DESIGN OFF-GRID NEGIN SAFARI PARK

Passive techniques to reduce the energy demand

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DESIGN OFF-GRID NEGIN SAFARI PARK

Passive techniques to reduce the energy demand

in partial fulfilment of the requirements for the degree of

Master of Science
in Building Technology

at the Delft University of Technology

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BUILDING TECHNOLOGY GRADUATION | TUDELFT

PREFACE

You are now about to read my graduation thesis 'Design off-grid Negin Safari Park'. This research is initiated by the Simba Nature Protection and Education Foundation and will look for an optimal design for a safari park in Iran. After 4 years of studying on the TU Delft I was interested in designing outside the Netherlands and discovering the opportunities of a different climate. This research is written in the context of my graduation on Building Technology. Therefore, not only a design is made for the safari park, but also the technical aspects are taken into account.

I want to thank several people, who helped me writing this thesis. Of course, first the Simba Nature Protection and Education foundation, and especially Marjan van der Schaaf, for her involvement in this research and for her meaningful feedback. But also Ali Reza Osanlou and the engineers from Zagros, who gave feedback during the process.

Next I want to thank my mentors, Frank Schnater and Christien Janssen, for helping to develop my thesis. They gave input every two weeks in the research, which made it better and they helped me when I got stuck. I want to thank them for answering all my questions and for the support during this process.

I also want to thank my friends and family for their wise advice and support the last 8 months. In particular my brother for reading my work and removing all spelling errors and giving me feedback.

I hope that you will find interesting parts in this research and that you enjoy reading it.

Naftany van Zwaaij
Delft, June 2019

ABSTRACT

This research will examine a design for an off-grid safari park in Iran. During this research different passive techniques from the vernacular architecture will be discussed. These principles will be used to reduce the energy demand of the safari park, since it should be an off-grid park, in order to deliver a design proposal with an achievable energy balance. One of the buildings, the entrance building, will be used as a case study to test the design principles. The courtyard, the increase of mass and the windcatcher are the most important principles to be implemented in the building. The energy reduction achievable with these techniques is weighted against the increase in cost of the building. In the design of the entrance building, a combination of windcatchers and underground ducts is used to cool the building, reducing the energy demand for cooling with 90%. Other principles, like an increase in mass and a courtyard also reduce the energy demand of the building significantly. The use of vernacular principles in the design will increase the cost of the building. However, it will decrease the cost needed for generating energy on site and, therefore, it is still beneficial. Future research, should focus on the exact amount of energy needed compared to the additional cost for the construction of the buildings. However, this research concludes that the use of vernacular principles in the park is beneficial.

CONTENTS

1

INTRODUCTION

This thesis studies a Safari Park in Iran for the Simba Nature Protection and Education Foundation. The Safari Park should be off-grid and, therefore, passive design strategies from the vernacular architecture are examined to reduce its energy demand. In this chapter, the research questions are introduced and provided with basic background information. Also the methodology and the relevance of the research are discussed.

1.1. THE PARK

The Simba Nature Protection and Education Foundation has asked students from different faculties to work on the Negin Safari Park in Iran. The park should attract tourists to Fīrūzābād county and will be built for the local people, the Qashqai tribe. The tourists can observe the wildlife, while walking through the park, where the native flora and fauna of Iran play a big role. This includes animals like gazelle, deer, mountain wild goat, ram, ewe and many kind of birds. Also animal protection and breeding will form an important aspect of the park. (Zagroz, 2018)

The park will offer activities for tourists, like hiking, rock climbing and sports. Excursions are offered from the park to nearby historical sites and villages. Besides this, the tourists can work as a volunteer in the park or assist the Qashqai in their daily life activities. An overnight stay will be offered to the tourists in different accommodations and the park will have a restaurant and shop, where daily necessities and traditional handmade Quashqai products can be purchased. (Zagroz, 2018)

The Negin Safari Park will be off-grid, which means that there should be technical solutions for water and electricity, like air to water technology, solar energy and wind energy. The park should be environmental friendly and adjusted to the specific climate of the area, both in summer and winter. (Stichting Simba Nature Protection and Education Foundation, 2018)

1.1.1. THE QASHQAI TRIBE

As mentioned, the Negin Safari Park will be built for the local people. Simba was approached by the Qashqai tribe to help establish the safari park. (Stichting Simba Nature Protection and Education Foundation, 2018) The Qashqai tribe lives in the Zagros Mountains. They speak Turkish and Shi'i Muslim. The Qashqai used to be nomads, who travelled hundreds of kilometres during spring and autumn for up to two or three months. (Beck, 1992) During these migrations, the Qashqai carried all their belongings, such as their tents, which had a few requirements; namely, they must be light, small, portable, warm in winter and cool in summer, resistant against wind, rain and winter storms, affordable, and easy to make by local people. To meet these requirements natural and light materials were used, like goat's hair, sheep's wool, thread, wood and straw. (Figure 1) (Hematalikeikhaa & Alinaghizadehb, 2012)

Figure 1: Qashqai tent
Source: Hematalikeikhaa & Alinaghizadehb, 2012

- The roof and the trunk is made out of goat's hair with tight and interwoven strands of thread.
- The ropes are woven out of sheep's wool or goat's hair.
- Columns, poles, chains, spikes and pins are made of different types of wood.
- Bowers are made of thin pieces of straw, wood and thread.

The tents can be adjusted to the season. During summer one side of the tent is left open. In winter, due to heavy rain falls, poles are connected lengthwise to the middle of the tent's roof, supported by columns from below. (Hematalikeikhaa & Alinaghizadehb, 2012) The Qashqai have occupations, such as animal husbandry, handicraft and agriculture. Their settlements were formed around a black tent with a clear place for the animals. (Figure 2) (Hematalikeikhaa & Alinaghizadehb, 2012)

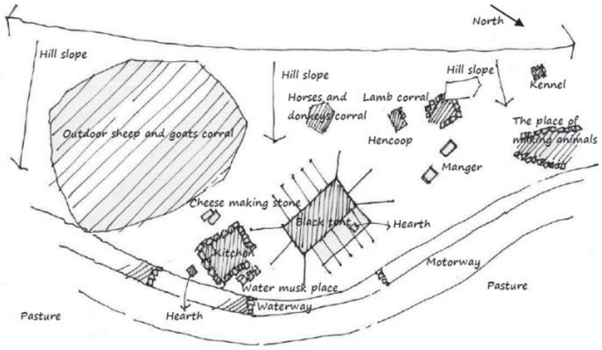


Figure 2: Settlement plan of Qashqai village
Source: Afshari Hematalikeikhaa & Alinaghizadehb, 2012

In the 1960s and 1970s, the regime pressured many Qashqai to settle in villages and towns. (Beck, 1992) Also other challenges have forced the Qashqai into settlement, such as too much drought to find grazing lands for their flocks. Also, while traveling, there was no platform for the Qashqai women to sell their handicraft. Nowadays, there are 25,000 Qashqai nomads left, most of which are settled.

The settlement plan of the Qashqai nomads changed when they became sedentary. In the Qashqai villages there are some important aspects, like the main living-room, the qapu, the kitchen, the granary, the corrals, the hayloft and the toilet. The qapu is the outdoor intermediate space, where the daily activities from the Qashqai are happening. The intermediate outdoor space is defined by a combination of elements, like trees and other natural elements. Nomads are only inside when they are forced to. The houses, which the nomads build, have walls made of plaster and stone. (Figure 3) Whereas, the ceiling is made of straw and wood. (Alinaghizadeha & Hematalikeikha, 2012)

Figure 3: Qashqai house and qapu
Source: Alinaghizadeha & Hematalikeikha, 2012

The Qashqai live outside most of the time, but their houses do protect them from the winter cold and rain. The Negin Safari Park wants to offer tourists a Qashqai life experience. The tourists can assist the Qashqai in their daily activities. (Zagroz, 2018) Workshops with the Qashqai will be offered and there will also be a Qashqai tent in the park, where the visitors can rest and enjoy the local culture. During the day in the form of drinking tea and listing to music, and, during the evening, with a bonfire, tea and folklore. (Haagh, Dekkers, & De Boer, 2019) The Qashqai's way of life is the basis of Negin Safari Park.

1.2. Problem Statement

A safari park will be realized in Iran. This park will house different animals and has different facilities for the visitors. The facilities will need energy for mostly lighting, heating and cooling. Also energy is needed for cooking and washing. Since a lot of energy is needed for cooling in the Middle East, a high energy demand is expected in the park. (Sadeghifam, Zahraee, Meynagh, & Kiani, 2015)

The Negin Safari Park should be off-grid and is, therefore, different than most other safari parks. The park should produce its own energy, which can be done in different ways, for example with solar energy, wind energy or with biomass. To reduce the cost for generating energy on site, the energy demand of the park should be reduced. This will be done with vernacular techniques, that are used in the Middle East for centuries.

1.2.1. Goal

The goal of this research is to make a conceptual design for the Negin Safari Park with an achievable energy balance system. Therefore, the energy demand of the buildings in the Negin Safari Park will be calculated and ways to generate this energy will be discussed. Thereafter, one of the buildings with a high energy demand will be selected and passive techniques will be implemented in the design of the building to calculate how much energy can be saved with passive techniques. On this basis, design principles will be given.

1.3. Research questions

The first part of this research focusses on the design of the Negin Safari Park. The second part is about passive techniques, which are used in Iran. The passive techniques will then be applied to the design of the Negin Safari park.

The main question of this research is:

To what extend can passive cooling techniques reduce the energy demand of Negin Safari Park in Iran?

To be able to provide an answer to the main research question of this thesis, a number of sub-research questions have been formulated that will need to be answered:

A. How can all the requirements set by Simba form a conceptual design for the Negin Safari Park?

The design will be based on case studies that were done and the requirements set by Simba. This sets the size of the Negin Safari Park, the required facilities and the park's organization. The design of the park is the first step to determine the energy requirements of the park.

B. What are the energy requirements for the Negin Safari Park and how can they be met?

The conceptual design will be used to determine the energy demand. From the total square meters of building area, the energy requirements and the amount of solar panels required to cover this energy demand will be calculated.

C. Which building in the park uses most energy and what are the requirements for this building?

The building with the highest predicted energy demand will be used as a case study to test the passive building techniques. In this chapter, the requirements for this building will be determined.

D. What design principles can be found in the vernacular architecture?

Different techniques, like domed roofs, thick walls and cooling with a courtyard demonstrate how the energy demand can be reduced and what design principles can be formed from these techniques.

E. What are the different types of windcatchers and which one can best be used for the Negin Safari Park?

The types and technical aspects of windcatchers are discussed, together with simulations. This results in the best windcatcher option for the site in Iran.

F. How can a building be designed with vernacular techniques to reduce its energy demand?

A single building of the park will be chosen as a case study to demonstrate the energy reduction through passive design techniques. The building will use windcatchers to reduce the energy demand of the building trough natural ventilation. The reduction of energy will be compared to the added construction costs to see if the use of a windcatcher is profitable.

1.4. Methodology

From the research questions one can see that this research will consist of a few different phases. The research was initiated by Simba to design the Negin Safari Park. The first stage is, therefore, to come up with a conceptual design. This will be done with case studies of different safari parks all over the world in combination with the requirements Simba has set. The conceptual design will give more information on the energy demand of the park, so that the energy can be balanced. The energy balance will give insight in the amount of energy the park needs and which building in the park will use most energy. This building will be used as a case study.

The next step is a literature study on passive design techniques, that can be used in the Negin Safari Park. To come up with design principles for the park, the vernacular architecture will be examined together with the windcatcher technology. The results of this literature study are design principles that can be used to reduce the energy demand in the case study building.

The design principles will be used to come up with a design for the building and see what the principles do for the energy demand of the building. Is it worth to invest in passive design techniques, or will it be cheaper to buy more solar panels? (Figure 4)

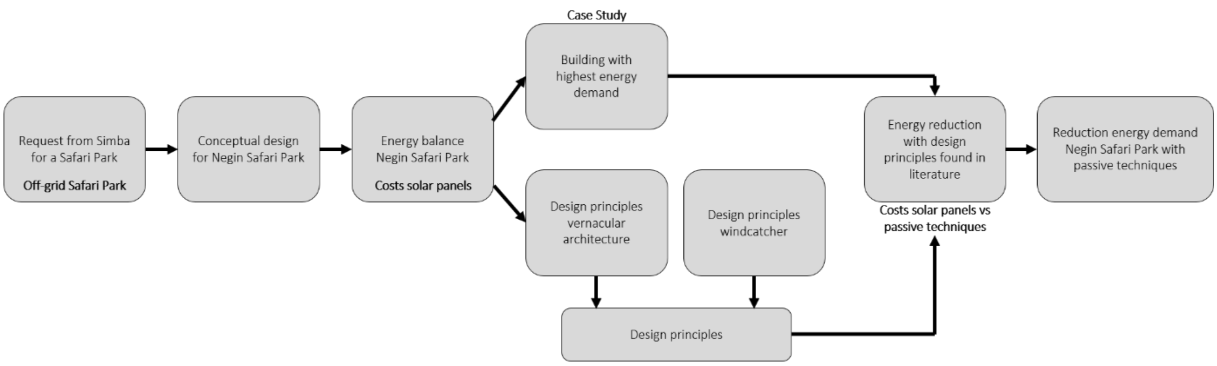


Figure 4: Methodology research

1.5. Relevance

1.5.1. Societal relevance

The majority of the buildings in the world are connected to the power grid. In 2009, building operation was globally responsible for 40% of the primary energy consumption. (Figure 5) ("Phase Change Composite Materials for Energy Efficient Building Envelopes", n.d.) Passive technologies in buildings reduce its high power consumption. In this graduation research, passive techniques that can be used in Iran will be examined. These techniques can, however, also be used in other countries with hot and arid climates, and help reduce the ecological footprint of buildings worldwide.

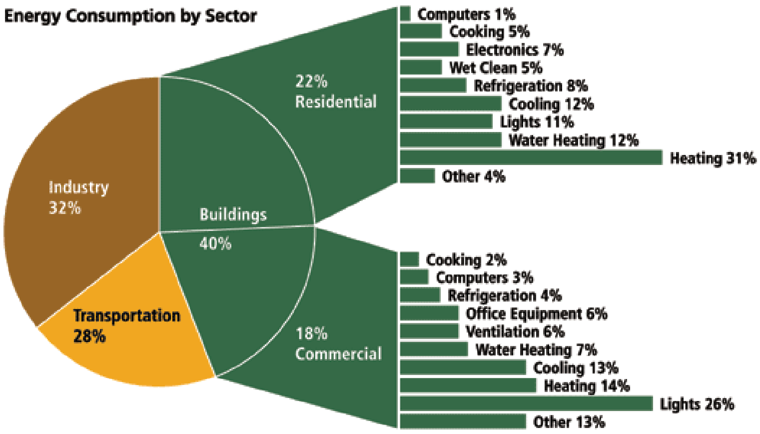


Figure 5: Energy consumption by sector
Source: "Phase Change Composite Materials for Energy Efficient Building Envelopes", n.d.

The evaluation of passive techniques is also relevant for the client, the Simba Nature Protection and Education Foundation, as they strive for an off-grid safari park in Iran. With the use of passive techniques, it might be cheaper to realize an off-grid safari park as the energy demand of the park will be lower and, therefore, less energy has to be generated on site.

The result of the research can be applied in practice as a comparison is made between the energy demand of a building with and without passive design techniques.

The research aims to give an innovation in the field of passive design techniques, with the vernacular techniques used to reduce the energy demand. An energy reduction overview highlights the difference in building construction costs with vernacular techniques and the corresponding reduction of energy costs.

This research contributes to sustainability through passive design techniques. This reduces the energy demand of the build sector, so that less energy has to be generated. The research also contributes to the People, Planet, Profit.

- People: because of natural ventilation in a building, the indoor air quality will be more pleasant.
- Planet: because of the use of natural ventilation and cooling less energy is needed in the building, so less energy has to be generated.
- Profit: cost reduction as less energy has to be used to cool the building. (Figure 6)

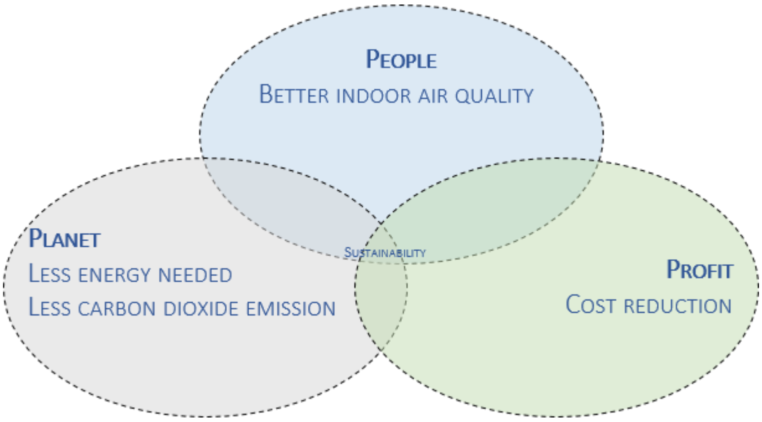


Figure 6: People, Planet, Profit

1.5.2. Scientific relevance

Passive design techniques have been used for decades in the construction of buildings. In this graduation research, the use of passive techniques will be examined on the energy reduction of a building. First, the energy demand of the building will be calculated without passive techniques. Then, the passive techniques are implemented in the design and again a calculation of the energy demand of the building will be done. Since less energy has to be generated on site, the costs of the building can be reduced.

Different methods for the energy production in the Negin Safari Park will be discussed and different passive design techniques will be evaluated.

2

CONCEPTUAL DESIGN NEGIN SAFARI PARK

In this chapter, requirements set by the Simba Nature Protection and Education Foundation are highlighted and several case studies are examined to create a conceptual design for the Negin Safari Park. The first research question, How can all the requirements set by Simba form a conceptual design for the Negin Safari Park?, will be answered.

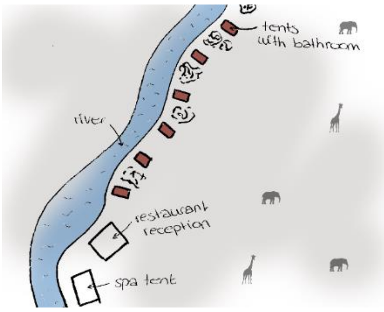
2.1. Case studies on different safari parks

To get more insight in what the safari park should look like, 6 different parks from all over the world are examined on aspects, like size, facilities, tourist housing and how the animals are kept. There are two types of safari parks, the first type consists of large natural parks, where the animals roam around freely. The tourists can drive through the park searching for the animals. The second type of safari parks are smaller and the animals live in cages. These parks are comparable to a zoo. (Haagh et al., 2019) These case studies highlight the facilities required in the Negin Safari Park.

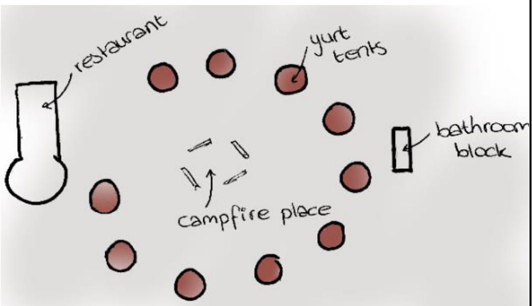
Table 1 shows the layout of the six examined parks. The difference between the large parks, where animals roam around freely (1, 2, 3) and the zoo-like animal parks (4, 5, 6) can be seen. The Beekse Bergen, the San Diego Zoo Safari Park and the Taronga Western Plains Zoo Dubbo have multiple animal cages with different facilities in between. APPENDIX I gives a more extensive overview of the examined parks.

Table 1: Overview case studies

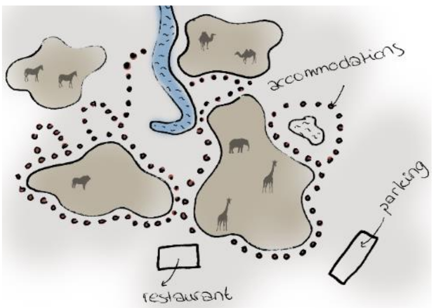
1. Governors' Camp (Kenya)



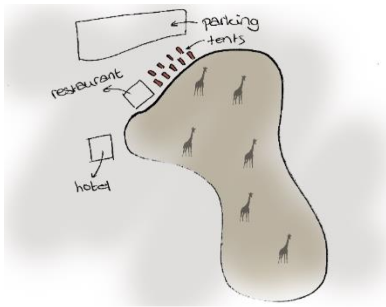
2. Safari Yurt Camp (Uzbekistan)



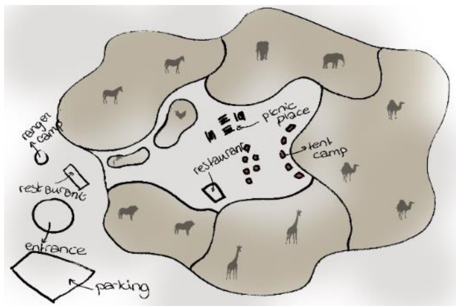
3. Beekse Bergen (Netherlands)



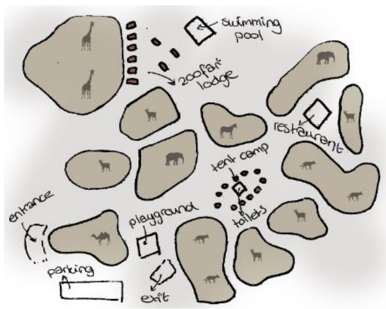
4. Giraffe Lodge (United Kingdom)



5. San Diego Zoo Safari Park (California)



6. Taronga Western Plains Zoo Dubbo (Australia)



2.1.1. Overview facilities safari parks

Table 2: Overview facilities

	Large park, animals roam around freely			Zoo-like safari park, animals caged			
	Safari Yurt Camp	Governors' Camp	Giraffe Lodge	Safari park Beekse Bergen	San Diego Zoo Safari Park	Taronga Western Plains Zoo Dubbo	Negin Safari Park Iran
Accommodations	20	37	9	425	46	-	15 - 20
Caged animals		✓	✓	✓	✓	✓	✓
Different type accommodations				✓	✓	✓	✓
Restaurant	✓	✓	✓	✓	✓	✓	✓
Souvenir Shop	✓	✓		✓	✓	✓	✓
Spa / swimming pool		✓		✓		✓	
Play ground				✓	✓	✓	✓
View on animals from bedroom		?	✓	?	?	?	✓
Private bathroom		✓	?	?		?	?

Available	✓
Might be available, dependent on type of accommodation	?

Table 2 gives an overview of the facilities in the examined safari parks. Most of the examined parks have between 25 – 50 accommodations, which differ in type. For some people, it is attractive to have a luxurious room with a private bathroom, while others want a cheaper option and do not mind a shared bathroom. This principle can also be applied in the Negin Safari Park. Qashqai tents can be used to give the tourists a back to basics feeling. However, small houses can be used to create a more luxurious feeling. A view on the animals from the bedroom is only offered in some accommodations, making them more attractive.

All parks offer at least one restaurant, while the bigger safari parks offer more than one restaurant or small kiosks. Most of the parks have a first aid spot and a souvenir shop or a small store for daily necessities.

Some of the parks offer a spa or a swimming pool. The safari park in Iran will be off-grid, which makes a swimming pool difficult, because it needs a lot of water. Also the safari park will not be that big, making a pool undesirable.

From the information of the different safari parks, requirements are set for the new safari park in Iran. Different types of accommodations can be mixed and a restaurant, a shop and a playground for the children should be part of the safari park.

2.2. Requirements Negin Safari Park

The Negin Safari Park will be a zoo-like safari park in which different species live together in bordered areas. (Haagh et al., 2019) The suggested area in Kel Plain is around 200 – 250 ha. This size will, however, be for a later stage of the Negin Safari Park. For the design of the Negin Safari Park, which will be used in the beginning, a smaller area of around 10 ha will be used. There will, in the first stage, be 27.926 day visitors and 2772 overnight visitors per year, see Table 3. (Haagh et al., 2019) This number of tourists is low compared to for example the Beekse Bergen, which has 900.000 visitors per year and is 120 ha.

Table 3: Overview visitors Negin Safari Park
Source: Haagh, Dekkers, & De Boer, 2019

	Average day visitors per year	Average overnight visitors per year
Amount of domestic visitors two-and-a-half hour drive radius	19.947	0
Amount of domestic tourists	7.303	2.434
Amount of foreign tourists	676	338
Total amount	27.926	2.772

2.2.1. Facilities

The safari park will be divided into three zones, namely a public zone, which everyone can enter, a semi-public zone, which only can be entered with a ticket, and a private zone, which is only for staff. (Figure 7) In the public zone, there will be a restaurant, a butterfly garden, a shop with a weaving demonstration area and a small playground. The semi-public zone, which can only be entered with a ticket, is the actual safari park, together with the tourist accommodations. There will also be education areas in this zone. (Haagh et al., 2019)

Figure 7: Zones in Negin Safari Park

The private zone features the accommodations for the staff and the management of the park. This area will also have quarantine and medical facilities for the animals. It will be separated from the park to give the visitors more of a safari feeling. For an overview of all facilities needed in the Negin Safari Park see Table 4. (Haagh et al., 2019)

Table 4: Different facilities in Negin Safari Park

Public	m^2	Semi-public (ticket)	m^2	Private	m^2
Butterfly Garden	800	Toilets	50	Quarantine	150
Restaurant	350	First Aid Post	50	Clinic/medial Area	150
Small Playground	100	Information Desk	100	Dog training centre	250
Parking area	1600	Educational Centre	250	Dog housing	100
Shop + Weaving area	150	Greenhouse	800	Public adoption/rehabilitation	250
Reception	250	Qashqai tent	25	Staff office	200
		Event Area	1200	Staff accommodation	150
		Playground	1000	Housing for overnight staff	150
		Geoforest-climb parkour	1000	Mechanical fixing	150
		Children's farm	3000	Watch tower and security	200
		Bird garden	2000	Administrations office	300
		Animal cages	16410		
		Tourist Accommodations	500		
		Parking Segway + Practice area	500		

2.2.2. Animals

The Negin Safari Park will have various animal species, that originate both from Iran and from abroad. An overview of the selected animals is shown in Table 5. Some species can be placed together in a cage, like the giraffe and the zebras. The Negin Safari Park will start with the number of animals mentioned in Table 5, which is to be extended in the future. (Figure 8) (Haagh et al., 2019)

Table 5: Animals in Negin Safari Park
Source: Haagh, Dekkers, & De Boer, 2019

Safari park			Children's farm	
Species	Amount	Required Area (m^2)	Species	Amount
Lion	15		Goat	5
Brown bear	2		Rabbit	5
Asiatic wild ass	9	2700	Peacock	1
Persian fallow deer	9	2700	Chicken	5
Urial	8	800	Camel	2
Wild goat	8	800	Horse	2
Persian gazelle	5			
Giraffe	4			
Zebra	4			
Total	64		Total	20

Figure 8: Animals Negin Safari Park
Source: Haagh, Dekkers, & De Boer, 2019

2.3. Park outline

The bubble diagram of Figure 9 shows the different functions in the park. It presents the size of the functions within the park and also which ones need to be close to each other. The diagram will be used for the design of the Negin Safari Park.

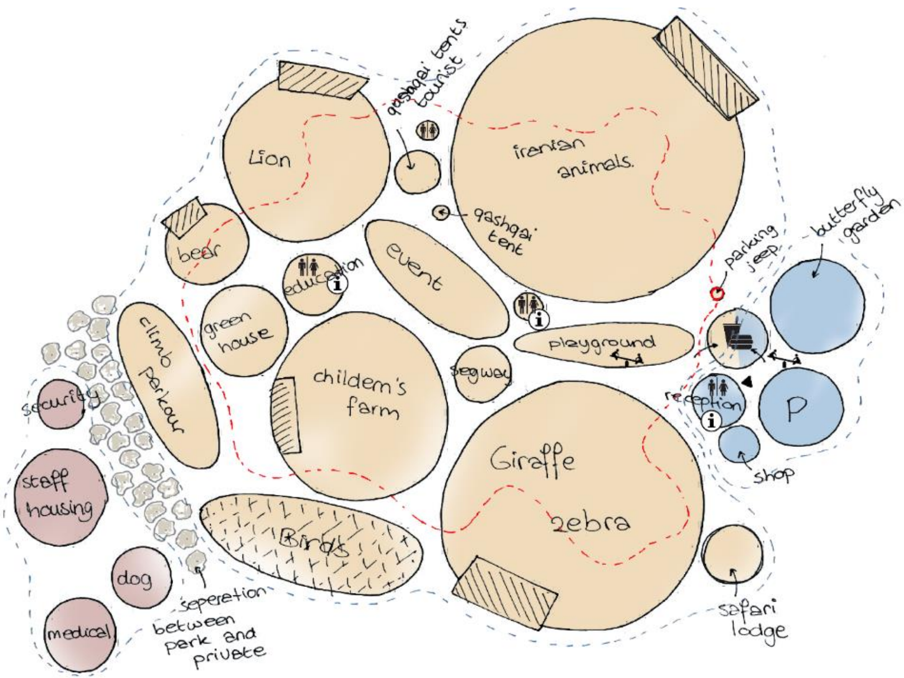


Figure 9: Bubble diagram Negin Safari Park

2.4. Site

The location of the Negin Safari Park is Kel Plain. Kel Plain is around 15 to 20 minutes' drive from Fīrūzābād. It is located in Fars province in the south west of Iran. (Figure 10)

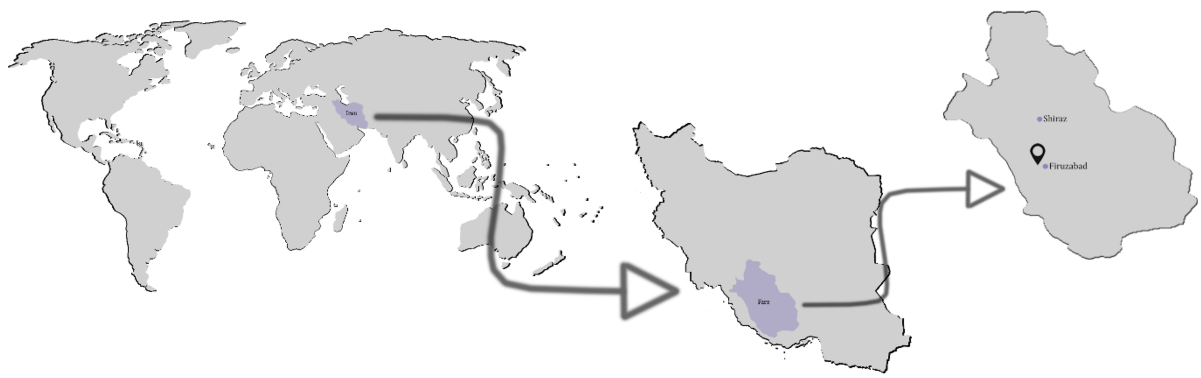


Figure 10: Location site in Iran

Nearby are some villages with around 30 to 50 inhabitants. On the plain field, some Qashqai settlements can be found with around 100 Qashqai people. The Kel Plain has some open fields, protected by the surrounding mountains. The area is green and has some small to medium sized trees. (Figure 11) (Haagh et al., 2019)

Figure 11: Site with small trees
Source: Haagh et al., 2019

The site is surrounded by mountains on the east and south, and villages in the west. (Figure 12) A regulation states that the park should be at least within 750 meters away from any establishments. (Haagh et al., 2019) This means that the Negin Safari Park should be placed in the location shown in Figure 13.

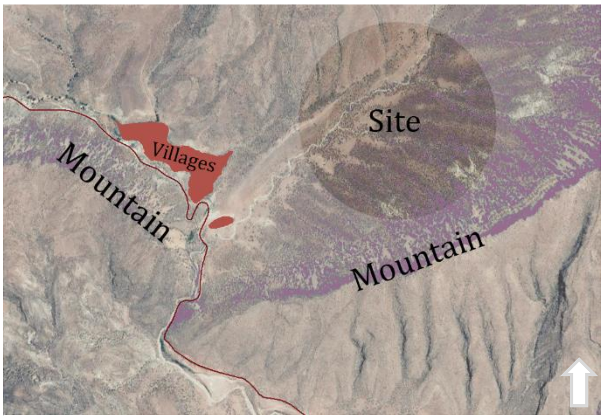


Figure 12: Site 2D

Figure 13: Location Negin Safari Park
Source: Priyadarshini Nanda

In Figure 14 the site plan for the Negin Safari Park is shown. The already existing road will be paved and used as access road to the park. The initial park has an area of around 10 ha. In the future, the Negin Safari Park will be extended to a 200 ha park.

