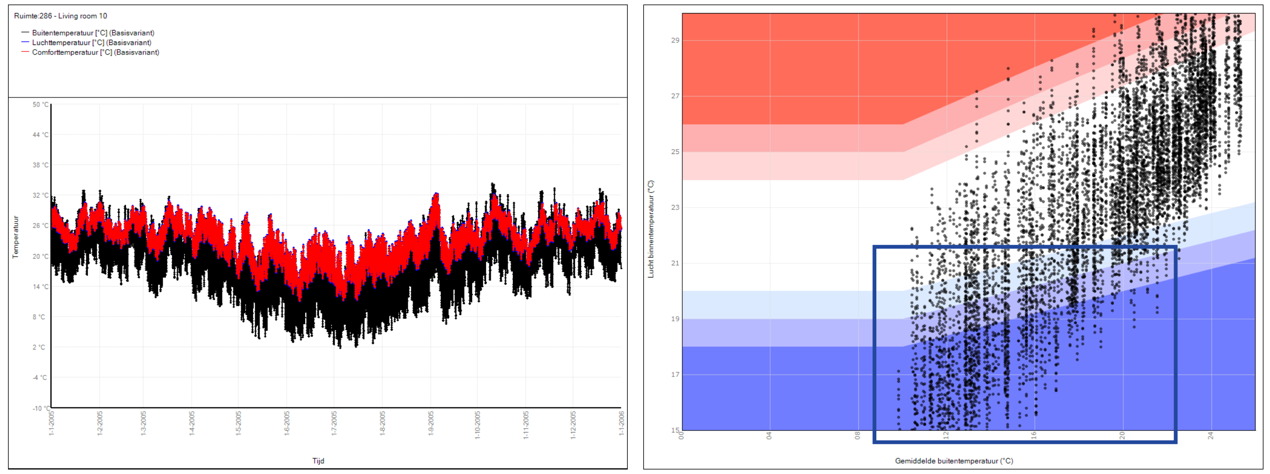


Fig. 116 Basic Butterfly living room 10 results

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4115	347	4462	51,94
Klasse C	3524	120	3644	42,42
Klasse D	3066	9	3075	35,79

Fig. 117 Basic Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	2688	664	3352	39,02
Klasse C	1991	274	2265	26,36
Klasse D	1433	76	1509	17,56

Fig. 118 Basic Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4300	260	4560	53,08
Klasse C	3668	99	3767	43,85
Klasse D	3138	13	3151	36,68

Fig. 119 Second simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4028	289	4317	50,25
Klasse C	3336	82	3418	39,79
Klasse D	2651	5	2656	30,92

Fig. 120 Second simulation Butterfly living room 10 results table

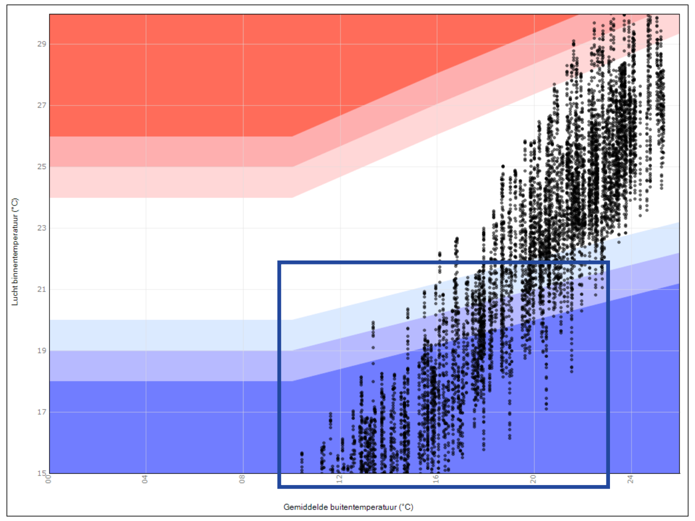


Fig. 121 Third simulation Butterfly living room 6 results

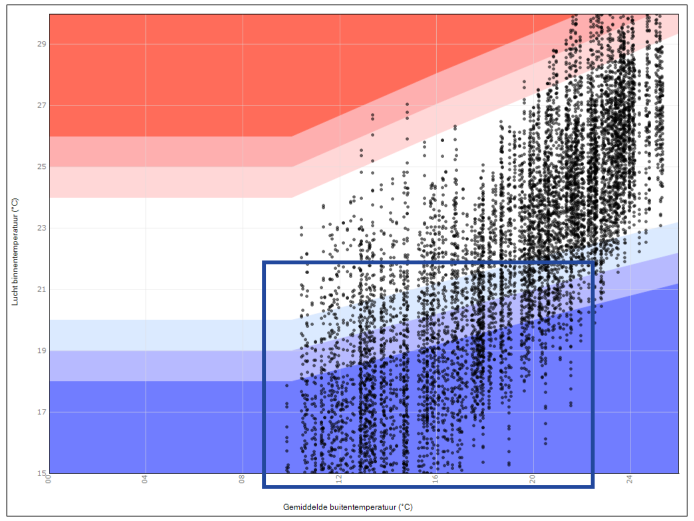


Fig. 122 Third simulation Butterfly living room 10 results

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4362	207	4569	53,18
Klasse C	3695	36	3731	43,43
Klasse D	3175	0	3175	36,96

Fig. 123 Third simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3798	386	4184	48,70
Klasse C	2947	153	3100	36,08
Klasse D	2258	23	2281	26,55

Fig. 124 Third simulation Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3584	210	3794	44,16
Klasse C	3141	20	3161	36,79
Klasse D	2721	0	2721	31,67

Fig. 125 Fourth simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1662	458	2120	24,68
Klasse C	1054	71	1125	13,10
Klasse D	572	14	586	6,82

Fig. 126 Fourth simulation Butterfly living room 10 results table

In the next simulation overhangs above the windows are added and extra glass on the north facade is added to use passive solar gain in winter. The geometry is shown in Fig. 127.

The expectation was that the glass on the north facade would have a lot of impact because it is completely located at the living room.

As expected the glass on the north facade has a lot of influence which is shown in the tables in Fig. 123 and Fig. 124. Still it is too cold, which can be explained by the uninsulated walls .

In the next simulation the walls and the roof are insulated. In Fig. 128 and Fig. 129 the comfort graphs are shown. It is visible that the points are less spread out, especially in living room 6, which means that the temperature is more stable. In the tables in Fig. 125 and Fig. 126 it is shown that there is a lot of difference between the amount of "cold" hours of the two living rooms. This can be explained by the combination of the orientation and the insulated walls, because of the insulated walls it is easier to hold the solar gain in winter.

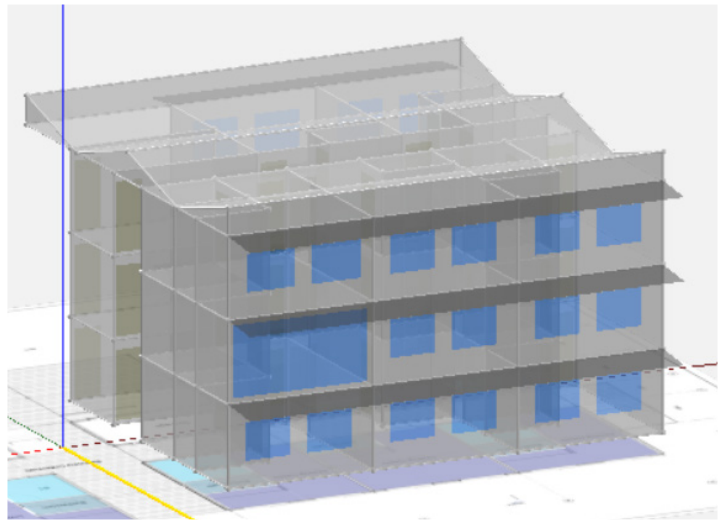


Fig. 127 Third simulation Butterfly geometry

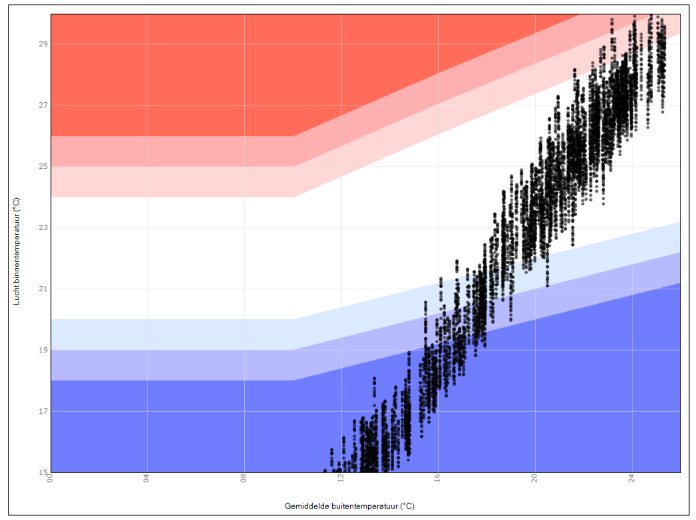


Fig. 128 Fourth simulation Butterfly living room 6 results

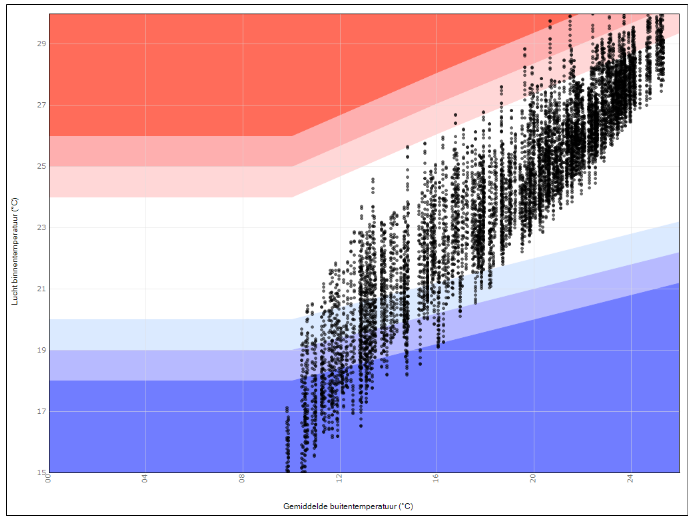


Fig. 129 Fourth simulation Butterfly living room 10 results

In the fifth simulation the single glass windows are replaced by e glass windows. Because only the windows are insulated, the result is less positive as the previous simulation. The points in the comfort graph are more spread and the amount of "cold" hours inreased.

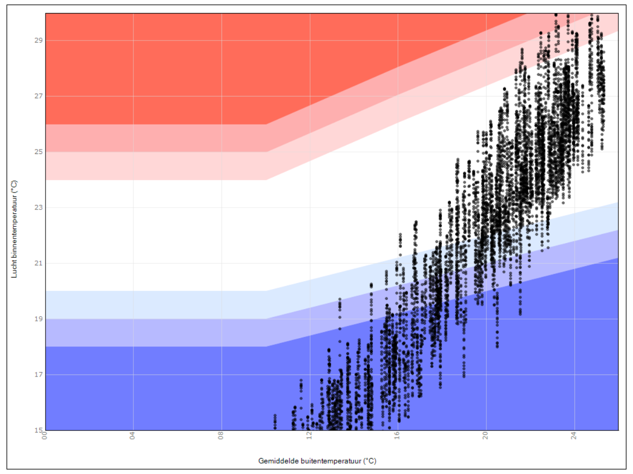


Fig. 130 Fifth simulation Butterfly living room 6 results

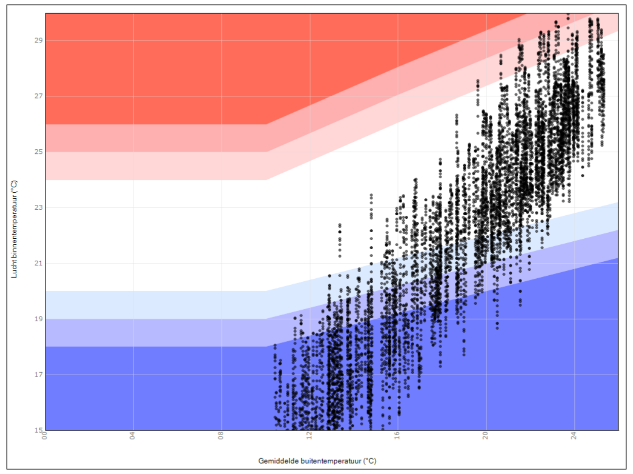


Fig. 131 Fifth simulation Butterfly living room 10 results

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4234	184	4418	51,43
Klasse C	3573	19	3592	41,81
Klasse D	3058	0	3058	35,60

Fig. 132 Fifth simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3714	247	3961	46,11
Klasse C	2992	32	3024	35,20
Klasse D	2356	0	2356	27,42

Fig. 133 Fifth simulation Butterfly living room 10 results table

5.7 Summary

After the first simulations, it was found that insulated windows walls and roofs, the orientation and extra glass on the north facade would improve the comfort when it is colder outside. It is expected that there is still shading needed for summer.

Still these simulations didn't give the result that is needed to really improve the comfort.

For this reason there will be a new set of simulations in the next chapter. In these simulations there will be different combinations of insulated windows, walls and roofs, the orientation, shading and extra glass on the north facade to find the most optimum situation.

Chapter VI - Final design

In this chapter the new set of simulations will be described to find out if the comfort could be further improved.

6.1 New simulations

The first simulations were the simulations of Butterfly Housing.

The first simulation is a simulation of living room 10 (because of the orientation) including:
- 145 mm insulation added to the walls and roof
- a lot of glass in the north facade (80%)
- double layered glass
- overhang above the windows on the north facade for summer, 1 m

As shown in Fig. 134 and Fig. 135, the results have improved compared to the previous simulations. Still, there are a lot of "cold" hours which is why in a new simulation the double layered glass will be replaced by HR++ glass.

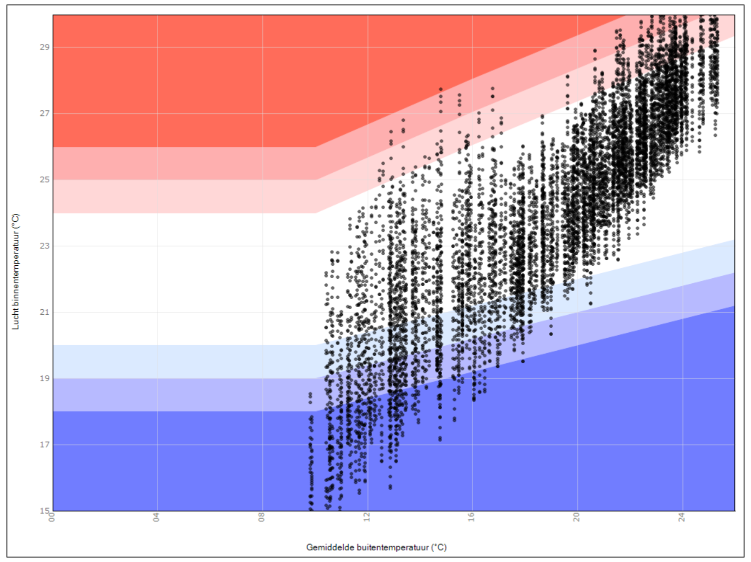


Fig. 134 New simulation 1 Butterfly living room 10

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1669	647	2316	26,96
Klasse C	1034	167	1201	13,98
Klasse D	559	2	561	6,53

Fig. 135 New simulation 1 Butterfly living room 10 results table

When changing the double glazing to the HR++ glazing, the results further improved.

Because of these positive results, there won't be another simulation for Butterfly Housing. Also because of the future climate it is important that there are more "too cold" hours than "too warm" hours, The expectation is that the results in the graph will move a little bit upwards.

The improvements will be validated by comparing the material costs with the energy use. The energy use will be calculated by calculating how much energy there is needed to cool or heat the living room that was simulated (living room 10). By using the "cold" hours and "warm" hours from VABI elements, an estimation can be made. This validation will be further described in the following paragraphs.

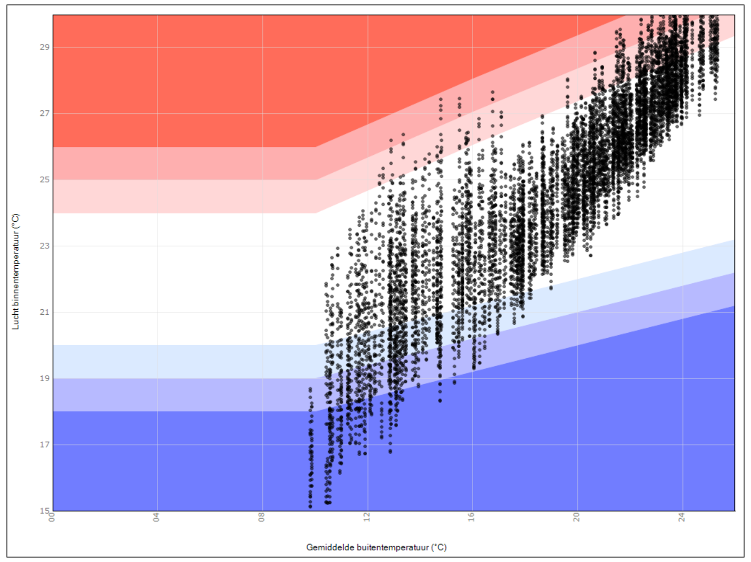


Fig. 136 New simulation 2 Butterfly living room 10

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1207	970	2177	25,34
Klasse C	650	242	892	10,38
Klasse D	304	8	312	3,63

Fig. 137 New simulation 2 Butterfly living room 10 results table

Because HR++ glass really improved the comfort in Butterfly Housing, the next simulation for Thembelihle Village (living room 8) will include:

- 145 mm insulation added to the walls and roof
- glass on north facade were possible
- HR ++ glass
- overhang above the windows on the north facade for summer, 1 m

Compared to the simulations from the previous chapter, the comfort has improved a lot. Still the "cold" hours are quite high. For this reason the bathroom at the north facade will be moved to the south facade in the next simulation. By doing this, more glass can be added in the north facade.

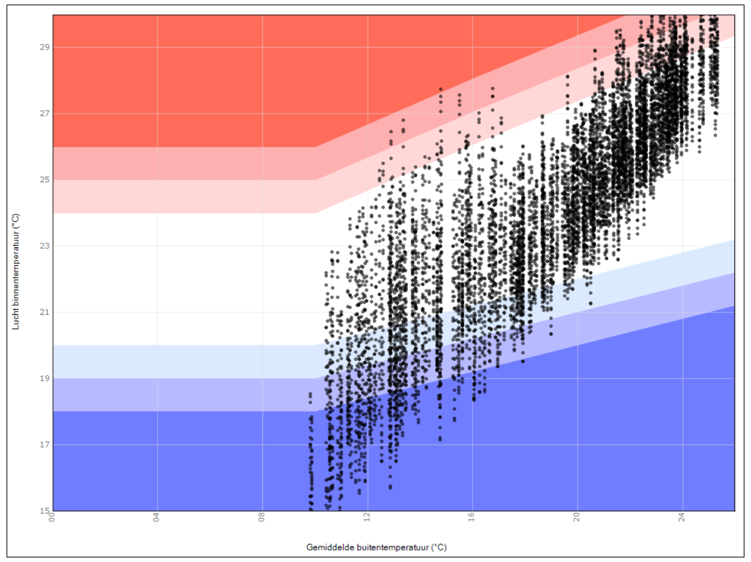


Fig. 138 New simulation 3 Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1548	941	2489	28,97
Klasse C	1011	245	1256	14,62
Klasse D	586	21	607	7,07

Fig. 139 New simulation 3 Thembelihle living room 8 results table

By moving the bathroom, the results have further improved as shown in the table in Fig. 141.

The improvements will be validated by comparing the material costs with the energy use. The energy use will be calculated by calculating how much energy there is needed to cool or heat the living room that was simulated (living room 8). By using the "cold" hours and "warm" hours from VABI elements, an estimation can be made. This validation will be further described in the following paragraphs.

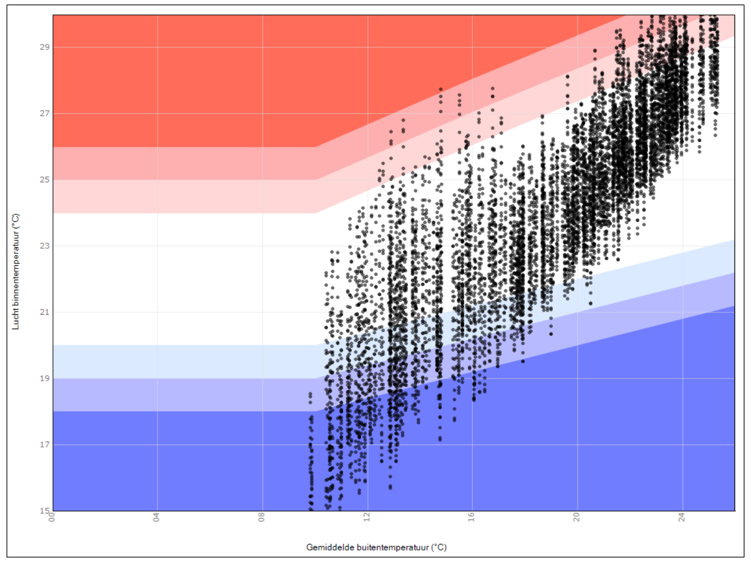


Fig. 140 New simulation 4 Thembelihle living room 8

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1568	910	2478	28,84
Klasse C	982	206	1188	13,83
Klasse D	550	13	563	6,55

Fig. 141 New simulation 4 Thembelihle living room 8 results table

6.2 Cost of the improvements compared with the current buildings

First the material costs (incl. labor) of the current situation for Butterfly Housing and Thembelihle Village were calculated. The material cost data is mostly derived from local companies (Johannesburg).