Figure 14: Site Plan Negin Safari Park

2.5. CLIMATE FĪRŪZĀBĀD

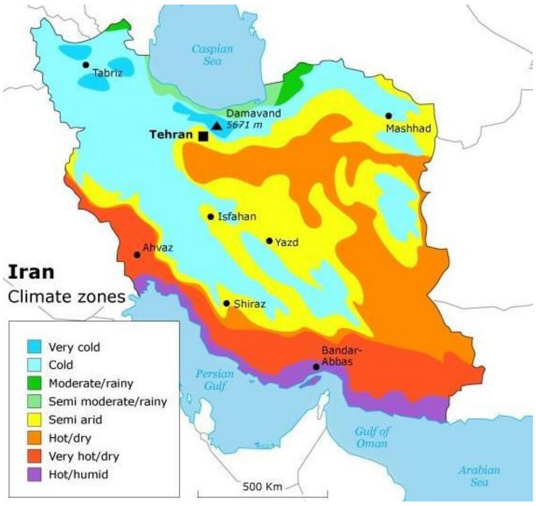


Figure 15: Climate zones of Iran
Source: Ghale, 2014

Iran is a multi-climate country with different climate zones. (Figure 15)

- Mild and wet on the coast of the Caspian Sea
- Continental and arid in the plateau
- Cold in high mountains
- Desert and hot on the southern coast and in the southeast

Iran is overall an arid country. However, in the west and the north the rains are more abundant than in the east and the south. The only rainy area is the Caspian Sea coast.

The Safari park will be built in Fars, Iran, close to Fīrūzābād, which is used to gather climate data. In Fīrūzābād, the summers are long, sweltering, arid, and clear and the winters are cold and mostly clear. Over the course of the year, the temperature typically varies from 1°C to 38°C and is rarely below -3°C or above 41°C. The monthly amount of rain is shown in Figure 16. The rainy period of the year lasts 5.1 months. Most rain falls during the 31 days centered around January 18. The rainless period of the year lasts for 6.9 months. The least rain falls around September 19. (https://weatherspark.com, 2018)

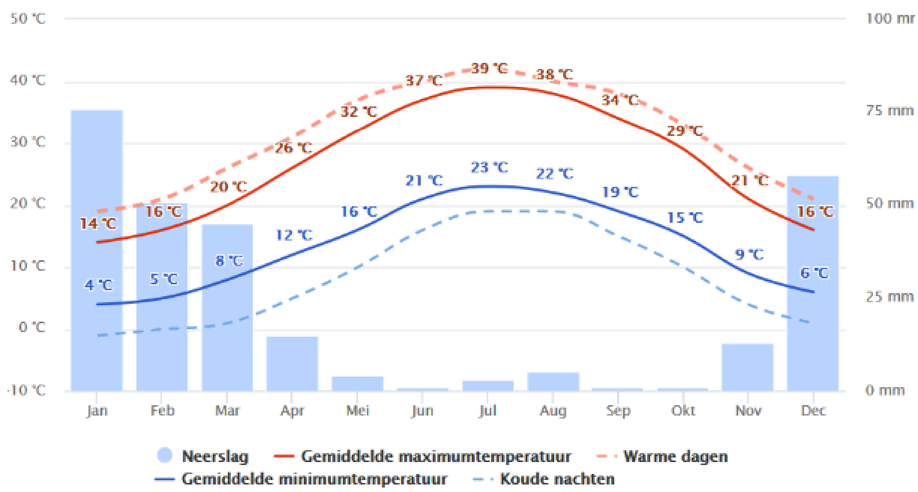


Figure 16: Temperature and rain in Fīrūzābād
Source: https://www.meteoblue.com, 2018

A building built in this climate should be able to stand the high temperatures up to 40°C. So abundant cooling is needed in the summer, which can be done with natural ventilation with the wind. The wind speed in Iran varies from 5 km/h to 28 km/h. (Figure 17) The predominant wind direction is the southwest. However, wind coming from the north-northeast is also common. The wind direction can be used in a building for passive cooling. For more information about the climate in Fīrūzābād see APPENDIX II

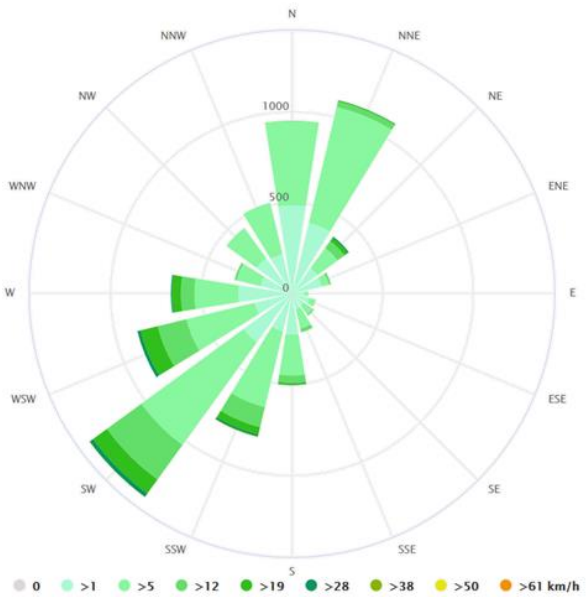


Figure 17 : Wind direction Fīrūzābād
Source: https://www.meteoblue.com, 2018

2.5.1. Wind speed on site

The main wind directions in Fīrūzābād are the southwest and the north-northeast. However, if the topography of the site is taken into account, it is likely that the wind direction is influenced by the mountains around the site. Therefore, the site is placed in a wind tunnel simulator, Autodesk Flow Design (2014), to investigate the wind direction on site.

Southwest wind

A southwest wind occurs most often. The highest wind speed is 28 km/h, or 7,8 m/s. Figure 18 shows the surface pressures caused by the southwest wind. The area behind the mountains has -30 Pa surface pressure caused by the wind, because the wind blows over the mountains. In the chosen location, there is also a negative surface pressure, which means that there is no wind impact. Figure 19 shows the wind flow on site. Most of the wind blows over the mountains with a wind speed of 9 m/s. Only a small windstream flows down to the valley. The wind into the valley has a low wind speed around 4 m/s.

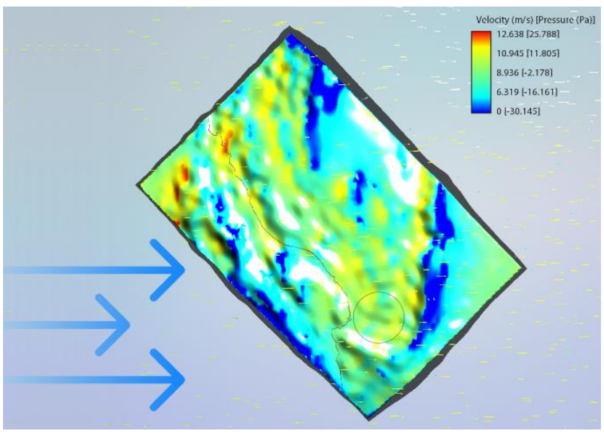


Figure 18: Wind direction and wind pressure
Source: Autodesk Flow design, 2014

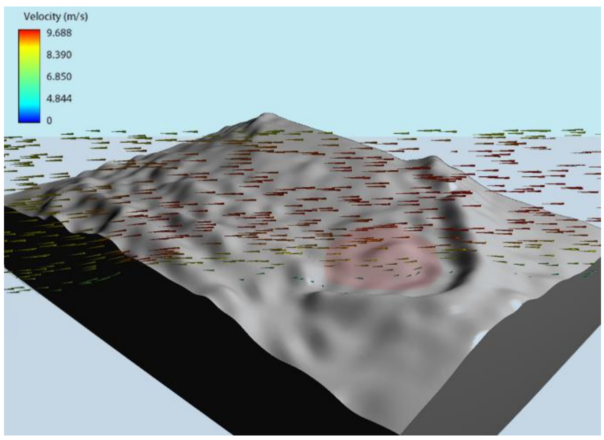


Figure 19: Wind flow
Source: Autodesk Flow design, 2014

North-northeast wind

The second dominant wind direction is the north-northeast. The wind from this direction has a lower speed around 12 km/h, or 3,3 m/s. Figure 20 shows the wind surface pressure when a north-northeast wind is dominant. Again the wind blows over the mountains and there is no wind surface pressure in the area. Figure 21 shows that the wind will blow over the mountains. The wind speed in the valley is around 2 m/s.

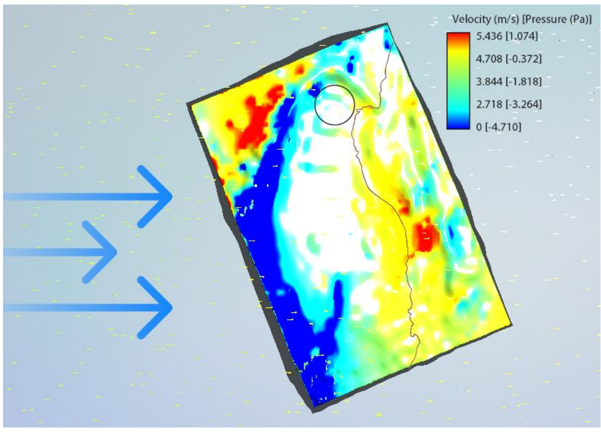


Figure 20: Wind direction and wind pressure
Source: Autodesk Flow design, 2014

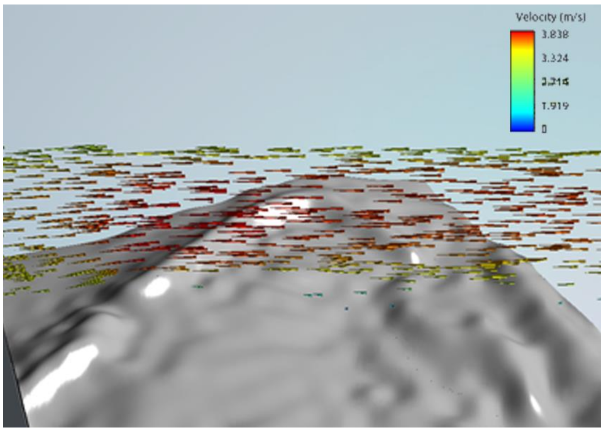


Figure 21: Wind flow
Source: Autodesk Flow design, 2014

The wind that blows from both the southwest and north-northeast blows mostly over the mountains surrounding the area. Therefore, there is not much wind in the valley, with a speed around 4 m/s. (Figure 22)

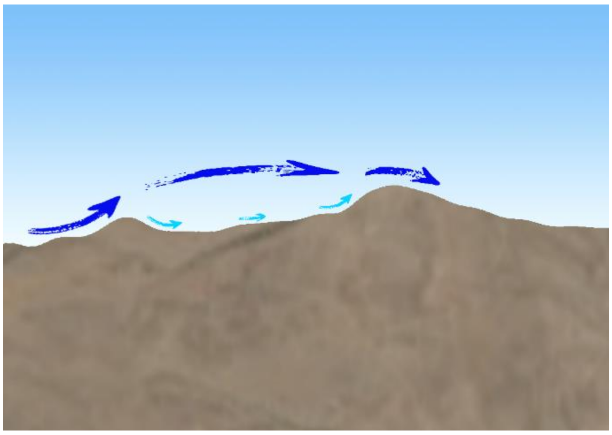


Figure 22: Slow wind in valley

2.6. DESIGN NEGIN SAFARI PARK

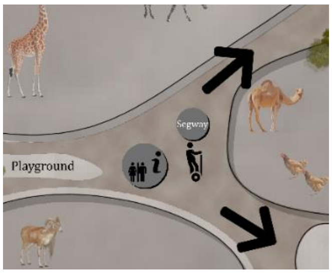
In the previous parts, all the facilities needed in the Negin Safari Park are discussed together with the animals that will be placed in the park. In this part, the bubble diagram is extended into a conceptual design as shown in Figure 23.

Figure 23: Design Negin Safari Park

The butterfly garden, the restaurant, reception and shop are placed near the parking. The restaurant will be divided into two parts. One part of the restaurant can be entered from the parking place. The other part can only be entered from the Negin Safari Park. In this way people with no ticket for the park can go to the restaurant and not go into the park.

When you enter the Negin Safari Park, you come to a small square, where you can choose three different paths. One path leads to the Safari Lodges, which are only for the overnight guests. The other two paths lead to the animal cages. The playground is placed in between the paths. The playground is close to the restaurant, so that the parents can sit on the terrace when the children are playing.

The overnights guest can choose two types of accommodation. The first one is the safari lodge. These lodges are placed around the safari cage of the park. Here the giraffe, zebra and gazelles are placed. All lodges have a view on the animals. The lodges will have a private bathroom and vary in size. There will be lodges for 2 persons up to 6 persons. The guests can have breakfast and dinner in the restaurant.

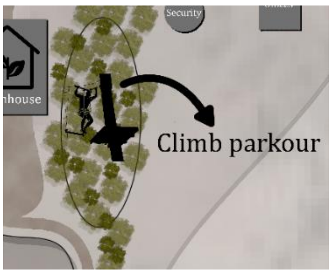


On the other side of the playground two small buildings can be found. One is the Segway rental, with a square where people can practice. The other building is the first aid and information desk, which also contains toilets. Adjacent to the square is the children's farm. From the square two routes can be chosen.

The event area is placed next to the children's farm. In this way, the area can have multiple uses. When there are no events, the area can be used as a camel and horse riding place. When there are events, the camels and horses will be in the children's farm.

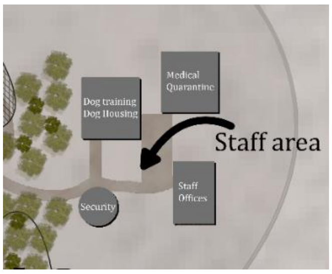
The other overnight accommodation that the tourists can choose is the Qashqai tent. In a small camp, seven Qashqai tents are placed. The first one next to the path is the main tent, where daily tourists can drink tea with the Qashqai or make lunch. The other six tents are for the overnight tourists. The tents are not luxurious and do not have a private bathroom. Therefore, a shared bathroom block is placed nearby the camp.

Next to the children's farm, the greenhouse and the education centre is placed. In the education centre, classrooms are placed. Also an information desk and toilets are located in this building. The greenhouse is located next to the education centre, because the greenhouse can also be used for educational proposes.



Next to the greenhouse and education centre the climb parkour is placed at the edge of the park. The climb parkour is fun for young and old. The trees of the climb parkour also separate the public and private part.

The aviary is a big part of the Negin Safari Park, containing different kinds of Iranian birds. It is accessible to the visitors.



The last and private part of the Negin Safari Park, which houses buildings for medical care and quarantine for the animals, is placed along the dog training and housing. Also a security watch tower is placed and the staff building, with both staff rooms and offices.

Another idea was to offer jeep safaris through the park. (Haagh et al., 2019) However, the park will be so small in the starting phase (10 ha) that it is not suitable for a jeep safari. When the Negin Safari Park is extended in the future to the 200 ha, it will be suitable for jeep safaris.

2.7. Summary

Chapter 2 answers the question: How can all the requirements set by Simba form a conceptual design for the Negin Safari Park? Six parks have been examined on their size, facilities and tourist accommodations. This study showed that most of the parks have different tourist accommodations, differing in luxuriousness and animal view. These different tourist accommodations are included in the conceptual design of the park. The tourists can choose the Safari Lodge, which is more luxurious and the Qashqai tent which is more back to basic. Besides the tourist accommodations, all parks have a restaurant and most parks have a souvenir shop; facilities also mentioned by Simba as a requirement for the Negin Safari Park.

The facilities in the Negin Safari Park are divided into three zones, namely a public zone with a butterfly garden and the restaurant. The Semi-public zone, which contains the animal cages and the tourist accommodations, and a private zone, which contains buildings for the staff. Haagh et al. (2019) also mentioned the expected number of visitors and the animals, which will be in the Negin Safari Park.

The park's location is on Kel Plain near Fīrūzābād. This location has small villages nearby, required as Negin Safari Park should be within 750 meter away from the closest settlement. Also the wind speed on site is examined and found to be 4 m/s.

All requirements, set by Simba and gathered from the case studies, have formed a conceptual design for the Negin Safari Park with an area of 10 ha.

3

ENERGY REQUIREMENT NEGIN SAFARI PARK

The conceptual design for the Negin Safari Park is finalized as shown in the previous chapter. The wish of the Simba foundation is an off-grid, environmentally friendly Safari Park. (Stichting Simba Nature Protection and Education Foundation, 2018) Therefore, the energy demand of the Negin Safari Park is calculated from the total building area used in the conceptual design. For this calculation, contemporary buildings are used, which are not adjusted to the climate and are equipped with an air conditioning system. Various methods to cover this energy use are examined. This chapter will answer the question: What are the energy requirements for the Negin Safari Park and how can they be met?

3.1. Energy demand

The energy demand of the Negin Safari Park is calculated from the used square meters, which can be divided into four categories, as shown in Table 6.

[1] **The square meters that need heating/cooling, lighting, cooking, washing and entertainment**
This includes mainly staff buildings, like their housing, which also needs cooking supplies, as well as buildings for the overnight visitors, with small refrigerators, and the restaurant.

[2] **The square meters that need heating/cooling and lighting**
This are mostly buildings for the day visitors, like the shop and weaving area, which needs acceptable temperatures during summer and winter, but also the Education Centre, where lessons will be given. These buildings should not be too hot during summer and not too cold during winter.

[3] **The square meters that only need lighting and a small amount of cooling**
These are the animal shelter buildings. In these buildings, lighting is needed and a fan to cool during the summer. These buildings will use less energy than the buildings in category 2.

[4] **The square meters of outdoor space that only needs lighting**
All the paths in the park need lights during the night.

Table 6: Square meters buildings

		Functions		m^2
[1]	Heating/cooling, light, cooking washing and entertainment	Restaurant Tourist Accommodations	Staff accommodation Housing for overnight staff	1150
[2]	Heating/cooling and light	Butterfly Garden Shop + Weaving area Reception Toilets First Aid Post Information Desk Educational Centre Greenhouse	Quarantine Clinic/medial Area Dog training centre Dog housing Public adoption/rehabilitation Staff office Watch tower and security Administrations office	4200
[3]	Light and small amount of cooling	Shelter Giraffe, zebra, gazelle Shelter Urial, wild goat, wild ass	Shelter lion Shelter brown bear	3400
[4]	Light	Small Playground Parking area Event Area	Playground Practice area Paths	12.000

According to Moshiri (2013) the electricity use of buildings in Iran is around 310 kWh per square meter per year. Households in Iran typically use most of their energy for cooling and lighting. (Moshiri & Lechtenböhmer, 2015)

Figure 24 shows the average electricity consumption for a household in a hot climate. Air conditioning and refrigerators consume nearly 70% of the electricity in residential buildings. (Sadeghifam, Zahraee, Meynagh, & Kiani, 2015) Figure 25 shows the average home electricity consumption for the Middle East. These pie charts are used to create pie charts for the four categories that can be found in the Safari Park.

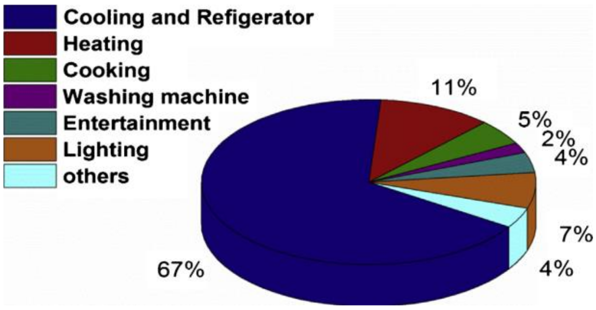


Figure 24: Average home electricity consumption Malaysia
Source: Sadeghifam, Zahraee, Meynagh, & Kiani, 2015

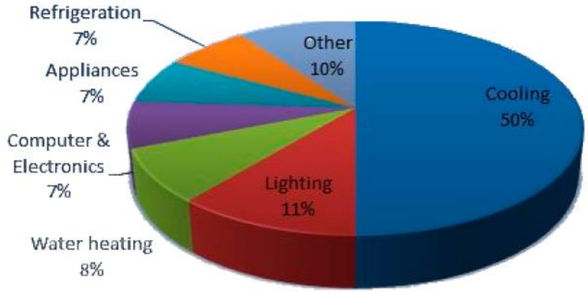


Figure 25: Average home electricity consumption Middle East
Source: "How to save on Energy Consumption", n.d.

The majority of the buildings in the Negin Safari Park do not require a supply for cooking, washing and entertainment, so they will consume less than the average of 310 kWh per square meter. Cooking, washing and entertainment contributes to 11% of the total energy consumption of a building. Also not all energy is needed for cooling and heating, as the temperature in the building does not have to deviate much from the outside temperature. All these factors will be deducted from the 310 kWh.

Table 9 shows the pie charts for the different categories in the Negin Safari Park. It shows which categories need what amount of energy and what it will be used for. The total energy consumption of the Negin Safari Park comes down to 1500 MWh per year. Table 7 shows what the energy is used for. It can be seen that most energy is used for cooling and lighting. Table 8 shows a list of buildings and their energy consumption. The entrance building needs most energy from all buildings in the Negin Safari Park.

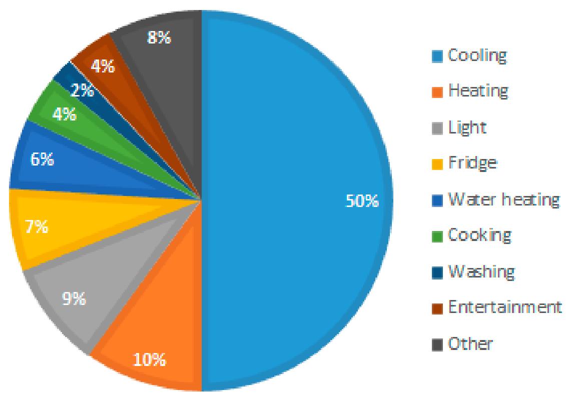
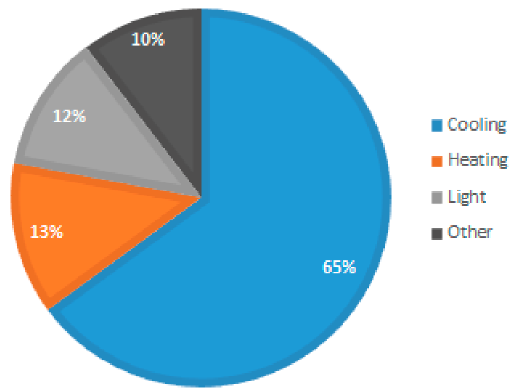
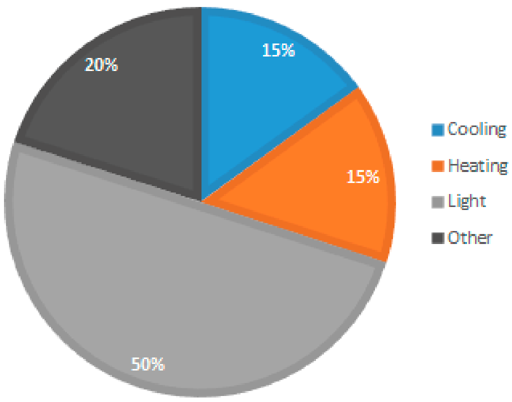
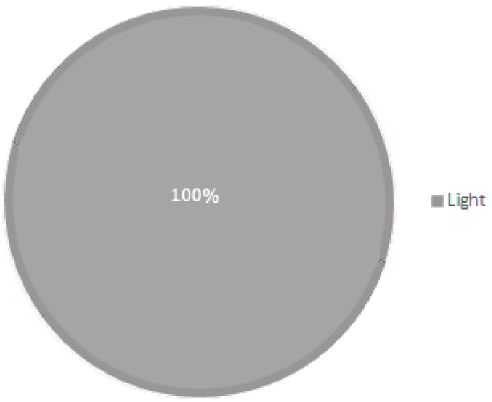
Table 7: Energy consumption Negin Safari Park

Cooling	742.100	kWh/year
Light	372.385	kWh/year
Heating	162.700	kWh/year
Other	136.320	kWh/year
Fridge	24.955	kWh/year
Water heating	21.390	kWh/year
Cooking	14.260	kWh/year
Entertainment	14.260	kWh/year
Washing	7.130	kWh/year
Total	1.495.500	kWh/year

Table 8: Energy consumption per building

1	Entrance building	188.500	kWh/year	10	Quarantine	30.000	kWh/year
2	Butterfly Garden	160.000	kWh/year	11	Clinic/medial Area	30.000	kWh/year
3	Greenhouse	160.000	kWh/year	12	Information Desk	20.000	kWh/year
4	Tourist Accommodations	155.000	kWh/year	13	Toilets	10.000	kWh/year
5	Staff building	133.000	kWh/year	14	First Aid Post	10.000	kWh/year
6	Dog and adoption building	120.000	kWh/year		Animal cages	119.000	kWh/year
7	Administration/watch tower	100.000	kWh/year		Paths	180.000	kWh/year
8	Educational Centre	50.000	kWh/year				
9	Parking Segway	30.000	kWh/year		Total	1.495.5000	kWh/year

Table 9: Energy consumption sectors Negin Safari Park

		m²	kWh/m²	Total kWh/year
[1]		1150	310	356.500
[2]		4200	200	840.000
[3]		3400	35	119.000
[4]		12.000	15	180.000
Total				1.495.500

3.2. Energy Production

The energy demand of the Negin Safari Park is calculated to be around 1500 MWh per year. The Negin Safari Park should be off-grid and, therefore, the electricity should be generated on site. There are different ways to generate energy, for example with sun, wind or biomass.

3.2.1. Solar Energy

Solar panels have been improved over the past years, which leads to solar energy development throughout the world. Solar energy is used for power generation and heat production. (Hosseini, Andwari, Wahid, & Bagheri, 2013) Iran is located in the world's Sun Belt and has 300 clear sunny days a year, which gives 2800 hours of solar irradiation. (Najafi, Ghobadian, Mamat, Yusaf, & Azmi, 2015) The solar irradiation on site is 2200 kWh per square meter. (Figure 26)

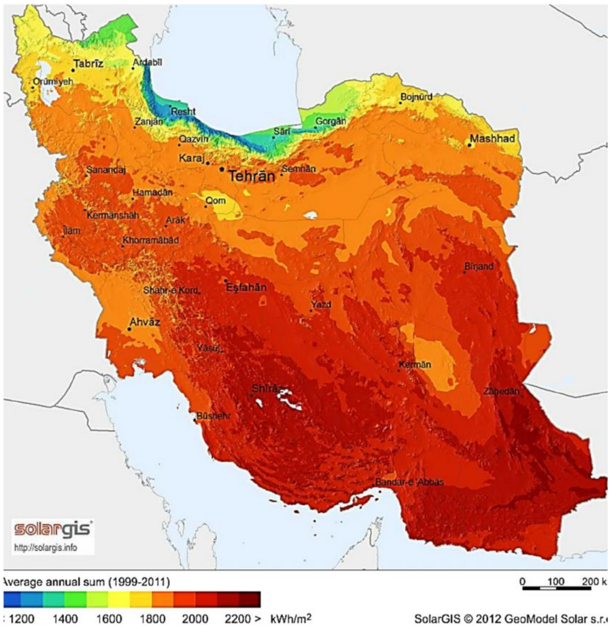


Figure 26: Global horizontal irradiation (kWh/m^2) in Iran
Source: Gorjian & Ghobadian, 2015

The yield of a solar panel can be calculated with the following formula (Swain, 2017):

$$E = r \times H \times PR$$

Where:

E = Energy production by PV (kWh/m^2)
r = Solar panel yield or efficiency (kWp)
H = Global incident radiation (kWh/m^2/year)
PR = Performance ratio of the solar PV system

- The solar panel yield is on average 280 Wp per solar panel of 1,65 m^2, equivalent to 170 Wp/m^2. (Schoenmakers, n.d.) Converted into 0,17 kWp/m^2.
- The incident radiation on site is mentioned before and is 2200 kWh/m^2/year. (Najafi et al., 2015)
- For this calculation a performance ratio of 0,75 is assumed. (Swain, 2017)

This will give:

$$E = 0{,}17 \times 2200 \times 0{,}75$$

$$E = 280\ kWh/m^2$$

The Negin Safari Park has an energy demand of 1.495.500 kWh/year. To cover this energy demand with solar panels alone means that 5400 m^2 of solar panels is needed. The total roof area in the conceptual design is around 8500 m^2, so, if the bigger roofs are filled with solar panels, the 5400 m^2 of solar panels can be placed on the roofs. (Figure 27) Another way is to place the solar panels in the desert next to the park. This method has as benefit that the roofs do not have to carry the weight of the solar panels. (Figure 28)

Figure 27: 5400 m^2 solar panels on roof

Figure 28: 5400 m^2 solar panels in field

3.2.1.1. STORAGE EN COSTS

Roughly 5400 m^2 of solar panels is required to cover the energy demand of the Negin Safari Park. However, there are a few aspects which are not yet taken into account:

- The energy system should be off-grid
- Energy production will only take place during the days with no overcast. (Figure 29) Thus, energy should be stored for days with overcast.

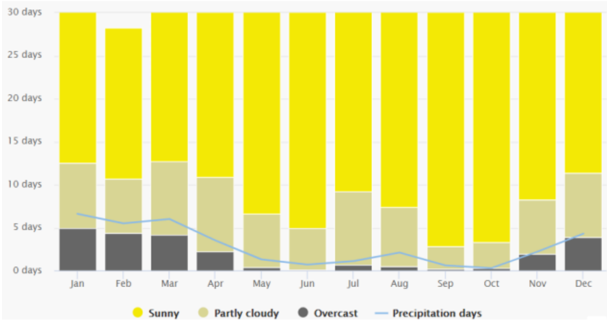


Figure 29: Cloudy days Fīrūzābād
Source: https://www.meteoblue.com

- Energy should be stored for the night. Most energy will be used during the day, but energy for the fridge and lighting is also needed during the night (Figure 30)

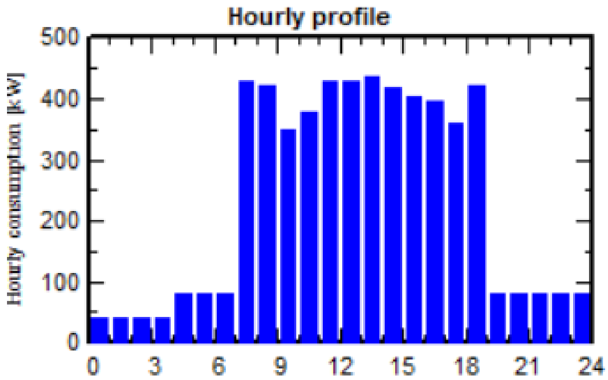


Figure 30: hourly distribution
Source: PVSyst (version 6.79), 2019

- The energy use of the park will not be the same for every month. During the summer more energy is needed for cooling and therefore, more energy should be stored (Figure 31)

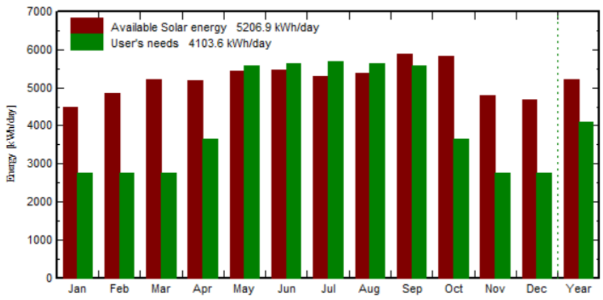


Figure 31: Available solar energy vs user's needs
Source: PVSyst (version 6.79), 2019

These aspects are taken into account to calculate the storage and cost of the PV system with PVSyst (2019). Batteries are used to store energy for the night and for two extra days. Because of this storage, more solar panels are needed than the estimation. 3920 solar panels with a surface area of 6377 m^2 will produce around 2200 MWh/year to cover the energy demand of the park. (PVSyst, 2019)

In the batteries the energy for the night and for two extra days will be stored. The park uses 4100 kWh/day and the storage has a capacity of 9200 kWh. 115 m^3 of battery is needed to store this amount of energy. (PVSyst, 2019)

An overview of the costs is shown in Figure 32. The initial system costs is 3.4 million euros and requires an annual amount of 640.000 euro for annuities and maintenance. The price for the energy comes down to 0,44 €/kWh which is calculated only from the total yearly cost (637.924), divided by the yearly amount of used energy (1.495.500). A more extended overview of the PVSyst (2019) outcome can be found in APPENDIX III.