The most important building parts are calculated. To be able to compare the two buildings, the same building parts were calculated using the same method.

As shown in Fig. 142 and Fig. 143 the material costs of Butterfly Housing are a bit higher. This can be explained by the steel structure from Butterfly Housing, which is more expensive compared to a concrete structure.

An extra advantage of insulated walls and windows is the noise reduction and the increase in safety. Which are both interesting aspects at this location.

Materials used Thembelihle, 16 apartments

Material	M2/number	Price	Price total
Concrete walls (m2)	209,83	970,00	203530,25
Masonry walls (per 1000), per 1,4 m3	53,42	1270,00	67838,32
Concrete floors (m3)	125,66	1470,00	184720,20
Tiling (m2)	557,40	400,00	222959,60
Windows single glass normal size	32,00	3445,20	110246,40
Windows single glass small size	18,00	1615,90	29086,20
Doors single glass	24,00	4840,00	116160,00
Roof, steel, chromadeck (m2)	176,43	420,00	74101,10
Timber roof structure 100mm x 50 mm (m)	249,92	135,00	33739,20

TOTAL **1042381,27** **ZAR**

1 AP. **65148,83** **ZAR**

Fig. 142 Material costs (incl. labor) current Thembelihle

Materials used Butterfly, 15 apartments

Materials	M2/number	Price/m2	Price total
Steel columns, IPE 180, per m.	220,71	616,00	135956,13
Steel beams, IPE 180, per m.	224,06	616,00	138023,42
Masonry walls (per 1000), per 1,4 m3	43,93	1270,00	55784,75
Concrete floors (m3)	118,39	1270,00	150354,03
Tiling (m2)	607,12	400,00	242849,20
Windows single glass	45,00	3445,20	155034,00
Doors single glass	18,00	4840,00	87120,00
Roof, steel, chromadeck (m2)	249,38	420,00	104739,60
Steel roof structure, beams IPE 180, per m.	61,27	616,00	37741,09

TOTAL **1107602,22** **ZAR**

1 AP. **73840,15** **ZAR**

Fig. 143 Material costs (incl. labor) current Butterfly

In Fig. 144 and Fig. 145 the material costs of the improvements are shown.

Compared to the current situation, Thembelihle (the building) has increased with an price of 295005,14 ZAR. Per apartment is that 18437,82 ZAR (1229,19 euro).

Compared to the current situation, Butterfly Housing (the building) has increased with an price of 277462,15 ZAR. Per apartment is that 18497,48 ZAR (1233,17 euro).

6.3 Costs of the improvements compared with the differences in energy use

After calculating the material costs, the improvement in energy use will be simulated. To be able to analyze how much energy will be saved by implementing the design solutions, the energy use was also simulated in VABI elements. First the current simulation of both buildings was simulated. Then the new situation of both buildings was simulated, to be able to compare the results.

In all of the simulations were the same installations used, as well as the same time schedules. By doing this, a logical comparison could be made.

In Appendix III the simulations and results are further described.

Materials used in NEW Thembelihle, 16 apartments

Material	M2/number	Price	Price total
Concrete walls (m2)	138,81	873,00	121181,13
Masonry walls (per 1000), per 1,4 m3	40,28	1143,00	46040,04
Insulated walls (m2), per 6 m2	23,14	450,00	10410,75
Concrete floors (m3)	125,66	1323,00	166248,18
Tiling (m2)	557,40	360,00	200663,64
Windows double layered glass normal size	24,00	6264,00	150336,00
Windows double layered glass small size	8,00	2938,00	23504,00
Large windows (double layered) on north facade	16,00	16000,00	256000,00
Doors double layered glass	24,00	8800,00	211200,00
Roof, steel, chromadeck insulated (m2)	176,43	504,00	88921,32
Timber roof structure 100mm x 50 mm (m)	249,92	121,50	30365,28
Overhang on north facade concrete (m3)	28,45	1143,00	32516,06

TOTAL	**1337386,41**	**ZAR**
1 AP.	**83586,65**	**ZAR**

Fig. 144 Material costs (incl. labor) with improvements Thembelihle

Materials used in NEW Butterfly, 15 apartments

Materials	M2/number	Price/m2	Price total
Steel columns, IPE 180, per m.	220,71	554,40	122360,52
Steel beams, IPE 180, per m.	224,06	554,40	124221,08
Masonry walls (per 1000), per 1,4 m3	33,74	1143,00	38564,36
Insulated walls (m2), per 6 m2	77,18	450,00	34731,00
Concrete floors (m3)	118,39	1323,00	156628,65
Tiling (m2)	607,12	360,00	218564,28
Windows double layered glass	15,00	6577,20	98658,00
Large windows (double layered) on north facade	15,00	16000,00	240000,00
Doors double layered glass	18,00	8800,00	158400,00
Roof, steel, chromadeck insulated (m2)	249,38	560,00	139652,80
Steel roof structure, beams IPE 180, per m.	61,27	554,40	33966,98
Overhang on north facade concrete (m3)	16,90	1143,00	19316,70

TOTAL	**1385064,37**	**ZAR**
1 AP.	**92337,62**	**ZAR**

Fig. 145 Material costs (incl. labor) with improvements Butterfly

On the page on the right the results of the simulations and the simple calculations of the energy use are shown

As an result the new version of Thembelihle village saves 48628,70 ZAR (3241,91 euro), which means a **payback time of 6 years.**

The newer version of Butterfly saves in total 15576,32 ZAR (1038,42), which means a **payback time of 17,76 years**.

Interesting is that the payback time of Thembelihle is a lot shorter. This can be explained by the fact that the comfort of the current Butterfly building was better compared to Thembelihle. The differences with the improvements were for this reason bigger for Thembelihle and smaller for Butterfly.

THEMBELIHLE

IMPROVED:

Living room 8	958,2690805	-931,2184393

0,86 Rand per kwh

current total	68637 kWh
new total	12092 kWh
difference	56545 kWh

(Kwh*0,86)

27,05064127	23,26355149	**50,31** ZAR

TOTAL SAVINGS FOR LIVING ROOM 8:

50,31 ZAR	**377,36** only 1 living room
3,35 EURO	**25,16** only 1 living room

48628,70 ZAR

3241,91 EURO

6,07 > years payback time

BUTTERFLY

IMPROVED:

Living room 10	251,4835535	-162,5731649

0,86 Rand per kwh

current total	58763 kWh
new total	40651 kWh
difference	18112 kWh

(Kwh*0,86)

216,275856	-139,8129218	**76,4629342** ZAR

TOTAL SAVINGS FOR LIVING ROOM 10:

76,46 ZAR	**573,472** only 1 living room
5,10 EURO	**360** only 1 living room

15576,32 ZAR

1038,42 EURO

17,76 > years payback time

6.4 Implement improvements

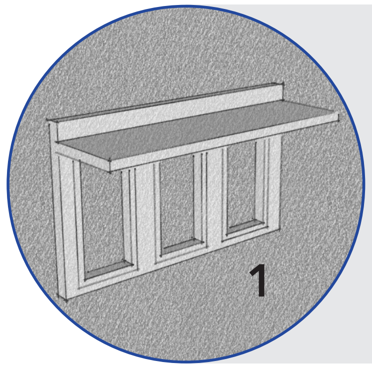
Earlier in this chapter the different improvements were described. In VABI elements the simple design improvements were simulated. Still, the same results or almost the same results can be achieved with other architectural elements.

On these pages different options of overhang/shading or glass in the north facade are visualized for the architect. Insulated walls and roofs and HR++ glass are materials and have for this reason no different architectural elements.

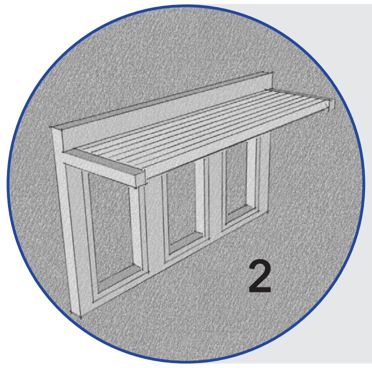
1
INSULATED WALLS & ROOFS

2
HR++ GLASS

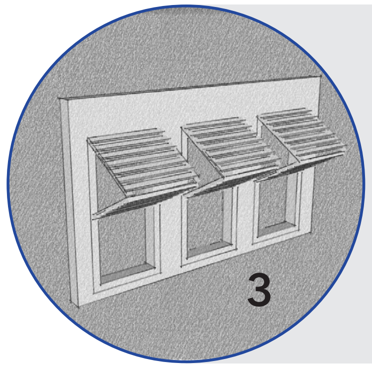
3
OVERHANG / SHADING



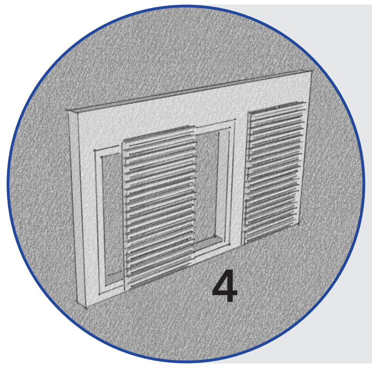
Simple overhang as simulated in VABI elements



Overhang with an integration of rotating lamellas

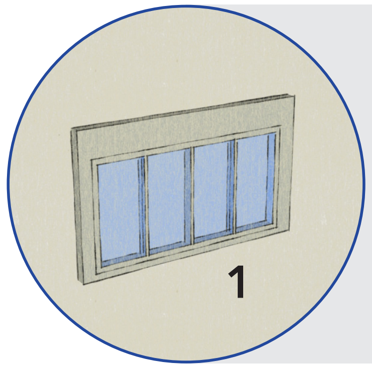


Foldable facade elements with an integration of rotating lamellas

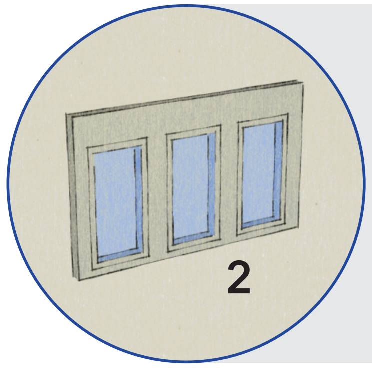


Sliding facade elements with an integration of rotating lamellas

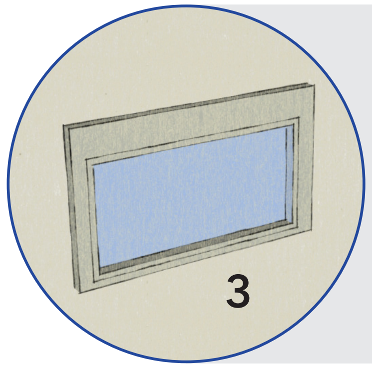
4
GLASS IN NORTH FACADE



One large window with a couple vertical mullions



Multiple windows divided over the wall



One large window with no vertical or horizontal mullions

6.5 Other improvements

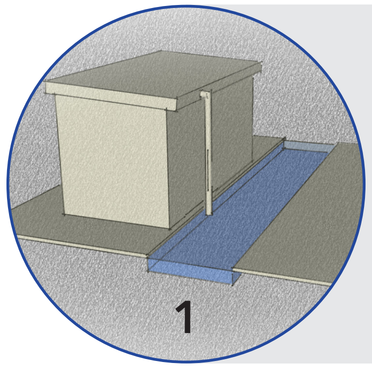
Not all of the research results, passive design strategies and other ideas were possible to simulate in VABI elements. Still, there are some important design parts that need to be taken into account.

- As written before, the climate will change and it will be a lot drier. For this reason it is important to integrate a water catching system in the roof.

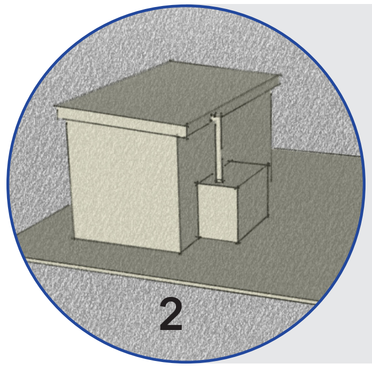
- There are a lot of sun hours within this climate, for this reason it is important to consider the use of solar panels on the roof (with the right orientation).

- To keep the plot and the air cool around the building, it is suggested to use a lot of green. Especially when the climate is changing and a lot of sun, green would be a better choice compared to concrete and stones.

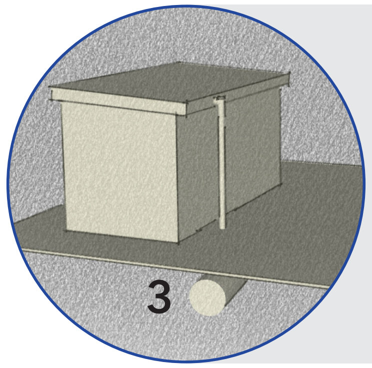
EXTRA
RAINWATER HARVESTING



A pond next to the building where the rainwater is stored

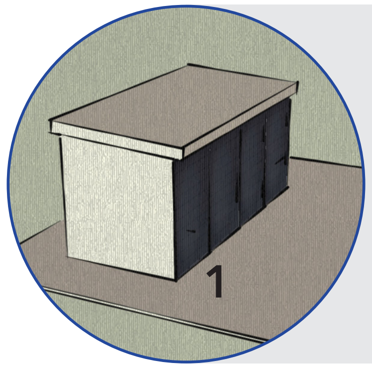


A tank above ground where the rainwater is stored

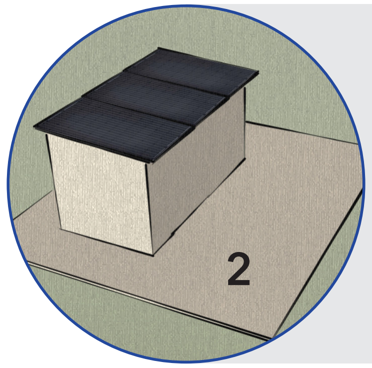


A tank below ground where the rainwater is stored

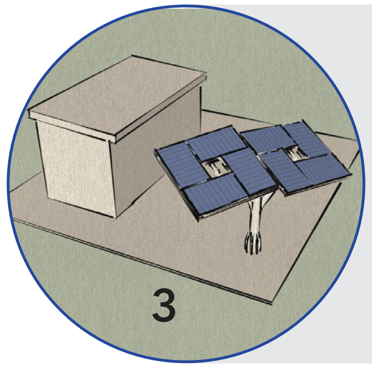
EXTRA
USE OF SOLAR ENERGY



Solar panels integrated in the facade

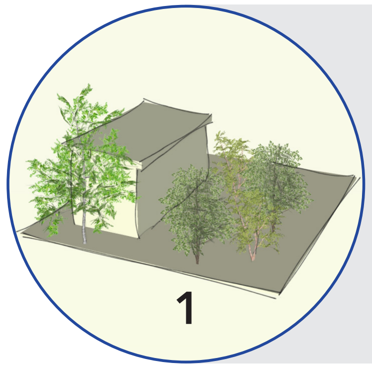


Solar panels integrated in the roof/solar panels which function as the roof

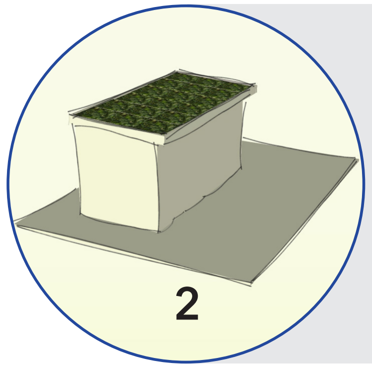


Solar trees on site, around the building

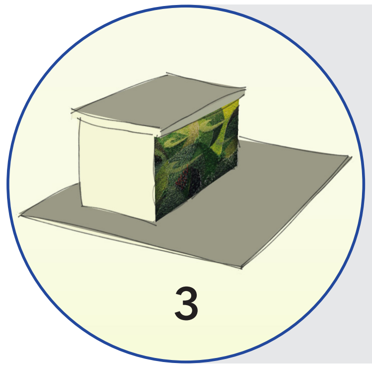
EXTRA
USE OF GREEN



Green around the building



Green roof on the building



Green integrated in the facade of the building

6.5 Summary

After creating new simulations for Thembelihle Village and for Butterfly Housing, some very positive results were found.

For Butterfly Housing the improvements include:
- 145 mm insulation added to the walls and roof
- a lot of glass in the north facade (80%)
- HR ++ glass in windows and doors
- overhang above the windows on the north facade for summer, 1 m

For Thembelihle Village the improvements include:
- 145 mm insulation added to the walls and roof
- a lot of glass in the north facade after moving the bathroom to the south facade
- HR ++ glass in windows and doors
- overhang above the windows on the north facade for summer, 1 m

Not all of the research results, passive design strategies and other ideas were possible to simulate in VABI elements. Still, there are some important design parts that need to be taken into account.

- As written before, the climate will change and it will be a lot drier. For this reason it is important to integrate a water catching system in the roof.

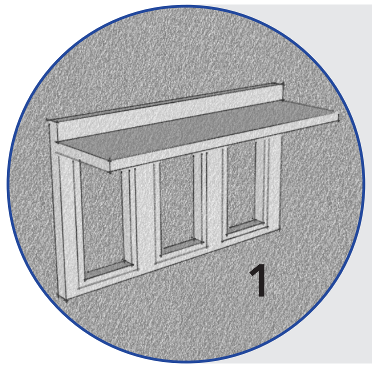
- There are a lot of sun hours within this climate, for this reason it is important to consider the use of solar panels on the roof (with the right orientation).

- To keep the plot and the air cool around the building, it is suggested to use a lot of green. Especially when the climate is changing and a lot of sun, green would be a better choice compared to concrete and stones.

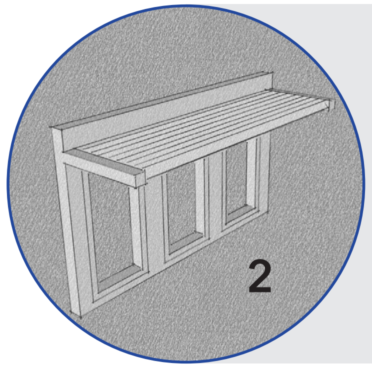
The material costs of the current Butterfly Housing Building and the improvement version were more expensive compared to Thembelihle Village because of the steel structure. The improvements for both the buildings were not too big, because it was not the goal to change a lot of the appearance of the buildings.

As an result the new version of Thembelihle village saves 48628,70 ZAR (3241,91 euro), which means a **payback time of 6 years.** The newer version of Butterfly saves in total 15576,32 ZAR (1038,42), which means a **payback time of 17,76 years**.