Module cost	702702	EUR
Battery cost	2006645	EUR
Regulator cost	82026	EUR
Transport/Fitting	615196	EUR
Total investment	**3406569**	**EUR**
Annuities	136263	EUR/yr
Maintenance costs	501661	EUR/yr
Total Yearly cost	**637924**	**EUR/yr**
Energy cost	**0.44**	**EUR/kWh**

Figure 32: Overview costs off-grid solar system
Source: PVSyst (version 6.79), 2019

If the investment cost will be included in the energy price, it will be 0,52 €/kWh. Since these cost are too high for the Negin Safari Park, another calculation on the cost is done in which a solar power plant in Iran is examined. A power plant with 3230 solar panels is realized in the north-western of Iran. The cost for this project is 90 billion rial, converted to 1.898.174 euro. ("Green Power Supply to 650 Ardabil Households," 2019) For the 3920 solar panels needed in the park a cost of 2.303.666 euro can be expected. This is the cost for the modules, the regulator and the transport. The cost of the battery will be around $209 per kWh. (184 euro) (Pickerel , 2018) The battery in the park has a capacity of 9200 kWh, so the cost will be €1.687.308. Table 10 shows the overview of the cost which is very similar to the cost calculated by the PVSyst software. The cost for this off-grid system is too high and, therefore, the energy demand of the park should be reduced.

Table 10: Overview cost energy

Module, Regulator, transport/fitting	2.303.666	€
Battery	1.687.308	€
Total investment cost	3.990.974	€
Yearly cost	637.924	€/year
Energy cost for 25 years	0,53	€/kWh

Figure 33 shows the energy balance for the park when only solar panels are used. In this case 3920 solar panels are needed and 115 m^3 of battery storage. According to PVSyst (2019) the energy price will be 0,44 €/kWh.

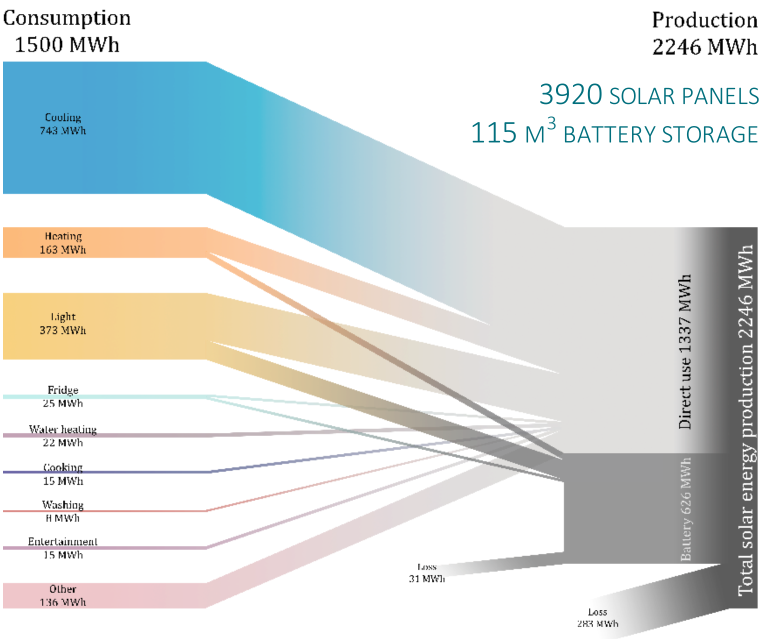


Figure 33: Energy balance solar panels

3.2.2. WIND ENERGY

The geographical conditions of Iran increase the probability of strong air flows in different months during summer and winter due to its low air pressure compared to the high air pressure in the north parts of the country. Most of the existing wind power generation sites in Iran are located in Gilan and Khorasan, provinces in the north of Iran. (Hosseini et al., 2013)

Figure 34 shows the wind speed at a height of 40 meter. Even though Iran falls in a medium wind velocity region, several regions have continuous winds, with suitable velocities capable of generating electricity. (Najafi & Ghobadian, 2011) The site for the Negin Safari Park is indicated with a black dot showing that the wind velocity is very low. (Alamdari, Nematollahi, & Mirhosseini, 2012) So wind energy is not the best solution for the Negin Safari Park.

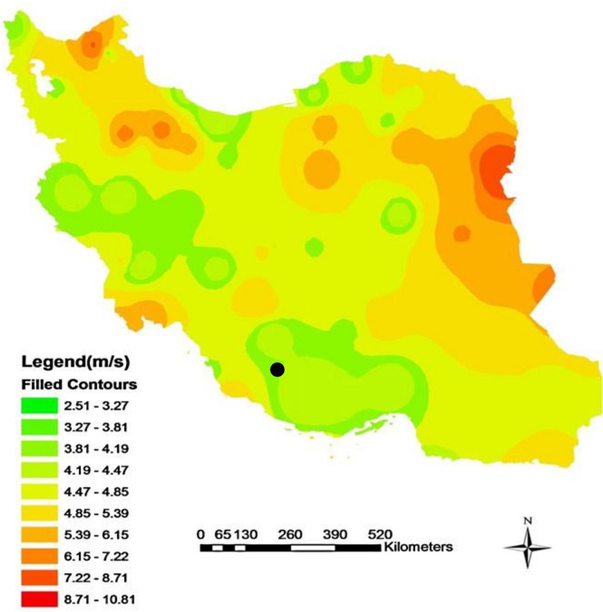


Figure 34: Mean wind velocity at height 40 m
Source: Alamdari, Nematollahi, & Mirhosseini, 2012

3.2.3. Biomass

Another source of energy is biomass, which contains all organic matter produced by photosynthesis. This includes vegetation and trees, municipal solid waste, municipal bio solids, animal waste (manures), forestry and agricultural residues, and certain types of industrial waste. (Khan, Paliwal, Pandey, & Kumar, 2015) Biomass can be relevant for the Negin Safari Park, since there will be animal waste.

The principle of biomass is that the energy of the sun is used by plants for photosynthesis. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates. When these carbon hydrates are burned, they turn back into carbon dioxide and water and release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. (Khan et al., 2015)

Biomass can produce heat and electricity, biogas and biofuels. (Moghtaderi & Ness, 2007) Biomass can be converted into electricity and heat in different ways. The most common way is direct combustion of biomass material. Most bio power plants use direct-fired combustion systems. They burn biomass directly to produce high-pressure steam that drives a turbine generator to make electricity. (Figure 35) (U.S. Department of Energy, 2016)

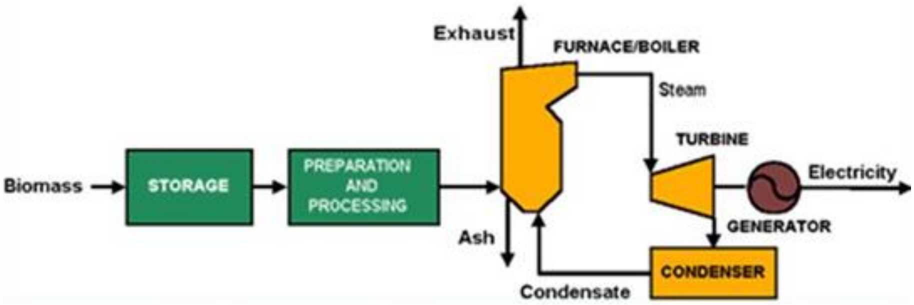


Figure 35: Direct combustion system
Source: U.S. Department of Energy, 2016

The energy content of biomass is around 17 – 21 MJ/kg. (McKendry, 2002)

Osuhor, Alawa, and Akpa (2002) stated that a goat can produce 138 kg dry manure per year. If we state that the bigger animals in the Negin Safari Park can produce even more manure the park can have around 13.000 kg of manure per year with 73 animals. With a yield of 20 MJ/kg the biomass can produce 260.000 MJ per year, equivalent to 72.000 kWh/year.

3.3. Energy Balance

The energy demand of the Negin Safari Park is estimated at 1.495.500 kWh/year. To cover this demand with an off-grid PV system, 6377 m^2 of solar panels is needed and 115 m^3 of battery storage. However, also the animal waste can be used to produce energy.

As not all energy has to come from the solar panels, less panels have to be used. 3200 solar panels are needed with a surface area of 5200 m^2. These panels will produce 2200 MWh per year, which is more than the energy demand of the park. There is loss in the energy production due to the irradiance level and the temperature of the solar panels. Also energy will be lost due to the battery efficiency and when the batteries are full. 100 m^3 of battery is needed. (PVSyst, 2019) An overview of the PVSyst (2019) outcome can be found in APPENDIX IV.

Figure 36 shows the energy balance of the Negin Safari Park. The biomass will be used mainly for cooking and water heating, because these need high temperatures. Furthermore, the energy produced by the solar panels will be partly stored, which will be used for lighting and the fridge during the night and there is spare energy for overcast days.

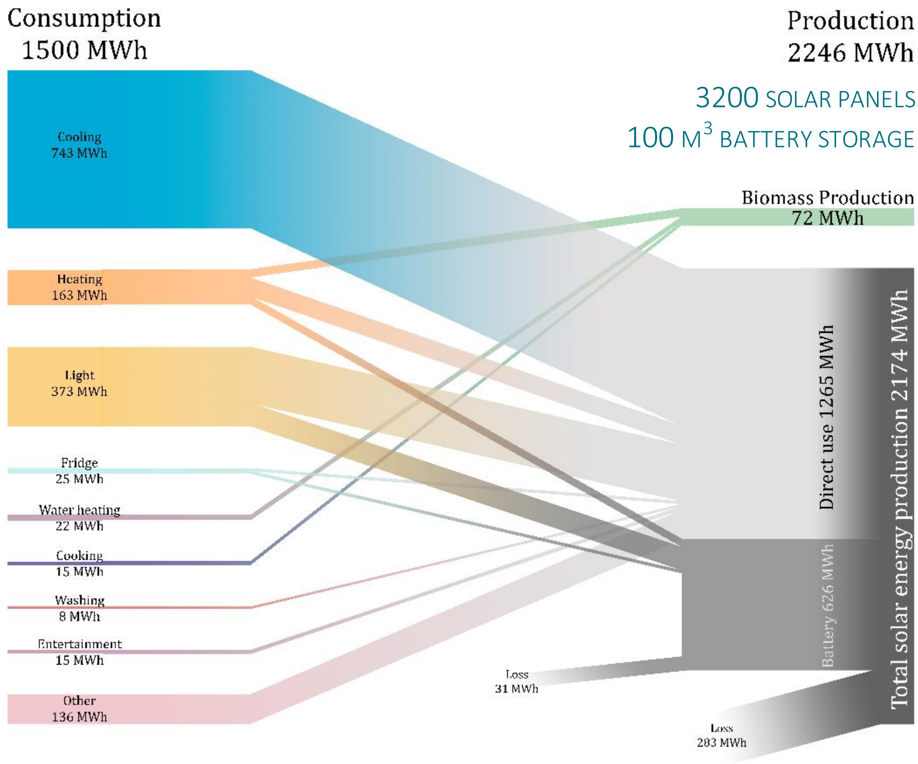


Figure 36: Energy Balance Negin Safari Park

3.4. Summary

Chapter 3 answers the question: What are the energy requirements for the Negin Safari Park and how can they be met? The first step in calculating the energy demand of the Negin Safari Park is to divide the different building types in the park into three categories. The last category is the outside area, which only needs lighting.

According to Moshiri (2013) the energy use of buildings in Iran is around 310 kWh/m^2/year. This is for household buildings, which need to heat and cool the house and use electricity for cooking and washing. Only a few of the buildings in the park fall in this category. The other buildings will use less energy. The energy demand of the Negin Safari Park is calculated to be around 1500 MWh/year.

Iran has a high potential for solar panels, because Iran is located in the world's Sun Belt. This means that the average solar irradiation is 2200 kWh per square meter. To cover the energy demand of the park, 5400 m^2 of solar panels are needed. However, the energy system should be off-grid and therefore more energy should be produced that can be stored. 3920 solar panels are needed with a battery storage of 115 m^3.

Wind energy has potential in the north and northeast of Iran. The Negin Safari Park is not located in a region with high wind speeds and, therefore, wind energy is not considered.

Biomass can be used in the Negin Safari Park, because animal waste is available. 13.000 kg of animal waste can be burned every year to produce 72.000 kWh of energy.

The energy balance gives and overview of the produced energy by solar panels and biomass and the used energy by buildings and lighting. The energy is stored in batteries to use during days without sunlight and during the night. The biomass produces 72.000 kWh of energy per year. 3200 solar panels produce the remaining energy for the park. The energy is stored in a battery of 100 m^3.

4

ENTRANCE BUILDING AS CASE STUDY

In the previous chapter, the energy demand of the Negin Safari Park was calculated per building type and the entrance building was found to consume most energy. Besides its energy use, the indoor air temperature of this building is required to be pleasant for the visitors in both winter and summer. Natural ventilation allows a higher indoor temperature than an air-conditioned environment, because of the continuous air flow. Vernacular architecture design techniques are applied to this building to reduce the energy demand and allow for natural cooling. This chapter will give an answer to the question: Which building in the park uses most energy and what are the requirements for this building?

4.1. Entrance building

Table 6 shows the different functions in the Negin Safari Park and their energy demand. The buildings in the first category, such as the restaurant, use most energy. In the conceptual design of the Negin Safari Park, the restaurant is combined with the reception, shop and weaving area into a single building consuming most energy. (Table 8)

The restaurant covers 350 m^2 and uses 310 kWh/m^2, whereas the reception and shop are 400 m^2 and use 200 kWh/m^2. Table 11 shows the energy consumption of this complete building, to be designed with vernacular architecture principles to reduce its energy demand. The batteries in the park have a capacity of two days to store energy, so when there are more overcast days in succession, energy should be saved, and not all categories can use the amount of energy they normally need. The fridge is the most important source, the cooling demand the least. The entrance building requires 188.500 kWh per year, distributed according to Figure 37. 57% of the total energy demand of the building is used for cooling. Figure 38 shows what the building looks like in the conceptual design.

Table 11: Energy consumption entrance building

			Priority
Cooling	106.300	kWh/year	9
Heating	21.300	kWh/year	5
Light	19.400	kWh/year	4
Fridge	7.600	kWh/year	1
Water heating	6.500	kWh/year	3
Cooking	4.300	kWh/year	2
Washing	2.200	kWh/year	6
Entertainment	4.200	kWh/year	7
Other	16.700	kWh/year	8
Total	188.500	kWh/year	

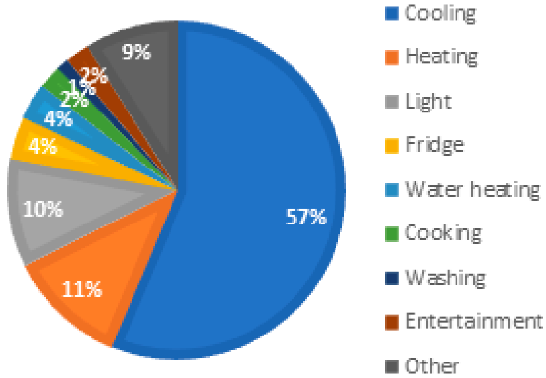


Figure 37: Energy usage entrance building

Figure 38: Entrance building conceptual design

4.2. TEMPERATURE REQUIREMENTS OF THE BUILDING

According to paragraph 2.5, the hot months are from April to October, when the daily outside temperature lies between 30°C and 40°C, this requiring cooling. During the summer, air movement reduces the feeling temperature, thus having a significant influence on human thermal comfort. Wind chill in cold conditions is considered disadvantageous, but air movement in neutral to warm environments is considered beneficial. This is because normally, under conditions with air temperatures above 23°C, the body needs to lose heat in order to maintain a constant internal temperature. (Figure 39) The cooling sensation is influenced by a number of factors, such as ambient air temperature, mean radiant temperature, metabolic rate, clothing insulation, humidity and skin wetness from perspiration. (Anysley, 2016)

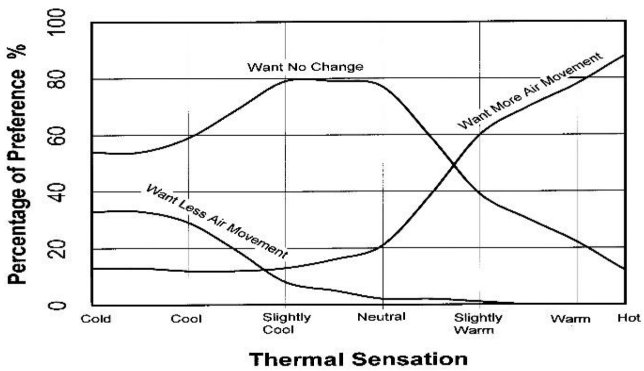


Figure 39: Preference for increased air movement
Source: Anysley, 2016

A building that is naturally ventilated or hybrid ventilated influences the thermal comfort. (Van Hoof et all., 2010) However, how a person experiences thermal comfort has to do with the contextual factors and the past thermal history of this person. People, who live their whole life in a warm climate zone, prefer a higher indoor temperature than people, who live in a cold climate zone. (Van Hoof, Mazej, & Hensen, 2010) As discussed in Paragraph 2.2, Simba expects most of the visitors of the Negin Safari Park to be domestic people, who are already adapted to the higher air temperature and would thus prefer a higher indoor temperature.

Figure 40 shows the acceptable range of operative temperature and air speed to reach a comfortable climate with a focus on domestic people. There are two different comfort zones: one where local control of air speed is required, and one where this is not required. When a local control of air speed is required, every six occupants can adjust the air speed in steps of 0,25 m/s. (ASHRAE Standard 55-2010, 2010) However, since the entrance building will be ventilated with windcatchers, the air speed cannot be adjusted.

A model for adaptive thermal comfort in naturally ventilated buildings is used to calculate the optimum comfort temperature: (Van Hoof et al., 2010)

$$T_{comf} = 17{,}8 + 0{,}31T_{air,out}$$

For the entrance building in Iran, with an outdoor temperature of 35°C, the optimum comfort temperature inside will be 29°C. According to Figure 40 an air speeds of 0,4 m/s is optimal. However, the inside temperature can be increased when the air speed is increased. The maximum air speed, when local control is not feasible, is 0,8 m/s, resulting in an operative temperature of 30°C.

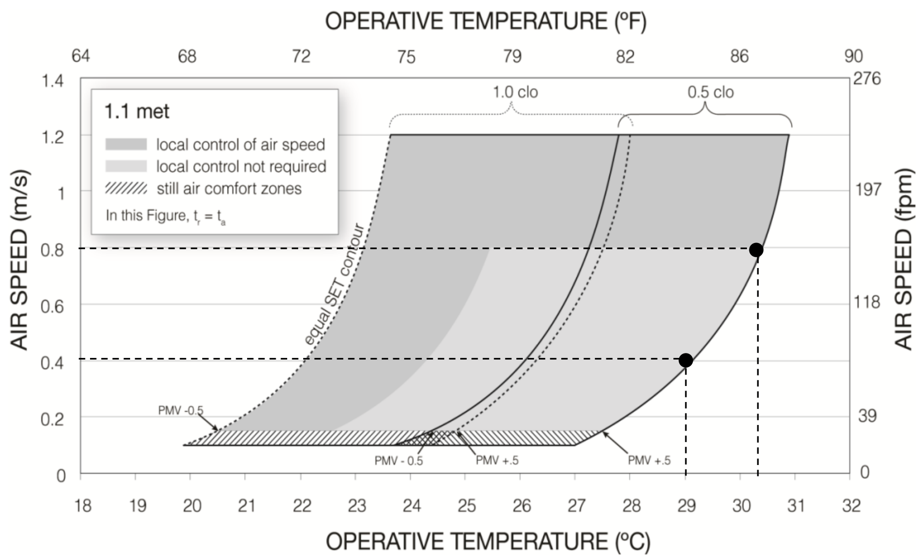


Figure 40: Acceptable range of operative temperature and air speeds for the comfort zone
Source: Lamberts, Candido, De Dear, & De Vecchi, 2013

4.3. Summary

Chapter 4 answers the question: Which building in the park uses most energy and what are the requirements for this building? The entrance building will use most energy of all buildings in the park, and uses more than 50% of its energy for cooling.

To test the passive design strategies, the temperature requirements for the building are set. A comfortable indoor temperature depends on different factors. The thermal history of a person influences the experience of thermal comfort. Residents of Iran will prefer a higher indoor temperature than the tourists. Also the air velocity can influence the comfortable temperature. A higher velocity increases the comfortable temperature. For this building, a temperature of 30°C with an air velocity of 0,8 m/s is optimal.

5

VERNACULAR ARCHITECTURE

Most buildings from the 20th century in hot climates are dependent on air-conditioning. The buildings are not designed for the specific climate, which leads to an extreme use of electricity to maintain a comfortable indoor climate. (Foruzanmehr & Nicol, 2008) Also the standard entrance building needs more than 50% of its energy for cooling. However, the principles from the vernacular architecture can be integrated in the design of modern, sustainable buildings, which are adapted to the climate and use less energy. (Foruzanmehr & Nicol, 2008) In this chapter, different vernacular architecture principles will be discussed to see if and how they can be integrated into the design of the entrance building. Principles like the courtyard, domed roofs and windcatchers will be discussed. This chapter will give an answer to the question: What design principles can be found in the vernacular architecture?

5.1. Courtyard

The courtyard is one of the most important elements in Persian architecture. The courtyard is a smart mechanism for maintaining privacy in an outdoor setting. The garden in the courtyard located around the pond is a symbol of paradise in the Persian architecture. (Mollayousef, 2018)

In the courtyard, different trees, flowers and shrubs are planted. (Soflaei & Shokouhian, 2005) This gives the sense of fresh air, mixed with the scent of flowers. (Figure 41) (Mollayousef, 2018) The plants provide shade and combined with the pond they increase the relative humidity of the air. (Maleki, 2011b) The courtyard is narrow enough to maintain a shaded area during the summer, but wide enough to receive solar radiation in winter. (Soflaei & Shokouhian, 2005)

Figure 41: Courtyard with trees and pond
Source: Mollayousef, 2018

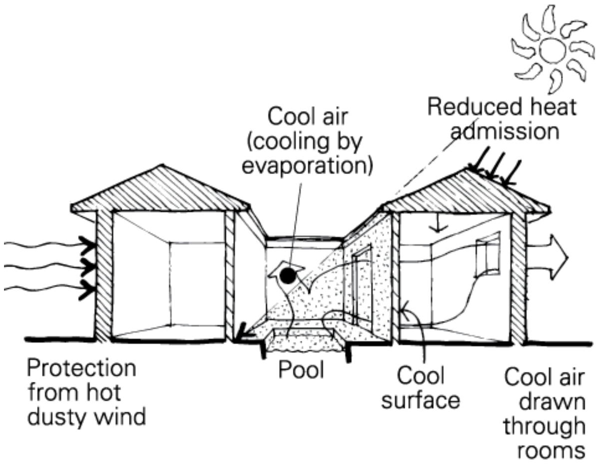


Figure 42: Courtyard with trees and pond
Source: Akande, 2010

A courtyard reduces the cooling needs of a building through evaporative cooling. This is effective in a hot and dry climate. In evaporative cooling, hot air evaporates the water, thereby cooling the air, which in turn cools the living space of the building. If the hot air comes in contact with more water, the rate of evaporation increases. (Figure 42) (Akande, 2010)

For the entrance building, a courtyard can be used as a design principle in two ways. The building can be designed around a central courtyard. (Figure 43) Or the courtyard can be designed around the building. In this case the courtyard will not be the centre of the building and the courtyard will be defined by the building on one side and a wall on the other side. (Figure 44)

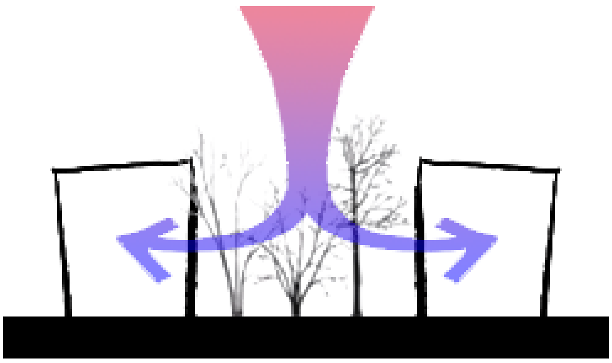


Figure 43: Principle internal courtyard

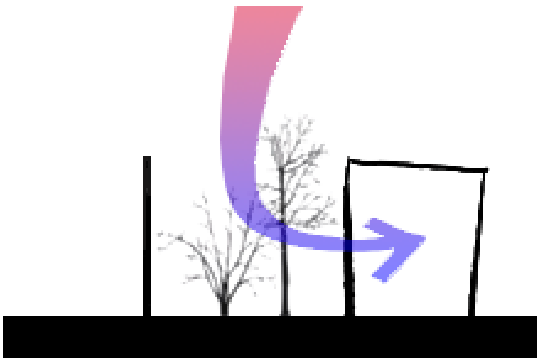


Figure 44: Principle external courtyard

5.2. Roof

In the vernacular architecture of Iran, two types of roofs can be found: flat and domed roofs. Flat roofs have a sheltering wall around them which is higher than vision level. The wall fences the entire roof, to make it usable as a living space and to provide privacy and security. However, the wall also protects the roof of the building from direct sun light and corresponding heat. (Figure 45) (Shoaie & Habib, 2013) Flat roofs are usually paved with square shaped bricks that receive most of the sun radiation. (Maleki, 2011a)

Figure 45: Flat roof with wall
Source: https://www.wecaravan.to/iran

Domed roofs were mostly used on mosques, water reservoirs and bazars, as they have structural and thermo-physical benefits. (Figure 46) (Shoaie & Habib, 2013) During the day, some area of the dome is always in the shade. Therefore, the radiant heating during the day is minimized. During the night the radiant cooling is maximized. Therefore, the building heats up less during the day and cools better during the night. (Figure 47) (Moossavi, 2014)

Figure 46: Domed roof
Source: Maleki, 2011

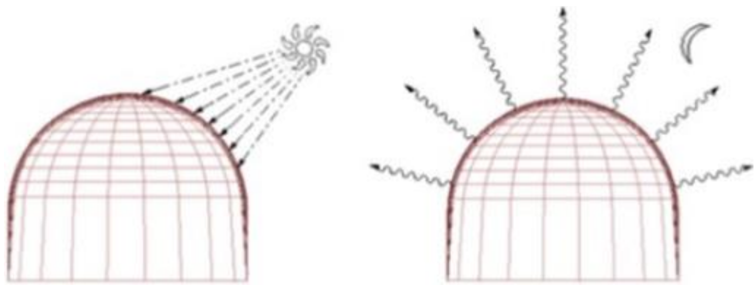


Figure 47: Radiant heating and cooling
Source: Moossavi, 2014

A domed roof is suitable for the entrance building, as it has a lot of benefits. (Figure 49) However, as solar panels need to be placed on top of the building the roof can also be adjusted to the panels. Therefore, the building's roof is adjusted to an angle that is most suitable for the solar panels. (Figure 48) This angle is close to the location's latitude which is 29°.

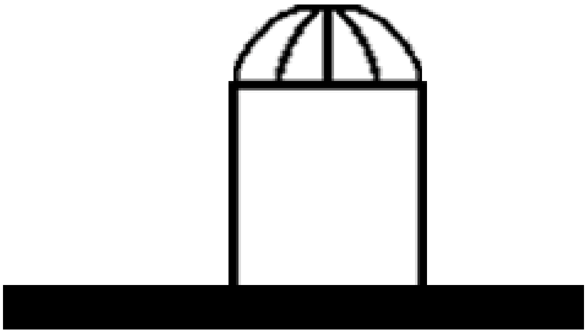


Figure 48: Principle domed roof

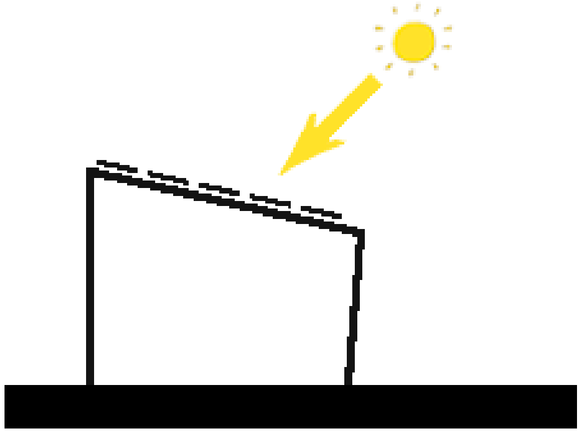


Figure 49: Principle roof adjusted to solar panels

5.3. Facade

In the vernacular architecture of Iran, environmentally friendly materials were used with low transportation costs, which are mostly native materials. (Shoaie & Habib, 2013) Mainly natural materials are used in Iran, because they are available and resistant against the burning sun, such as adobe and mud brick. (Keshtkaran, 2011) Adobe is typically made from sand, clay, water, and a fibrous or organic material, and is shaped using molding techniques and dried in the sun. (Figure 50) (Mollayousef, 2018)

Figure 50: Material in desert architecture
Source: Maleki, 2011

For the choice of the material the thermo-physical specifications are most important. Natural materials have thermal resistance, a high heat capacity and they absorb the sun radiation. The many pores in these materials are filled with air, which makes them work similar to a thermal insulator. (Maleki, 2011a) The high thermal capacity of adobe and mud, ensures that it takes a long time before the outdoor heat passes through the walls. Adobe can delay the heat transfer from the outside to the inside for several hours, which ensures that the heat captured in the walls during the day heats the house during the night. (Keshtkaran, 2011)

Besides the material, also the thickness of the walls has an influence on the indoor climate of a building. In a hot and dry climate, walls with a thickness of one meter or even more are commonly employed. (Maleki, 2011a) These thick walls have a few benefits, since they increase the delay in absorbing the heat on one side of the wall and releasing the heat on the other side. Therefore, the building heats up less. Another benefit is the decreased temperature swing between day and night.