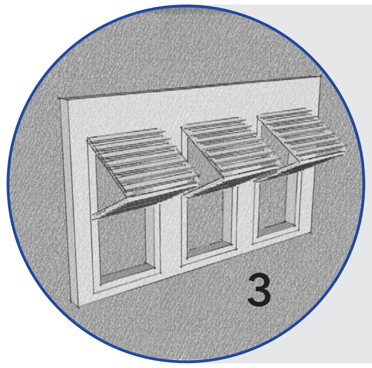
1
OVERHANG / SHADING



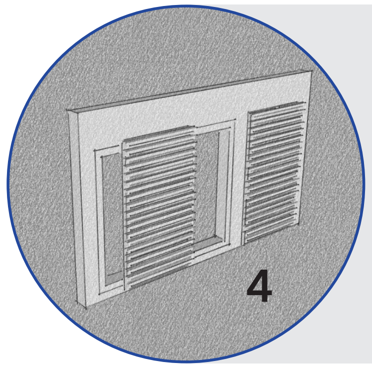
Simple overhang as simulated in VABI elements



Overhang with an integration of rotating lamellas

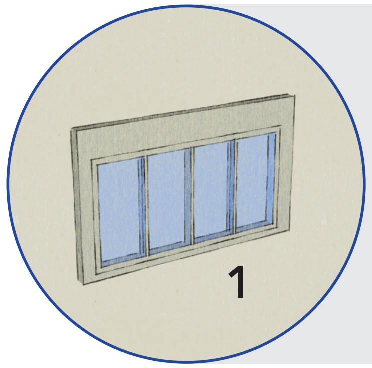


Foldable facade elements with an integration of rotating lamellas

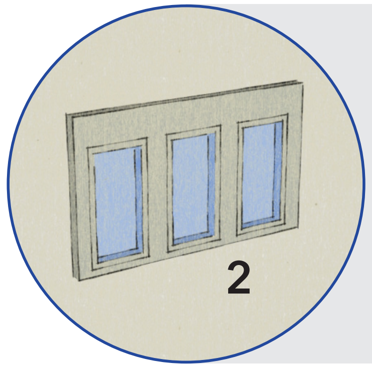


Sliding facade elements with an integration of rotating lamellas

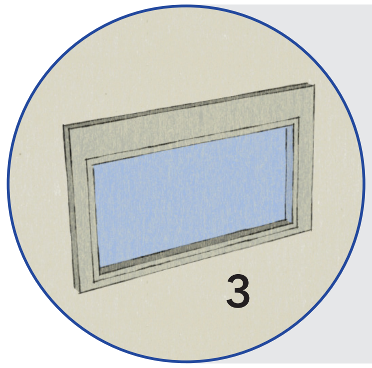
2
GLASS IN NORTH FACADE



One large window with a couple vertical mullions



Multiple windows divided over the wall

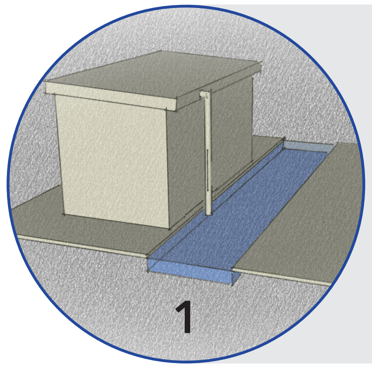


One large window with no vertical or horizontal mullions

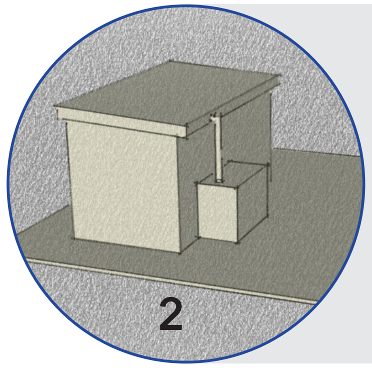
3
INSULATED
WALLS & ROOFS

4
HR++
GLASS

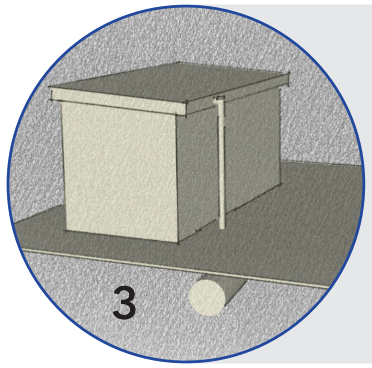
EXTRA
RAINWATER
HARVESTING



A pond next to the building where the rainwater is stored

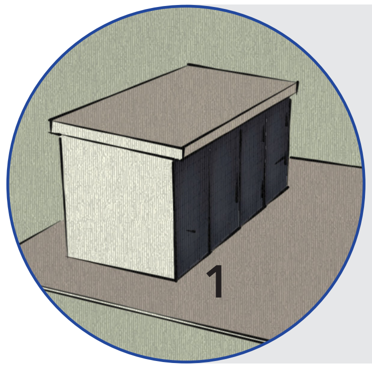


A tank above ground where the rainwater is stored

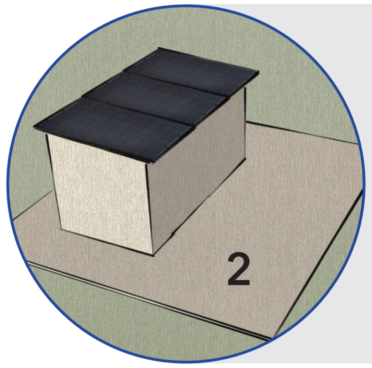


A tank below ground where the rainwater is stored

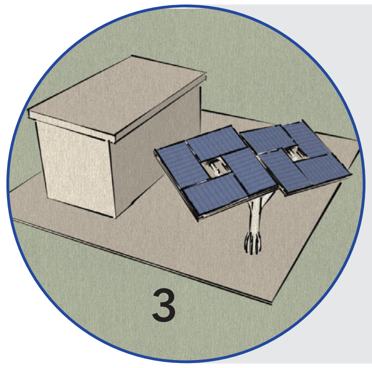
EXTRA
USE OF SOLAR
ENERGY



Solar panels integrated in the facade

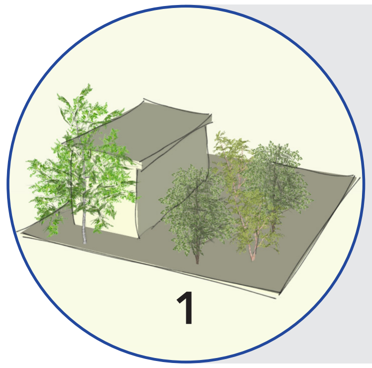


Solar panels integrated in the roof/solar panels which function as the roof

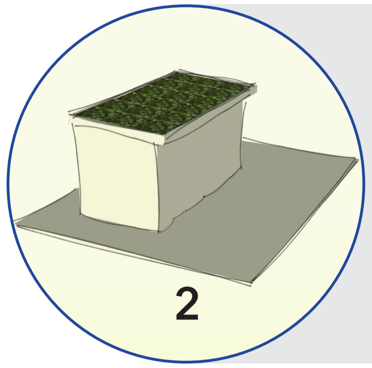


Solar trees on site, around the building

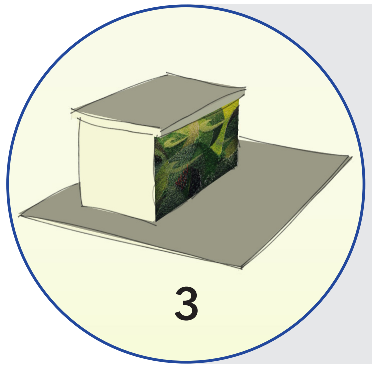
EXTRA
USE OF
GREEN



Green around the building



Green roof on the building



Green integrated in the facade of the building

Chapter VII - Conclusion

This research aimed to provide sustainable housing solutions for the middle class of the centre of Pretoria, South Africa, which enable climate change adaptation and mitigation.

The research question that is answered in this thesis is: ''What are the sustainable design solutions for the middle class of Pretoria, South Africa, which enable climate change adaptation and mitigation?''

To answer this question, eight subquestions are answered. For every sub-question a short summary is provided below.

7.1 Summary research results

<u>What is the definition of the middle class in Pretoria?</u>

According to Zizzamia, et al. (2016) the vulnerable middle class has a population share of 17.99%, an income range of R1283-R3104, an expenditure share of 16,8% and 73,4% is employed. The stable middle class has a population share of 13,53%, an income range of R3104-R10,387, an expenditure share of 35,2% and 82,5% is employed.

According to Yeast City Housing, the developer of Thembelihle village, the income of the households start from R2200 till R7500 (2014). Which means that both the vulnerable middle class as the stable middle class should live in this type of building.

The middle class of the centre of Pretoria, South Africa has an income range of R1283 - R10,387 and lives in multilevel appartment buildings. The profession of the people who live in these buildings could be for example: security guard, cleaner, receptionist, delivery driver, handyman or office assistant.

<u>What are important, location related, circumstances for middle class homes in the centre of Pretoria?</u>

Because the transport is quite expensive, a lot of people would like to live in the centre. Furthermore, living in the centre of Pretoria is interesting because it is close to government departments, shops, social amenities and public transport, which again is very interesting for people with a lower income because of the high transport costs.

<u>What is the (geographical) history of Pretoria?</u>

Gauteng, the province where Pretoria is located, is the smallest province of South Africa. However, it is also the province with the highest population because two of the three largest cities of South Africa are located in this Province (Johannesburg and Pretoria).

Pretoria has always been involved with major political changes in South Africa, with the inauguration of President Nelson Mandela at the Union Buildings In 1994 as high point. Building a church in August 1854 was the beginning of the town.

<u>What are the climate conditions in Pretoria?</u>

Pretoria is located in multiple climate zones, which are: BSh (Arid steppe, hot arid), Cwa (Warm temperature, dry winter, hot summer) and Cwb (Warm temperature, Dry winter, Warm summer).

According to the Köppen-Geiger Climate Classification map Pretoria will be located in just one climate zone in the future: BSh (Arid steppe, hot arid). The climate will then be a lot drier with less rain which is very important to include in the design.

<u>What materials, resources and production techniques are locally available?</u>

Almost all of the materials, resources and production techniques are locally available because Pretoria is located next to Johannesburg. In Johannesburg a lot of material companies and factories are located.

<u>What are the current building methods used in middle class homes?</u>

Thembelihle village and Germiston Fire station were used to analyse the current building methods in Gauteng. Both of the buildings have concrete structures which consist of concrete floors, concrete columns and concrete walls. The walls are masonry and some parts are plastered and painted. Furthermore, the roofs are made of a timber structure with steel roof sheeting.

<u>What are the current developments for middle class homes?</u>

One of the new housing concepts for South Africa is Butterfly Housing. This concept is designed by a dutch architect (robert van kats) as a product which is completely different from the current building methods. The building/concept consists of a steel structure (columns, roof and floors) with a finish of different infill materials.

During the visit to Pretoria, I was told that there were not a lot of other developments for middle class homes. Most of the buildings have the same building methods and are designed in a similar way.

<u>What are the solutions for climate change adaptation and mitigation for this location?</u>

After creating new simulations for Thembelihle Village and for Butterfly Housing, some very positive results were found.

The improvements include:
- 145 mm insulation added to the walls and roof
- a lot of glass in the north facade (80%)
- HR ++ glass in windows and doors
- overhang above the windows on the north facade for summer, 1 m

Not all of the research results, passive design strategies and other ideas were possible to simulate in VABI elements. Still, there are some important design parts that need to be taken into account.

- The climate will change and it will be a lot drier. For this reason it is important to integrate a water catching system in the roof.

- There are a lot of sun hours within this climate, for this reason it is important to consider the use of solar panels on the roof (with the right orientation).

- To keep the plot and the air cool around the building, it is suggested to use a lot of green. Especially when the climate is changing and a lot of sun, green would be a better choice compared to concrete and stones.

The material costs of the current Butterfly Housing Building and the improvement version were more expensive compared to Thembelihle Village because of the steel structure. The improvements for both the buildings were not too big, because it was not the goal to change a lot of the appearance of the buildings.

As an result the new version of Thembelihle village saves 48628,70 ZAR (3241,91 euro), which means a **payback time of 6 years.** The newer version of Butterfly saves in total 15576,32 ZAR (1038,42), which means a **payback time of 17,76 years**.

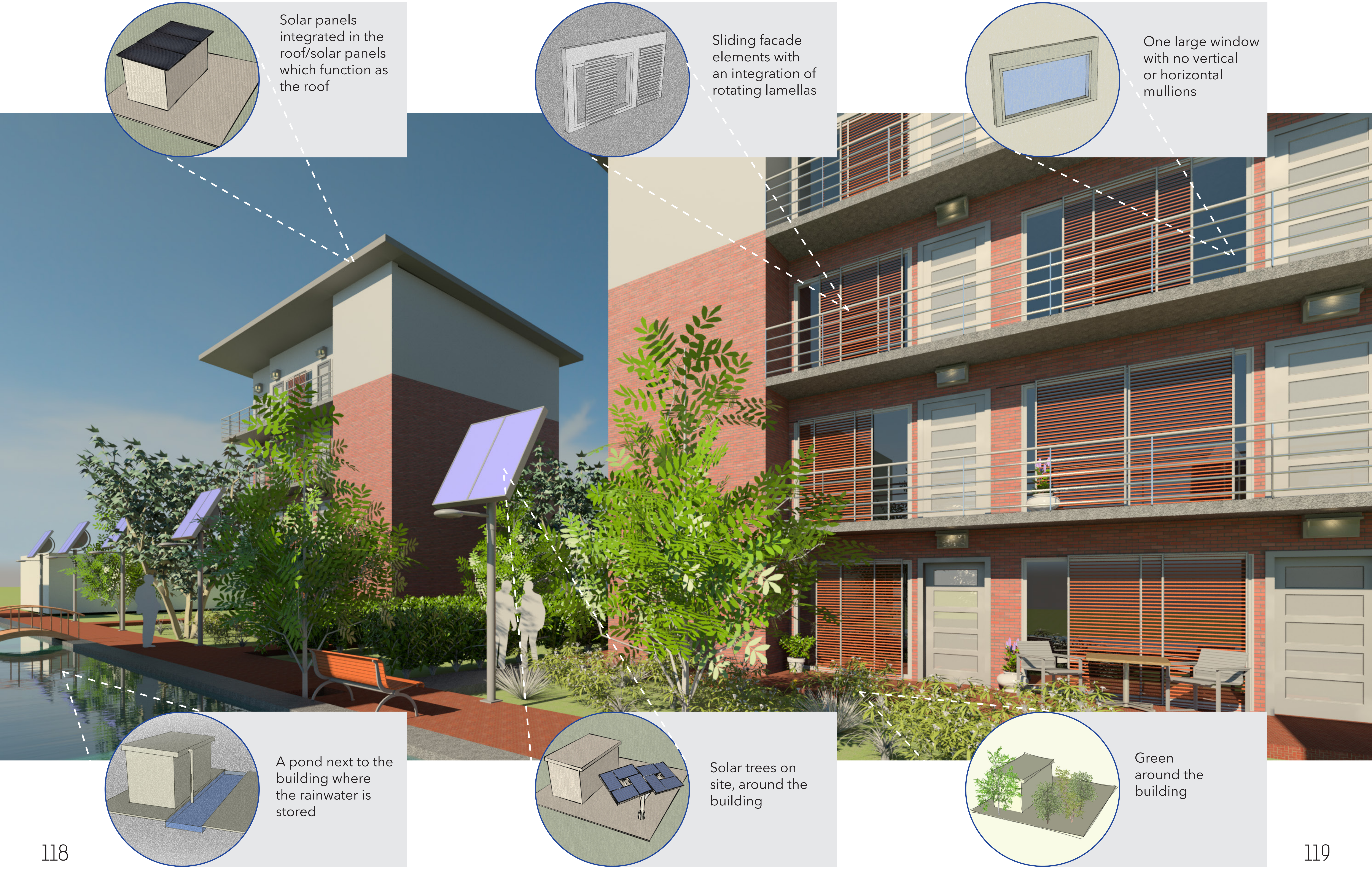
Altogether, simple design solutions will easily improve the comfort for the user and furthermore it is economically interesting because it can save a lot of energy.

7.2 Recommendations for future research

Since the time was limited, not all questions were answered. The following questions remained unanswered and are a recommentation for future research:

- The design solutions and simulations were focused on comfort and for a small part on energy use and material cost. For this reason it would be integrate to further investigate the energy use and material costs to be able to further define the economic value.

- There were two buildings used as an base for this research. It would be valuable to analyse multiple buildings at the same location to find some differences which could be used as input in the design process.


Solar panels integrated in the roof/solar panels which function as the roof
Sliding facade elements with an integration of rotating lamellas
One large window with no vertical or horizontal mullions
A pond next to the building where the rainwater is stored
Solar trees on site, around the building
Green around the building

Reflection

Introduction

My graduation topic is about sustainable design solutions for the middle class housing in the centre of Pretoria, South Africa. The research consists of a literature study, a visit to Pretoria and a comparison between the current housing and a new housing concept.

Fig. 146 During an excursion in the centre of Pretoria with the students of the University of Pretoria

According to the united nations Johannesburg will be one of the megacities of the world and Pretoria will grow by 27% between 2016 and 2030. Despite these rapid developments, the housing sector is not able to deliver enough housing solutions at the rate and scale needed. Furthermore it is not able to deliver housing solutions for the different social classes, because housing solutions have been provided at the lowest and uppermost ends of the market. In addition there has been far too little innovation in the field of housing, where climate is also changing.
The final aim was to find sustainable design solutions for the middle class housing in the centre of Pretoria in South Africa with a focus on comfort, energy use and material cost. The sustainable design solutions were found by analysing two different projects/buildings: a new different housing concept (butterfly housing) and an existing housing project in the centre of Pretoria (Thembelihle Village). The research resulted in an improved version of both the buildings.

Process

The first phase of my research consisted of a literature study. I started with the housing concept of Butterfly Housing (as shown in figure 147) as a base for this project and the goal was to analyse how this project would function at this location and if it needed some improvements. At the beginning of the visit to Pretoria teachers and professionals were not very positive about this concept and using this as a base for the research because it is not directly connected to this location, it is very different from the current housing in Pretoria and it is not tested (or build) yet.

Fig. 147 Design of Butterfly Housing (visual by VDNDP bouwingenieurs bv and Butterfly Housing bv)

For this reason I chose an existing housing project in the centre of Pretoria next to Butterfly Housing, which would be integrated in my research. By doing this, I changed my research method and plan. The new plan was to compare the existing housing project (as shown in figure 148) with a new and different housing concept (butterfly housing) and find sustainable design solutions for both. The research became more realistic and logic, and there was always a reference to an existing housing project in the centre of Pretoria. By choosing another building/project which would be part of the comparison with butterfly housing, my graduation plan changed. Furthermore, I learned that comfort is most of the challenging parts because it is quite "easy" to design a sustainable building but it is more difficult to make it comfortable. For this reason comfort has got a larger role in my research. That was also the reason why I used the software VABI elements, which is focused on comfort.

Fig. 148 One of the eleven buildings of Thembelihle Village, in the centre of Pretoria

During my literature study it was very difficult to define the middle class. After my visit to Pretoria it was easier, because I spoke with the people, with professionals and visited locations where the middle class lives. Some teachers and professionals in Pretoria advised me to use the existing housing in the centre of Pretoria to define the middle class, which I did. I also spoke with Dirk Conradie from CSIR. We spoke a lot about the climate in Pretoria and the value of the software Climate Consultant. Climate Consultant uses existing climate data as input and shows passive design strategies specifically for that climate (as shown in figure 149). It was a challenge to find how these results could be implemented and validated. I chose to implement some of these passive design strategies in the current designs of Thembelihle and butterfly and then simulate these situations in VABI elements to see if it would improve the design in comfort. If these results were positive they were further validated by comparing it with energy use and material costs.

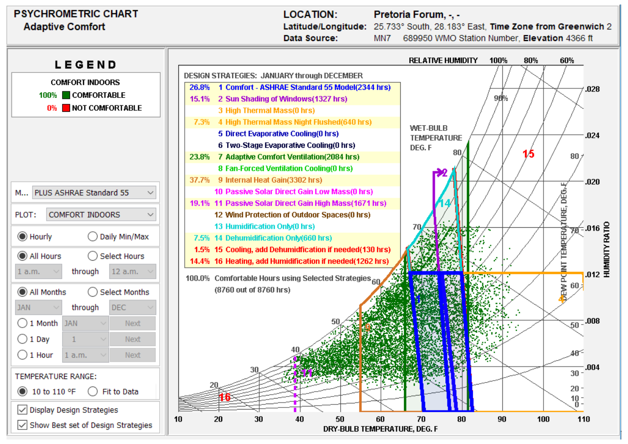


Fig. 149 Design strategies in Climate Consultant software

Relationship between research and design

Throughout the design process there was a strong relationship between research and design. The design process started with the design requirements. The design requirements were formed by the research results and the results from the software Climate Consultant (by using climate data from the project location in the software). After choosing the passive design strategies from Climate Consultant to implement in the current designs of Thembelihle and Butterfly and combining those with my own ideas and with the research results, some new design options were formed. Those design options were directly simulated in VABI elements to see if those changes would improve the comfort, which is shown in figure 150 and figure 151. When the results were optimal, the new design elements or changes were compared with material costs and energy use. If the extra material cost would result in less energy use and so less energy cost, it would be a economic advantage and for that reason interesting for the project developers in Pretoria.

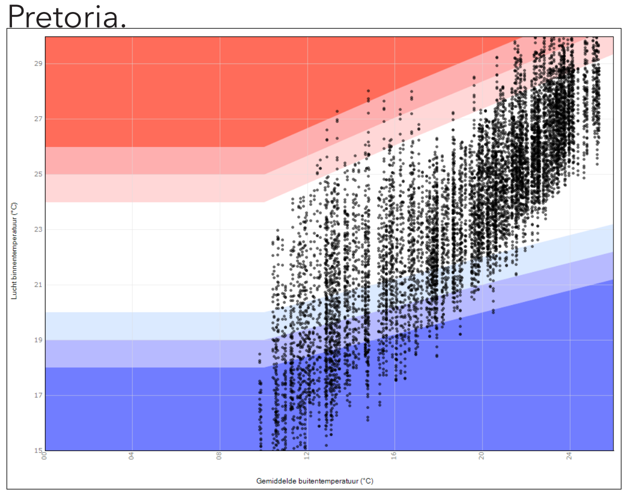


Fig. 150 Comfort graph in VABI elements

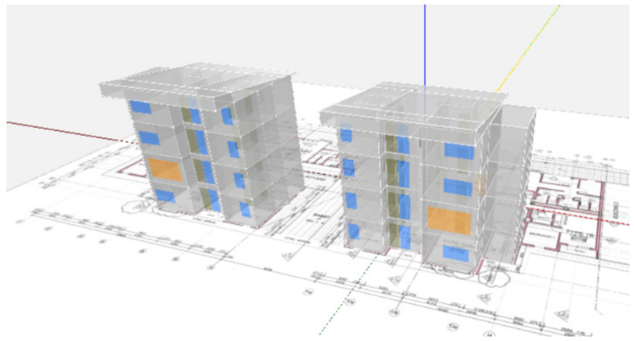


Fig. 151 One of the geometries used for one of the simulations

Societal impact

Yeast City Housing, the project developer of Thembelihle Village which send me the drawings for the research, told me that it would be really interesting for them to see the results of the research. For project developers in Pretoria, but also at other locations with similar climates, the results of this research would be very valuable. The design solutions, as a result of the research, should improve the comfort and reduce the energy use. Which eventually will give a positive result once the extra material costs have been compensated.

Conclusion

Because my visit to Pretoria changed my total research plan I would recommend other students to plan the visit earlier in the process. The people I spoke to in Pretoria could then also help more with the direction of the research and I think that would be very valuable.

Overall, I feel that the research was successful because it was possible to find sustainable design solutions for this location and specific climate. However, I only simulated two buildings. For future research it would be interesting to simulate more buildings to further analyse how the design solutions would work for different housing projects in Pretoria.

List of appendix

Appendix I - Climate Consultant

During my visit to Pretoria I spoke with Dirk Conradie from CSIR. We spoke a lot about the climate in Pretoria and the value of the software Climate Consultant. Climate Consultant uses existing climate data as input and shows passive design strategies specifically for that climate. Dirk Conradie shared the climate file with the climate data so it could be used as input for this research.

The climate file was directly opened with Climate Consultant. The first window shows a summary with all the weather data, as shown in Fig 152. This is the most important data used for the output in Climate Consultant.

The next step was to choose a Comfort Mode as shown in FIg. 153. The adaptive comfort model would fit best to this situation, because there is no mechanical cooling or heating system. Furthermore, the buildings are naturally ventilated where occupants can open and close windows.

WEATHER DATA SUMMARY

LOCATION: **Pretoria Forum, -, -**
Latitude/Longitude: 25.733° South, 28.183° East, **Time Zone from Greenwich** 2
Data Source: MN7 689950 WMO Station Number, **Elevation** 4366 ft

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	158	152	146	129	125	119	126	144	161	162	161	166	Btu/sq.ft
Direct Normal Radiation (Avg Hourly)	135	138	139	136	173	189	199	203	188	167	148	150	Btu/sq.ft
Diffuse Radiation (Avg Hourly)	63	55	54	47	36	29	28	30	40	51	58	60	Btu/sq.ft
Global Horiz Radiation (Max Hourly)	386	359	333	298	270	236	250	295	331	363	385	395	Btu/sq.ft
Direct Normal Radiation (Max Hourly)	345	329	330	319	316	306	307	318	327	335	339	345	Btu/sq.ft
Diffuse Radiation (Max Hourly)	168	161	163	133	116	101	101	119	139	148	170	174	Btu/sq.ft
Global Horiz Radiation (Avg Daily Total)	2133	1971	1775	1479	1348	1245	1342	1615	1913	2050	2147	2257	Btu/sq.ft
Direct Normal Radiation (Avg Daily Total)	1822	1790	1693	1555	1865	1971	2114	2261	2227	2116	1967	2040	Btu/sq.ft
Diffuse Radiation (Avg Daily Total)	856	717	665	540	386	312	302	334	476	657	777	815	Btu/sq.ft
Global Horiz Illumination (Avg Hourly)	5166	4947	4743	4188	3989	3779	3979	4555	5075	5168	5208	5370	footcandles
Direct Normal Illumination (Avg Hourly)	3827	3966	3905	3894	4877	5305	5610	5780	5372	4695	4192	4317	footcandles
Dry Bulb Temperature (Avg Monthly)	72	72	70	65	58	53	52	60	66	71	70	72	degrees F
Dew Point Temperature (Avg Monthly)	59	59	57	51	41	39	32	37	39	49	54	58	degrees F
Relative Humidity (Avg Monthly)	66	66	65	65	58	61	49	45	40	50	59	62	percent
Wind Direction (Monthly Mode)	80	70	80	300	290	290	290	310	50	90	70	70	degrees
Wind Speed (Avg Monthly)	2	2	2	1	1	2	1	2	3	3	3	3	mph
Ground Temperature (Avg Monthly of 1 Depths)	67	69	69	69	67	65	63	62	61	62	63	65	degrees F

Fig. 152 Weather data summary in CC

COMFORT MODEL

LOCATION: **Pretoria Forum, -, -**
Latitude/Longitude: 25.733° South, 28.183° East, **Time Zone from Greenwich** 2
Data Source: MN7 689950 WMO Station Number, **Elevation** 4366 ft

COMFORT MODELS:

Human Thermal comfort can be defined primarily by dry bulb temperature and humidity, although different sources have slightly different definitions. Select the model you wish to use:

○ **California Energy Code Comfort Model, 2013 (DEFAULT)**

For the purpose of sizing residential heating and cooling systems the indoor Dry Bulb Design Conditions should be between 68°F (20°C) to 75°F (23.9°C). No Humidity limits are specified in the Code, so 80% Relative Humidity and 66°F (18.9°C) Wet Bulb is used for the upper limit and 27°F (-2.8°C) Dew Point is used for the lower limit (but these can be changed on the Criteria screen).

○ **ASHRAE Standard 55 and Current Handbook of Fundamentals Model**

Thermal comfort is based on dry bulb temperature, clothing level (clo), metabolic activity (met), air velocity, humidity, and mean radiant temperature. Indoors it is assumed that mean radiant temperature is close to dry bulb temperature. The zone in which most people are comfortable is calculated using the PMV (Predicted Mean Vote) model. In residential settings people adapt clothing to match the season and feel comfortable in higher air velocities and so have wider comfort range than in buildings with centralized HVAC systems.

○ **ASHRAE Handbook of Fundamentals Comfort Model up through 2005**

For people dressed in normal winter clothes, Effective Temperatures of 68°F (20°C) to 74°F (23.3°C) (measured at 50% relative humidity), which means the temperatures decrease slightly as humidity rises. The upper humidity limit is 64°F (17.8°C) Wet Bulb and a lower Dew Point of 36F (2.2°C). If people are dressed in light weight summer clothes then this comfort zone shifts 5°F (2.8°C) warmer.

◉ **Adaptive Comfort Model in ASHRAE Standard 55-2010**

In naturally ventilated spaces where occupants can open and close windows, their thermal response will depend in part on the outdoor climate, and may have a wider comfort range than in buildings with centralized HVAC systems. This model assumes occupants adapt their clothing to thermal conditions, and are sedentary (1.0 to 1.3 met). There must be no mechanical Cooling System, but this method does not apply if a Mechanical Heating System is in operation.

Fig. 153 Comfort models in Climate consultant

After the choice of comfort model, the criteria can be changed. In Fig. 156 the criteria are shown. When needed the criteria within the "white boxes" can be changed. For this research these numbers weren't changed, because they are quite standard and there was no reason to change these.

After the criteria, the first graph is shown with the temperature range (Fig. 154). Climate Consultant also creates other graphs with data about: monthy diurnal averages, radiation range, illumination range, sky cover range, wind velocity range, ground temperature, dry bulb x relative humidity, dry bulb x dew point, sun chart (Fig. 155), time table plot and 3D charts which is very interesting and useful to use in the design proces.

After the different graphs, Climate Consultant shows the psychrometic chart, which was the most interesting for this research. The psychrometic chart is described in paragraph 5.3.

At the end, the list with design guidelines for this specific climate is shown (Fig. 157) which were used as input for the design process.

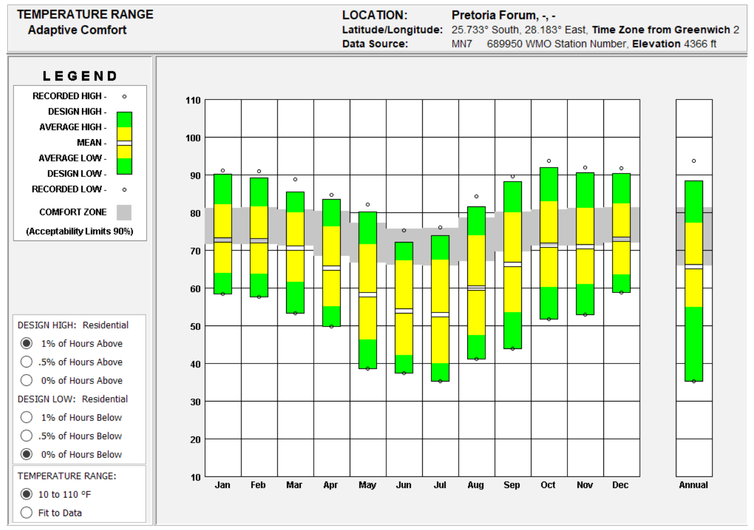


Fig. 154 Temperature range in CC

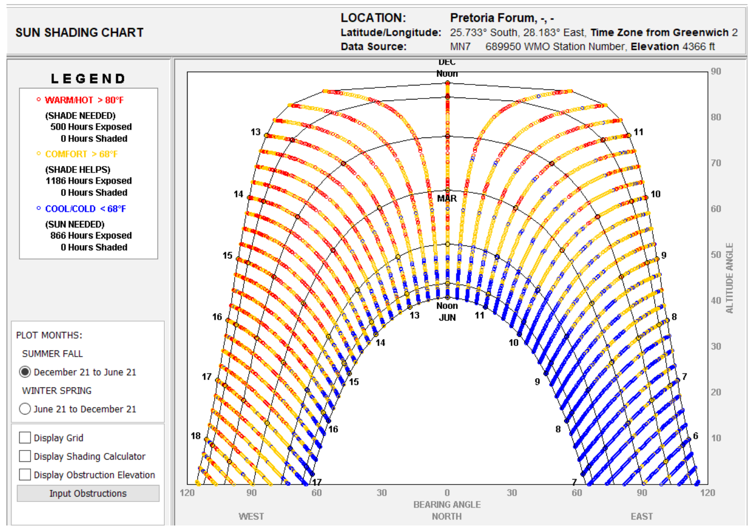


Fig. 155 Sun chart in CC

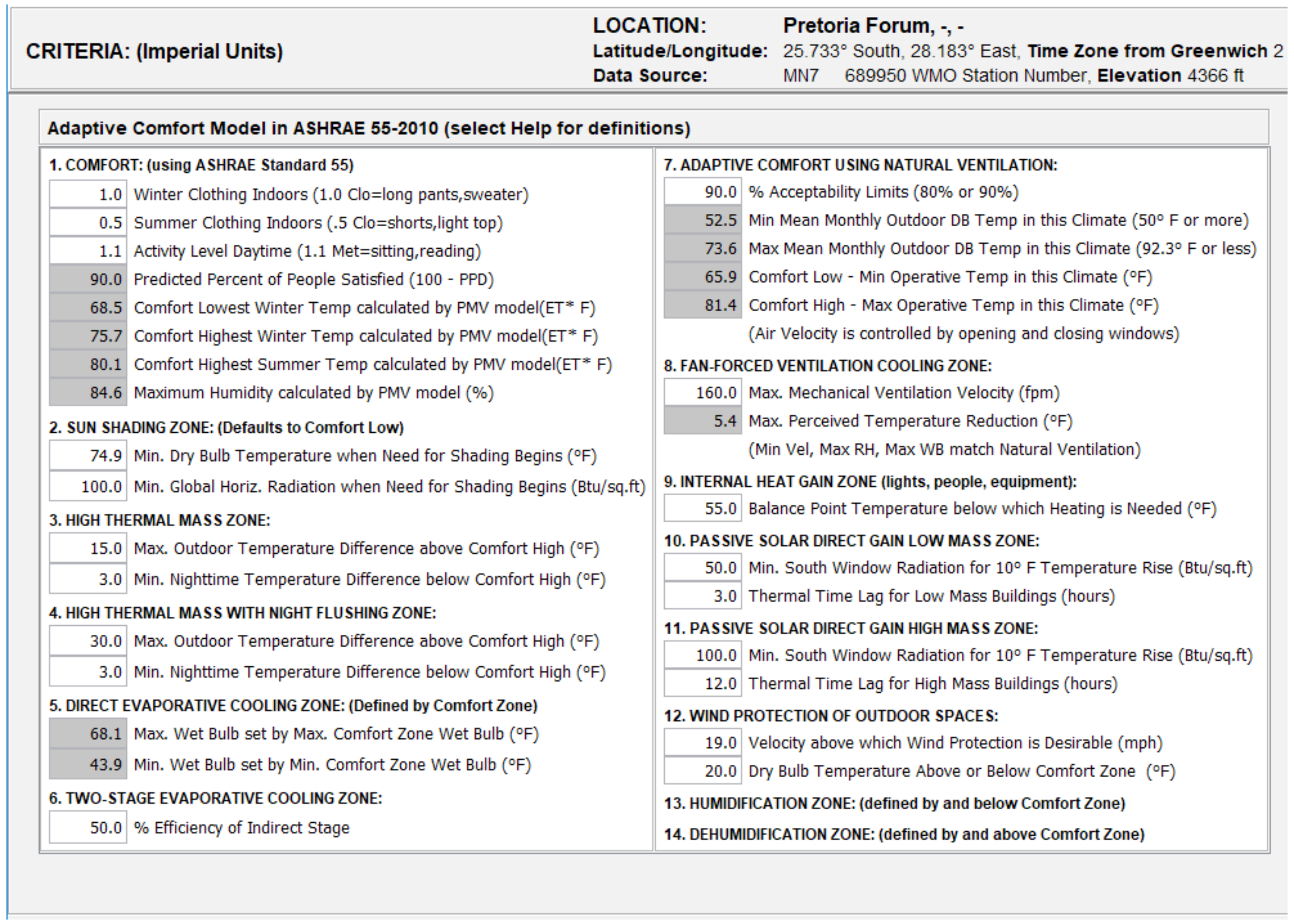


Fig. 156 Crtiteria in Climate Consultant

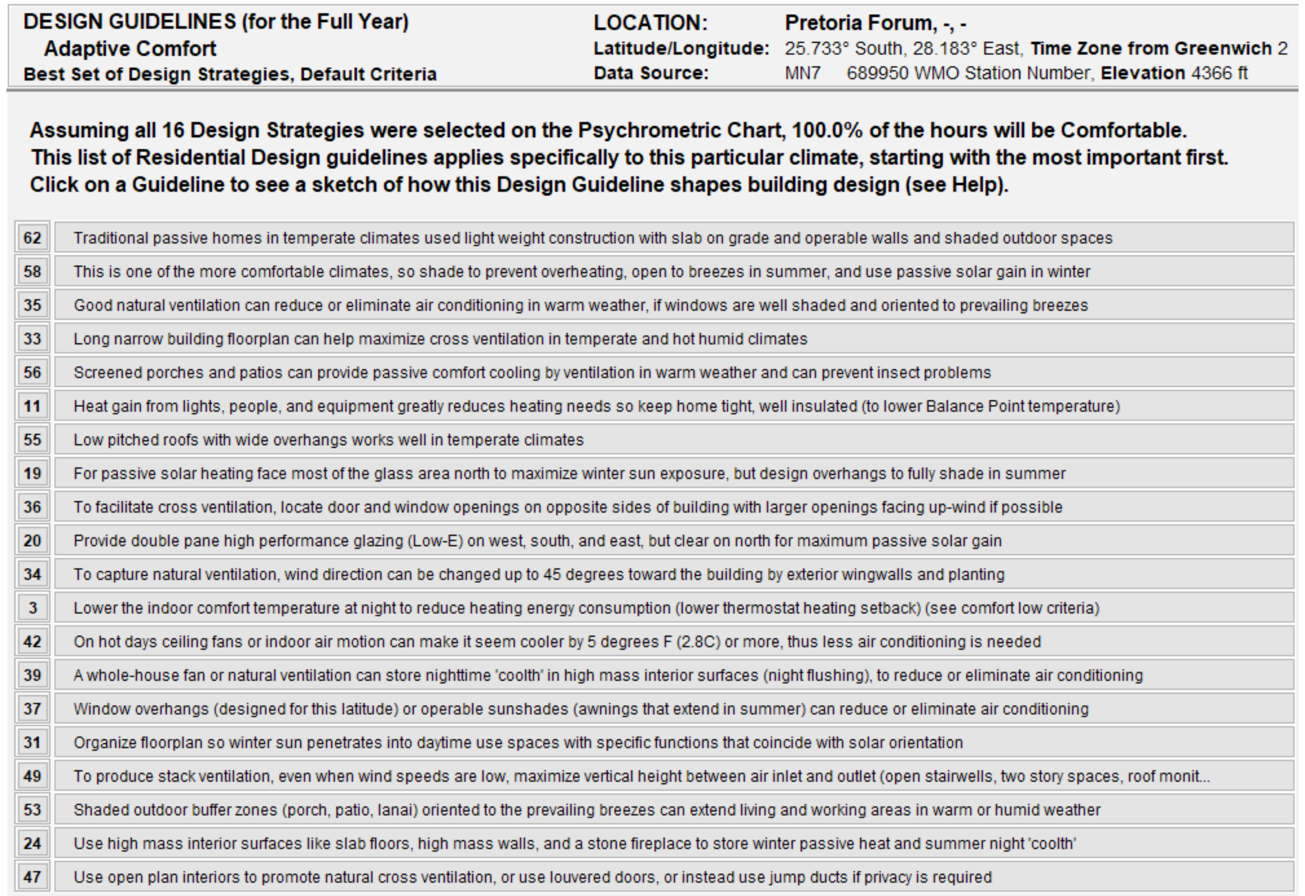


Fig. 157 Design guidelines in Climate Consultant

Appendix II - VABI elements

The Thembelihle simulations are organised the same way as the Butterfly simulations. The things that are different are the materials, the amount of windows and doors and the geometry (the building design).

The basic Thembelihle simulation will be used to describe all of the steps in the software. After this first simulation, the results of the other simulations will be shown. In Chapter 5 the most interesting and important results will be further described.

For both of the buildings two living rooms were picked to simulate with different orientations (north and south), so it would also be visible to see the influence of the orientation. VABI elements simulates the comfort per room, which is why it is possible to compare different rooms.

A2.1 Basic simulation of Thembelihle Village with methodology

After opening the software VABI elements, the project information ("projectgegevens") can be added. The most important step is to import the climate file with the correct climate data for this location, which is shown in Fig. 158. The climate file can be imported within the tab environment ("omgeving"). It is important to check if the file is correct, which is also described on the VABI elements website.

After importing the correct climate file, the tools ("hulpmiddelen") can be set up, as shown in Fig. 159. The correct materials, internal heat gain ("IWP"), the installations for cooling, heating and ventilation and the time schedules of those installations can be chosen and organised for the next step ("sjablonen"), where those parts will be defined.