(Figure 51) (Shoaie & Habib, 2013) Thick walls are most beneficial when there is a big difference between day and night temperatures. (Zandieh, Khaleghi, & Rahgoshay, 2012)

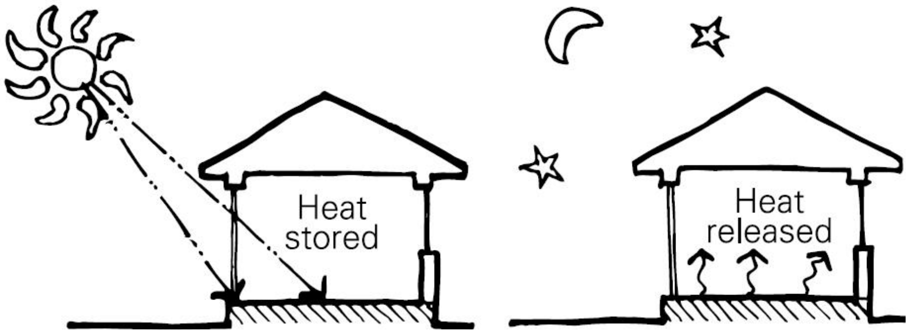


Figure 51: Thermal mass performance
Source: Zandieh, Khaleghi, & Rahgoshay, 2012

Besides material and thickness also the colour of the wall has an influence on the indoor climate. Light colours absorb less heat. Smooth and glossy surfaces are also used to reflect light. (Keshtkaran, 2011)

For the entrance building in the Negin Safari Park, these principles from the vernacular architecture can be used. Natural material like mud brick or adobe can be used for the façade and roof with a high thermal mass. Walls can be up to one meter thick. The walls and roof should have light colours so less heat is gained. (Figure 52)

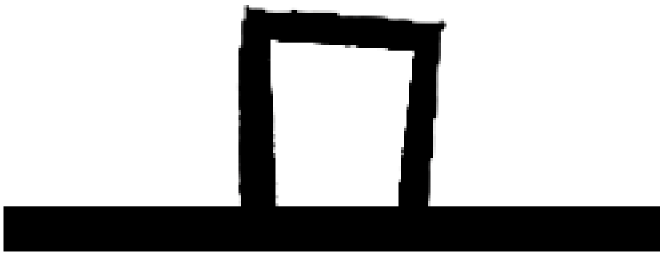


Figure 52: Principle thermal mass

5.4. Openings

The number and size of the openings in a buildings depends on the climate. In hot areas, the openings are small and located in the upper part of the wall, to minimize the heat gain during summer and the heat loss during winter. (Shoaie & Habib, 2013) Less dust and excessive sunlight enters the building. (Keshtkaran, 2011) The windows are oriented on the north and east side. (Shoaie & Habib, 2013)

Most of the windows are facing the courtyard. The air in the courtyard is cooler and, therefore, the heat gain through these windows is smaller. (Maleki, 2011a) The windows facing the courtyard are decorated with wooden frames and coloured glasses to provide privacy and hamper direct sunlight. (Figure 53) (Sahebzadeh, Heidari, Kamelnia, & Baghbani, 2017)

The number of openings on the exterior façade is minimized to prevent dust and unfavourable hot air entering the house. (Figure 54) (Sahebzadeh et al., 2017)

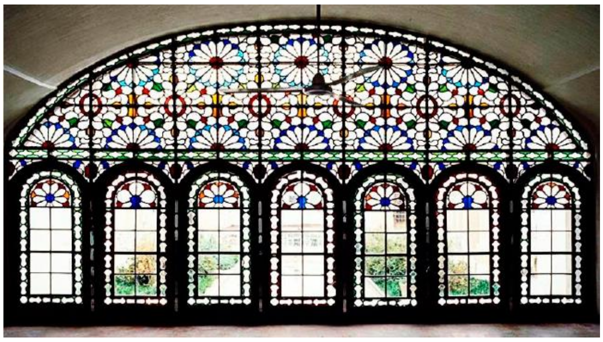


Figure 53: Windows facing courtyard
Source: Sahebzadeh, Heidari, Kamelnia, & Baghbani, 2017

Figure 54: Windows exterior facade
Source: Sahebzadeh, Heidari, Kamelnia, & Baghbani, 2017

The principles from the vernacular architecture on openings can give some design guidelines for the entrance building in the Negin Safari Park. If the building gets a courtyard, the bigger window openings can be placed on this side of the building. On the other side, the building will get small window openings. If the courtyard is not be integrated in the design, the openings can best be located on the north and east side and must be small to prevent the building from heating up. (Figure 55)

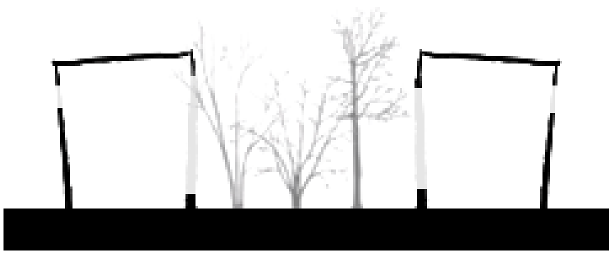


Figure 55: Principle windows

5.5. Windcatcher

Another principle used in the vernacular architecture in Iran is the windcatcher. Windcatchers have been used in the Middle East since 1300 BC. A windcatcher functions as a ventilator and is placed on the side from which the wind comes to create an airflow in the building. (McCabe & Roaf, 2013)

A windcatcher provides natural ventilation, from natural driving forces, such as wind and temperature differences. (Dehghan, Manshadi, & Esfeh, 2014) It works on the principle of air moving from a high pressure to a low pressure zone. Windcatchers are tall structures with a height from 5 to 30 meters above the building's roof. Elevated windcatchers are able to catch fresher air with higher velocity and less dust. (Saadatian, Haw, Sopian, & Sulaiman, 2012) Figure 56 shows that buildings with only one window opening have poor ventilation, because the wind cannot change its direction to enter the building. The windcatcher solves this problem. The wind will give a positive pressure on the windward side and a negative pressure on the leeward side. This pressure difference allows the outside air to enter the building and sucks out the air from the building. (Dehghan, Manshadi, & Esfeh, 2014)

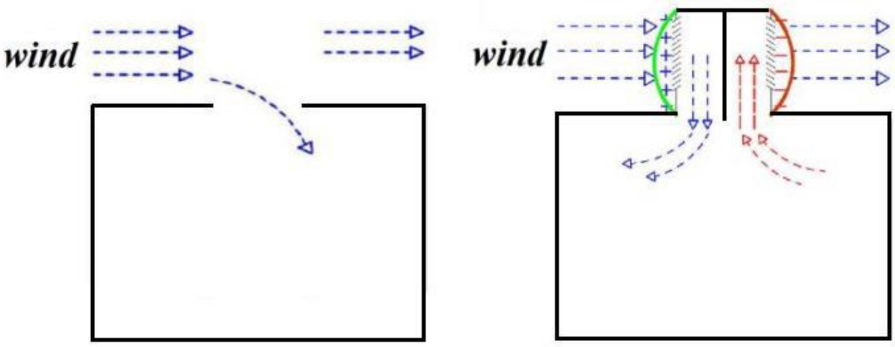


Figure 56: Windcatcher function as natural ventilation device
Source: Dehghan, Manshadi, & Esfeh, 2014

Due to differences in the geographical location, the wind power and the direction of the wind, windcatcher designs differ. These differences can be found in the height, the cross section, the placement and number of openings, and the placement of the windcatcher relative to the ventilated space. Figure 57 shows different windcatchers with different configurations built in Iran. (Dehghan, Manshadi, & Esfeh, 2014)

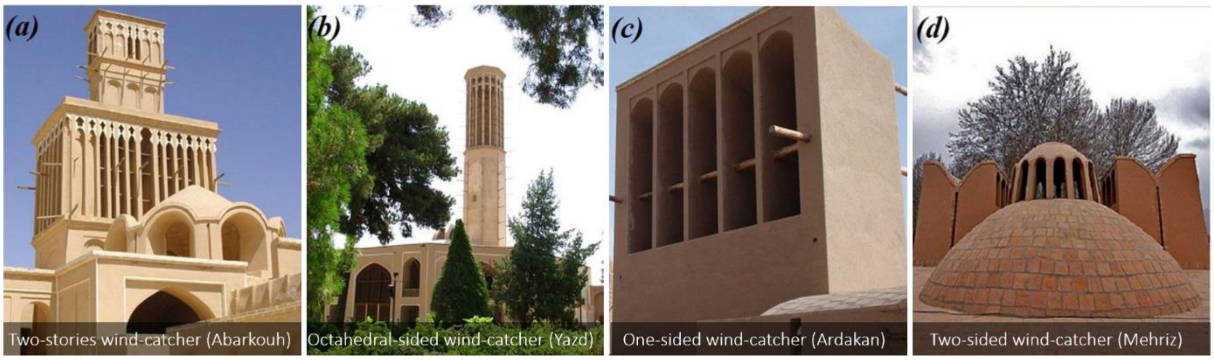


Figure 57: Typical windcatchers with different configurations
Source: Dehghan, Manshadi, & Esfeh, 2014

A windcatcher can be used in the entrance building to provide natural ventilation. (Figure 58) Different types of windcatchers exists, for example a windcatcher based on wind or temperature difference. Windcatchers also differ in height, openings and cross section. Therefore, more research should be done on the kind of windcatcher that can be used for the Negin Safari Park.

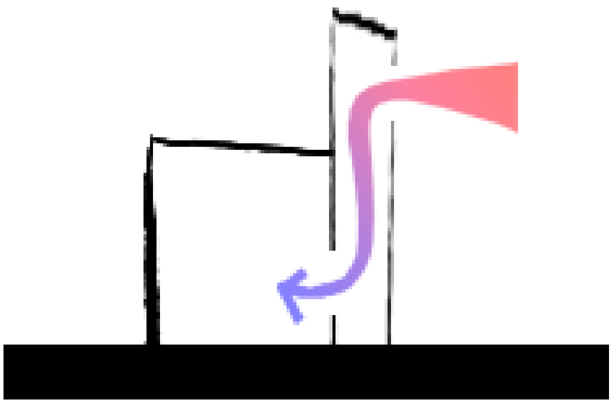


Figure 58: Principle windcatcher

5.6. SUMMARY

Chapter 5 was looking for an answer to the question: What design principles can be found in the vernacular architecture? In hot and arid regions, the indoor air temperature during a sunny summer day can get unpleasantly high due to the solar radiation heating up the walls and the roof and radiant heat entering the building through openings. The designers of the vernacular architecture in Iran found innovative strategies to maximize the indoor thermal comfort, with techniques like domed and vaulted roofs, materials and windcatchers. This chapter showed five techniques that were mostly used in the vernacular architecture. An overview of which can be found in Table 12.

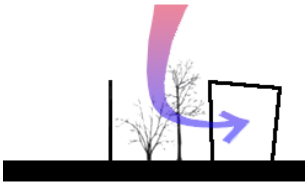
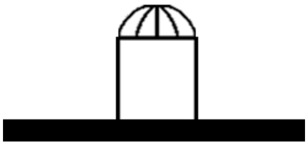
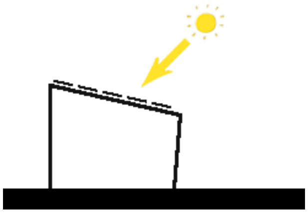
The first technique is the courtyard, which is used as a pleasant outdoor area with plants and a pond. The area is cooler, because of the shade the building and the plants give and because of evaporative cooling. The building ventilation is done through the courtyard to cool the building.

The second principle was about the roofs. Both domed roofs and flat roofs are common in Iran. Domed roofs have several benefits for keeping the building cool; however, in combination with solar panels, they are not optimal. Therefore, it is better to orient the roof towards the sun so the panels catch most sun.

The next part was about the façade of the building. In the vernacular architecture mostly natural building materials were used, such as mud and adobe. These materials have a high thermal resistance, a high heat capacity and they absorb the sun radiation. In combination with a high mass, these façades prevent the building from heating up during the day. The openings in the façade must be small on the south and west side, and can be bigger on the north and east side. In combination with a courtyard, the windows can be located facing the courtyard.

The last principle was the windcatcher, which is used throughout Iran. A windcatcher naturally ventilates the building and ensures less dust enters the building. A windcatcher is thus a good solution for cooling a building.

Table 12: Vernacular principles

Vernacular architecture principle		Design principles	
Courtyard		 	Internal courtyard External courtyard Courtyard used for evaporative cooling
Roof		 	Domed roof to minimize radiant heating during the day and maximize radiant cooling during the night Roof adjusted for solar panels
Facade			Natural material like mud or adobe Thermal mass, walls up to 1 meter Light coloured surfaces Less solar heat gain
Openings			Openings faced north and east Small openings high in the wall exterior Big openings facing courtyard Less solar heat gain
Windcatcher			Windcatcher for natural ventilation

6

WINDCATCHER

In the previous chapter, various design principles from the vernacular architecture have been presented, one of which the windcatcher. As buildings use most energy for cooling, natural ventilation offers an opportunity. Nowadays, due to technological developments and easy access to fossil fuel resources and electricity, fresh air is supplied in buildings with mechanically driven air conditioners. However, with increasing environmental issues, as well as increased energy consumption rates due to higher living standards, natural ventilation is reconsidered as a viable alternative. (Dehghan, Manshadi, & Esfeh, 2014)

In several cities, the air conditioners take almost full capacity of the power grid. Natural ventilation has been used for centuries and has some important sustainable benefits, like energy requirement, environmental impact and indoor air quality. (Khanal & Lei, 2011)

The Negin Safari Park must be off-grid and environmentally friendly. Therefore, natural ventilation offers a viable cooling solution. This chapter will answer the question: What are the different types of windcatchers and which one can best be used for the Negin Safari Park?

6.1. Size and dimension of windcatcher

In different countries, the circumstances are different and, therefore, the windcatcher is different. Figure 59 shows how windcatchers differ in size, height and ceiling slope. However, even windcatchers in Iran differ. In the south of Iran, windcatchers are large and short, while the intensity of the wind blast in these regions is rather low. Windcatchers in hot and dry areas are higher, because the fresh air is higher and there is little dust. Also the volume of these windcatchers is less. (A'zami, 2005)

	Iran's arid zone	Persian gulf	Iraq	Egypt	Pakistan	Afghanistan
Climatic zone	Hot and dry	Hot and humid	Hot and dry	Hot and dry	Hot and humid	Dry and semi hot
Air direction	North-east	Breeze	North-west	North-west	South-west	North
Shape of cross-section	Square/rectangle hexagon, octagon	Square	Rectangle	Rectangle	Square	Square
Average dimensions (m)	0.5 × 0.8 0.7 × 1.1	1 × 1	0.5 × 0.15 1.20 × 0.60	-	1 × 1	1 × 1
Height (m)	3–5	3–5	1.80–2.10	One story above roof	5 And above	1.5 From roof
Direction according to the airblow	Diagonal	Diagonal	Ordinary	Ordinary	Diagonal	Ordinary
Ceiling of the Wind tower	45° Slope	30° Slope	45° Slope	30° Slope	45° Slope	30° Slope
Ventilated area	Dining room and basement	Dinning plus others	Only basement	Dinning plus one room	All rooms	All rooms
Airblow	Multi-side	Multi-side	One, two-side	One-side	One-side	One-side
Evaporative cooling	Sometimes	Never	Sometimes	Sometimes	Never	Never

Figure 59: Types of windcatcher
Source: Dehghani-sanij, Soltani, & Raahemifar, 2015

Windcatchers are usually small towers in the form of quadrilateral and regular polygons. (A'zami, 2005) Four types of wind catchers are found in traditional houses: one, two, four, or eight sided. (Figure 60) (Mollayousef, 2018) When the wind comes from multiple directions a four or eight directional orientation is used in order to use all of the desirable winds. (Maleki, 2011b)

The number of openings in a windcatcher affects its efficiency in a way that as much as the number of openings increases, its efficiency decreases. However, in places without a prevailing wind, the best option is the use of multi-opening windcatchers. (Saadatian et al., 2012)

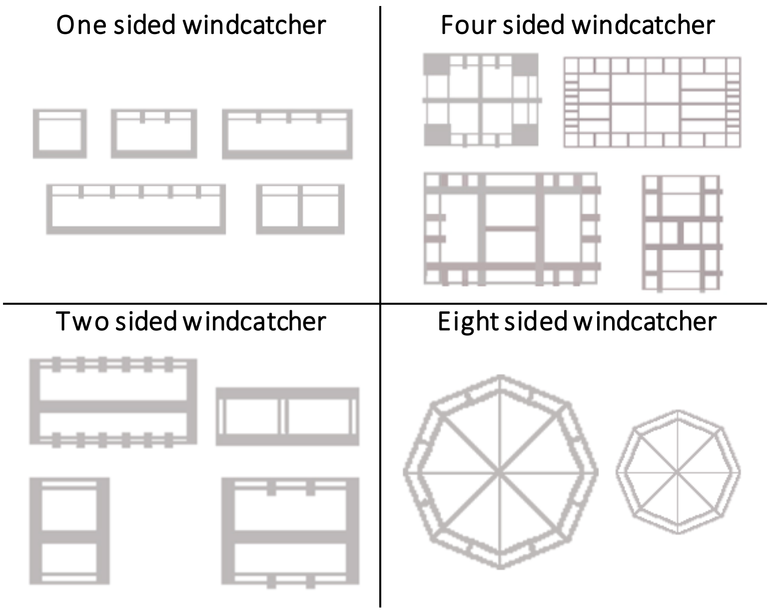


Figure 60: Top view types of windcatcher
Adjusted from source: Mollayousef, 2018

When the wind comes from one specific direction, a one-sided windcatcher is used. (Figure 61) The opening is faced in the wind direction and on the other side of the room an exhaust is required. (Tavakolinia, 2011) A two sided windcatcher has two openings on the top of the shaft. The openings are in opposite direction. One side leads the cool air down into the house, and the warm air leaves trough the other side. (Figure 62) (Tavakolinia, 2011) Figure 17 shows that the wind direction on the park's location comes from two directions that are almost opposite. Therefore, a two-sided windcatcher can best be used. When the wind comes from the southwest, the wind can enter from one opening and leave trough the other. When the wind comes from the north-northeast this will be opposite.

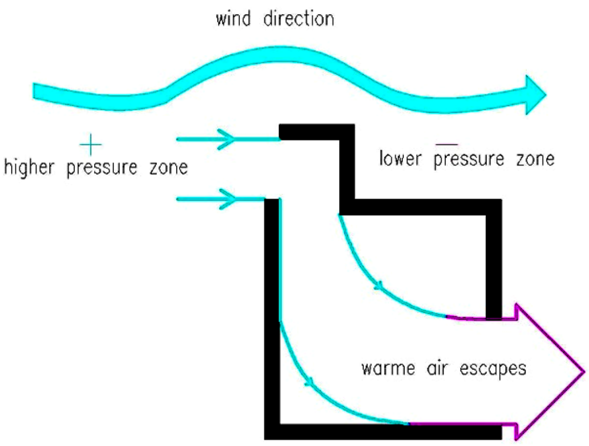


Figure 61: One-sided windcatcher
Source: Tavakolinia, 2011

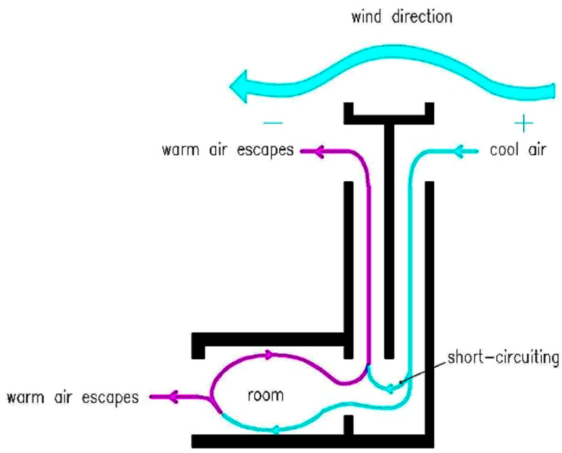


Figure 62: Two-sided windcatcher
Source: Tavakolinia, 2011

6.2. MATERIALS AND STRUCTURE

The windcatcher's materials depend on the climate, in a hot and dry climate mud brick or baked brick, covered with mud plaster, is used. Windcatchers in a hot and humid climate are covered with a moisture resistant plaster. (Jazayeri & Gorginpour, 2011) The façade colour of the windcatcher is cob or white, which reflects the sun radiation. The presence of straw in the mud bricks increases the coarseness of the façade, which also hinders the absorption of sun radiation. (A'zami, 2015)

For the structure of the windcatcher, wood hanks are used inside the mud bricks to increase the resistance against lateral forces. (Figure 63) The wooden hanks tie the structure, and wooden bars on the outside of the structure create a ladder for constructing the upper part of the windcatcher, and to allow for easy access for maintenance. (Figure 64) Chandal wood is regularly used as it is resistant against humidity, rottenness and termite. (A'zami, 2015)

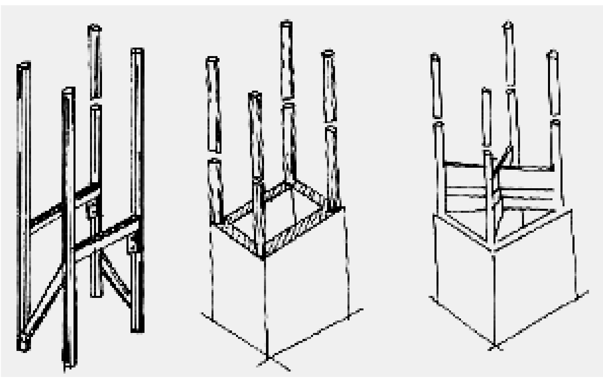


Figure 63: Wood hanks inside mudbrick structure
Source: A'zami, 2015

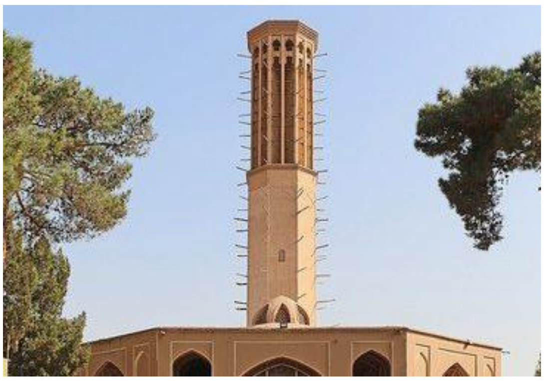


Figure 64: Wood hanks inside mudbrick structure
Source: https://www.atlasobscura.com/places/dolat-abad-windcatcher

6.3. Function of a windcatcher

The windcatcher, or Badgir, is one of the signature elements in the traditional houses of Iran and has been used since early times. The most common way of windcatcher operation is creating a temperature difference from the wind. Another way is using thermal buoyancy to create air flow in the building. (Khanal & Lei, 2011) Also, a combination of these systems is a possibility.

6.3.1. Positive and negative pressure created by the wind

When the wind hits the building, it creates a positive pressure on the windward side. On the other side, it creates a negative pressure. (Khanal & Lei, 2011) The wind is pushed into the opening facing the wind and pulled out on the other side. (Figure 65) The windcatcher takes fresh air into the building, and hot and polluted air is pushed out. (A'zami, 2005) The building is thus ventilated without supplying energy. (Moghaddam, Amindeldar, & Besharatizadeh, 2011)

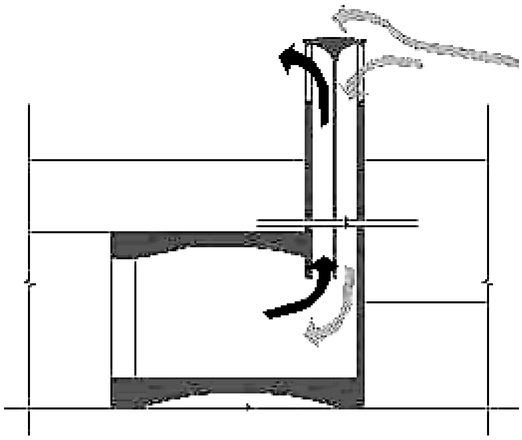


Figure 65: Windcatcher air suction and air pulling
Source: A'zami, 2005

6.3.2. Air flow created by thermal buoyancy

Another principle is an air flow created by thermal buoyancy. (Khanal & Lei, 2011) When there is insufficient wind, the windcatcher functions through temperature difference. During the day, the sun hits the south side of the windcatcher and heats the air, which then goes up, creating a pressure difference inside the building. Therefore, fresh cold air is pulled down in the northern opening. (Figure 66) (A'zami, 2005)

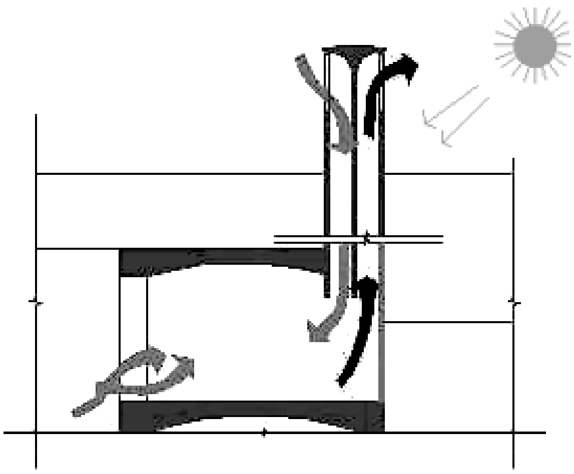


Figure 66: Windcatcher function during day
Source: A'zami, 2005

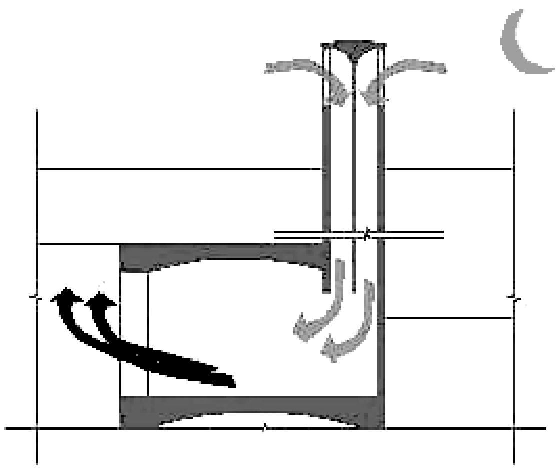


Figure 67: Windcatcher function during night
Source: A'zami, 2005

During the night, the outside air cools and moves down. Cold air enters the building, heats up and is then forced out of the building. (Figure 67) This continues until the temperature of the walls and the outside air equalized. However, this situation does usually not arrive before the end of the night. (A'zami, 2005) This way of natural ventilation is called stack ventilation and can be compared to a solar chimney.

A solar chimney is designed to maximize the ventilation effect by maximizing solar gain, thereby creating a sufficient temperature difference between the inside and outside of the building to drive an adequate air flow. The combined radiation and convection inside a solar chimney results in air movement and improved ventilation. A solar chimney is a thermo-syphoning air channel in which the principal driving mechanism of air flow is through thermal buoyancy. There are variations in solar chimney design, caused by a number of factors, such as the location, climate, orientation, size of the space to be ventilated and the internal heat gain. However, the basic elements, such as solar collector, transparent cover, and inlet and outlet are part of every design. (Figure 68) (Khanal & Lei, 2011)

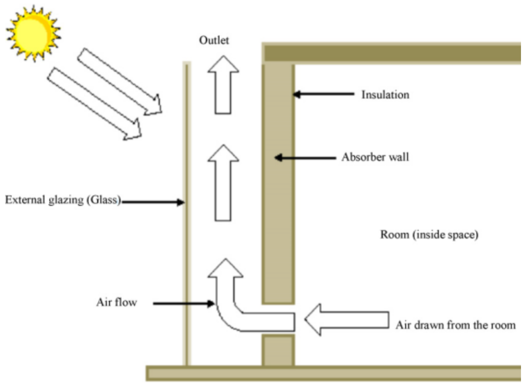


Figure 68: Solar chimney
Source: Khanal & Lei, 2011

6.3.3. Windcatcher and solar chimney

The windcatcher, which works with pressure difference, can be combined with the solar chimney. (Figure 69) After hot air enters the windcatcher, it becomes cooler, because of passing over a water pond. Then it enters interior spaces of the building and makes them cooler. After it becomes warmer, it goes up through wetted grating, placed at the top of the wall between windcatcher and chimney. This passing cools down the air and helps to keep the temperature of interior spaces pleasurable. After this cool air is absorbed in the interior spaces it becomes warmer, it goes up and is led out of the building through the chimney, which is hot because of the sun. (Mahdavinejad & Khazforoosh, 2014)

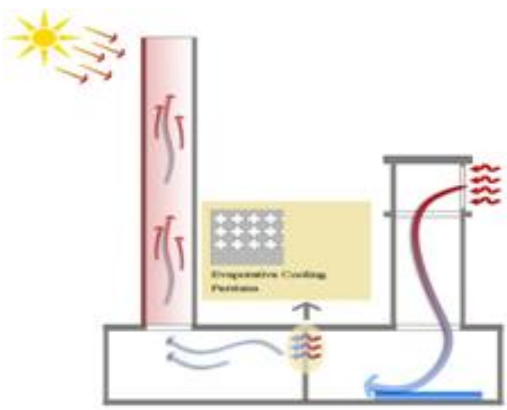


Figure 69: Combination windcatcher - solar chimney
Source: Mahdavinejad & Khazforoosh, 2014

6.4. EVAPORATIVE COOLING

Although the windcatcher creates natural ventilation, the captured wind is still warm. Therefore, the captured wind at the top of the windcatcher is funnelled down into the basement, where a small pool with water is situated. (Figure 70) (Mollayousef, 2018) The air is cooled by evaporation and brings more humidity to the other spaces of the building. (Maleki, 2011b) (May, 2014) The combination of windcatchers with courtyards and domes produces far more effective ventilation. (Mollayousef, 2018)

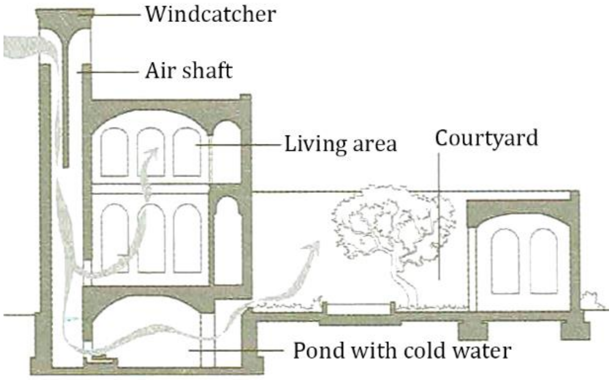


Figure 70: Windcatcher pond
Adjusted from source: May, 2014

Using water, the inside temperature decreases and the relative humidity increases. This is achieved by a water pond with fountain at the bottom of the windcatcher or in the courtyard. However, the water can also be integrated in the windcatcher itself, with wetted surfaces or wetted columns to improve the ventilation and thermal performance of the building. (Figure 71) (Jomehzadeh et al., 2017)

Three ways to integrate the evaporative cooling in the windcatcher design are compared. One with wetted columns in the airshaft, one with wetted curtains in the airshaft and one with a wetted surface before the entrance of the windcatcher. (Bahadori, Mazidib, & Dehghanic, 2008) The curtains are wetted by spraying drops of water through a nozzle system at the top of the tower. (Hughes et al., 2010) The thermal performance of windcatchers with integrated evaporative cooling methods is higher than that of traditional windcatchers. The relative humidity is increased and the indoor air temperature is decreased. The results highlight the suitability of the windcatcher with wetted surfaces in low wind conditions and the wetted column system in high wind speeds. (Jomehzadeh et al., 2017)

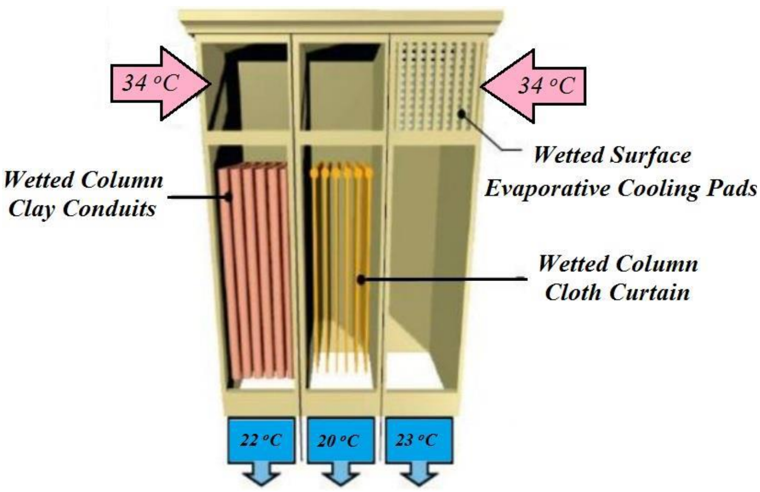


Figure 71: Windcatcher cooling systems
Source: Dehghan, Manshadi, & Esfeh, 2014

The Zion National Park Visitor Centre (ZNPVC) uses windcatchers with a wetted surface and is located in southwest Utah. (Figure 72) In summer, the outside temperature in Zion Park is around 39°C with a humidity lower than 20% and a wind speed around 1,5 – 2,6 m/s. (Soelberg & Rich, 2014) These values are comparable with the site in Iran. In the building, it is around 23°C with a humidity higher than 20% in summer. (Soelberg & Rich, 2014)

The pads located at the top of the tower are sprayed with water to cool the hot, dry air. The cool air falls through the tower to cool the building. The desired temperature is regulated by controlling an opening at the bottom of the tower to manipulate the airflow. The cooling towers, along with the clerestory windows, help natural air to flow through and cool the building. (Figure 73) (Lea, 2010)