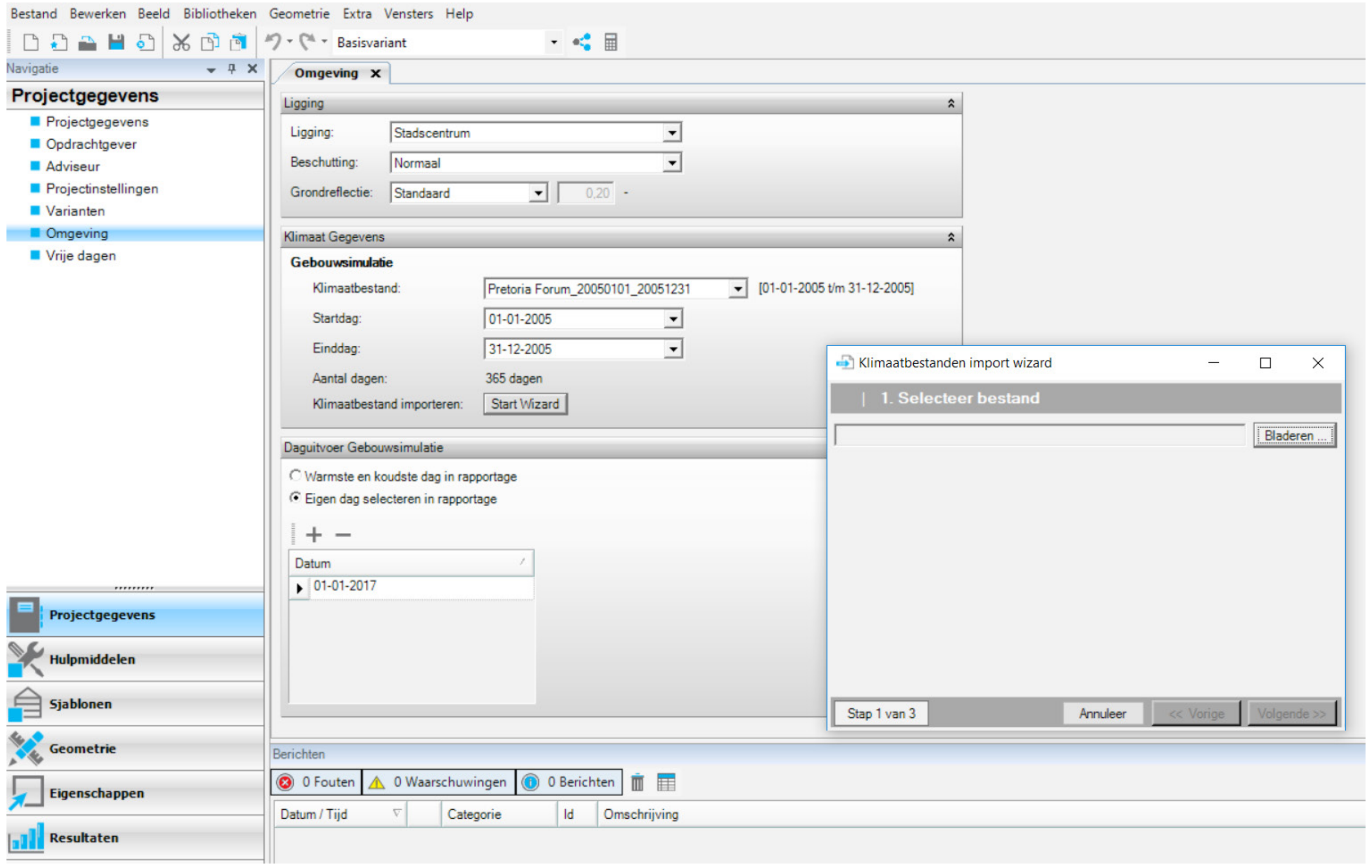


Fig. 158 Import climate file ("klimaatwizard") in VABI elements

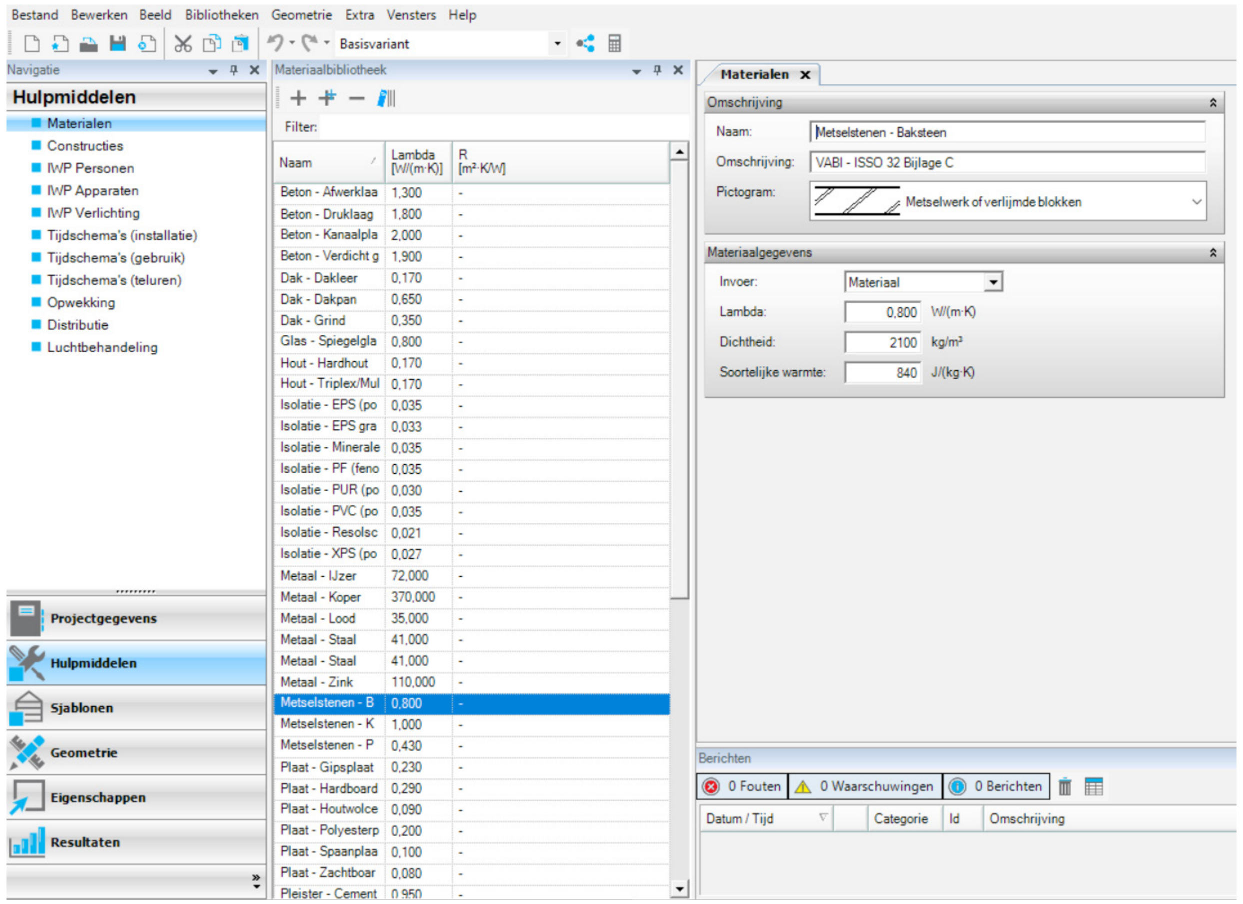


Fig. 159 Tools ("hulpmiddelen") in VABI elements

After organising materials, internal heat gain data, etc. the templates ("sjablonen") with the materials, room specifications and installations data (in this case not needed) could be further defined. In Fig. 160 all of the materials and the different material layers were added. The information from the templates will be used in the simulation. If the materials need to change for some of the improvements, it has to be changed within this part of VABI elements.

The next step is to create the geometry. All of the rooms are created seperately. VABI recognizes the outside walls, the roof and the ground floor. Furthermore the windows and doors need to be added. In Fig. 161 the geometry of Thembelihle Village is shown.

After creating the geometry, the room properties were added. It is important to add the right function to every room, because every function has other properties (venilation, internal heat gain, etc.). In Fig. 162 it is shown how these rooms were organised.

In this part of VABI elements also the building parts could be organised and changed. Most of the building parts were recognized correctly by VABI elements, so it was not necessary to change chose.

This was the last step of preparing the simulations. VABI elements is now able to simulate the building and the rooms.

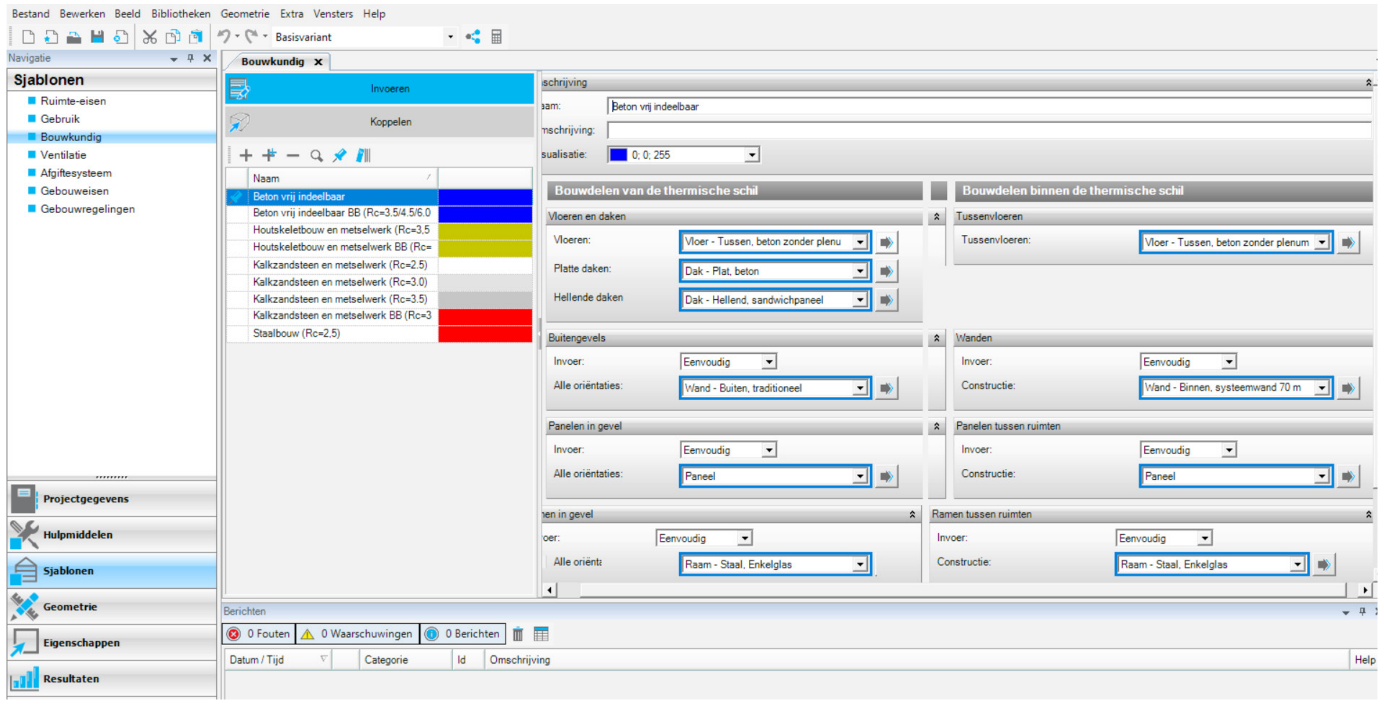


Fig. 160 Templates ("sjablonen") in vabi elements

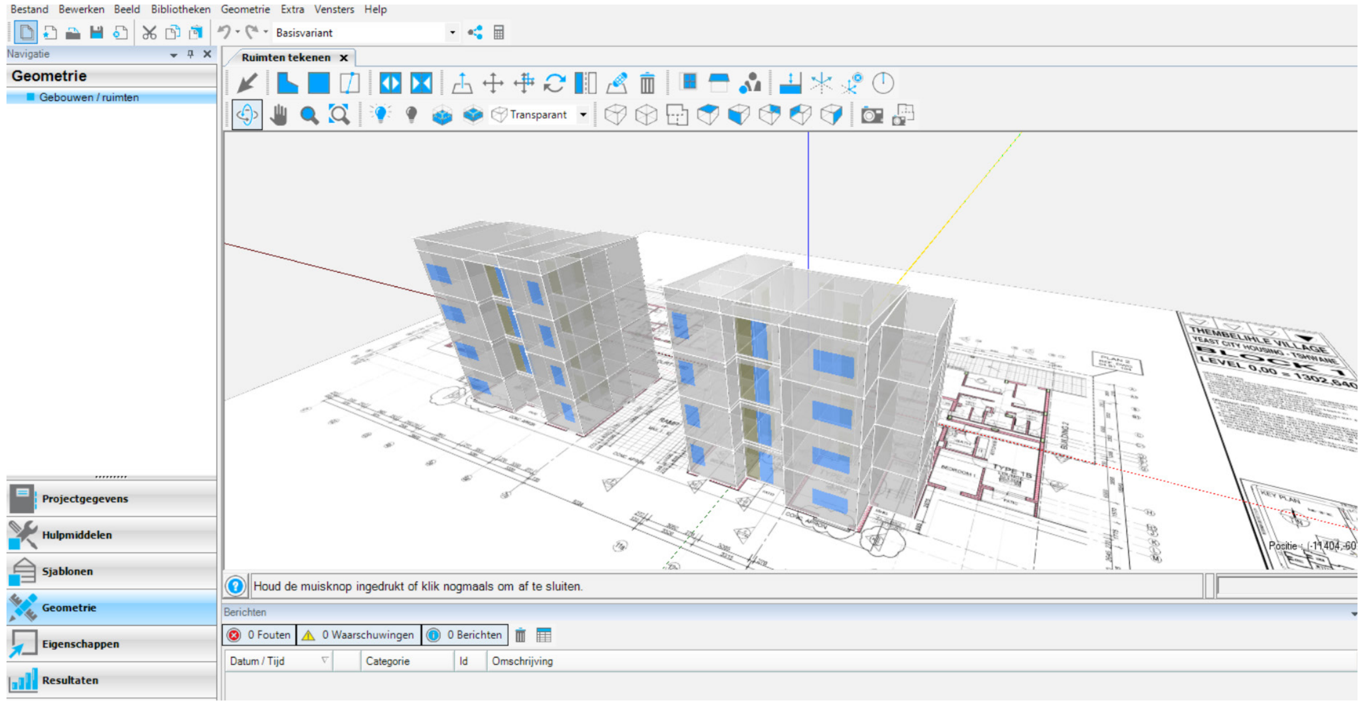


Fig. 161 Geometry in vabi elements

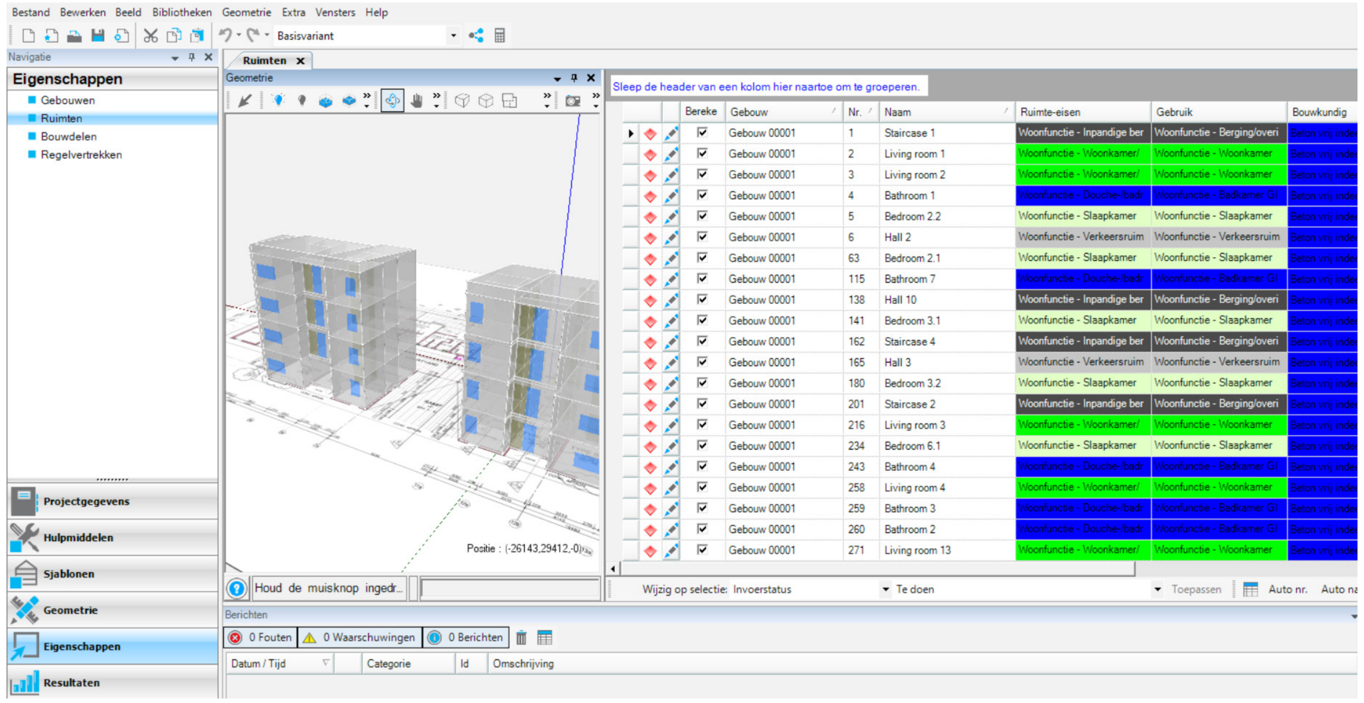


Fig. 162 Geometry in vabi elements

This was the last step of preparing the simulations. VABI elements is now able to simulate the building and the rooms.
When VABI elements simulated the comfort different graphs and figures can be viewed. For this research the comfort graph (Fig. 163) and the comfort temperature and outside temperature year graph (Fig. 164) were used.

The comfort graph shows the comfort in the room per year. Every point in the graph shows a moment per year with different outside temperatures. The vertical axis shows the average outside temperature and the horizontal axis shows the inside temperature. The white area is the "comfort area", the red area is too warm and the blue area is too cold. It is visible that the shape of the "comfort area" changes with higher outside temperatures. This is because the comfort temperature will be higher with higher outside temperatures.

Below the comfort graph a table is shown with three different classes: Klasse A, Klasse C and klasse D. These are the "comfort classes", which predict the percentage of dissatisfaction: Klasse A (5%), Klasse C (15%) and Klasse D (25%). For this research the goal is to focus on Klasse C, with an dissatisfaction of 15%. The table shows the moments when it is too cold ("onderschrijdingen") and when it is too warm ("overschrijdingen"). This means that the numbers in the table for Klasse C should be as low as possible.

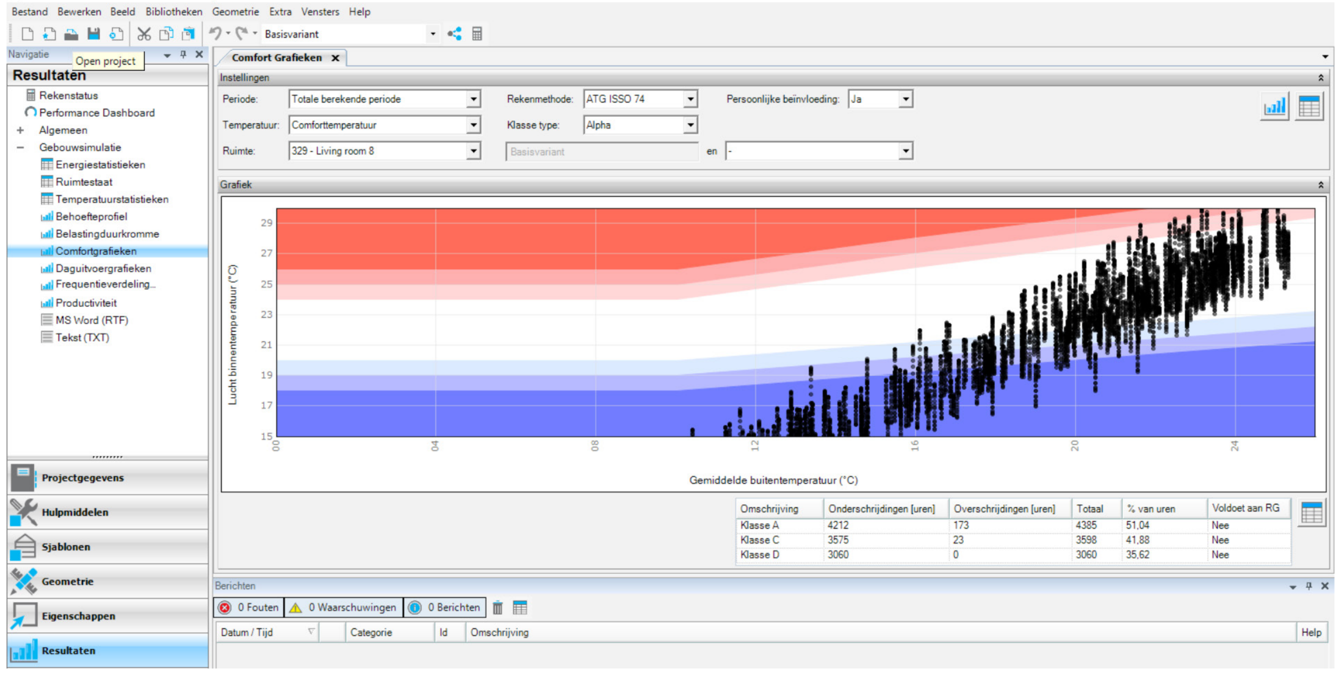


Fig. 163 Comfort graph in VABI elements

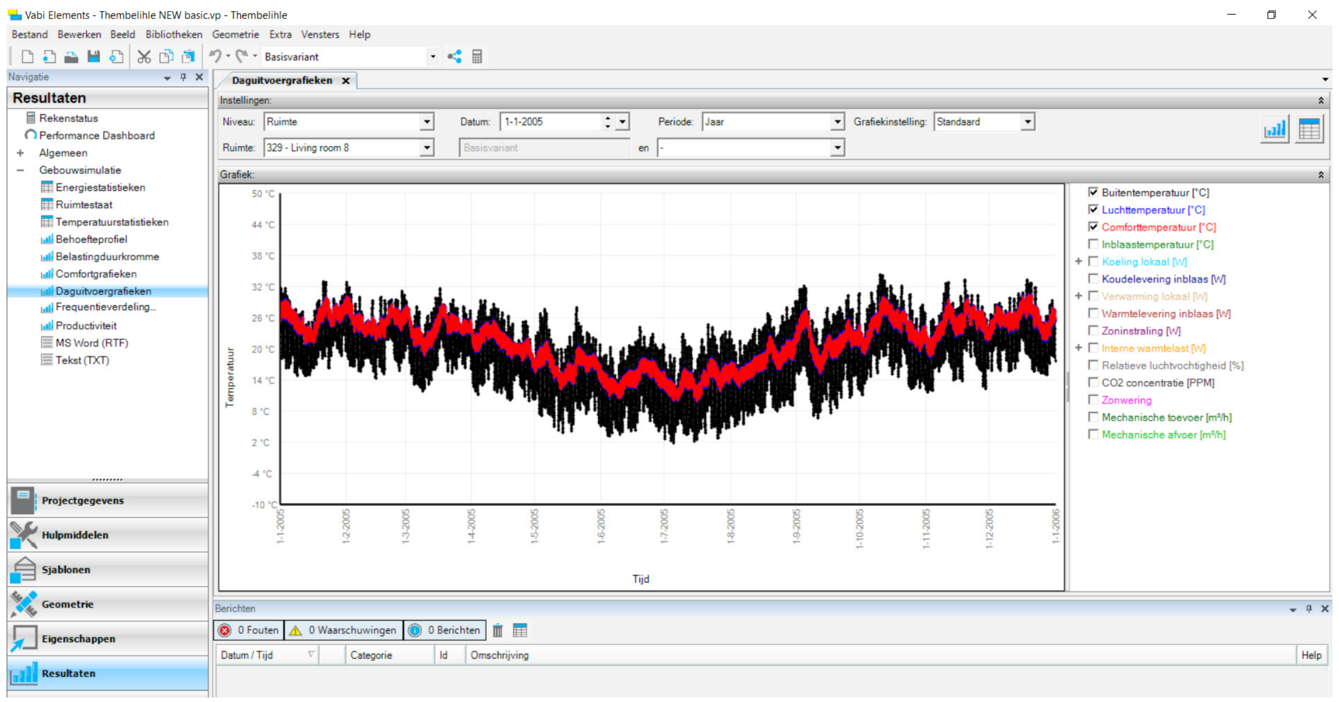


Fig. 164 Comfort temperature and outside temperature year graph in VABI elements

A2.2 Basic simulation of Thembelihle and Butterfly Housing

In Fig. 165 and Fig. 167 the geometrys of Butterfly Housing and Thembelihle village are shown. Two different
living rooms were chosen for both of the buildings.
For Butterfly Housing living room 6 and living room 10 were chosen (as shown in Fig.166). For Thembelihle Vilage living room 5 and living room 8 were chosen (as shown in Fig. 168).

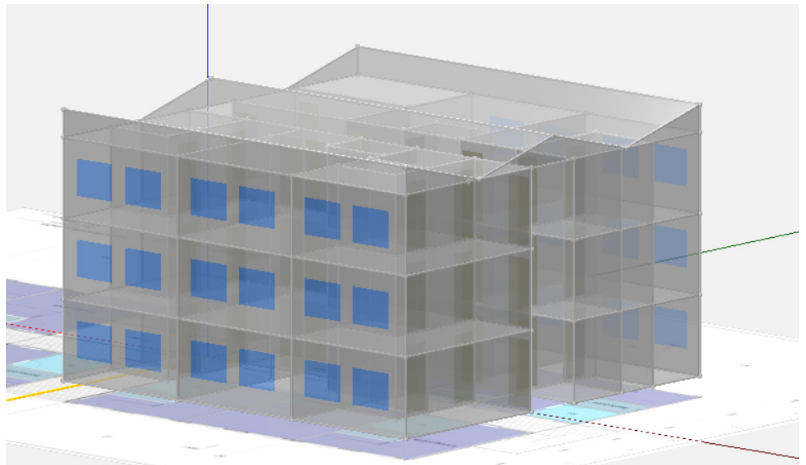


Fig. 165 Geometry in vabi elements

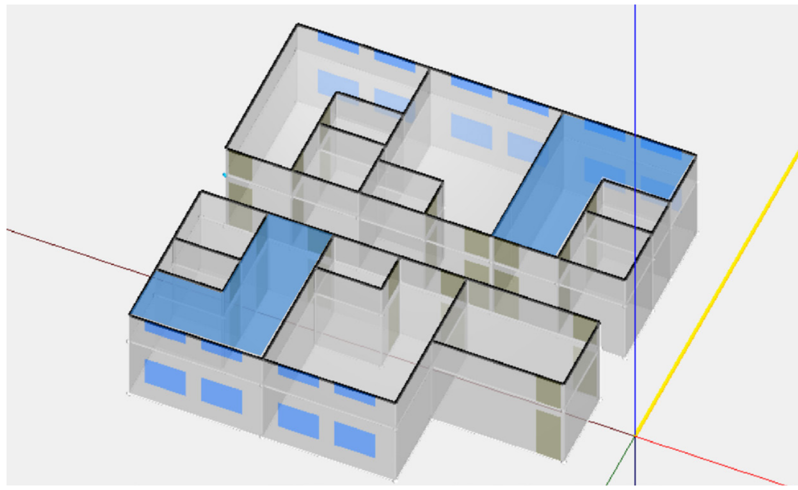


Fig. 166 living room 6 and 10, butterfly

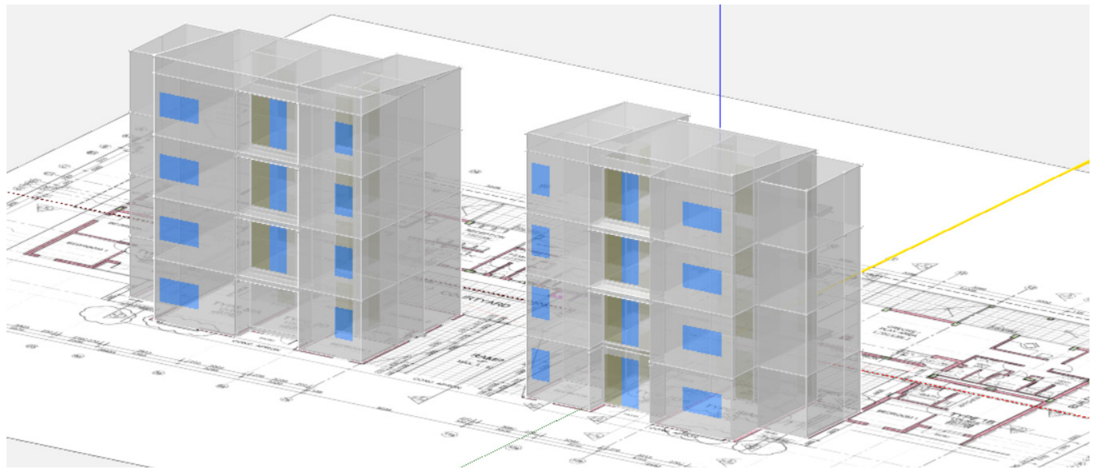


Fig. 167 Geometry in vabi elements

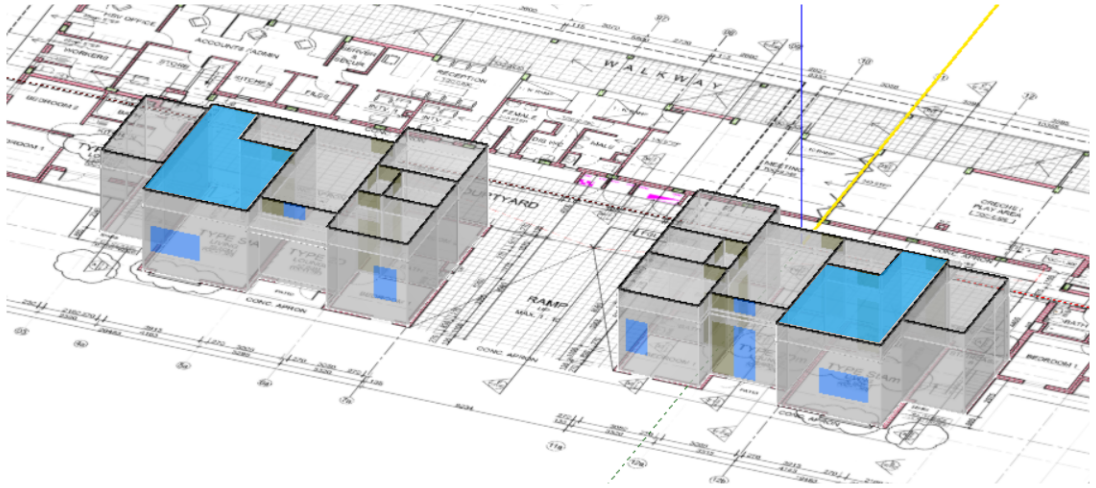


Fig. 168 living room 5 and 8, thembelihle

In Fig. 169 till Fig. 176 the results of the simulations are shown with the comfort graphs and the temperature during the year graphs. Below the tables with the comfort classes are shown.

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4115	347	4462	51,94
Klasse C	3524	120	3644	42,42
Klasse D	3066	9	3075	35,79

Fig. 169 Basic Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	2688	664	3352	39,02
Klasse C	1991	274	2265	26,36
Klasse D	1433	76	1509	17,56

Fig. 170 Basic Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4217	154	4371	50,88
Klasse C	3576	9	3585	41,73
Klasse D	3075	0	3075	35,79

Fig. 171 Basic Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4212	173	4385	51,04
Klasse C	3575	23	3598	41,88
Klasse D	3060	0	3060	35,62

Fig. 172 Basic Thembelihle living room 8 results table

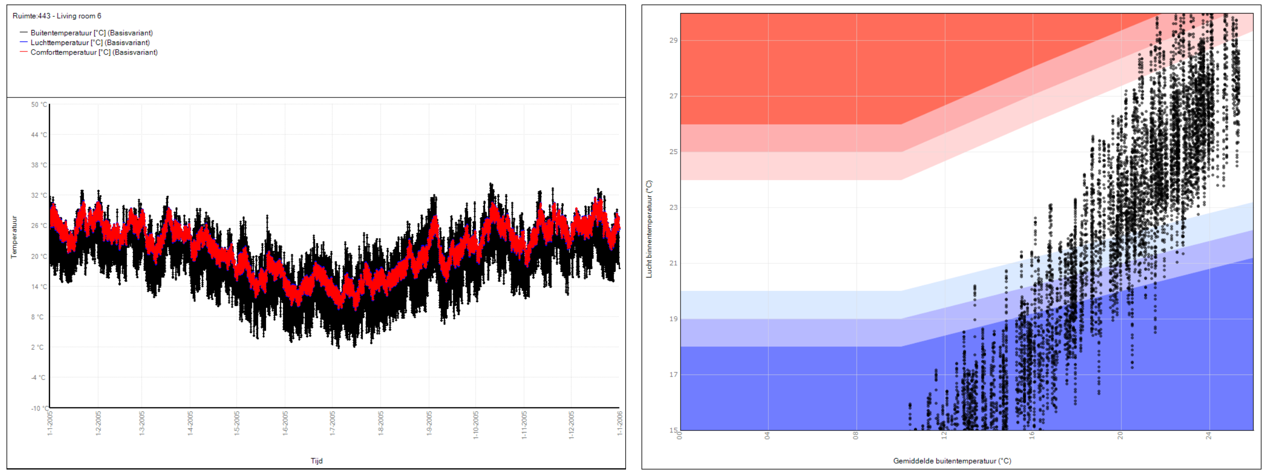


Fig. 173 Basic Butterfly living room 6 results

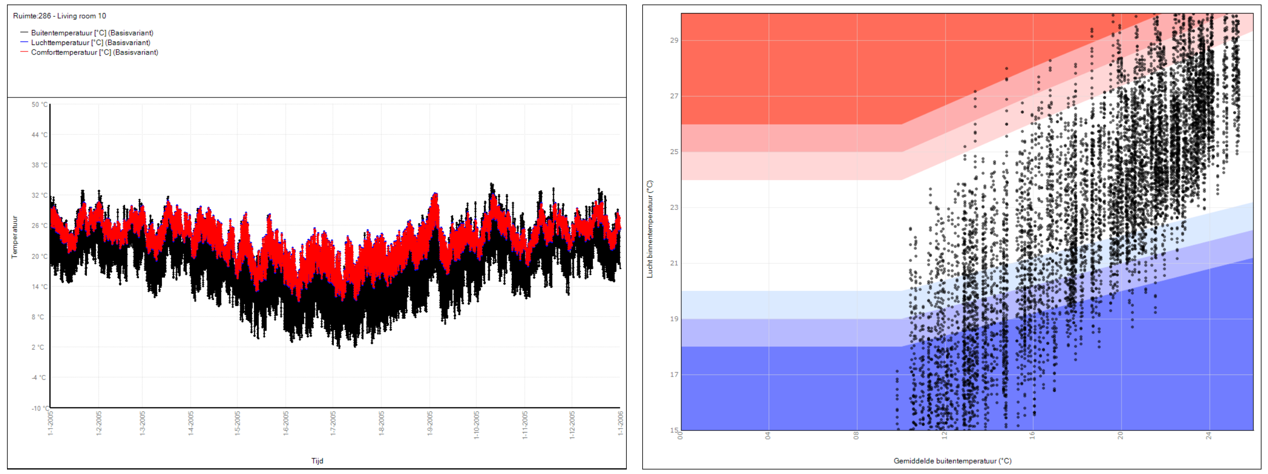


Fig. 174 Basic Butterfly living room 10 results

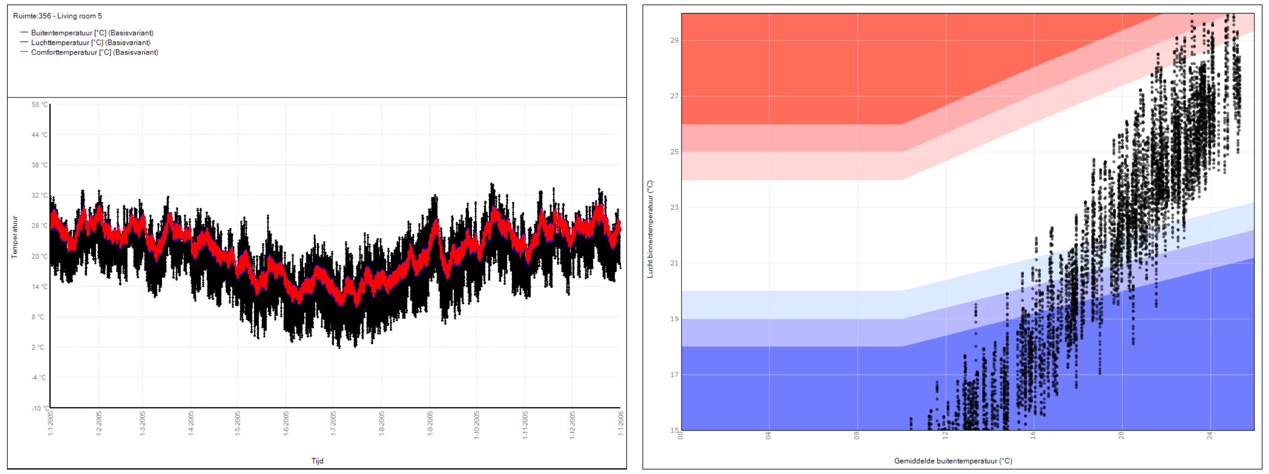


Fig. 175 Basic Thembelihle living room 5 results

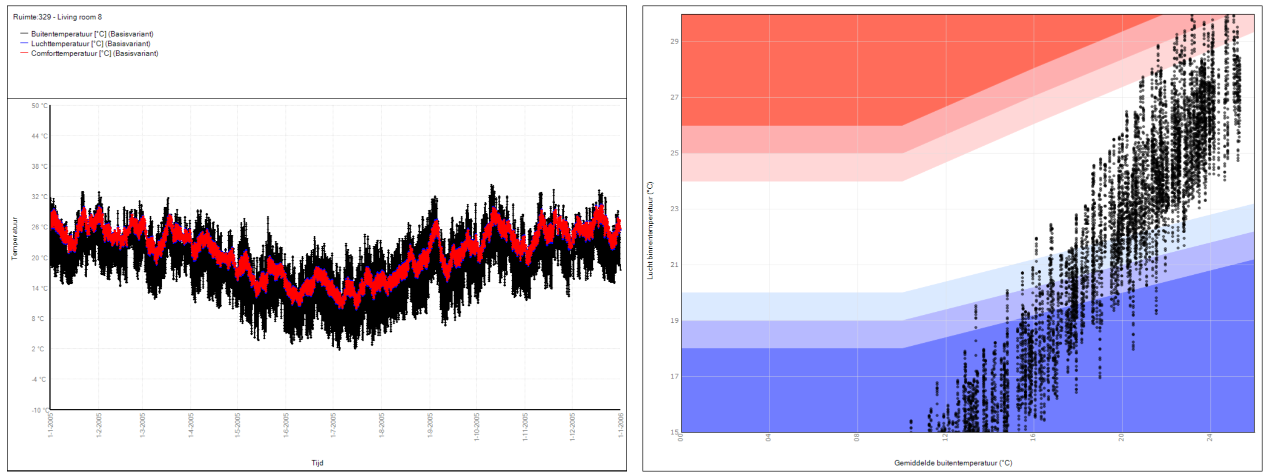


Fig. 176 Basic Thembelihle living room 8 results

A2.3 Second simulation of Thembelihle and Butterfly housing

The second simulation includes:
- a lightweight construction
- overhang by the roof
- operable walls

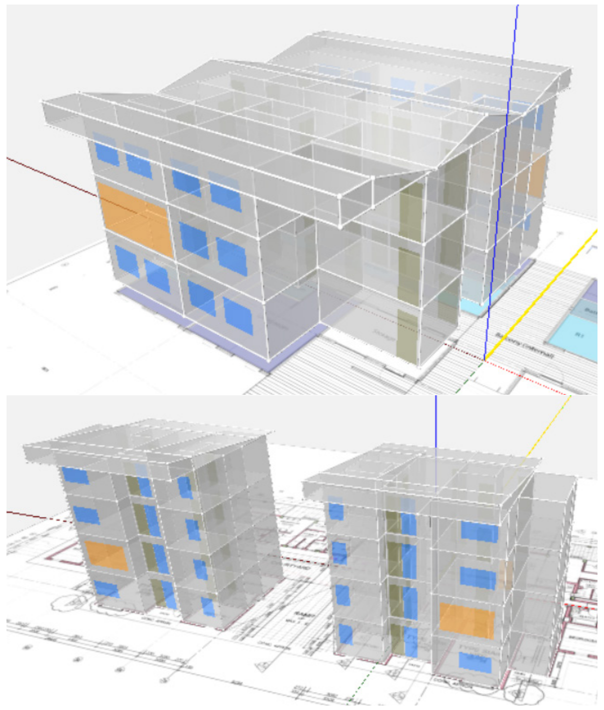


Fig. 177 Geometries Butterfly Housing and Thembelihle Village for second simulation

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4300	260	4560	53,08
Klasse C	3668	99	3767	43,85
Klasse D	3138	13	3151	36,68

Fig. 178 Second simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4028	289	4317	50,25
Klasse C	3336	82	3418	39,79
Klasse D	2651	5	2656	30,92

Fig. 179 Second simulation Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4703	325	5028	58,53
Klasse C	3983	119	4102	47,75
Klasse D	3346	41	3387	39,42

Fig. 180 Second simulation Thembelihle living room 5 table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4672	294	4966	57,80
Klasse C	3949	109	4058	47,24
Klasse D	3339	22	3361	39,12