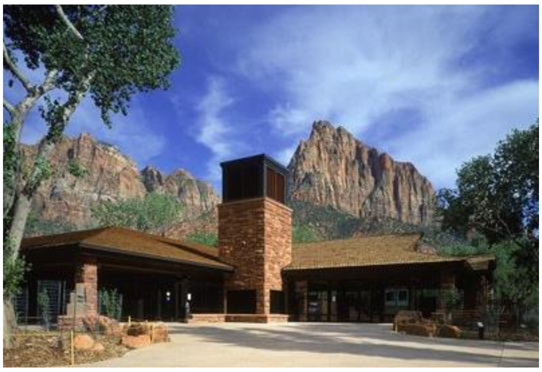


Figure 72: Zion National Park Visitor Centre
Source: Lea, 2010

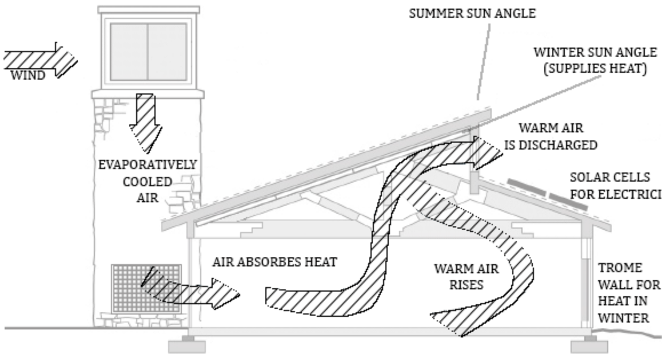


Figure 73: Zion National Park Visitor Centre scheme
Adjusted from source: Soelberg & Rich, 2014

6.4.1. Underground tunnels

The hot outside air can be cooled by evaporation with water integrated in the windcatcher. Another concept of cooling the outside air is a combination of windcatchers and underground tunnels. An example of this is cooling with qanats: excavated tunnels used to irrigate the land. The qanats can be used for cooling the building when an air intake is dug into the qanat at an upstream location and another underneath the building. The outside air flows over the cold water in the qanat before entering the building. A windcatcher is used as a solar chimney to draw the cool air from below through the building. (Figure 74) (Soelberg & Rich, 2014)

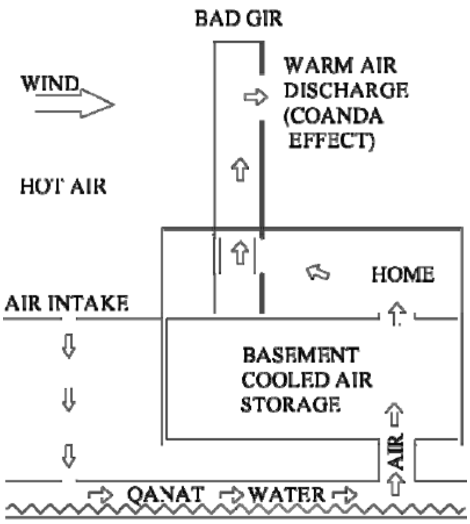


Figure 74: Windcatcher connected to qanat
Source: Soelberg & Rich, 2014

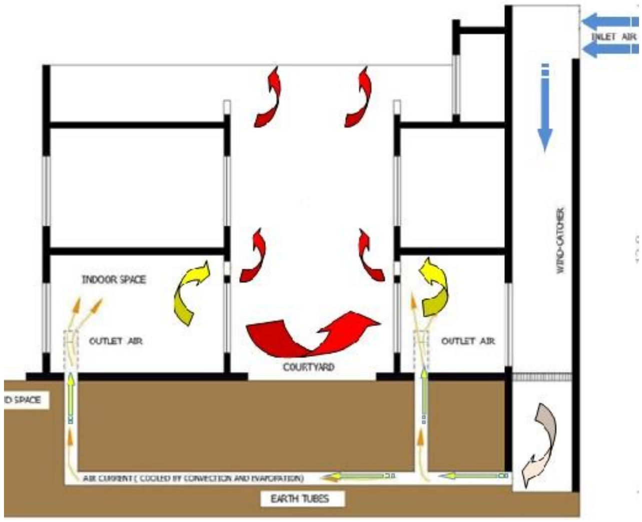


Figure 75: Windcatcher underground tunnels
Source: Jassim, 2015

Another way of cooling with tunnels is with an earth-to-air heat exchanger. Underground tunnels are connected to the windcatcher. The air from the windcatcher goes into the tunnels and is cooled. (Figure 75) The tunnels should be 2 – 3 meters underground. The cooling effect of air in the underground tunnels is comparable to the windcatcher with wetted surfaces. (Jassim, 2015)

Figure 76 shows the ground temperature at different depths in Shiraz. During the hot summer months, the temperature at 2 meters depth is around 25°C, and at 4 meters depth around 23°C. (Climate Consultant 6, 2018)

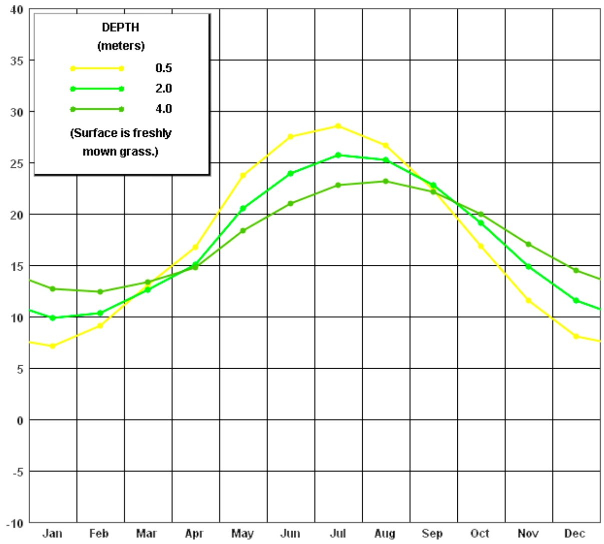


Figure 76: Ground temperature Shiraz
Source: Climate Consultant 6, 2018

Such a system can be used in the Negin Safari Park. Compared to the other techniques, the underground tunnels do not need any water, which is an asset for the park as little water is available. To reduce the temperature of the outside air in the underground tube some length of the tunnel is required, depending on the outside air temperature and the ground temperature. (Jassim, 2015) Figure 77 shows the design principle for a windcatcher in combination with an underground tunnel.

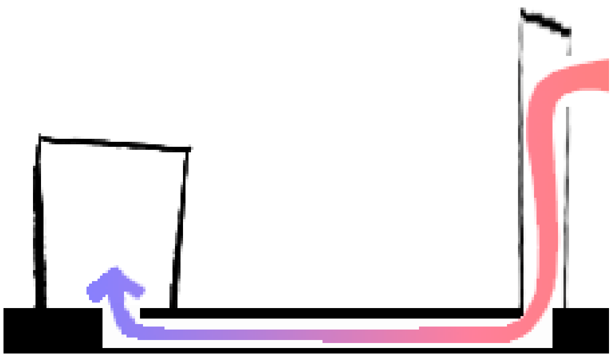


Figure 77: Design principle windcatcher underground tunnel

6.5. CFD WINDCATCHER TYPES

A computational fluid dynamics (CFD) study provides inside in the performance of the various windcatcher types. This study is executed with Phoenics VR (2018). For the CFD study some default values are set;

- A building of 16m x 18m x 4m
- Walls that are 1000 mm thick.
- Outside air velocity 5 m/s at a height of 10 meters
- Outside temperature of 35 °C

A CFD study is done on a simple building with natural ventilation but without a windcatcher, as a control for the results. (Figure 78).

Figure 78: Standard building

The first study is done during the night. In this case the building should not be heated up. Figure 79 shows the temperature in the building during the night, which indeed does not heat up. The temperature will be equal to the outdoor temperature. Figure 80 shows the velocity in the building.

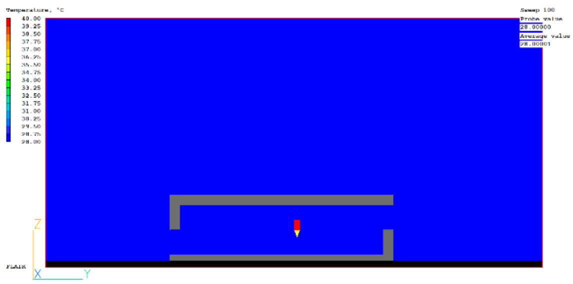


Figure 79: Temperature in and around building, night
Source: Phoenics VR, 2018

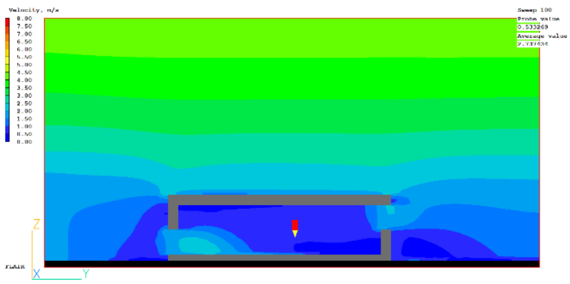


Figure 80: Air velocity in and around building, night
Source: Phoenics VR, 2018

During the day, the building should not be heated up to much as well, as the walls are 1 m thick. Figure 81 shows the temperature in the building during the day, which is 40°C, so 5°C warmer than the outside temperature. Figure 82 shows the velocity, which is 0,9 m/s.

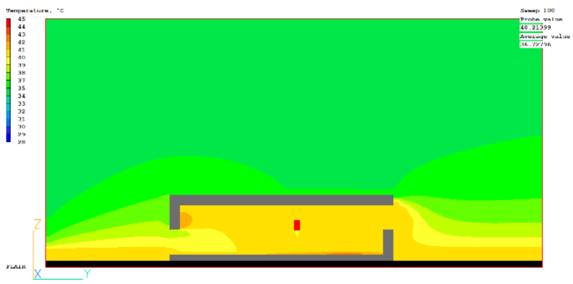


Figure 81: Temperature in and around building, day
Source: Phoenics VR, 2018

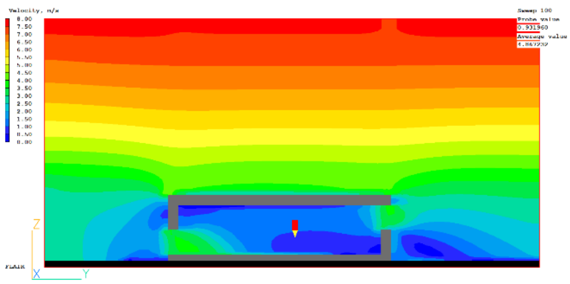


Figure 82: Air velocity in and around building, day
Source: Phoenics VR, 2018

Buildings with a low air inlet heat up more, because during the day, the ground heats up and, therefore, the lower air is warmer than the higher air. The windcatcher captures cooler air, which is higher up to cool the building. (Tavakolinia, 2011) Another advantage of a windcatcher is that it captures faster winds with less dust. (Saadatian, Haw, Sopian, & Sulaiman, 2012)

The temperature and wind speed in a building without windcatcher is examined. Now five types of buildings with a windcatcher or solar chimney will be researched to learn more about their performance. A building with a windcacther is evaluated. The building has no evaporative cooling effect and the windcatcher works as the air inlet and air outlet. (Figure 83)

I.

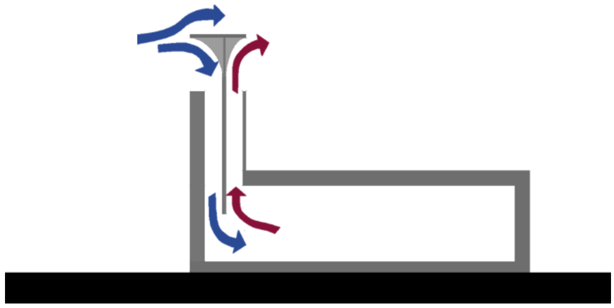


Figure 83: Building with windcatcher

Figure 84 shows the temperature inside the building which is 38°C. The windcatcher can get higher air which is cooler, causing an increase in temperature of 3°C relative to the outside temperature. The velocity in the building is 0,5 m/s. (Figure 85) Compared to the standard building the temperature inside the building is lower, but also the velocity is lower.

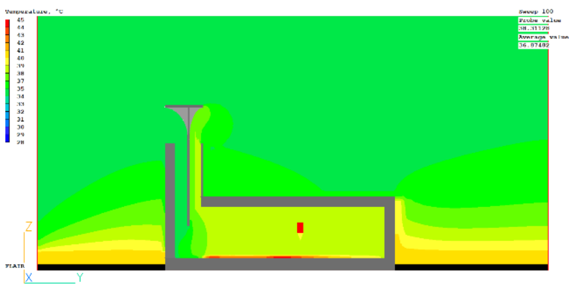


Figure 84: Temperature in and around building
Source: Phoenics VR, 2018

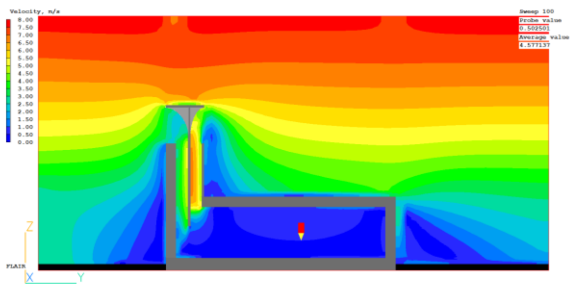


Figure 85: Velocity in and around building
Source: Phoenics VR, 2018

The next CFD study is done on a variation of the windcatcher building. Now there is an extra outlet on the other side of the building to create a higher airflow trough the building. (Figure 86)

II.

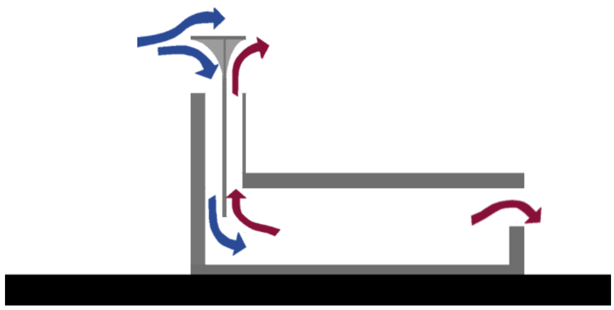


Figure 86: Building with windcatcher and extra opening

Figure 87 shows the temperature inside the building of 37°C. The extra air outlet creates a higher airflow of 0,6 m/s (Figure 88) and a cooler temperature. The extra air outlet decreases the air temperature by 1°C compared to the windcatcher building with no extra air outlet.

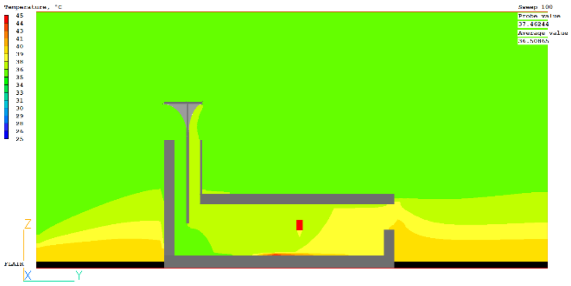


Figure 87: Temperature in and around building
Source: Phoenics VR, 2018

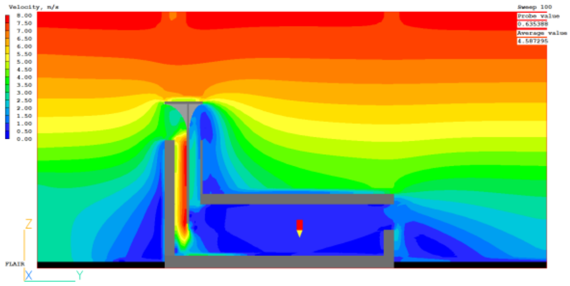


Figure 88: Velocity in and around building
Source: Phoenics VR, 2018

In this case the windcatcher is situated in the middle of the building. (Figure 89)

III.

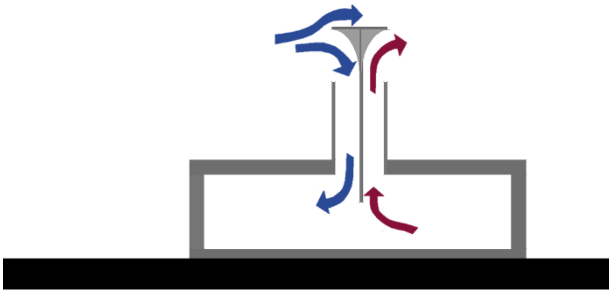


Figure 89: Building with windcatcher in de middle

The airflow in the building is quite low, namely 0,4 m/s. (Figure 91) The temperature is higher and is 39°C. Therefore, this windcatcher type is not suitable for the site in Iran. (Figure 90)

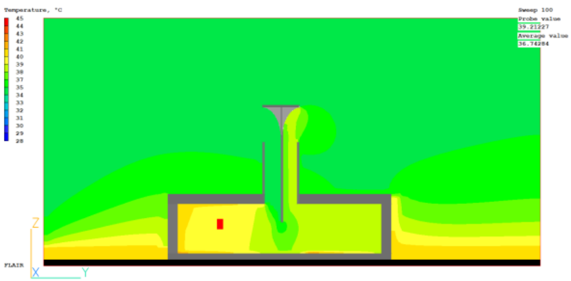


Figure 90: Temperature in and around building
Source: Phoenics VR, 2018

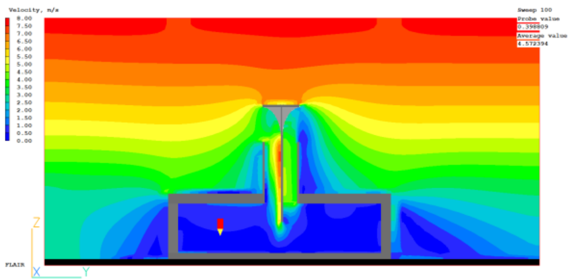


Figure 91: Velocity in and around building
Source: Phoenics VR, 2018

Another form of the windcatcher which is discussed is the solar chimney. In this case the airflow is created by a temperature difference. The solar chimney part is made out of glass and therefore the air in this part will heat up and pushed out of the building. (Figure 92)

IV.

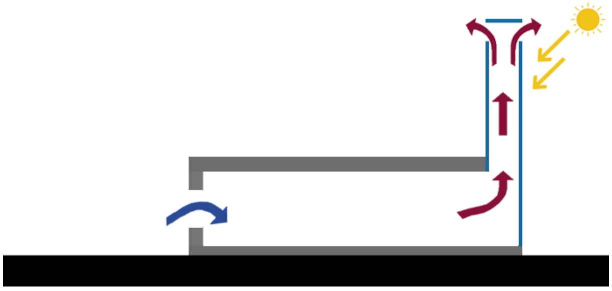


Figure 92: Solar chimney

Figure 93 shows the temperature inside the building. The ground temperature is warmer than the air higher up and therefore, the building will heat up to 40°C. The air velocity is 0,7 m/s. (Figure 94) The performance of this building is comparable to the first CFD studied building which has no extra elements. This building type is therefore not suitable to use in this climate conditions.

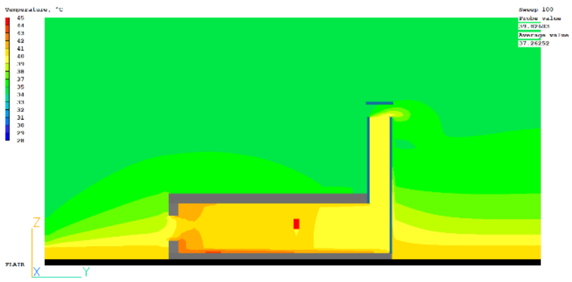


Figure 93: Temperature in and around building
Source: Phoenics VR, 2018

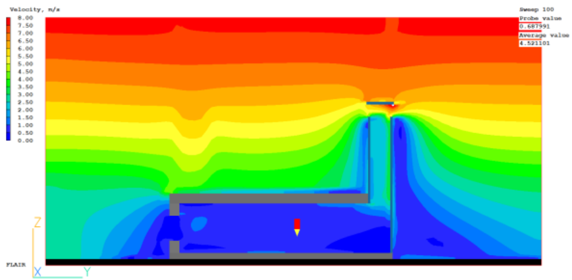


Figure 94: Velocity in and around building
Source: Phoenics VR, 2018

The last building without extra cooling effect has both a windcatcher and a solar chimney. The windcatcher will bring fresh air into the building and the solar chimney will suck out the air out of the building. (Figure 95)

V.

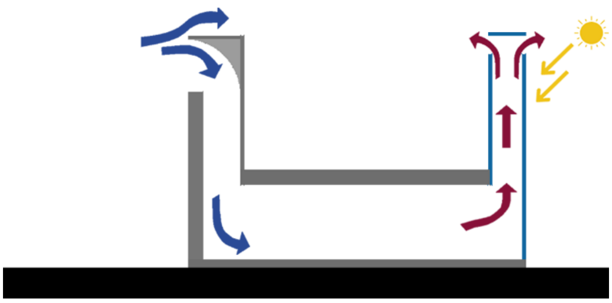


Figure 95: Combination solar chimney and windcatcher

Figure 96 shows the temperature which is 38°C and the velocity is 0,7 m/s (Figure 97)

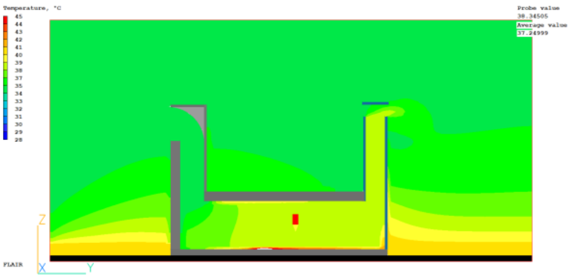


Figure 96: Temperature in and around building
Source: Phoenics VR, 2018

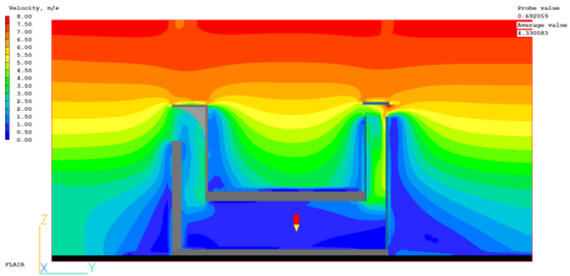
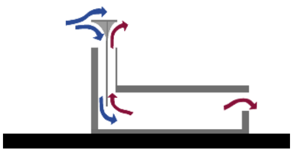
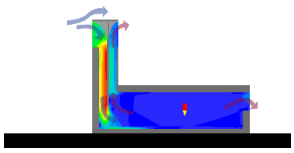
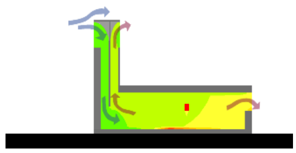
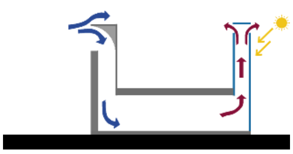
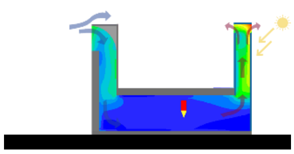
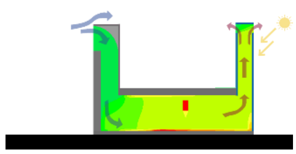
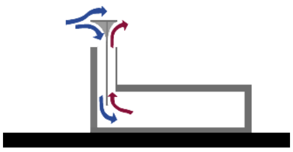
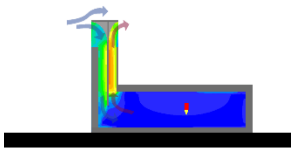
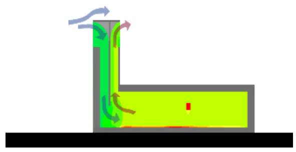
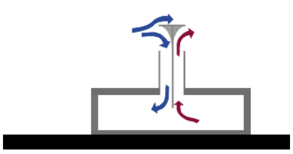
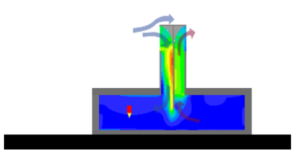
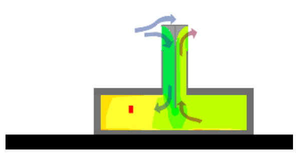
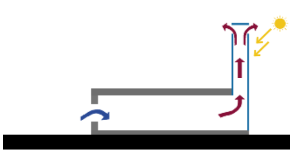
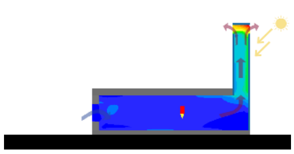
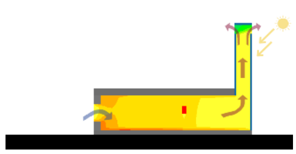


Figure 97: Velocity in and around building
Source: Phoenics VR, 2018

Table 13 shows an overview of the different buildings that are analysed. The buildings are placed in order from the best performance building to the worst.

Table 13: Overview CFD study with an air velocity of 5 m/s and an outside air temperature of 35°C

	Building type	Velocity [m/s]		Temperature [°C]	
II.		0,6 m/s		37°C	
V.		0,7 m/s		38°C	
I.		0,5 m/s		38°C	
III.		0,4 m/s		39°C	
IV.		0,7 m/s		40°C	

6.5.1. Windcatcher with cooling

Another advantage of the windcatcher is the fact that evaporative cooling can be applied. The outside air is passed through wetted columns or over underground water streams before entering the building. Evaporative cooling is a traditional method used in Middle Eastern buildings to improve the natural ventilation and the thermal performance. Evaporative cooling is particularly effective in dry and humid climates. (Hughes, Calautit, & Ghani, 2010) However, the amount of water in the Negin Safari Park is limited. Therefore, the evaporative cooling might not be beneficial. A pool is not the best option, because it requires a lot of water. However, the wetted column or wetted surface technique integrated in the windcatcher might be an option. Windcatchers with wetted columns or wetted surfaces improve the ventilation and thermal performance of the building. The evaporative cooling systems cool the external air before it enters the building. (Figure 98)

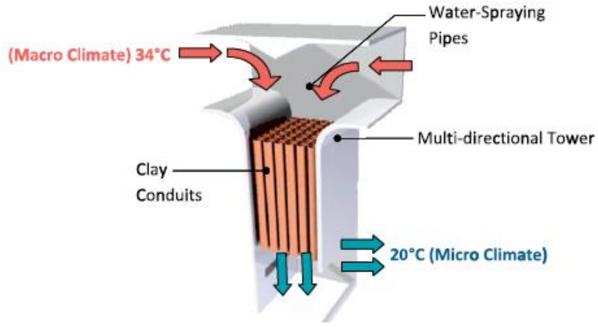


Figure 98: Windcatcher with wetted columns or clay conduits
Source: Hughes, Calautit, & Ghani, 2010

The effectiveness of the evaporative cooling system integrated in the windcatcher is simulated through a CFD study. (Figure 99)

VI.

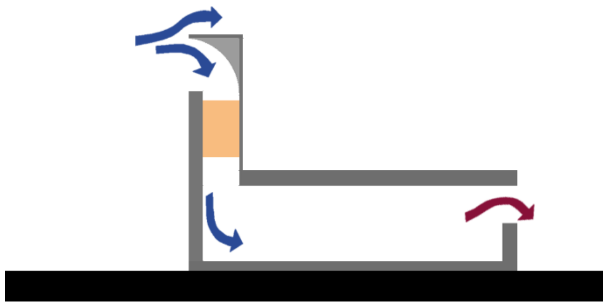


Figure 99: Evaporative cooling integrated in windcatcher

With an outside temperature of 35°C, the evaporative cooling can bring the inside temperature down to 29°C (Figure 100) with an air velocity of 0,7 m/s (Figure 101). This cooling method can be very effective in hot and dry climates with low humidity. However, a lot of water is needed.

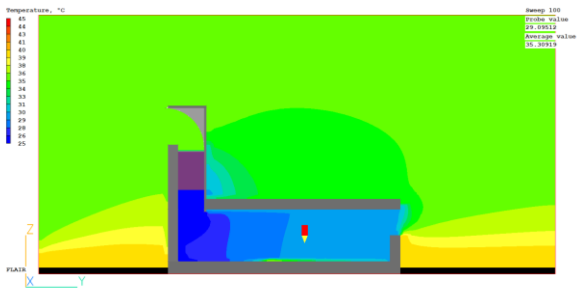


Figure 100: Temperature in and around building
Source: Phoenics VR, 2018

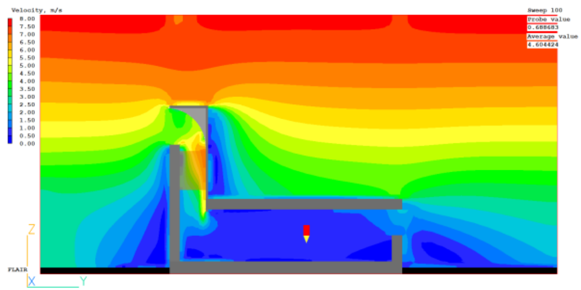


Figure 101: Velocity in and around building
Source: Phoenics VR, 2018

Another method for cooling without the need of water is with underground tunnels. This is also examined in Phoenics VR (2018). The tunnel in this study is 24 meters long (Figure 102)

VII.

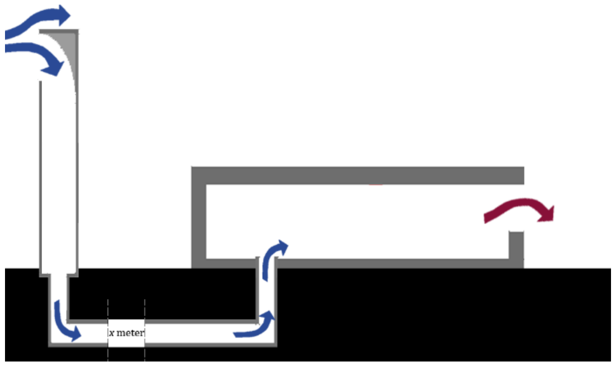


Figure 102: Underground tunnels to cool the building

The temperature of this building will be 33 °C. (Figure 103) The cooling effect is less than the evaporative cooling integrated in the windcatcher. The wind speed is 1,2 m/s which is too high to be comfortable. (Figure 104) To use the underground tunnels more calculations should be done on the length and the amount of tunnels to create a pleasant airflow through the building.

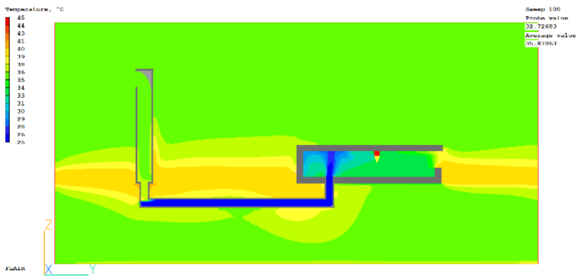


Figure 103: Temperature in and around building
Source: Phoenics VR, 2018

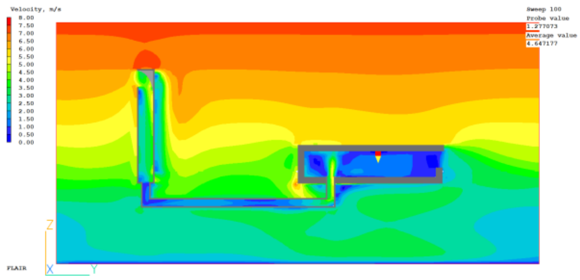
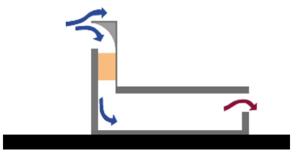
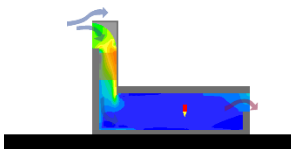
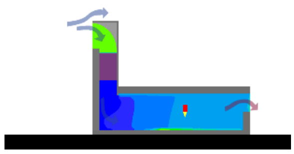
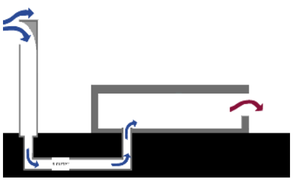
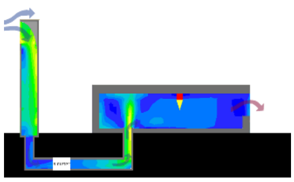
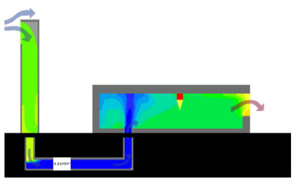


Figure 104: Velocity in and around building
Source: Phoenics VR, 2018

Table 14 gives an overview of both cooling techniques with windcatchers. The evaporative cooling works better, however the underground tunnels can cool the building 3°C compared with the outside temperature and do not need any water supply. An overview of all CFD studies can be found in APPENDIX V.