Fig. 181 Second simulation Thembelihle living room 8 table

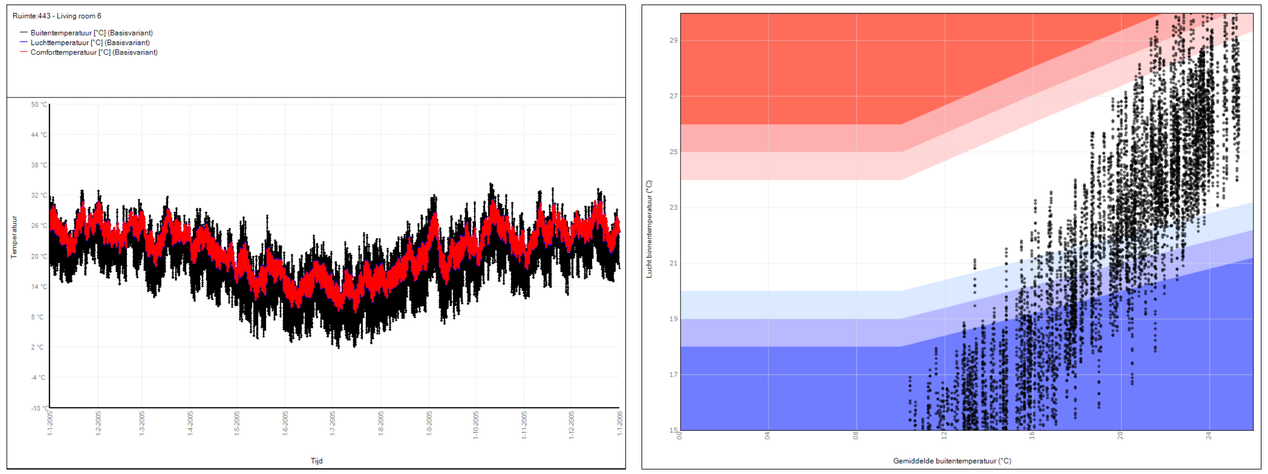


Fig. 182 Second simulation Butterfly living room 6 results

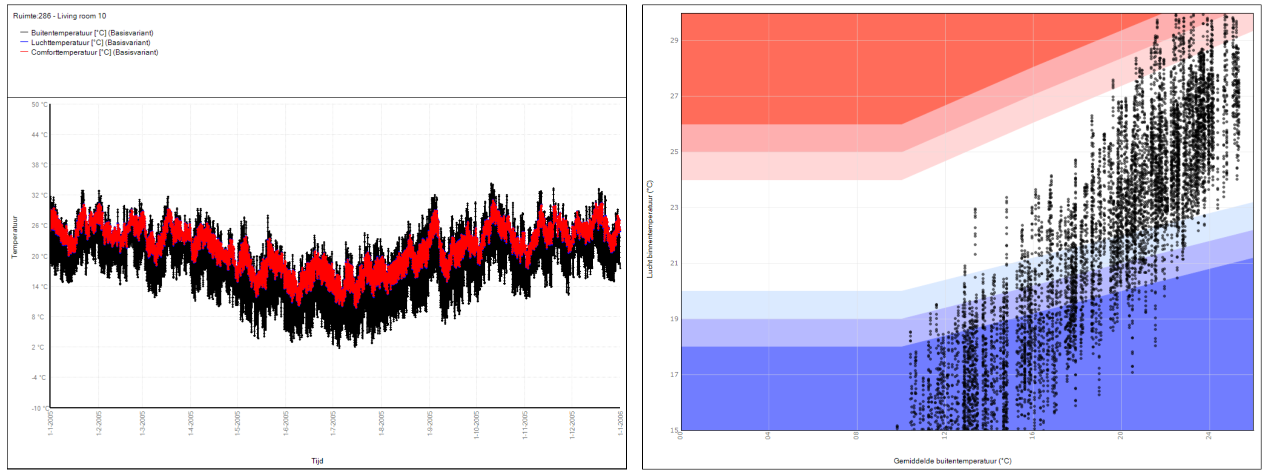


Fig. 183 Second simulation Butterfly living room 10 results

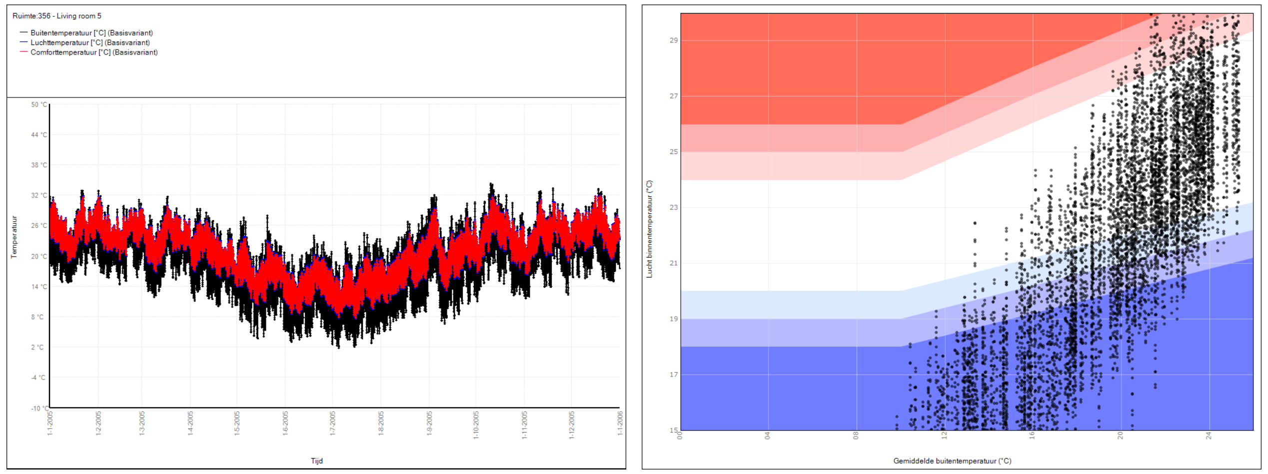


Fig. 184 Second simulation Thembelihle living room 5 results

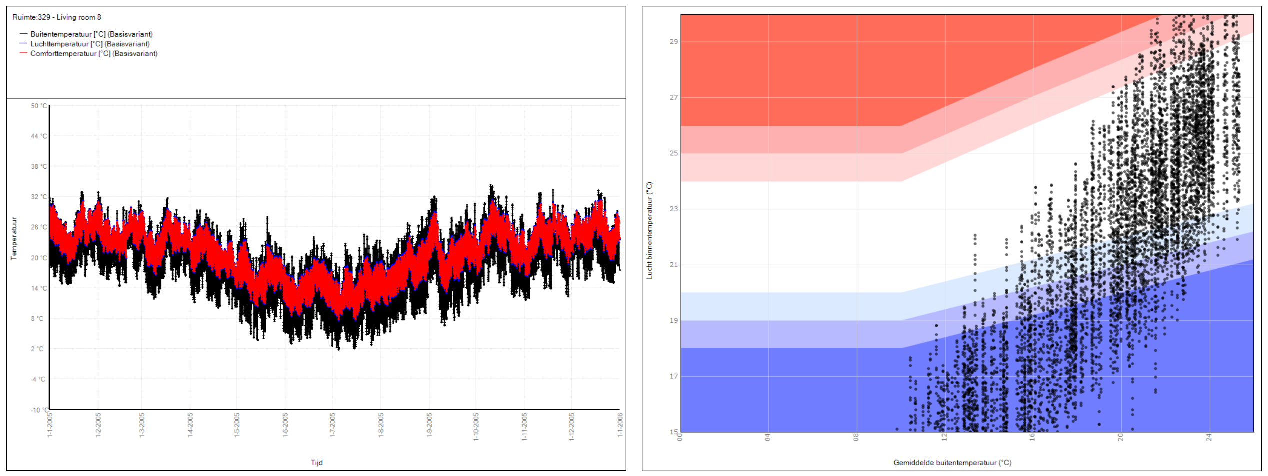


Fig. 185 Second simulation Thembelihle living room 5 results

A2.4 Third simulation of Thembelihle and Butterfly Housing

The third simulation includes:
- shading above the windows
- open windows to breeze
- use of passive solar gain in winter (glass on north facade)

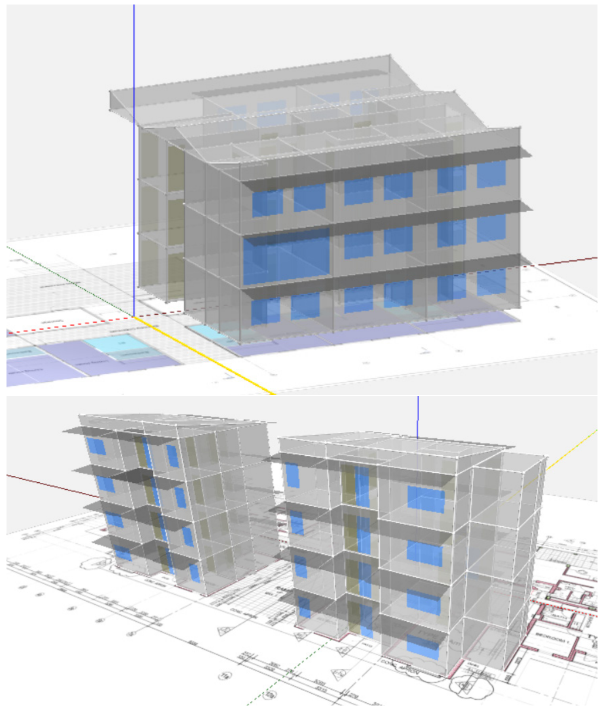


Fig. 186 Geometries

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4362	207	4569	53,18
Klasse C	3695	36	3731	43,43
Klasse D	3175	0	3175	36,96

Fig. 187 Third simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3798	386	4184	48,70
Klasse C	2947	153	3100	36,08
Klasse D	2258	23	2281	26,55

Fig. 188 Third simulation Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4405	86	4536	52,80
Klasse C	3768	4	3772	43,91
Klasse D	3213	0	3213	37,40

Fig. 189 Third simulation Thembelihle living room 5 table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4472	100	4572	53,22
Klasse C	3773	0	3773	43,92
Klasse D	3230	0	3230	37,60

Fig. 190 Third simulation Thembelihle living room 8 table

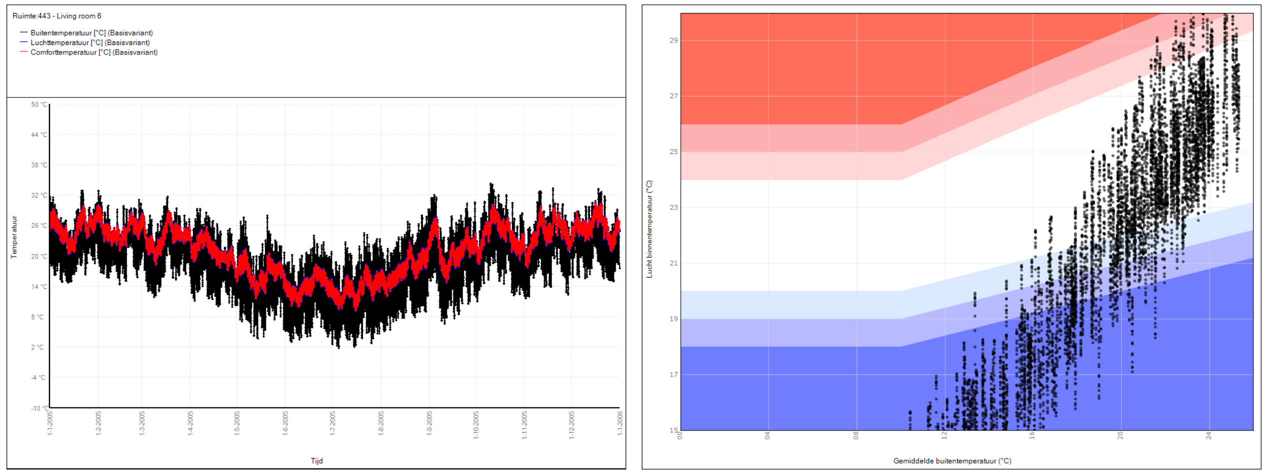


Fig. 191'8 Third simulation Butterfly living room 6 results

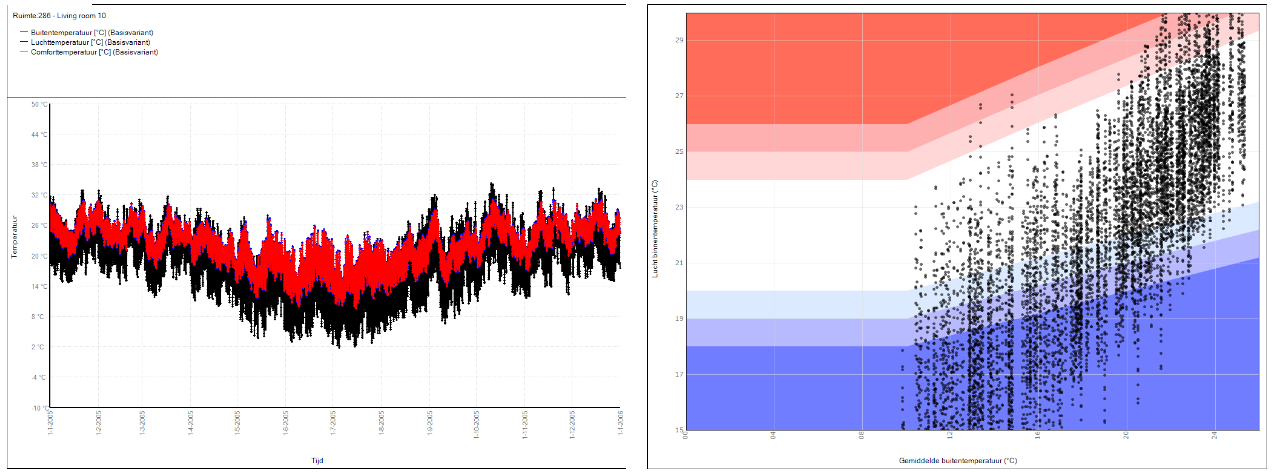


Fig. 1920 Third simulation Butterfly living room 10 results

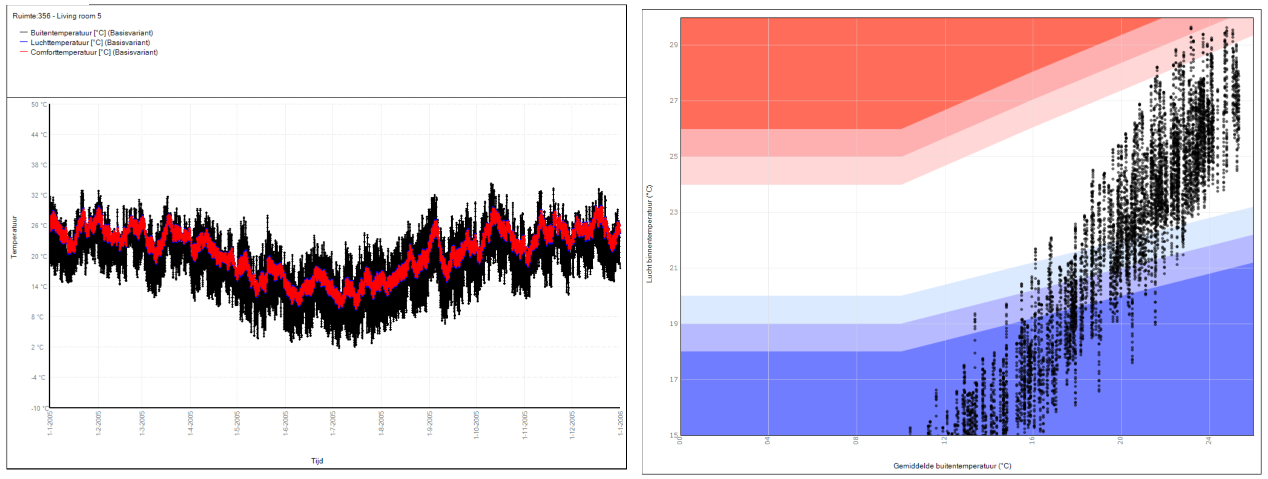


Fig. 193'0 Third simulation Thembelihle living room 5

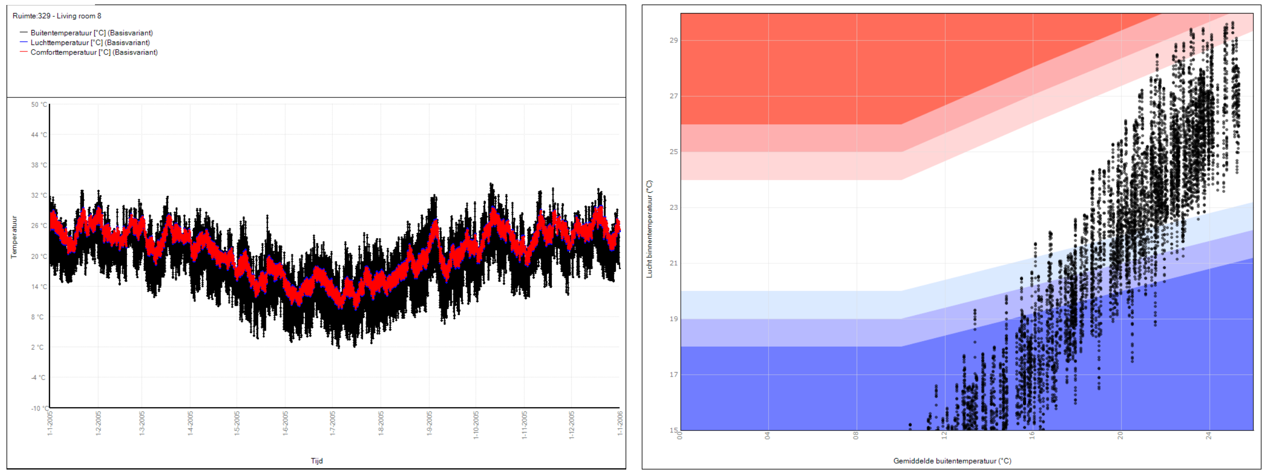


Fig. 194'1 Third simulation Thembelihle living room 8

A2.5 Fourth simulation of Thembelihle and Butterfly Housing

The fourth simulation includes:
- insulated walls and roofs

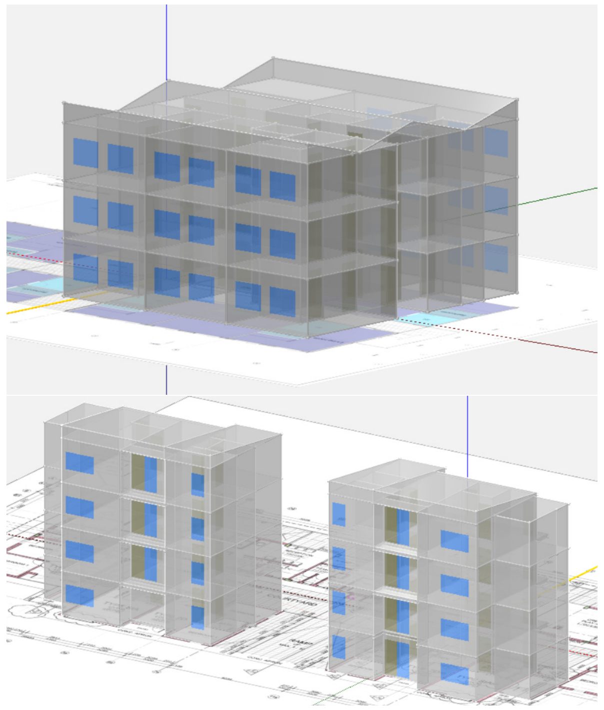


Fig. 195 Geometries

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3584	210	3794	44,16
Klasse C	3141	20	3161	36,79
Klasse D	2721	0	2721	31,67

Fig. 196 Fourth simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	1662	458	2120	24,68
Klasse C	1054	71	1125	13,10
Klasse D	572	14	586	6,82

Fig. 197 Fourth simulation Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3656	17	3673	42,75
Klasse C	3149	0	3149	36,65
Klasse D	2704	0	2704	31,47

Fig. 198 Fourth simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3672	15	3687	42,92
Klasse C	3158	0	3158	36,76
Klasse D	2709	0	2709	31,53