Table 14: CFD study cooling

		Velocity [m/s]	Temperature [°C]
VI. Evaporative cooling		0,7 m/s 	29°C 
VII. Underground tunnels		1,3 m/s 	32°C 

6.6. Summary

Chapter 6 answers the question: What are the different types of windcatchers and which one can best be used for the Negin Safari Park? In different countries and regions in Iran the windcatcher types are varying. The wind on the park's location originates from two directions that are almost opposite. Therefore, a two sided windcatcher is optimal. The windcatcher is oriented on the southwest wind. When the wind comes from the north-northeast the performance is reduced, but still acceptable.

The materials used for a windcatcher are similar to those used for buildings, namely mud brick or baked brick. The structure of the windcatcher consists of wooden hanks.

A windcatcher can work in different ways to ventilate a building. The most common way is by creating a pressure difference by the wind. The windcatcher is placed in the direction of the wind and when the wind hits the building, it creates a positive pressure on the windward side, and a negative pressure on the other side. The wind is thus sucked into the opening facing the wind and pulled out on the other side. Another way to create natural ventilation with a windcatcher is through thermal buoyancy. During the day, the sun hits the south side of the windcatcher and heats the air, which goes up, thus creating a pressure difference inside the building. Therefore, fresh and cold air is pulled down in the northern opening. These two principles can also be combined.

To cool the building, evaporative cooling is used. The captured air is lead over water, which is either in a pool in the basement or integrated in the windcatcher shaft. The water cools the air and gives it more humidity before it enters the building. While little water is available in the Negin Safari Park, this is not a good option. Another option is to cool the air with underground tunnels. The cooling effect of air in the tunnels is comparable to the windcatcher with wetted surfaces.

A CFD study shows the performance of different windcatcher types. A windcatcher that works by creating pressure difference by the wind with an extra opening on the other side of the building works best. A combination of a windcatcher and a solar chimney also has a good performance, so both types of windcatchers can be used. A windcatcher with underground tunnels can cool the building. The exploitation of this windcatcher type requires calculations on the tunnel depth, length and size.

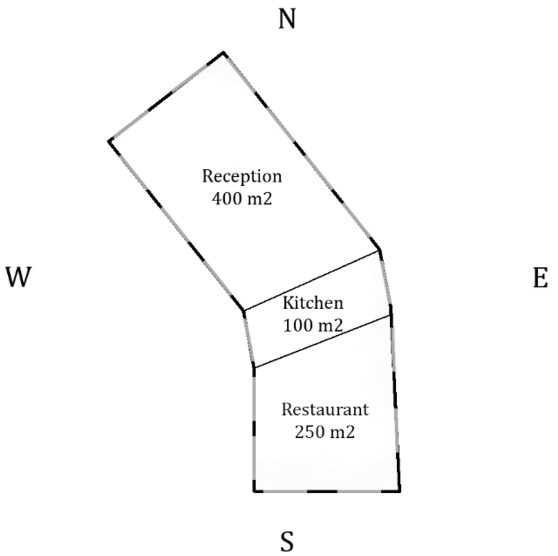
7

DESIGN PRINCIPLES FOR THE ENTRANCE BUILDING

Several design principles have been found in the vernacular architecture to reduce the energy demand of the entrance building. In the conceptual design of the Negin Safari Park, a building was designed and the energy demand of this building was calculated. In this chapter, different design principles will be implemented in the design to reduce the energy demand of the building. Then, the costs of the solar panels will be compared to the cost of these passive design principles. This chapter will give an answer to the question: How can a building be designed with vernacular techniques to reduce its energy demand?

7.1. VERNACULAR TECHNIQUES IMPLEMENTED

The entrance building in the conceptual design is the starting point for implementing the design principles from the vernacular architecture. The principles from the vernacular architecture will be tested and an estimation will be given for the reduction in energy. Figure 105 shows the standard building and the square meters for the facilities inside the building. The building will have a wall thickness of 500 mm and the glazing covers 30% of the wall surface. The indoor air conditions will be regulated with a heating and cooling system.



Building information:

Reception:	400 m^2
	35 people
Kitchen:	100 m^2
	10 people
Restaurant:	250 m^2
	70 people

- Wall thickness 500 mm
- Windows are the same size (30% glazing)

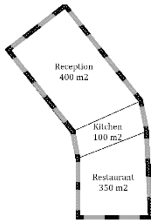
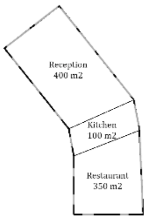
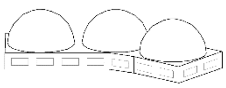
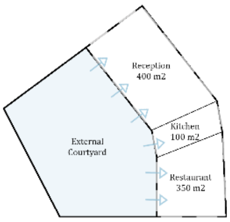
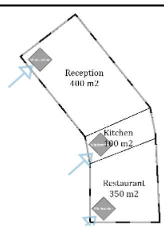
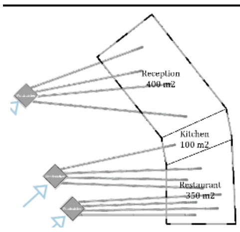
Figure 105: Entrance building as a case study

DesignBuilder (2019) is used to estimate the reduction in energy. An overview of the examined principles can be found in Table 15. Different principles found in the vernacular architecture are examined, like increase in mass, the size and orientation of the windows, the courtyard and the windcatcher technology. An estimation of the energy reduction relative to the standard building, which is shown in Figure 105, is given in Table 15. The complete outcome from DesignBuilder (2019) can be found in APPENDIX VI.

Also an indication in increase of cost is given. According to A. R. Osanlou (personal communication, May 11, 2019) the price for buildings in Iran lies around 100 euro/m^2 for a 7 stories apartment. Since the entrance building is only a single story, the price will be less and 70 euro/m^2 is taken. The entrance building, shown in Figure 105, is 750 m^2 and will thus cost around 52.500 euro. The cost for the building material is 7 euro/m^3. Table 15 shows the increase of cost for the different principles.

The windcatcher in combination with the underground ducts can reduce most cooling load for the building. The incoming air from the ground ducts is 26°C and in Chapter 4 the comfortable indoor air temperature is discussed to be around 29 – 30°C, therefore, no extra cooling is needed. For the reduction of energy this option is the best. However, the increase in cost is fairly high. In the next part, a design will be made for the entrance building and the building costs will be compared with the cost of the solar panel system.

Table 15: Overview vernacular techniques and energy reduction

Building information		Energy reduction	Increase costs
	**Increase of mass** ◦ Walls and roof **1000** mm thick ◦ Walls and roof **1500** mm thick ◦ Windows are the same size (30% glazing)	1000 mm mass -10% 1500 mm mass -15%	+450 m³ material +5% +900 m³ material +10%
	**Openings** ◦ Small openings south and west 8% glazing high in the walls ◦ Big openings north and east 40% glazing	-10%	Window surface equal
	Combination increase mass ◦ Walls and roof **1000** mm thick ◦ Small openings south and west ◦ Big opening north and east	-15%	+5%
	**Domed roof** ◦ Minimize heating during the day ◦ Maximize cooling during the night ◦ 3 domes on the roof	-5%	+40%
	**Courtyard** ◦ Lower temperature ◦ Natural ventilation trough courtyard	-15%	+5% 200 m³ material 2500 euro plants
	Combination courtyard and mass increase ◦ Walls and roof 1000 mm	-20%	+10%
	Combination courtyard and windows ◦ Big windows courtyard side	-30%	+5%
	Combination courtyard, mass and windows ◦ Walls and roof 1000 mm ◦ Big windows courtyard side	-35%	+15%
	**Windcatcher** ◦ No evaporative cooling ◦ Higher winds, cooler air ◦ Building heats to 37°C instead of 40°C	-10%	+50% 10.000 euro per windcatcher
	**Ducts** ◦ Cooling by ground temperature ◦ 27 ducts with an air temperature of 26°C ◦ Calculations can be found in APPENDIX VI.	-90% No more cooling needed in summer	+150% 10.000 euro per windcatcher 5000 euro per duct

	Ducts with a diameter of 0,2 m and a length of 27 meter		
	Reception	Kitchen	Restaurant
Number of ducts	4	1	7

7.2. Design proposal entrance building

A design proposal is made for the entrance building, where the underground ducts are used in combination with windcatchers. Figure 110 shows the plan of the building. Seven windcatchers will be used with 12 ducts to cool the building. The windcatchers will form a courtyard where the terrace for the restaurant and a playground can be placed. (Figure 106) The restaurant consist of two parts. One part is accessible to all visitors; the other part only by those who will buy a ticket to visit the park. (Figure 107)

The other part of the building houses a workshop area, where the Qashqai women can give weaving workshops (Figure 108), and the reception (Figure 109).

Figure 106: Courtyard

Figure 107: Restaurant

Figure 108: Workshop area

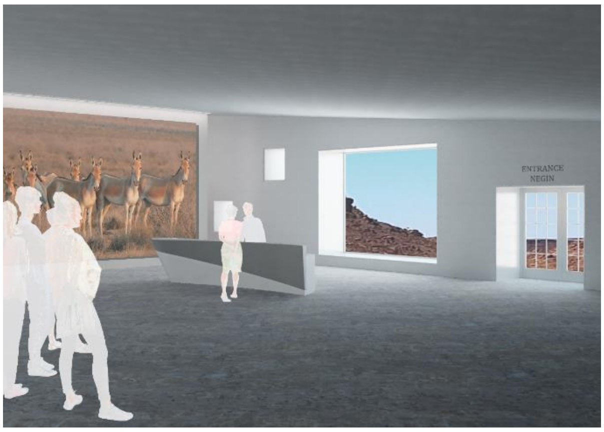


Figure 109: Reception

The courtyard is surrounded by the windcatchers. However, they do not close the courtyard. Therefore, fabric can be strained in between the windcatchers to create more shade in the courtyard. This fabric can also be used to show the name of the safari park or attractive photos of the animals. (Figure 111)

Figure 110: Plan entrance building

Figure 111: Fabric between windcatchers with the name of the park

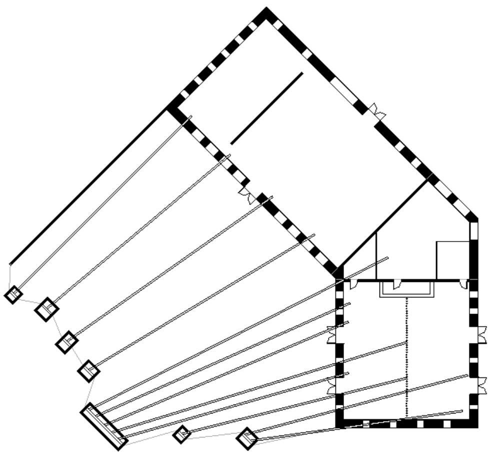


Figure 112: Ground ducts

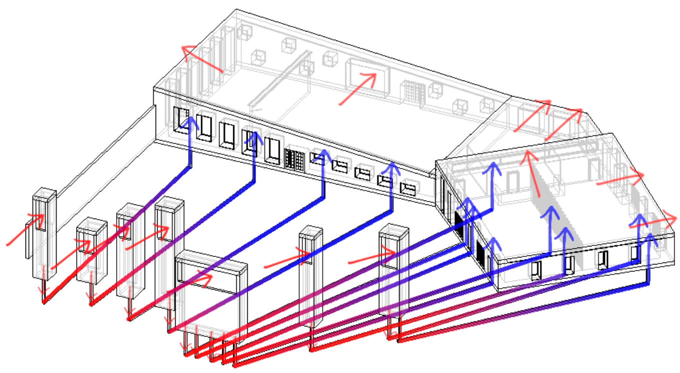


Figure 113: Ventilation scheme building

Figure 112 shows the ground ducts connected to the windcatchers and the building. The ducts are scattered over the spaces in the building. Figure 113 shows the ventilation scheme of the building. The hot air is captured by the windcatchers and cooled by the ground before entering the building. When the air is heated up in the building it can leave trough openings near the roof and windows.

7.2.1. COST ENTRANCE BUILDING

The cost of the standard entrance building lies around 60.000 euro. However, with seven windcatchers and 12 underground ducts this will rise to almost 200.000 euro. Therefore, it is important to compare it with the cost of the solar panel system that can be saved.

In chapter 4, the energy demand of the standard building is discussed. The cooling load was 57%. However, in this building the cooling will be done by the ground ducts and, therefore, the cooling demand is reduced with 90%. Table 16 shows the energy demand for this improved building, and Figure 114 its distribution. The new cooling load is only 12%.

Table 16: Energy consumption entrance building

Cooling	10.630	kWh/year
Heating	20.235	kWh/year
Light	19.400	kWh/year
Fridge	7.600	kWh/year
Water heating	6.500	kWh/year
Cooking	4.300	kWh/year
Washing	2.200	kWh/year
Entertainment	4.300	kWh/year
Other	16.700	kWh/year
Total	91.865	kWh/year

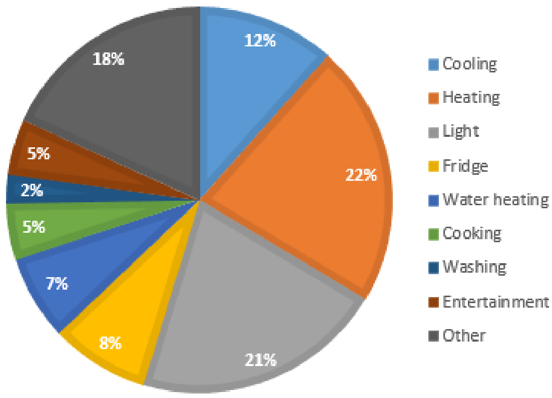


Figure 114: Energy usage entrance building

The energy demand of the standard entrance building and the improved entrance building is evaluated in PVSyst (2019) to examine the cost for solar panels. The standard entrance building would have an investment cost of 405.000 euro and a yearly cost of 61.000 euro.

The improved building will have an investment cost of 251.000 euro and a yearly cost of 32.000 euro. The solar panels can be approximately used for 25 years. After this new solar panels must be purchased. For the 25 years a total of 1.9 million euro is needed for the solar panel system for the standard building. For the improved building 1 million euro is needed. Table 17 gives an overview of the costs of both buildings. The last row of Table 17 gives the total investment cost for both buildings. This are the cost for the solar panel system and the building cost. The improved building is 700.000 euro cheaper regardless of the higher cost for the building itself.

Table 17: Overview cost standard and improved building

Standard building		Improved building	
Energy use:	188.500 kWh/year	Energy use:	91.865 kWh/year
Building cost:	€ 52.500	Building cost:	€ 200.000
Module cost	76696 EUR	Module cost	57378 EUR
Battery cost	180411 EUR	Battery cost	88647 EUR
Regulator cost	17400 EUR	Regulator cost	12397 EUR
Transport/Fitting	130501 EUR	Transport/Fitting	92976 EUR
Total investment	**405009 EUR**	**Total investment**	**251398 EUR**
Annuities	16200 EUR/yr	Annuities	10056 EUR/yr
Maintenance costs	45103 EUR/yr	Maintenance costs	22162 EUR/yr
Total Yearly cost	**61303 EUR/yr**	**Total Yearly cost**	**32218 EUR/yr**
Energy cost	**0.34 EUR/kWh**	**Energy cost**	**0.37 EUR/kWh**
Investment solar panels:	€ 405.000	Investment solar panels:	€ 251.000
Yearly cost solar panels:	€ 61.000	Yearly cost solar panels:	€ 32.000
Investment for 25 years:	€ 1.940.000	Investment for 25 years:	€ 1.057.000
Building cost for 25 year	€ 2.000.000	Building cost for 25 year	€ 1.300.000

7.3. Design proposal Negin Safari Park

Figure 115 shows the conceptual design with the proposed changes. The mass of all buildings will be increased to save energy. Besides, the private buildings for the staff (quarantine, medical area, dog training/housing/adoption, staff office, staff accommodation, administration office) will be combined into one big building with a courtyard. In this way, the energy of all buildings can be reduced and the staff can have a comfortable outdoor space to stay in their brake.

The new entrance building is incorporated into the design. Besides, the roofs of all buildings will be adjusted to the south orientation for the solar panels. An extra building will be placed for the battery storage of the solar energy and the biomass production. Figure 116 shows the design proposal for the Negin Safari Park.

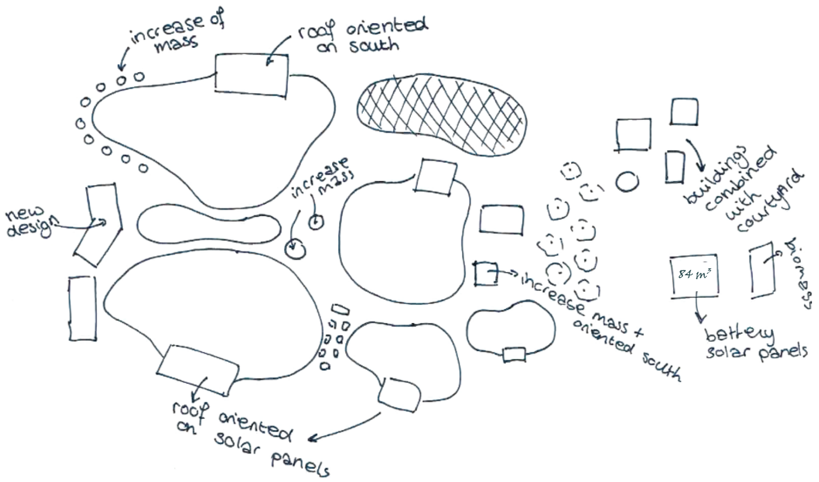


Figure 115: Entrance building as a case study

Figure 116: Design proposal Negin Safari Park

7.3.1. Reduction in energy

The design principles shown before will reduce the energy demand of the park. In Chapter 3, the energy demand is shown based on the used square meters of buildings. Most demands are unchanged, but the energy required for heating and cooling has decreased due to the vernacular architecture principles, like the courtyard and the increase in mass. Table 18 shows the different functions in the park and the applied principles. Table 19 shows the new pie charts for each category and the annual power consumption. An energy reduction of 15% has been achieved.

The proposed changes mentioned in Table 18 will increase the building costs for the park with 15%, which is around 200.000 euro. However, the cost for the solar panel system will be reduced, which saves 800.000 euro. Also the yearly costs for the maintenance of the solar panels will be reduced.

Table 18: Principles vernacular architecture applied on functions in the park

	Entrance building -90% energy cooling -5% energy heating	m²	Increase mass -5% energy cooling -5% energy heating	m²	Courtyard -30% energy cooling -5% energy heating	m²	No adjustments	m²
[1]	◦ Restaurant	350	◦ Tourist Accommodations	500	◦ Staff accommodation ◦ Housing overnight staff	150 150		
[2]	◦ Shop + Weaving area ◦ Reception	150 250	◦ Toilets ◦ First Aid Post ◦ Information Desk ◦ Educational Centre ◦ Watch tower	50 50 100 250 200	◦ Quarantine ◦ Clinic/medial Area ◦ Dog training centre ◦ Dog housing ◦ Public adoption ◦ Staff office ◦ Administrations office	150 150 250 100 250 200 300	◦ Butterfly Garden ◦ Greenhouse	800 800
[3]			◦ Shelter giraffe, .. ◦ Shelter urial, .. ◦ Shelter lion ◦ Shelter brown bear	1600 1100 500 200				
[4]							◦ Small Playground ◦ Parking area ◦ Event Area ◦ Playground ◦ Practice area ◦ Paths	100 600 1200 1000 500 8600

Table 19: New energy demand Negin Safari Park

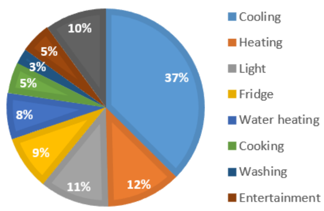
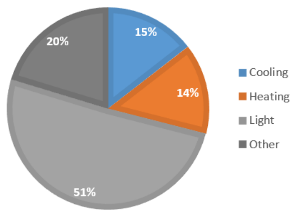
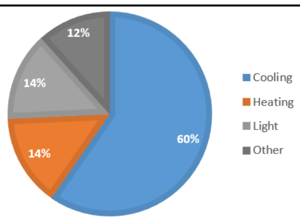
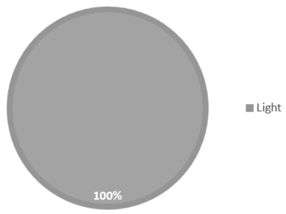
		Total kWh/year			Total kWh/year
[1]		282.900	[3]		117.300
[2]		718.200	[4]		180.000
TOTAL: 1 298.400 KWH/YEAR					

Figure 117 shows the final energy balance for the Negin Safari Park. With the use of vernacular architecture principles, 2600 solar panels are needed and a battery storage of 84 m³. (PVSyst, 2019) The energy price will be 0,34 euro/kWh. (PVSyst, 2019) An overview of the PVSyst outcome can be found in APPENDIX VII.

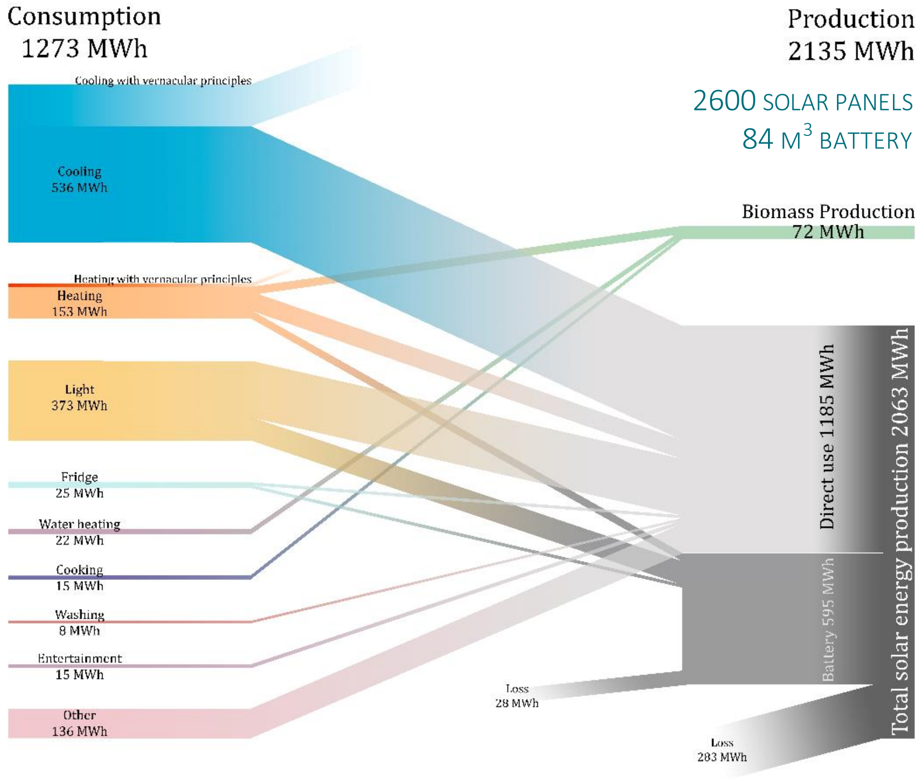


Figure 117: Final energy balance Negin Safari Park

7.4. SUMMARY

Chapter 7 investigates the question: How can a building be designed with vernacular techniques to reduce its energy demand? The influence of the vernacular architecture on the energy demand of the building is examined. For example, the increase of mass can reduce the energy by 10%. However, the building cost will increase by 5%. A courtyard reduces the energy demand by 15%, while the building cost will increase by 5%. The principle that reduces most energy is the combination of windcatchers with underground ducts. An energy reduction of 80% is achievable, while almost no extra cooling is needed in the summer. However, the building cost will increase significantly.

A design proposal is made for the entrance building, where a combination of windcatchers and underground ducts is used, halving the energy demand of the building. Besides this, the windcatchers create a courtyard, where the terrace and playground can be placed. The building will stand for at least 25 years like the solar panels, the standard building will cost 2 million euro. The improved building will cost 1.3 million euro. Regardless of the higher building cost for the improved building, the benefit is still high, while less money has to be spend on the solar panel system. Overall, the improved building will be cheaper over the years.

Now that the entrance building is designed, the design of the whole park is improved. All buildings will increase in mass to reduce the energy demand. The buildings for the staff will be combined into a courtyard building, which reduces the energy demand and gives a pleasant outdoor area for the staff. The building cost for the park will increase, but the benefit of the decrease of the solar panel system is higher. The energy price will be 0,34 euro/kWh. Therefore, it is recommended to use principles from the vernacular architecture to decrease the energy demand of the park.

8

CONCLUSION

This thesis answers the question: To what extend can passive cooling techniques reduce the energy demand of the Negin Safari Park in Iran?

Different safari parks all over the world were examined and the facilities found in this study were combined with the requirements set by Simba to deliver a conceptual design for the Negin Safari Park. The design for the park can be divided into three areas, namely a public area with a butterfly garden and the restaurant, the Semi-public area, which contains the animal cages and the tourist accommodations, and a private area which contains buildings for the staff. This conceptual design was used to calculate the energy demand of the park. The buildings in the park were divided into three categories, as not all buildings have the same energy demand. The total energy demand of the park is approximated to be 1500 MWh/year. The site has no potential for wind energy, but the energy demand can be covered with the use of solar panels and biomass. 3200 solar panels are needed with a storage capacity of 100 m^3. The animal waste can produce 72.000 kWh of energy per year.

The building in the park that uses most energy is the entrance building, this building will be used as a case study to test the vernacular architecture principles. Different principles have been examined, like the courtyard, the increase of mass and the windcatcher. The courtyard is used as a pleasant outdoor area. The plants and the pond in the courtyard can cool the air by evaporation. Another principle is the increase of mass, which increases the delay in absorbing the heat on one side of the wall and releasing the heat on the other side. Also the orientation of the openings in the walls is discussed. The openings in the façade must be small on the south and west side and can be bigger on the north and east side. The windows can also face the courtyard, of one is present in the design.

The last discussed principle is the windcatcher, which can work in different ways, for example by pressure difference from the wind, thermal buoyancy or a combination of these two. To cool the building, evaporation is used. The hot captured air is lead over water which is either in a pool in the basement or integrated in the windcatcher shaft. However, the water amount in the Negin Safari Park is limited and therefore this is not an option. Another option is to cool the air with underground tunnels. The cooling effect of air in the underground tunnels is comparable to a windcatcher with wetted surfaces.

The entrance building is used to test the different principles on the energy reduction and the increase in cost. The combination of windcatchers and underground ducts can reduce the cooling demand by 90% and, therefore, a design proposal is made including this principle. This improved design for the entrance building has a higher building cost, but lower cost for the energy system. Around 700.000 euro can be saved on the building, when the windcatchers and underground ducts are used. In the whole park, the energy demand can be reduced with different principles. All buildings in the park will get thicker walls and the buildings for the staff will be combined into a courtyard building. The building cost for the park will increase, but the benefit of the decrease of the solar panel system is higher. With the reduced energy demand the park will need 2600 solar panels and a storage with a capacity of 84 m^3. The energy price will be around 0,34 euro/kWh.

So, the passive cooling techniques can reduce the energy demand of Negin Safari Park. The building cost for the park will be higher, but the cost for the energy system will be much lower. The energy demand of the park can be reduced with the different principles shown in this research.

DISCUSSION

This study shows that the principles from the vernacular architecture can be applied to decrease the energy demand of the safari park. Although the building cost for the park is increased, the cost for the energy system is much lower. The exact energy demand can only be calculated when a final design for the park is made, but the current calculations give a good indication. The same applies to the cost of the solar panel system. PVSyst can be used to do a more expanded study, but more information about the site and the cost for solar panels in Iran is needed to do this. The same applies for the building cost and the maintenance cost for the building. This information is not known and more research should be done to give a better indication for the cost. Again, current figures give just an estimation.

A future research can be done on for example the energy storage. As almost 10.000 kWh should be stored some big batteries are needed. They are expansive and need some maintenance. Also they will mostly not least for more than 10 years. To reduce the energy cost it is interesting to look into other methods for large scale energy saving. When a grid-connected solar panels system is used on the same location the energy price is 0,07 euro/kWh (PVSyst, 2019) so, the energy price rises a lot because of the storage.

Even though the energy demand and the cost in the research are based on a preliminary estimation, a clear overview is given of the different techniques that can be used in the safari park. The same principles can be applied to the final design. So, the next step is to finalize the designs for all buildings, taking into account the discussed principles and their pros and cons. When this is done more research can be done on the underground tunnels and their cooling effect. Some simulations should be done for the building to calculate the indoor air temperature and the velocity to learn more about the performance of the building.

REFLECTION

This graduation topic was provided by the Simba Nature Protection and Education Foundation. They want to build a Safari Park in Iran and need a design for this park. Therefore, this graduation research made a conceptual design for the safari park, which Simba can use to start fundraising. Research is done to improve the conceptual design. Passive design techniques were explored to reduce the energy demand of the park and thus reduce the costs of the park. The passive design techniques are translated into design principles that could be used for the park. One of the buildings in the park is designed using these principles to reduce its energy demand. A research for design method is used as the principles found in the literature study are used to improve the design.

The relation between this research and the Building Technology master can be found in different aspects of the research. It can be placed in the climate track of the master as different methods are evaluated to reduce the energy demand of the buildings. However, the research is done for an external party and is therefore not immediate connected to any other research done at the Building Technology master at this moment.

The method for this research consist on a few different phases. The first part is about the conceptual design for the Negin Safari Park which is used to estimate the energy demand. After this the literature study started, in which different principles from the vernacular architecture are examined. The research approach was to first come up with a design for the Negin Safari Park, which than could be used as a case study for the passive design techniques. This approach did work out, however, it took a long time to come up with a design for the Negin Safari Park. The scientific relevance of this work is that a comparison is made between the vernacular principles and the energy generation, on efficiency and cost. An overview is given for different principles and their energy reduction. With this overview an architect can easily decide which principles can be used in the building design to reach a lower cooling demand.

The research has also social relevance. The use of passive techniques can reduce the price for off-grid buildings. However, the passive techniques can also be used to improve the indoor air quality of the building. The use of mechanically driven air conditioning systems increases the energy demand of the building but also decreases the indoor air quality. Natural ventilation can increase the indoor air quality and less energy is needed. An energy reduction overview highlights the difference in building construction costs with vernacular techniques and the corresponding reduction of energy costs. The research also contributes to the sustainability through passive design techniques.

The research approach did work out as an overview of the principles from the vernacular architecture is given compared to the increase in cost of these techniques. However, some times during this research it got stuck. Then the feedback of the mentors was used to pursue the research. Every two weeks a meeting with the mentors helped to ask questions and get feedback. This feedback is used to improve the research.

Reflection

Priyadarshini Nanda & Naftany van Zwaaij

In this reflection some conclusions will be drawn from both the report of Priyadarshini and Naftany.

1. Roof

In the report from Naftany the energy demand of the Negin Safari Park is calculated. Is it found that 2500 solar panels are needed. The solar panels can be placed on the roof like shown in Figure 118 The optimal angle is 29°, which is very steep for a roof. The angle can be less, however the performance of the solar panels will than decrease in the winter months (Figure 119).

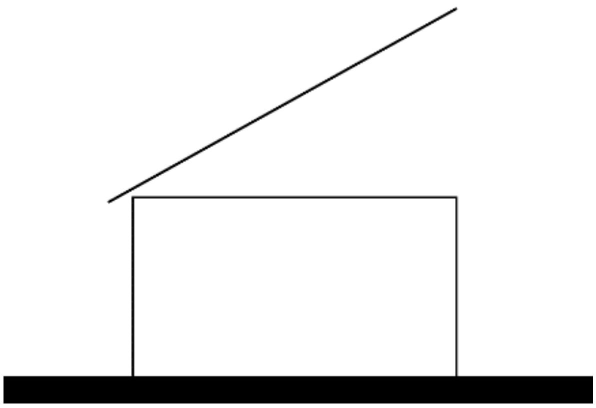


Figure 118: Solar panels on roof

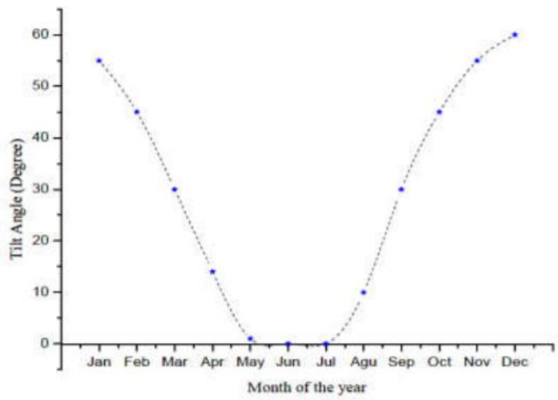


Figure 119: Optimal tilt solar panels Iran

According to Priyadarshini's work the optimal roof shape consist of two tilted plates with a gutter in the middle. (Figure 120) The plates have an angle of 15° - 30° to optimize the runoff coefficient for the rainwater and the runoff coefficient of the roof is 0.95. This roof shape is however not optimal for the solar panels as only one plate is oriented towards the sun. In this case the solar panels can be placed in the desert outside the park. (Figure 121) The cost of the solar panel system will in this case increase, because more support elements should be placed for the panels.

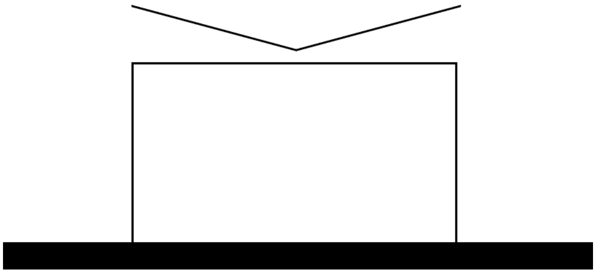


Figure 120: Optimal roof for rainwater

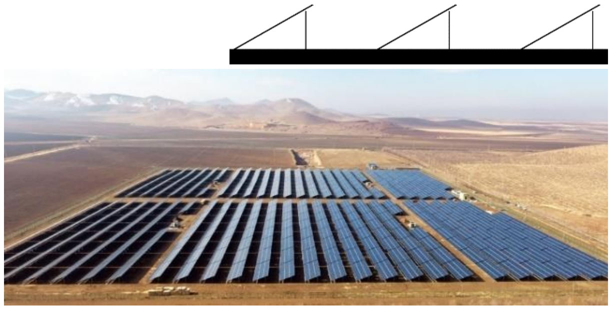


Figure 121: Solar panels placed on the ground

2. CONSTRUCTED WETLAND TO DECREASE THE BUILDING FROM HEATING UP

In Priyadarshini's report the constructed wetland is mentioned as a method to filter the black water. The constructed wetland was intended to be placed at a lower level on the site so it is easily visible to the tourists but limits accessibility. (Figure 122) However, since the plant used in the constructed wetland is cattail, which can grow up to 3 meter, the plants present an opportunity to reduce direct solar heat gain by the built form if placed adjacent to it. When the constructed wetland is placed at the south or west façade of the building the sun will not be able to heat up the building. (Figure 123)

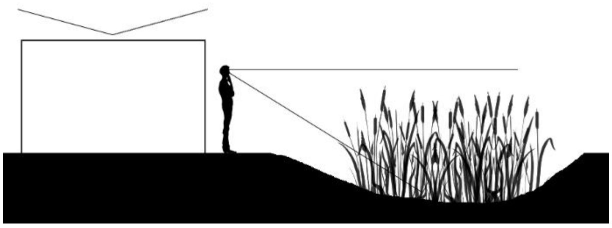


Figure 122: Optimal roof for rainwater

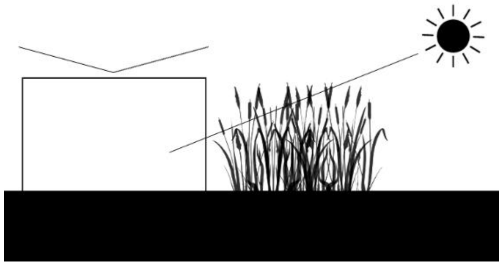


Figure 123: Solar panels placed on the ground

3. GREENHOUSE CONNECTED TO THE BUILDING

Priyadarshini has also proposed a closed greenhouse which also collects water for reuse. This greenhouse will have an internal temperature range of 20 - 35°C all year round. The greenhouse can therefore be connected to the buildings to prevent them from heating up during the summer and help them heat up during the winter. The greenhouse should ideally be located on the west side of the built form to shade the wall from direct solar heat gain. (Figure 124)

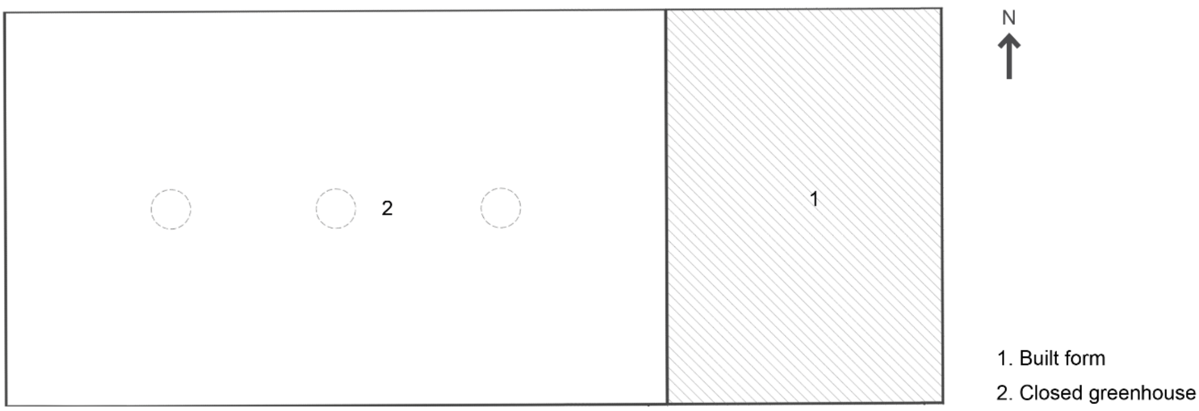


Figure 124: Closed greenhouse attached to build form

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Case studies on different safari parks.

1. Governors' Camp (Kenya)

Governors' Camp is located near the Mara River in Kenya. The camp is the first permanent tented camp in Masai Mara National Reserve, where animals roam around freely. The camp consists of 37 tents lined along the riverbank, some tents have a view over the river while others have a view across the sweeping plains. The tents are luxurious, big, bright and allow for lots of natural light. All tents have an en-suite bathroom, a private veranda and electricity for charging camera's and phones. The camp has a mess tent with bar and deck overlooking the Mara River, dining tent, souvenir shop, reception and spa tent. (https://www.governorscamp.com/stay/governors-camp/, 2018)

Figure 1: Tents Governors' Camp
Source: https://www.governorscamp.com

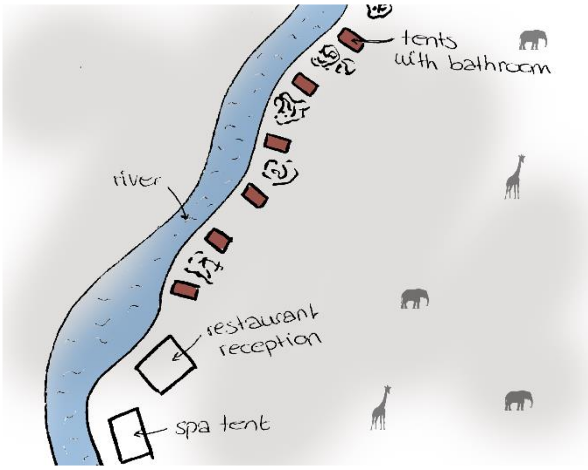


Figure 2: Organisation Governors' Camp

2. Safari Yurt Camp (Uzbekistan)

The Safari Yurt Camp is located 60 kilometres from Nurata, Uzbekistan. The camp is close by the sandy Kyzyl Kum Desert and Lake Aydarkul, with 20 yurt tents in a quiet area. The direct surrounding of the camp has not more to offer than some small bushes. The camp is used as a base to explore the surroundings by a camel ride or by car. The tents are equipped with mattresses and sheets. There are tents for two people and bigger tents for up to 5 people. There is a separate building with toilets, sinks and showers. A decorated brick building is used as a restaurant, where the breakfast and dinner are served. (http://uzbek-travel.com/hotels/safari_yurt_camp/#information, 2018)

Figure 3: Yurt tent camp
Source: http://uzbek-travel.com/hotels/safari_yurt_camp

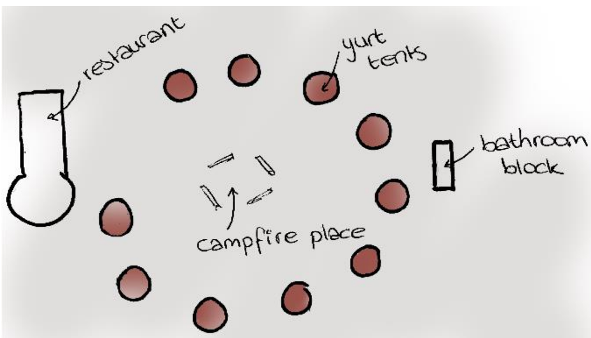


Figure 4: Organisation tent camp

3. Giraffe Lodge (United Kingdom)

The Giraffe lodge is located in a wildlife park in Port Lympne, United Kingdom. Port Lympne is home to over 700 animals and 88 species, including tigers, lions, leopards, gorillas, bears, giraffes and the UK's biggest herd of black rhinos. The focus of Port Lympne is on conservation and breeding animals to release into the wild. It is run as a charity and most animals are in open enclosures rather than cages. The Giraffe lodge offers an overnight stay nearby the animals. There is a luxurious hotel and wooden camping pods. The tents are in two rows and built of canvas with a wooden base and a balcony. The animals can be seen right from your room. Some of the tents have an en-suite bathroom, while others have a shared bathroom block. Next to the row of tents there is the Laapa, being the camp's communal lounge and dining room. When the place is fully booked, 18 people can stay in the tents. (https://www.ontheluce.com/uk-safari-port-lympne-giraffe-lodge/, 2018)

Figure 5: Giraffe Lodge
Source: https://www.ontheluce.com/uk-safari-port-lympne giraffe-lodge/

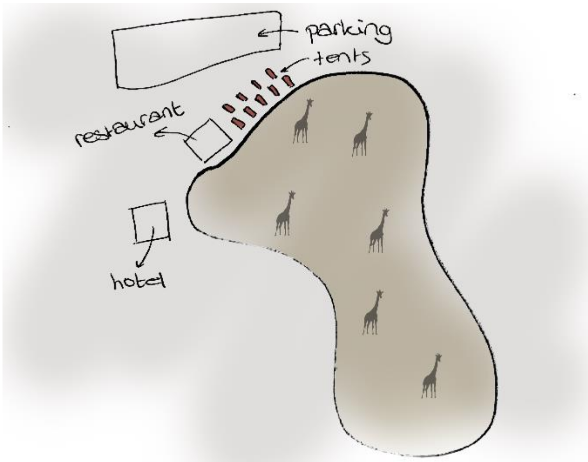


Figure 6: Organisation Giraffe Lodge

4. Beekse Bergen (Netherlands)

Safari park Beekse Bergen is the largest wildlife zoo of the Benelux region and provides a home to approximately 1,250 animals from over 150 species, varying from small mammals to large birds. In Beekse Bergen, there are different ways to stay overnight, in the safari resort, the holiday resort or the camping. These accommodations offer different luxuriousness. In the safari resort the accommodations are nearby the animals. Different accommodations are offered, like a safari tent, a lodge or a treehouse. In the holiday resort offers a stay in a bungalow in a more bushy environment. Safari park Beekse Bergen offers more than 400 accommodations in different sizes and types, from 15 – 150 m^2. The small houses do not have a bathroom. Larger houses have a bathroom and a kitchen. The safari park is very big and offers a lot off facilities. The park has multiple restaurants and places to eat. There is a swimming pool, a bowling place and multiple playgrounds for the kids. There is also an animation team and a small market. (https://www.beeksebergen.nl/overnachten, 2018)

Figure 7: Lodges with view on the animals
Source: https://www.beeksebergen.nl

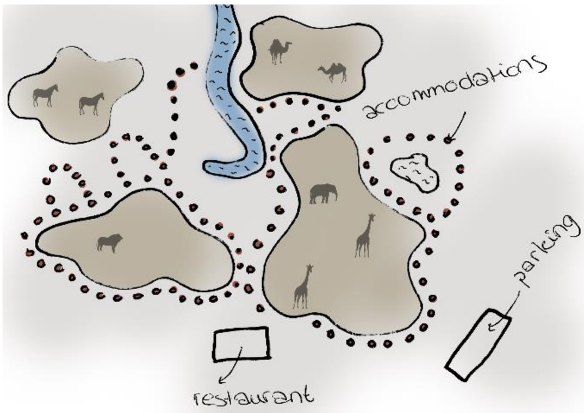


Figure 8: Organisation Beekse Bergen

5. San Diego Zoo Safari Park (California)

The San Diego Zoo Safari Park is a 730 ha zoo located in the San Pasqual Valley. The park houses over 2600 animals from 300 species. The park is in a semi-arid environment. The San Diego Zoo offers overnight stay when a roar and snore safari is booked. This includes camp activities, an after-hours look at the wildlife of the animals, guided walks, a campfire program, dinner, an evening snack, and breakfast the following morning. There are three different types of tents, namely the classic tent, which is 3 x 4 meters and for up to 5 persons. The tent has a traditional vinyl-covered tent floor and sleeping bag pads. The vista tent, also is 3 x 4 meters but up to 6 persons. The tent has a traditional vinyl-covered tent floor, two chairs and two sets of bunk beds and two single beds. These tents have a view looking out over the animals. Or the premium tent, which is 3,5 x 5 meters. This is the most luxurious tent and has electrical outlets, nightstand/storage, queen bed, plus two cots, bed linen, pillows and a wooden floor with area rug. The safari park has different facilities, like restaurants, toilets, an amphitheatre and playgrounds for the kids. (https://www.sdzsafaripark.org/safari/roar-snore-safari, 2018)

Figure 9: Safari Park
Source: https://hope-amundson.com/projects/san-diego-zoo-safari-park-lion-camp/

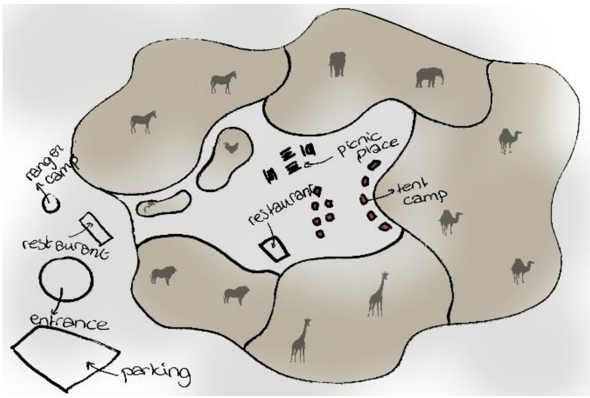


Figure 10: Organisation Safari Park

6. Taronga Western Plains Zoo Dubbo (Australia)

Taronga Western Plains Zoo is a large zoo near Dubbo. It offers different accommodations for overnight stay. The Zoofari Lodge is a luxurious lodge with a view overlooking the animals. The lodge has a private en-suite, a mini-bar, a fridge and a shaded veranda. The Billabong Camp offers 3 x 3 meter tents, where two people can sleep. The Savannah cabins are self-contained and offer a place for up to six people. The cabin has two bedrooms and two bathrooms, a kitchen and an outdoor area. The Taronga Western Plains Zoo has a restaurant, swimming pool, library and they offer car and bike rental.
(https://taronga.org.au/dubbo-zoo/accommodation, 2018)

Figure 11: Zoofari Lodge
Source: https://taronga.org.au/dubbo-zoo

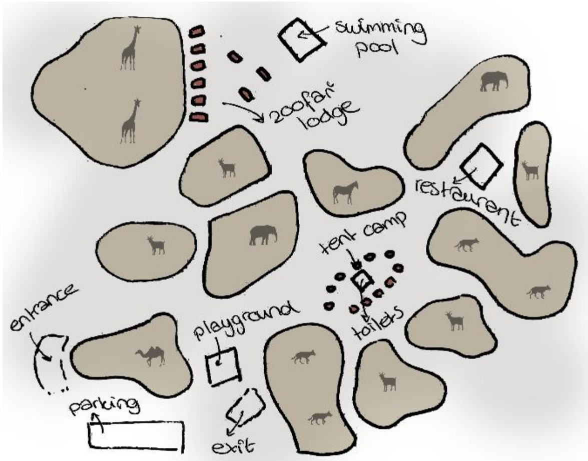
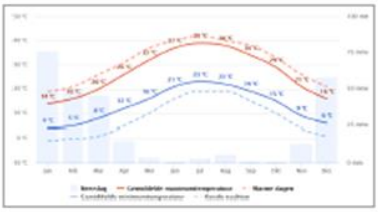
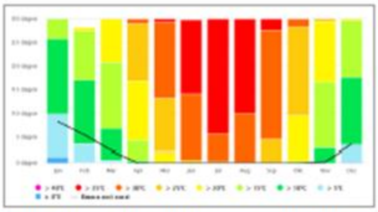
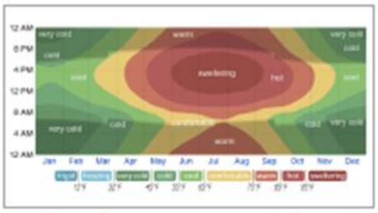
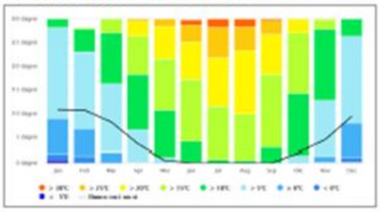
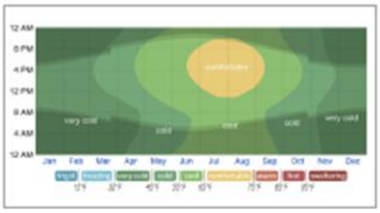
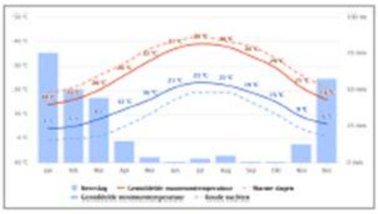
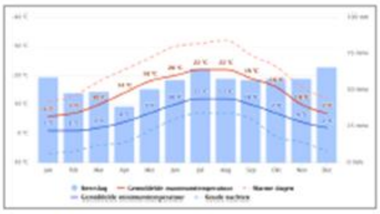
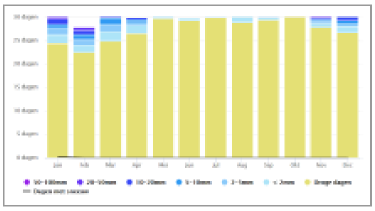
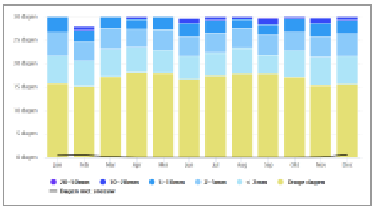
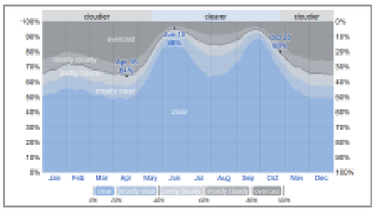
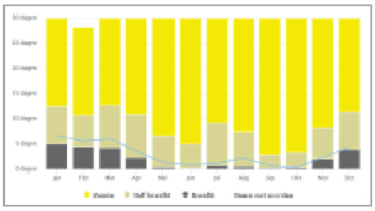
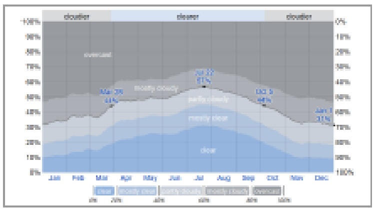
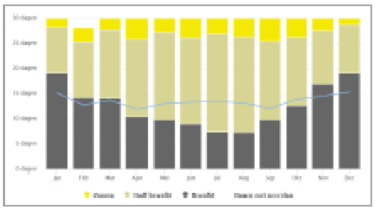
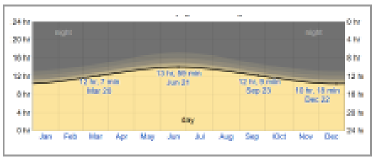
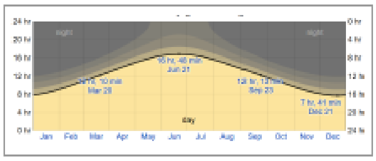
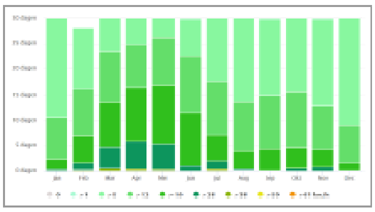
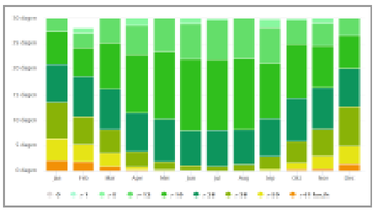
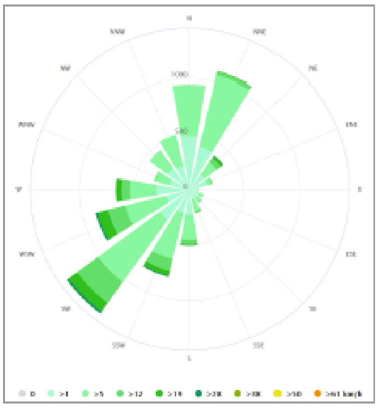
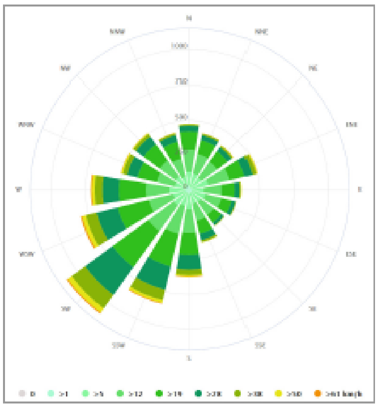
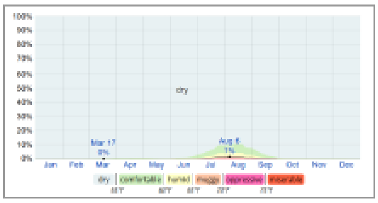
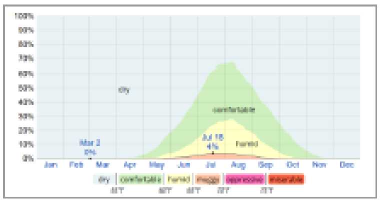
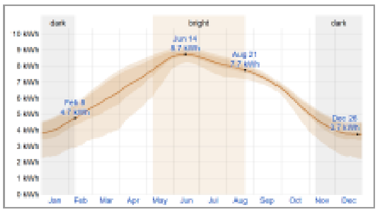
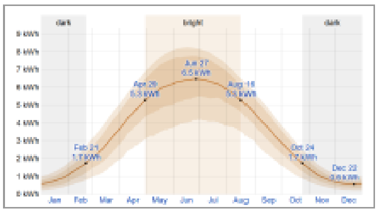


Figure 12: Organisation Taronga Zoo

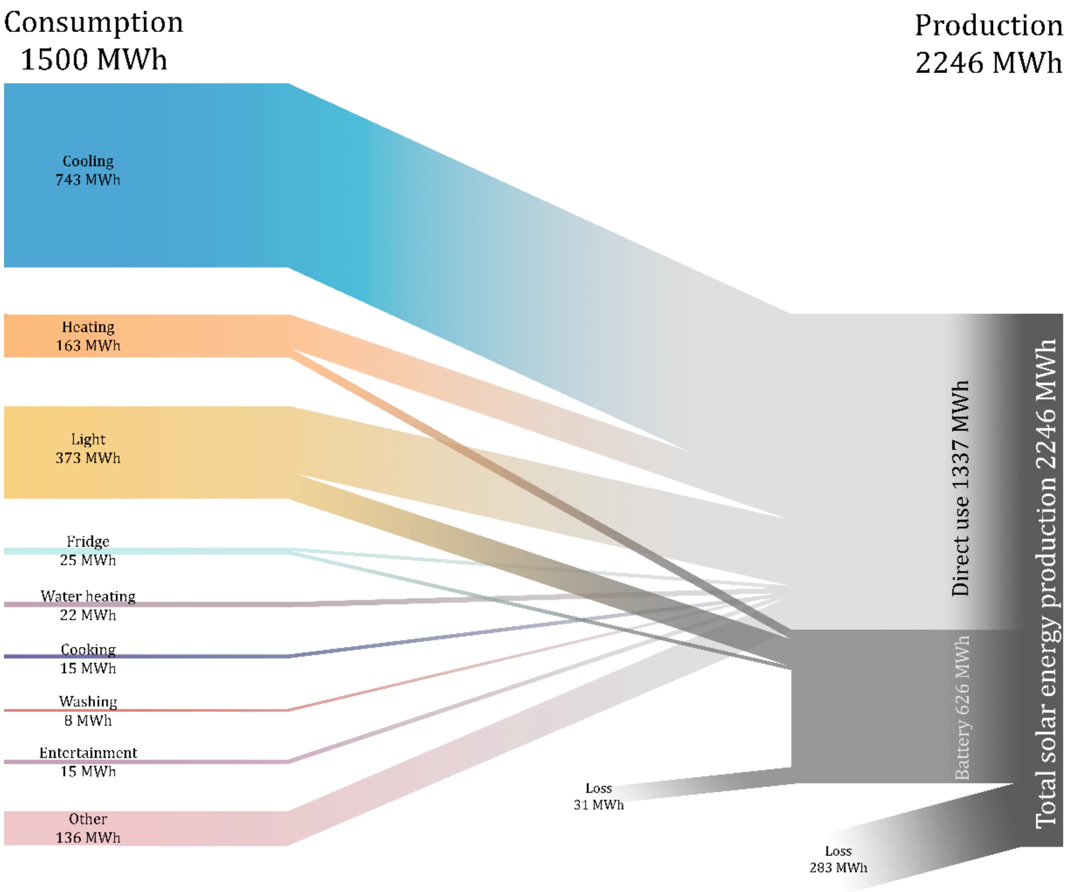
Climate of Firuzabad compared to the climate in Amsterdam.

	Fīrūzābād, Iran	Amsterdam, Netherlands
CLIMATE	In Fīrūzābād, the summers are long, sweltering, arid, and clear and the winters are cold and mostly clear. Over the course of the year, the temperature typically varies from 1°C to 38°C and is rarely below -3°C or above 41°C.	In Amsterdam, the summers are comfortable and partly cloudy and the winters are long, very cold, windy, and mostly cloudy. Over the course of the year, the temperature typically varies from 1°C to 22°C and is rarely below -6°C or above 27°C.
TEMPERATURE	 The average daily maximum is showed in the red line. The average daily minimum with the blue line. We can see a difference of 10 - 16 °C. The dotted blue and red line show the average of the hottest day and coldest night.  The Figure above shows how many days a month a certain temperature is reached. In July there are almost no days where the temperature is lower than 30 °C.  The figure above shows you a compact characterization of the entire year of hourly average temperatures. The horizontal axis is the day of the year, the vertical axis is the hour of the day, and the colour is the average temperature for that hour and day.	 In winter in Iran the temperature varies from 4 to 14 °C. There is a difference of 10 °C. In summer the temperature varies between 23 and 39 °C, a difference of 16 °C. In the Netherlands the winter is a bit colder with temperatures from 1 to 6 °C. A difference of only 5 °C. The summer is colder with temperatures from 12 to 22 °C, a difference of 10 °C.  The temperatures in Iran a much higher in comparison with Amsterdam.  The hourly average temperatures also differ a lot. In Iran a big part of the day in summer it is sweltering where in the Netherlands it is comfortable.
PRECIPITATION	 In the figure the monthly amount of rain is shown. The rainy period of the year lasts for 5.1 months. The most rain falls during the 31 days centered around January 18. The rainless period of the year lasts for 6.9 months. The least rain falls around September 19.	 The rainfall diagram shows the big difference between the Dutch climate and the climate in Iran. In Amsterdam the rainfall is similar during the whole year. Where in Iran it becomes clear that the most rain falls during winter.

	 This figure shows how many days a month a certain amount of rail falls. This figure makes clear that the climate is very arid. Most months there are only 5 days or less of rainfall.	 The average of rainy days per month in the Netherlands is around 15. In Iran this is less than 5.
CLOUDS	 The average percentage of the sky covered by clouds experiences significant seasonal variation over the course of the year. The clearer part of the year in Fīrūzābād begins around May 17 and lasts for 5.3 months. The cloudier part of the year begins around October 25 and lasts for 6.7 months. 	 Both these figures show the difference in clouds in Amsterdam and in Fīrūzābād. In Fīrūzābād there are less clouds all year round. 
SUN	 The length of the day in Fīrūzābād varies over the course of the year. In 2018, the shortest day is December 22, with 10 hours 18 minutes of daylight; the longest day is June 21, with 13 hours 59 minutes of daylight.	 The shortest day in Iran is 10 hours 18 minutes. In the Netherlands it is 7 hours 41 minutes. The longest day in Iran is 13 hours 59 minutes. In Amsterdam it is 16 hours 48 minutes. The differences are therefore bigger in Amsterdam than in Iran.
WIND	 This figure shows how many days a month a certain wind speed appears. The windspead in Iran varies from 5 km/h to 28 km/h. The windspeed will rarely be above the 28 km/h	 If we compare the windspead in Iran and the Netherlands we see a huge difference. In the Netherlands the windspead can go up to 61 km/h and is a big part of the time between 19 and 28 km/h which is the highest it will get in Iran.

	 The figure shows the wind direction, which is most often from the southwest. The wind is then the most often from the north northeast.	 Also in the wind direction a difference is visible. In the Netherlands the wind comes most of the time from the southwest. In Iran the wind comes also from the southwest, but also a lot of the time from the north northeast.
HUMIDITY	 The humidity comfort level is based on the dew point, as it determines whether perspiration will evaporate from the skin, thereby cooling the body. Lower dew points feel drier and higher dew points feel more humid. The perceived humidity level in Fīrūzābād does not vary significantly over the course of the year.	 Also in humidity there is a difference. In the Netherlands the humidity is much higher during the summer months.
SOLAR ENERGY	 The figure shows the solar energy reaching the ground. The brighter period of the year has an average daily incident shortwave energy per square meter above 7.7 kWh. The darker period of the year has an average daily incident shortwave energy per square meter below 4.7 kWh.	 The amount of solar energy that will reach the ground is much higher in Iran than it is in the Netherlands.

The extended overview of the PVSyst outcome for solar panels only.



In this part an overview of the PVSyst can be found where only the solar panels are used to produce all energy for the Negin Safari Park.