Fig. 199 Fourth simulation Thembelihle living room 8 results table

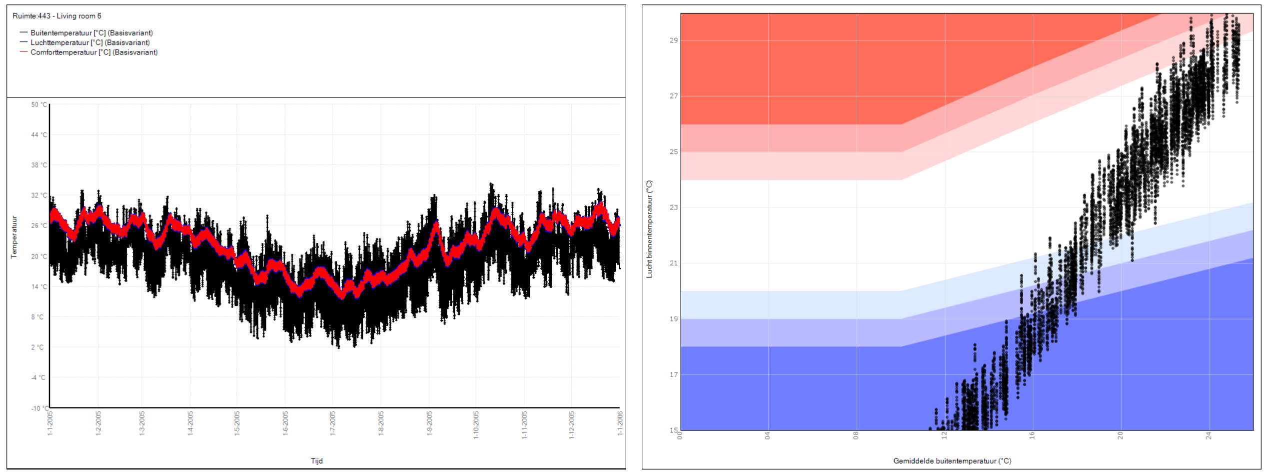


Fig. 200 Fourth simulation Butterfly living room 6 results

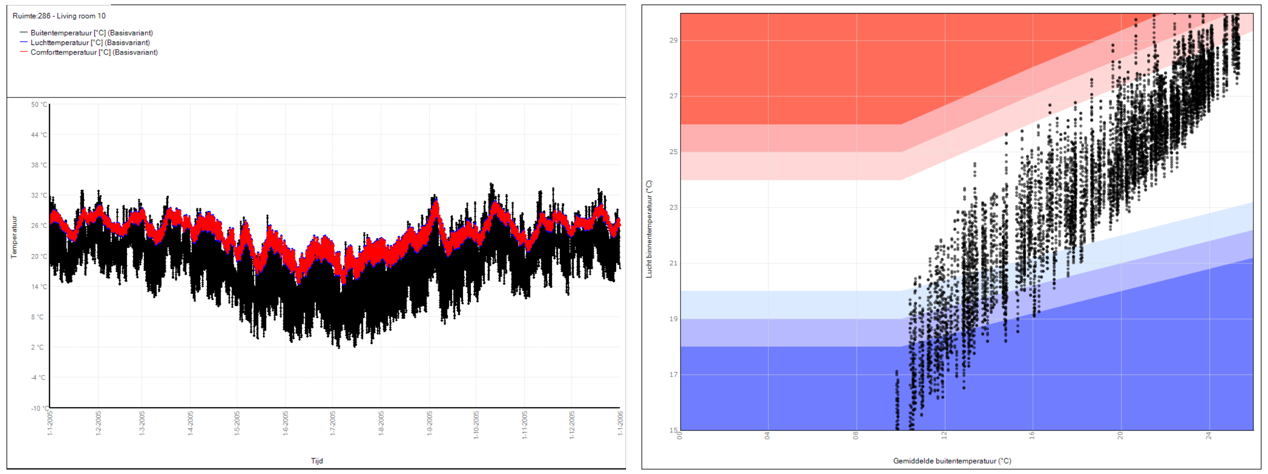


Fig. 201 Fourth simulation Butterfly living room 10 results

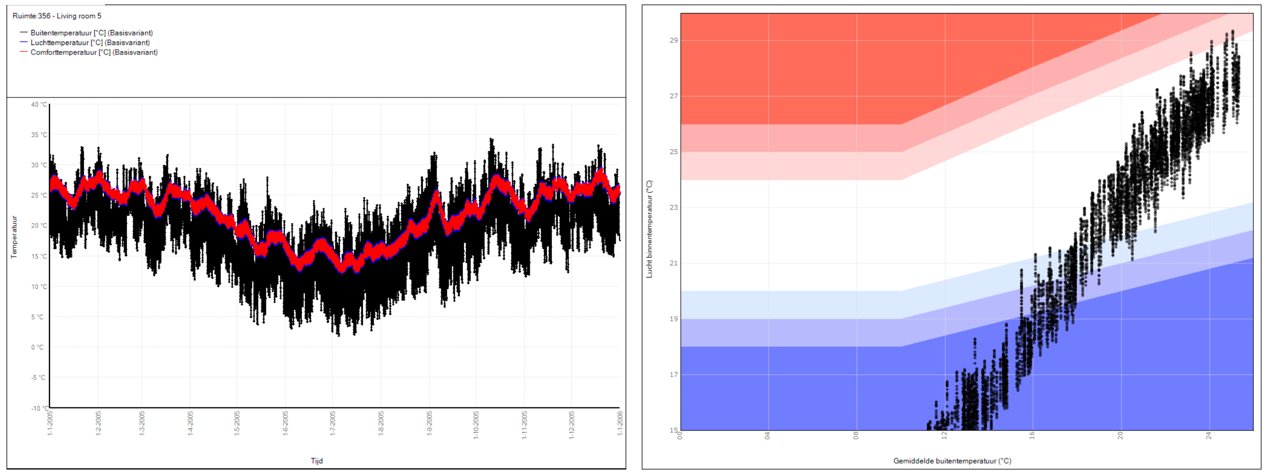


Fig. 202) Fourth simulation Thembelihle living room 5

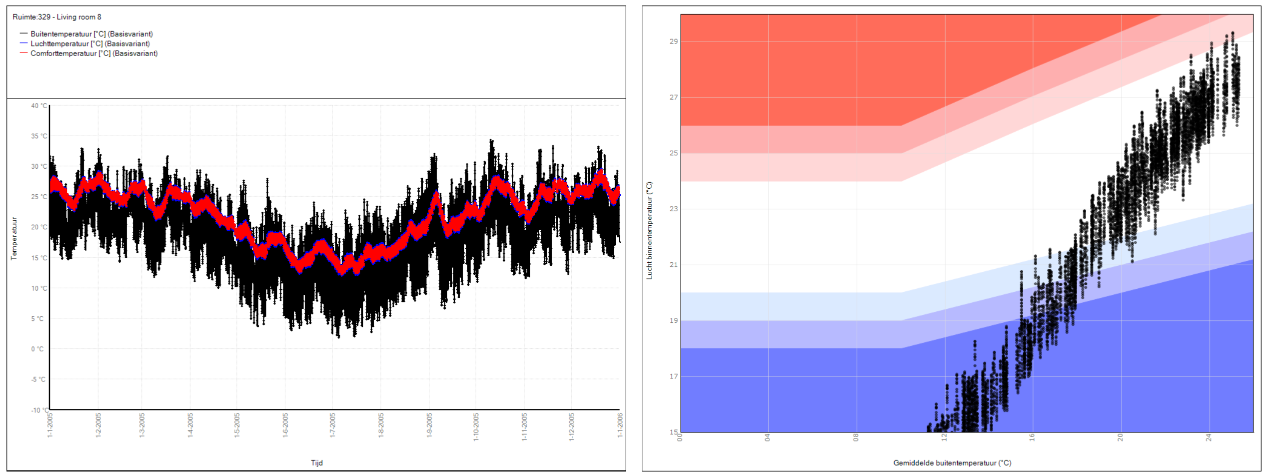


Fig. 203 Fourth simulation Thembelihle living room 8

A2.6 Fifth simulation of Thembelihle and Butterfly Housing

The fifth simulation includes:
- singe glass windows and doors changed to e glass

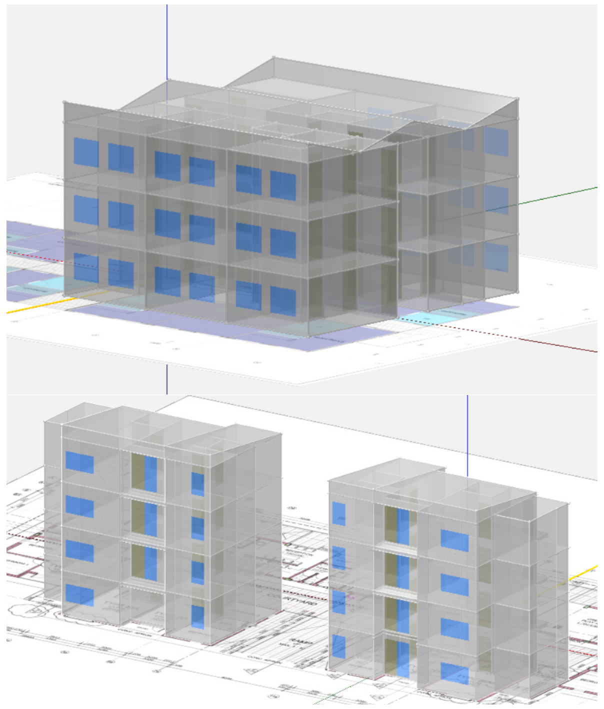


Fig. 204 Geometries

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4234	184	4418	51,43
Klasse C	3573	19	3592	41,81
Klasse D	3058	0	3058	35,60

Fig. 205 Fifth simulation Butterfly living room 6 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	3714	247	3961	46,11
Klasse C	2992	32	3024	35,20
Klasse D	2356	0	2356	27,42

Fig. 206 Fifth simulation Butterfly living room 10 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4310	67	4377	50,95
Klasse C	3616	0	3616	42,09
Klasse D	3089	0	3089	35,96

Fig. 207 Fifth simulation Thembelihle living room 5 results table

Class	Too cold [h]	Too warm [h]	Total	% hours
Klasse A	4318	82	4400	51,22
Klasse C	3620	0	3620	42,14
Klasse D	3075	0	3075	35,79

Fig. 208 Fifth simulation Thembelihle living room 8 results table

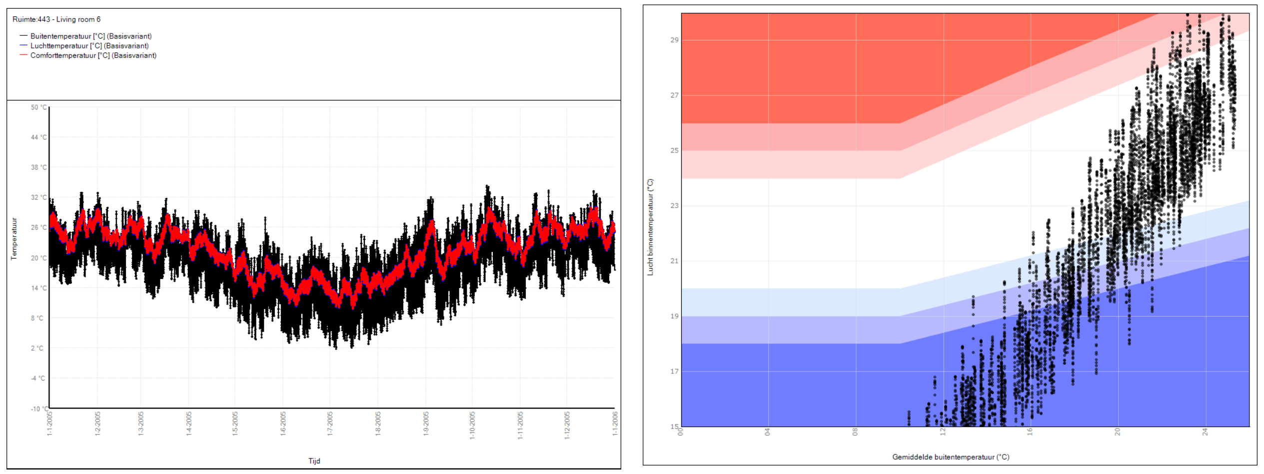


Fig. 209 Fifth simulation Butterfly living room 6 results

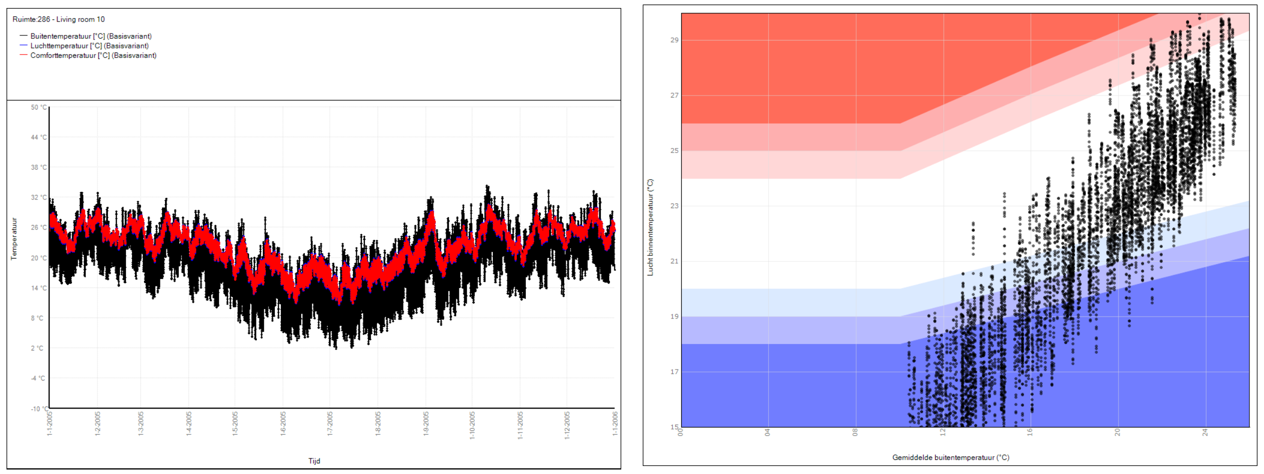


Fig. 210 Fifth simulation Butterfly living room 10 results

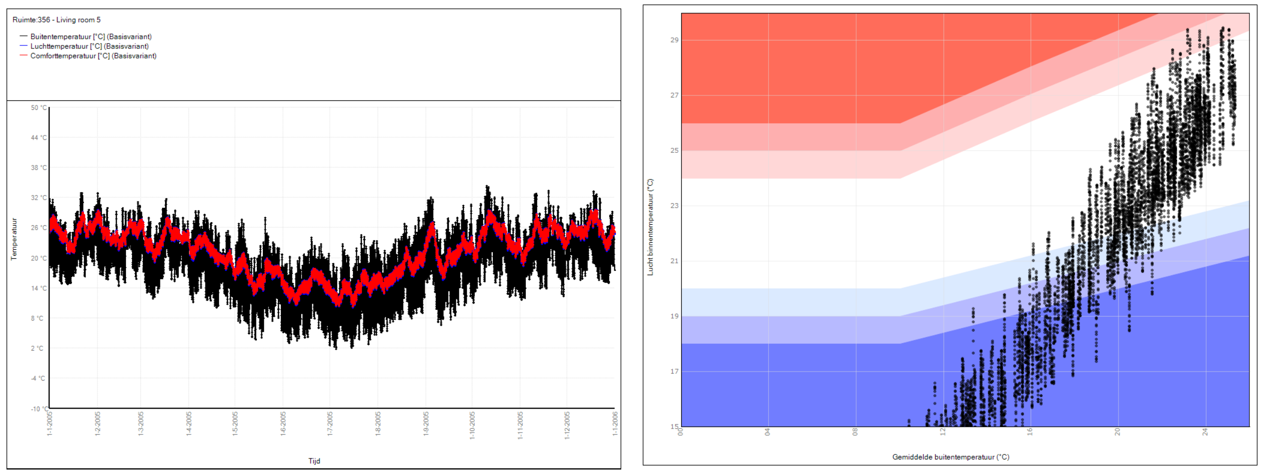


Fig. 211 Fifth simulation Thembelihle living room 5 results

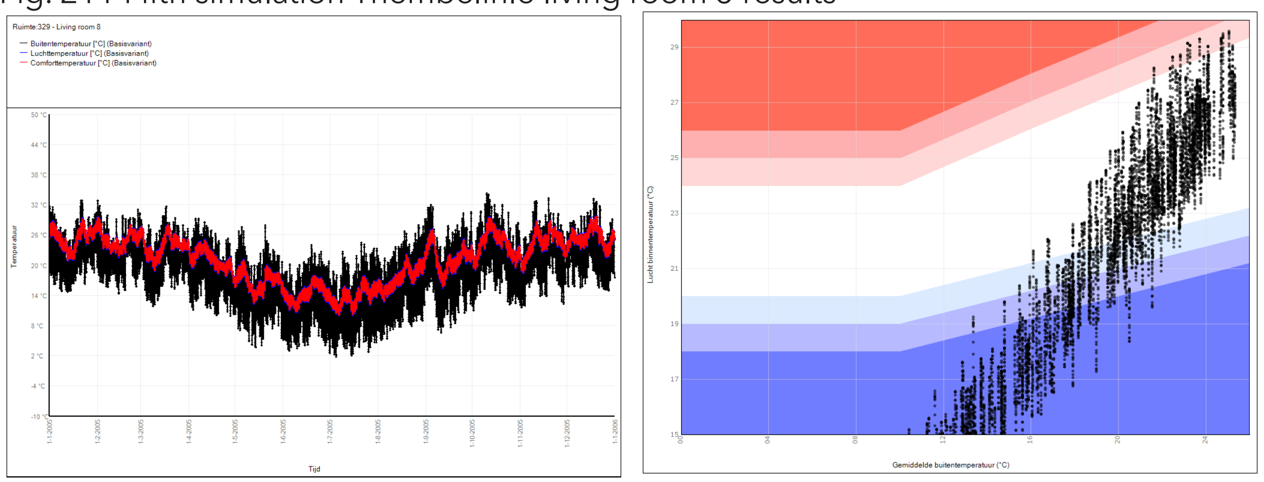


Fig. 212 Fifth simulation Butterfly living room 8 results

Appendix III - Simulations energy use

To be able to analyze how much energy will be saved by implementing the design solutions, the energy use was simulated in VABI elements. First the current simulation of both buildings was simulated. Then the new situation of both buildings was simulated, to be able to compare the results.

In Fig. 213 it is shown how the installations were added in VABI. The time schedule shows when the installations could be used. At the tab "afgifte-apparaten" the small radiators and airconditioning devices were added.

On the following pages the results of the simulations are shown, starting with Thembelihle.

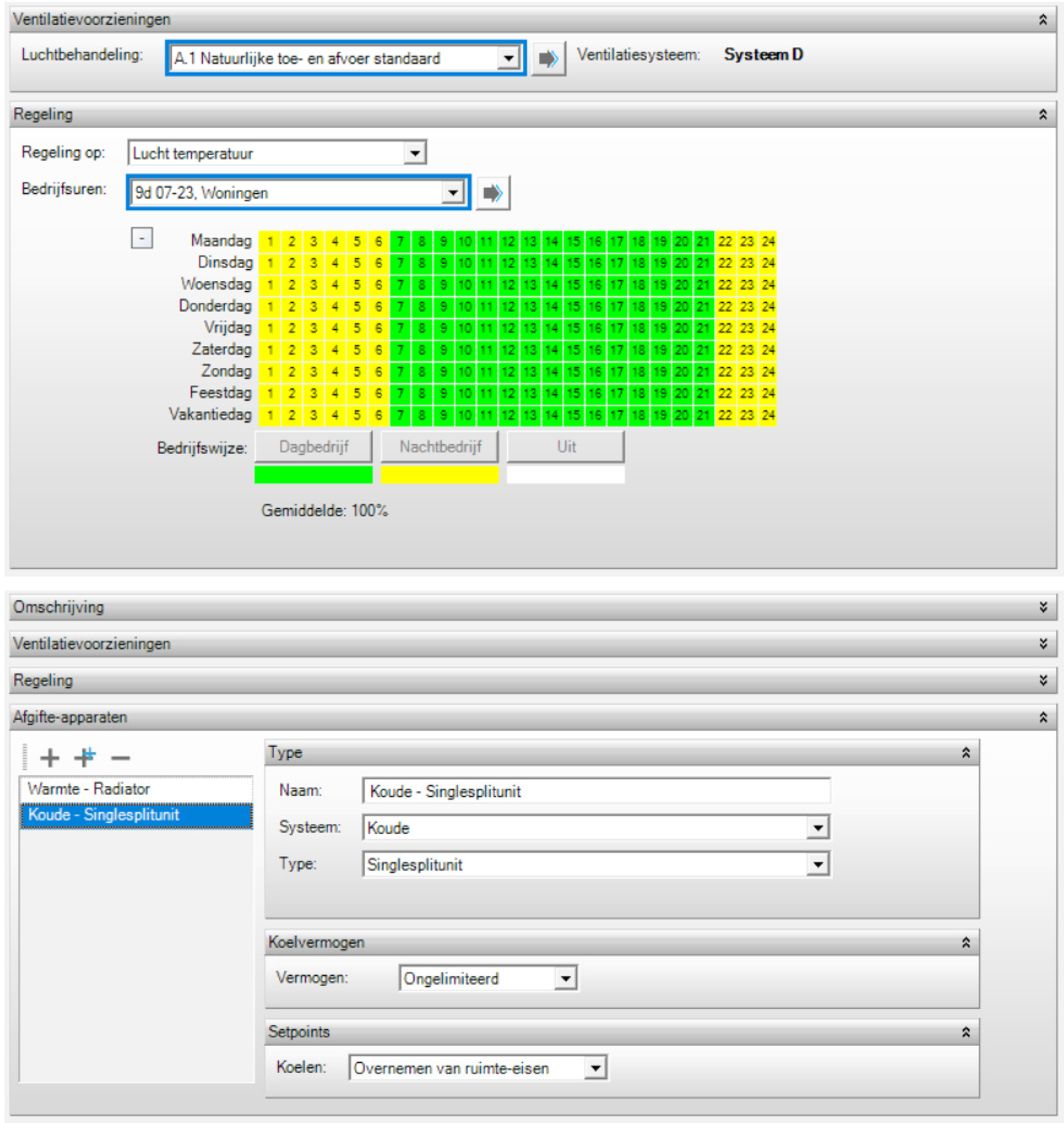


Fig. 213 Creating time schedules and adding installations to VABI elements

THEMBELIHLE

IMPROVED:

Living room 8	958,2690805	-931,2184393

0,86 Rand per kwh

basis totaal	68637	kWh
nieuw totaal	12092	kWh
verschil	56545	kWh

(Kwh*0,86)

27,05064127	23,26355149	**50,31**	ZAR

TOTAL SAVINGS FOR LIVING ROOM 8:

50,31	ZAR	**377,36**	only 1 living room
3,35	EURO	**25,16**	only 1 living room

Totaal hele gebouw in VABI: **48628,70 ZAR**

3241,91 EURO

6,07 > years payback time

BUTTERFLY

IMPROVED:

Living room 10	251,4835535	-162,5731649

0,86 Rand per kwh

basis totaal	58763	kWh
nieuw totaal	40651	kWh
verschil	18112	kWh

(Kwh*0,86)

216,275856	-139,8129218	**76,4629342**	ZAR

TOTAL SAVINGS FOR LIVING ROOM 10:

76,46	ZAR	**573,472**	only 1 living room
5,10	EURO	**360**	only 1 living room

Totaal hele gebouw in VABI: **15576,32 ZAR**

1038,42 EURO

17,76 > years payback time

	Nummer Ruimte	Naam Ruimte	Warmtelevering lokale apparaten [kWh]	Maximum warmteafgifte lokale apparaten [W]	Datum maximum warmteafgifte lokale apparaten	Koudelevering lokale apparaten [kWh]	Maximum koudeafgifte lokale apparaten [W]	Datum maximum koudeafgifte lokale apparaten
CURRENT	329	Living room 8	**958,2838695**	1078,381348	5-7-2005 06:00	**443,8062796**	674,2233887	16-12-2005 18:00

	Nummer Ruimte	Naam Ruimte	Warmtelevering lokale apparaten [kWh]	Maximum warmteafgifte lokale apparaten [W]	Datum maximum warmteafgifte lokale apparaten	Koudelevering lokale apparaten [kWh]	Maximum koudeafgifte lokale apparaten [W]	Datum maximum koudeafgifte lokale apparaten
NEW	439	Living room 8	**0,014789019**	14,78901863	9-6-2005 06:00	**1375,024719**	1075,65979	21-5-2005 15:00

	Nummer Ruimte	Naam Ruimte	Warmtelevering lokale apparaten [kWh]	Maximum warmteafgifte lokale apparaten [W]	Datum maximum warmteafgifte lokale apparaten	Koudelevering lokale apparaten [kWh]	Maximum koudeafgifte lokale apparaten [W]	Datum maximum koudeafgifte lokale apparaten
NEW	**286**	**Living room 10**	**2,008667708**	**215,7467041**	**9-6-2005 07:00**	**1009,071148**	**893,300354**	**21-5-2005 17:00**

	Nummer Ruimte	Naam Ruimte	Warmtelevering lokale apparaten [kWh]	Maximum warmteafgifte lokale apparaten [W]	Datum maximum warmteafgifte lokale apparaten	Koudelevering lokale apparaten [kWh]	Maximum koudeafgifte lokale apparaten [W]	Datum maximum koudeafgifte lokale apparaten
CURRENT	**286**	**Living room 10**	**253,4922212**	**832,0667114**	**15-7-2005 06:00**	**846,4979831**	**1012,89386**	**4-9-2005 16:00**

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