It is found that 3920 solar panels are needed and a battery storage of 115 m^3.

	kWh/year	Wh/year	Wh/day
Cooling	742.100	742.100.000	2.033.151
Heating	162.700	162.700.000	445.753
Light	372.385	372.385.000	1.020.233
Fridge	24.955	24.955.000	68.370
Water heating	21.390	21.390.000	58.603
Cooking	14.260	14.260.000	39.068
Washing	7.130	7.130.000	19.534
Entertainment	14.260	14.260.000	39.068
Other	136.320	136.320.000	373.479
Total	1.495.500	1.495.500.000	4.097.260

Stand alone system: Detailed User's needs

Project : Park

Simulation variant : Household at Marseille, MPPT Universal controller

Main system parameters	System type	**Stand alone system with batteries**	
PV Field Orientation	tilt	28°	azimuth 0°
PV modules	Model	AXN6M610T285	Pnom 285 Wp
PV Array	Nb. of modules	3920	Pnom total **1117 kWp**
Battery	Model	Powerwall2	Technology Lithium-ion, NCA
Battery Pack	Nb. of units	850	Voltage / Capacity **101 V / 113900 Ah**
User's needs	Daily household consumers	Monthly Specifications	Global 1498 MWh/year

Daily household consumers, Monthly Specifications, average = 4104 kWh/day

January and February

	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Heating	100	1000 W tot	12 h/day	1200000 Wh/day	100	1000 W tot	1200000 h/day	1200000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				2780495 Wh/day				2780495 Wh/day

March and April

	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Other uses					320	1000 W tot	1920000 h/day	1920000 Wh/day
Heating	100	1000 W tot	12 h/day	1200000 Wh/day	30	1000 W tot	360000 h/day	360000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				2780495 Wh/day				3840495 Wh/day

May and June

	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Cooling	330	1000 W tot	12 h/day	3960000 Wh/day	330	1000 W tot	4200000 h/day	4200000 Wh/day
Heating	15	1000 W tot	3 h/day	45000 Wh/day	15	1000 W tot	45000 h/day	45000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				5585495 Wh/day				5825495 Wh/day

July and August

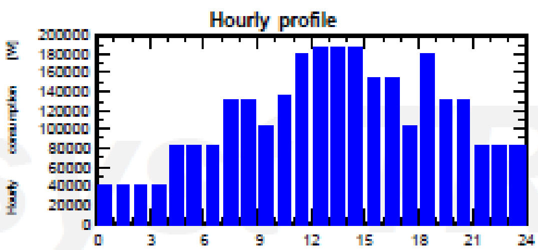
	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Cooling	340	1000 W tot	12 h/day	4080000 Wh/day	330	1000 W tot	4200000 h/day	4200000 Wh/day
Heating	15	1000 W tot	3 h/day	45000 Wh/day	15	1000 W tot	45000 h/day	45000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				5585495 Wh/day				5825495 Wh/day

September and October

	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Cooling	330	1000 W tot	12 h/day	3960000 Wh/day	320	1000 W tot	1920000 h/day	1920000 Wh/day
Heating	15	1000 W tot	3 h/day	45000 Wh/day	30	1000 W tot	360000 h/day	360000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				5585495 Wh/day				3840495 Wh/day

November and December

	Number	Power	Use	Energy	Number	Power	Use	Energy
Light	3824	20 W/lamp	13 h/day	1032240 Wh/day	3824	20 W/lamp	1032240 h/day	1032240 Wh/day
Entertainment	104	75 W/app	5 h/day	39000 Wh/day	104	75 W/app	39000 h/day	39000 Wh/day
Other	340	200 W/app	6 h/day	374000 Wh/day	340	200 W/app	374000 h/day	374000 Wh/day
Fridge	86		24 Wh/day	68731 Wh/day	86		68731 Wh/day	68731 Wh/day
Dishwashers	195		6 Wh/day	58500 Wh/day	195		58500 Wh/day	58500 Wh/day
Heating	100	1000 W tot	12 h/day	1200000 Wh/day	100	1000 W tot	1200000 h/day	1200000 Wh/day
Standby consumers			24 h/day	24 Wh/day			24 h/day	24 Wh/day
Total daily energy				2780495 Wh/day				2780495 Wh/day



Stand alone system: Main results

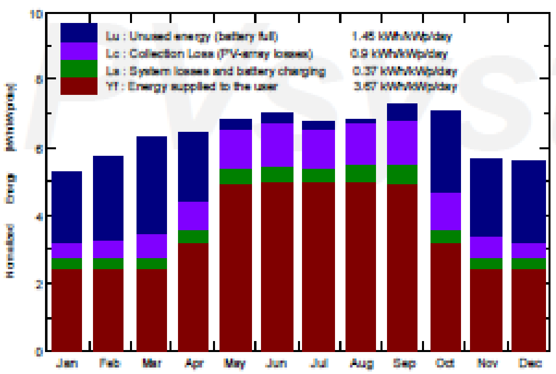
Project : Park

Simulation variant : Household at Marseille, MPPT Universal controller

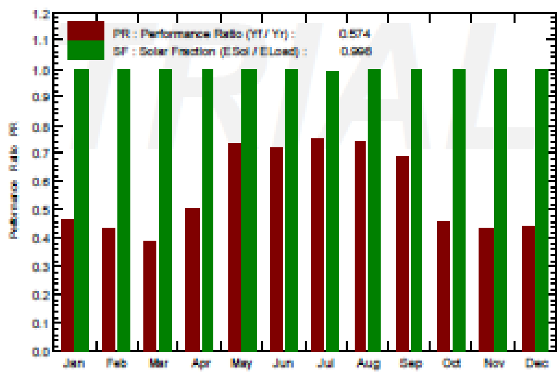
Main system parameters	System type	**Stand alone system with batteries**			
PV Field Orientation	tilt	28°	azimuth	0°
PV modules	Model	AXN6M610T285	Pnom	285 Wp
PV Array	Nb. of modules	3920	Pnom total	**1117 kWp**
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA
Battery Pack	Nb. of units	850	Voltage / Capacity	**101 V / 113900 Ah**
User's needs	Daily household consumers	Monthly Specifications	Global	1498 MWh/year

Main simulation results				
System Production	**Available Energy**	**2137 MWh/year**	Specific prod.	1913 kWh/kWp/year
	Used Energy	1495 MWh/year	Excess (unused)	592 MWh/year
	Performance Ratio PR	57.36 %	Solar Fraction SF	99.84 %
Loss of Load	Time Fraction	0.1 %	Missing Energy	2 MWh/year
Battery ageing (State of Wear)	Cycles SOW	93.2%	Static SOW	77.6%
	Battery lifetime	4.5 years		

Normalized productions (per installed kWp): Nominal power 1117 kWp



Performance Ratio PR and Solar Fraction SF



Household at Marseille, MPPT Universal controller

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail MWh	EUnused MWh	E_Miss MWh	E_User MWh	E_Load MWh	SolFrac
January	113.7	160.3	163.4	72.75	0.000	85.6	85.6	1.000
February	124.5	157.1	156.7	75.39	0.000	77.3	77.3	1.000
March	169.7	190.5	186.6	97.08	0.000	85.6	85.6	1.000
April	187.9	187.0	179.0	65.60	0.000	109.2	109.2	1.000
May	227.6	204.2	185.7	9.28	0.000	172.5	172.5	1.000
June	235.0	203.3	181.4	8.27	0.000	168.8	168.8	1.000
July	228.5	201.6	178.8	4.21	2.436	173.8	176.3	0.986
August	213.1	203.7	180.8	1.52	0.000	174.4	174.4	1.000
September	197.2	212.2	189.7	16.29	0.000	167.0	167.0	1.000
October	173.5	214.5	200.4	82.92	0.000	112.9	112.9	1.000
November	121.1	166.0	162.9	76.38	0.000	82.8	82.8	1.000
December	113.3	169.0	171.7	82.38	0.000	85.6	85.6	1.000
Year	2105.2	2269.4	2137.2	592.07	2.436	1495.4	1497.8	0.998

Legends:
- GlobHor: Horizontal global irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E_Avail: Available Solar Energy
- EUnused: Unused energy (battery full)
- E_Miss: Missing energy
- E_User: Energy supplied to the user
- E_Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

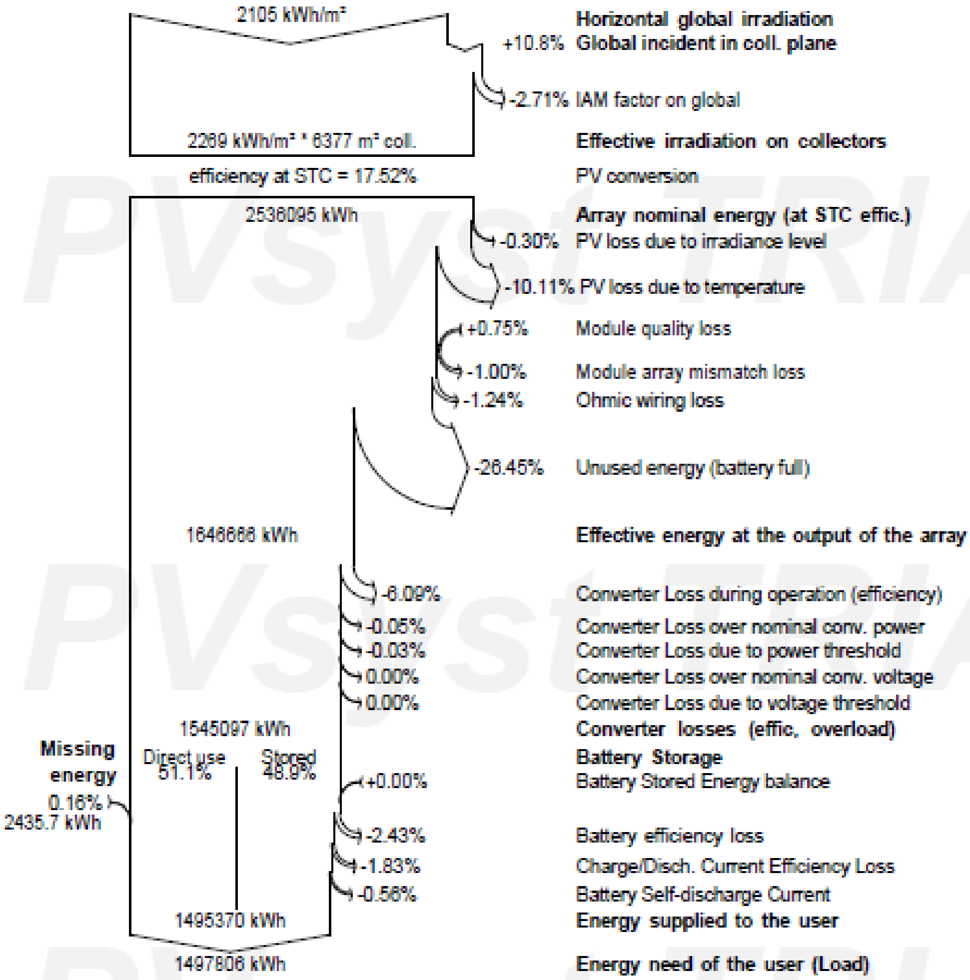
Stand alone system: Loss diagram

Project : Park

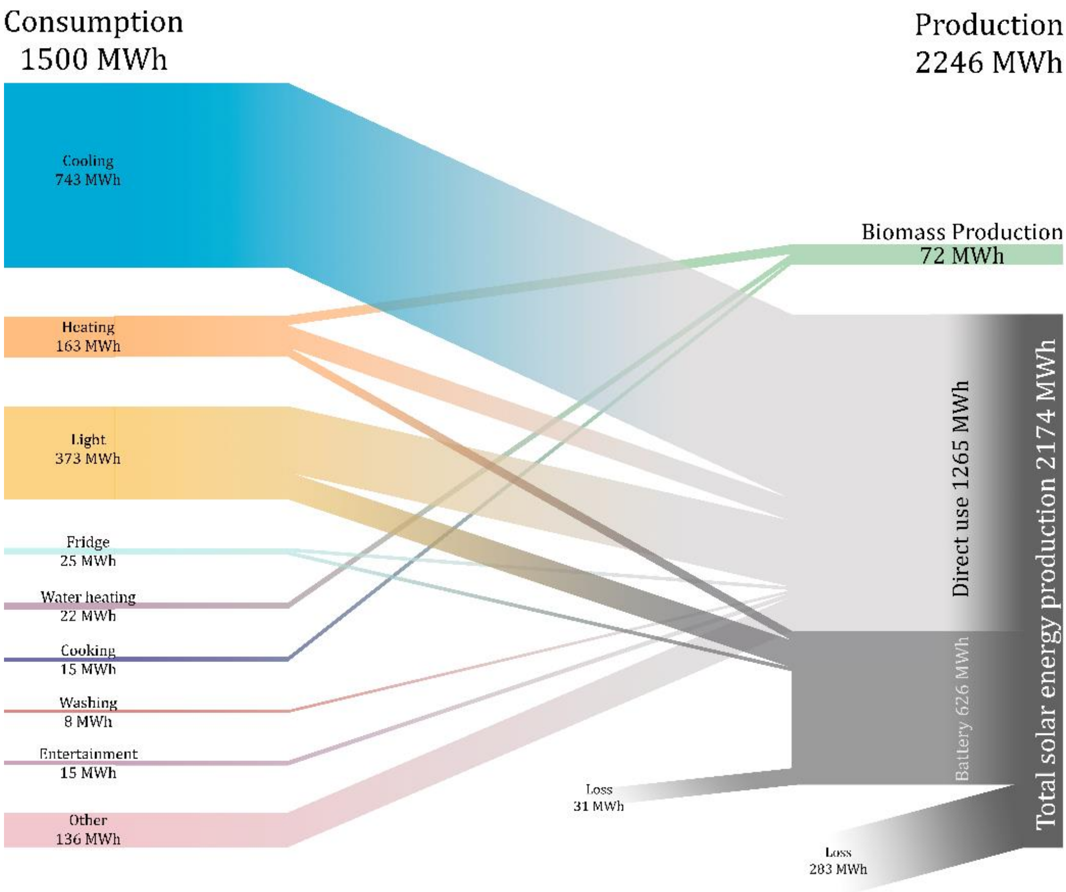
Simulation variant : Household at Marseille, MPPT Universal controller

Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	28°	azimuth	0°
PV modules	Model	AXN6M610T285	Pnom	285 Wp
PV Array	Nb. of modules	3920	Pnom total	**1117 kWp**
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA
Battery Pack	Nb. of units	850	Voltage / Capacity	**101 V / 113900 Ah**
User's needs	Daily household consumers	Monthly Specifications	Global	1498 MWh/year

Loss diagram over the whole year



The extended overview of the PVSyst outcome for solar panels combined with the biomass.



In this case the solar panels will produce around 72.000 kWh/year less as this amount is covered by the biomass production. Water heating and cooking is provided by the biomass, together with a part of the heating demand.

It is found that 3200 solar panels are needed and a battery storage of 100 m^3.

	kWh/year	Wh/year	Wh/day
Cooling	742.100	742.100.000	2.033.151
Heating	127.700	127.700.000	349.863
Light	372.385	372.385.000	1.020.233
Fridge	24.955	24.955.000	68.370
Water heating	21.390	21.390.000	58.603
Cooking	14.260	14.260.000	39.068
Washing	7.130	7.130.000	19.534
Entertainment	14.260	14.260.000	39.068
Other	136.320	136.320.000	373.479
Total	1.460.500	1.460.500.000	4.001.370

Stand alone system: Simulation parameters

Project : **Park**

Geographical Site		**Āteshkadeh**	Country	**Iran**
Situation	Latitude	28.92° N	Longitude	52.57° E
Time defined as	Legal Time	Time zone UT+3.5	Altitude	1657 m
	Albedo	0.20		
Meteo data:	**Āteshkadeh**	Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic		

Simulation variant : **Simulation oud zonnepanelen**

Simulation date 25/06/19 10h19

Simulation parameters	System type	**Stand alone system with batteries**		
Collector Plane Orientation	Tilt	28°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
User's needs :	Daily household consumers	Constant over the year		
	average	3904 kWh/Day		

PV Array Characteristics

PV module Si-mono	Model	**AXN6M610T285**		
Original PVsyst database	Manufacturer	Auxin Solar		
Number of PV modules	In series	8 modules	In parallel	400 strings
Total number of PV modules	Nb. modules	3200	Unit Nom. Power	285 Wp
Array global power	Nominal (STC)	**912 kWp**	At operating cond.	860 kWp (40°C)
Array operating characteristics (50°C)	U mpp	241 V	I mpp	3569 A
Total area	Module area	**5206 m²**	Cell area	4557 m²

System Parameter	System type	**Stand alone system**		
Battery	Model	**Powerwall2**		
	Manufacturer	Tesla		
Battery Pack Characteristics	Nb. of units	2 in series x 356 in parallel		
	Voltage	101 V	Nominal Capacity	95408 Ah
	Discharging min. SOC	10.0 %	Stored energy	8730.8 kWh
	Temperature	External ambient temperature		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0 / 95.0 %		
Battery Management control	Threshold commands as	SOC calculation		
	Charging	SOC = 0.96 / 0.80		
	Discharging	SOC = 0.10 / 0.35		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	1.1 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.3 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Stand alone system: Main results

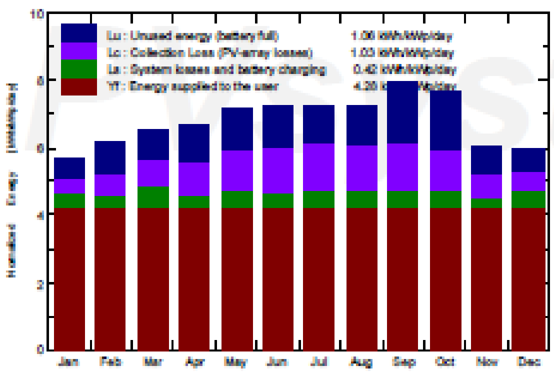
Project : **Park**

Simulation variant : **Simulation oud zonnepanelen**

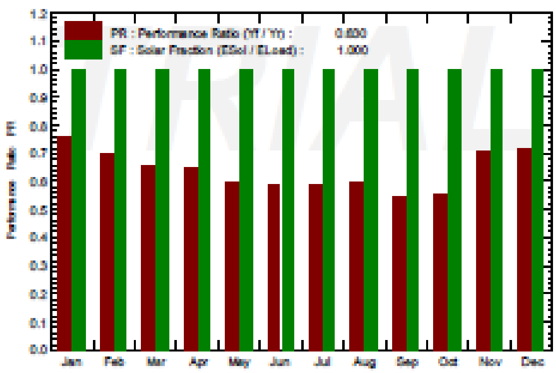
Main system parameters	System type	**Stand alone system with batteries**			
PV Field Orientation	tilt	28°	azimuth	0°	
PV modules	Model	AXN6M610T285	Pnom	285 Wp	
PV Array	Nb. of modules	3200	Pnom total	**912 kWp**	
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA	
Battery Pack	Nb. of units	712	Voltage / Capacity	**101 V / 95408 Ah**	
User's needs	Daily household consumers	Constant over the year	Global	1425 MWh/year	

Main simulation results				
System Production	**Available Energy**	**1821 MWh/year**	Specific prod.	1997 kWh/kWp/year
	Used Energy	1425 MWh/year	Excess (unused)	354 MWh/year
	Performance Ratio PR	63.05 %	Solar Fraction SF	100.00 %
Loss of Load	Time Fraction	0.0 %	Missing Energy	0 MWh/year
Battery ageing (State of Wear)	Cycles SOW	90.5%	Static SOW	76.9%
	Battery lifetime	4.3 years		

Normalized productions (per installed kWp): Nominal power 912 kWp



Performance Ratio PR and Solar Fraction SF



Simulation oud zonnepanelen

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail MWh	EUnused MWh	E_Miss MWh	E_User MWh	E_Load MWh	SolFrac
January	119.8	171.8	139.4	15.23	0.000	121.0	121.0	1.000
February	131.7	169.3	134.3	23.96	0.000	109.3	109.3	1.000
March	175.6	197.6	153.3	24.18	0.000	121.0	121.0	1.000
April	195.1	192.7	147.2	27.99	0.000	117.1	117.1	1.000
May	238.7	214.7	158.8	33.34	0.000	121.0	121.0	1.000
June	243.9	211.0	153.7	33.43	0.000	117.1	117.1	1.000
July	247.3	217.7	156.6	31.80	0.000	121.0	121.0	1.000
August	225.8	216.0	155.6	30.55	0.000	121.0	121.0	1.000
September	212.4	230.9	167.7	47.04	0.000	117.1	117.1	1.000
October	186.3	233.1	173.1	48.03	0.000	121.0	121.0	1.000
November	127.5	177.0	137.7	21.28	0.000	117.1	117.1	1.000
December	119.7	180.3	144.1	17.64	0.000	121.0	121.0	1.000
Year	2223.8	2412.1	1821.5	354.46	0.000	1424.9	1424.9	1.000

Legends:
- GlobHor: Horizontal global irradiation
- GlobEff: Effective Global, corr. for IAM and shadings
- E_Avail: Available Solar Energy
- EUnused: Unused energy (battery full)
- E_Miss: Missing energy
- E_User: Energy supplied to the user
- E_Load: Energy need of the user (Load)
- SolFrac: Solar fraction (EUsed / ELoad)

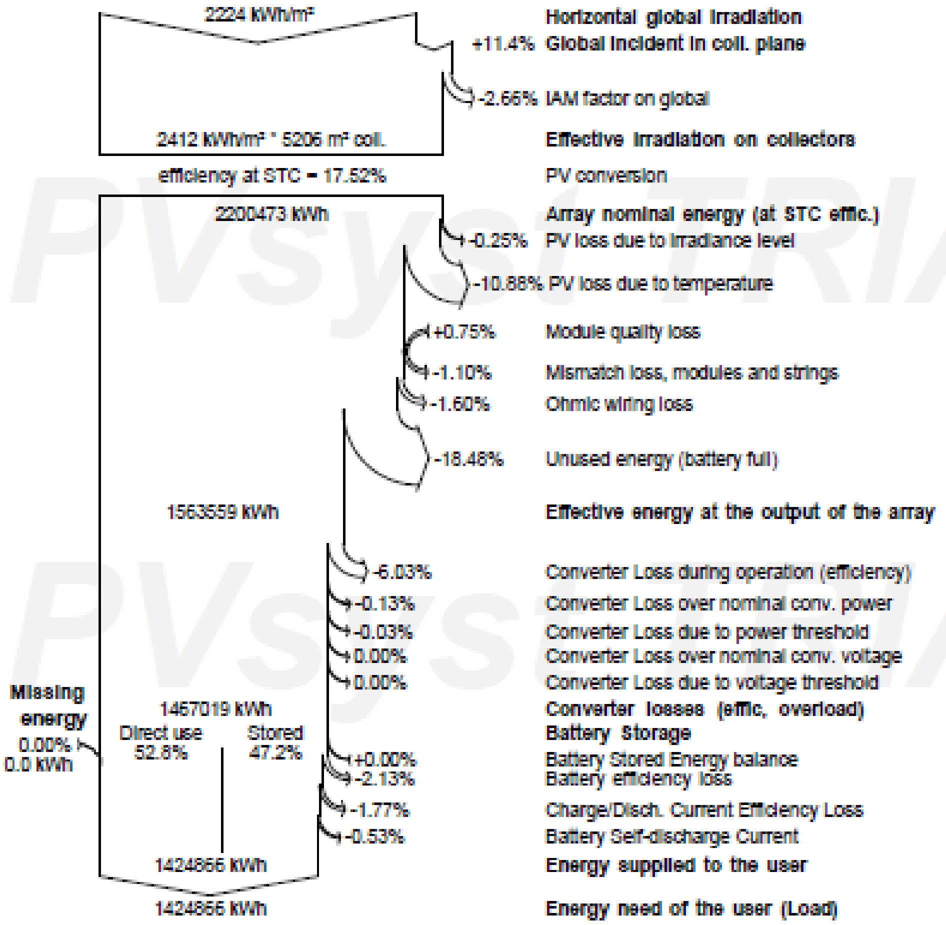
Stand alone system: Loss diagram

Project : **Park**

Simulation variant : **Simulation oud zonnepanelen**

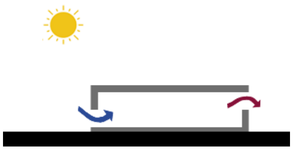
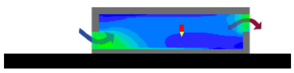
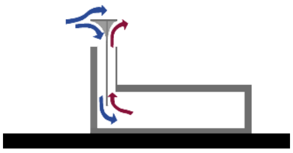
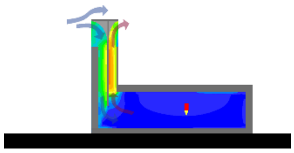
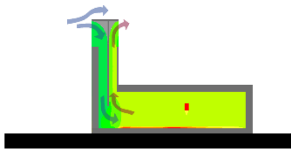
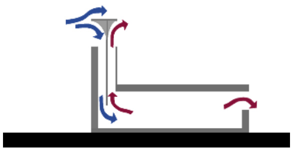
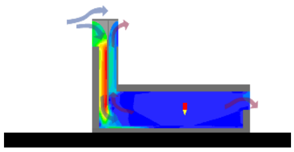
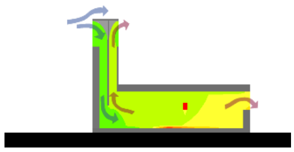
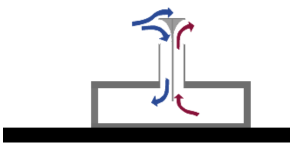
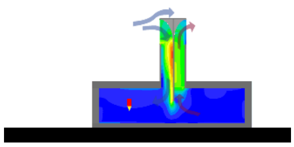
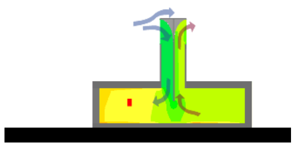
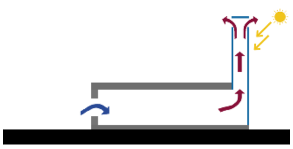
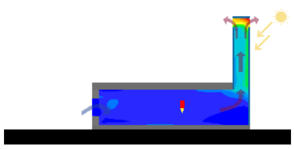
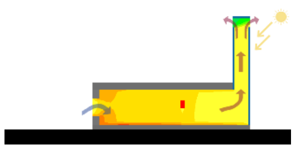
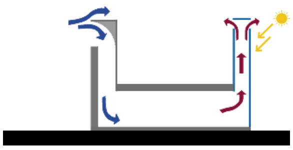
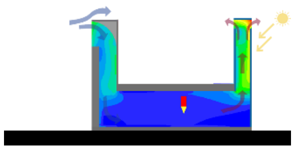
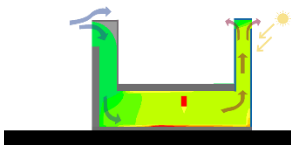
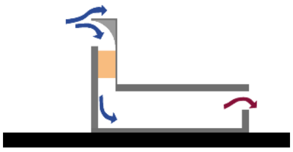
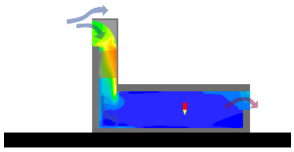
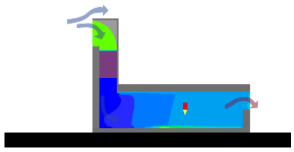
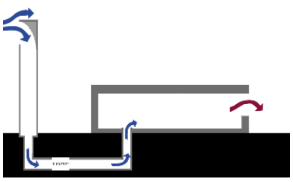
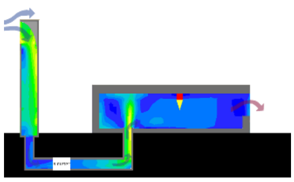
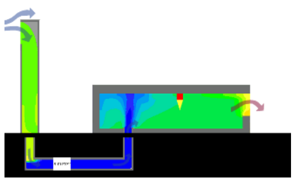
Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	28°	azimuth	0°
PV modules	Model	AXN6M610T285	Pnom	285 Wp
PV Array	Nb. of modules	3200	Pnom total	**912 kWp**
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA
Battery Pack	Nb. of units	712	Voltage / Capacity	**101 V / 95408 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1425 MWh/year

Loss diagram over the whole year



Phoenics VR (2018) computational fluid dynamics study on different building types overview.

Table 1: Overview

		Velocity [m/s]		Temperature [°C]	
		0,5 m/s		28 °C	
		0,9 m/s		40 °C	
I.		0,5 m/s		38 °C	
II.		0,6 m/s		37 °C	
III.		0,4 m/s		39 °C	
IV.		0,7 m/s		40 °C	
V.		0,7 m/s		38 °C	
VI.		0,7 m/s		29 °C	
VII.		1,3 m/s		32 °C	

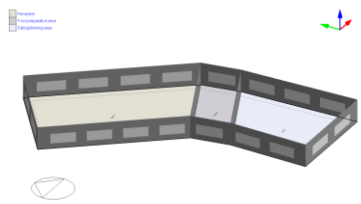
DesignBuilder (2019) outcome.

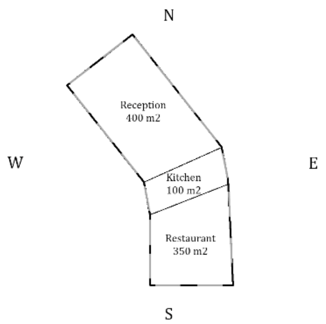
The energy demand of the standard building is calculated in chapter 4. Now DesignBuilder (2019) is used to give an estimation on the reduction in energy with the adaptions found in the vernacular architecture. These adaptations will only influence the heating and cooling demand of the building. Other factors, like lighting and water heating will remain the same. Therefore, the heating and cooling demand of the standard building will be set as 100%. The heating and cooling demand of the other buildings examined in DesignBuilder (2019) will give an estimation of the reduction.

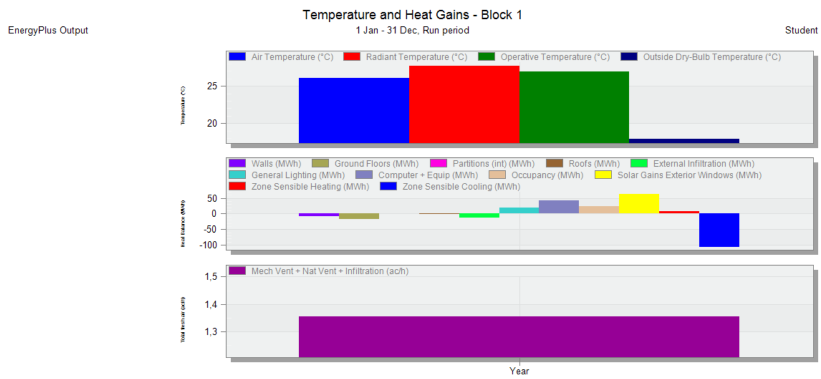
1. STANDARD BUILDING ENERGY USE

This building is the result of the conceptual design. The building has walls which are 0,5 meter thick and windows that are the same on every side of the building. The walls have 30% glazing.

The energy use for heating and cooling of this building is 113.310 kWh/year.







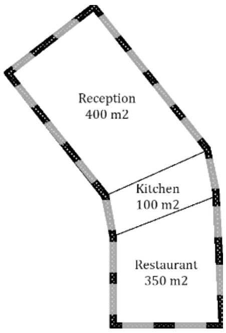
Air Temperature (°C)	26,04
Radiant Temperature (°C)	27,73
Operative Temperature (°C)	26,89
Outside Dry-Bulb Temperature (°C)	17,88
Walls (MWh)	-7,08
Ground Floors (MWh)	-17,97
Partitions (int) (MWh)	-0,00
Roofs (MWh)	-1,64
External Infiltration (MWh)	-12,56
General Lighting (MWh)	19,57
Computer + Equip (MWh)	42,77
Occupancy (MWh)	24,95
Solar Gains Exterior Windows (MWh)	62,66
Zone Sensible Heating (MWh)	6,94
Zone Sensible Cooling (MWh)	-106,37
Mech Vent + Nat Vent + Infiltration (ac/h)	1,36

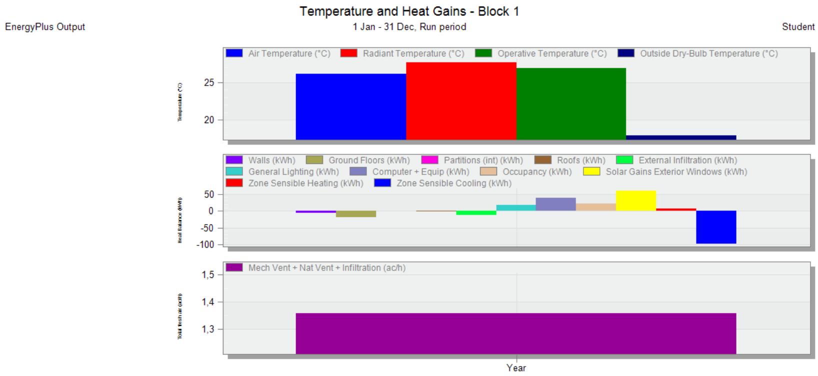
Energy use for heating and cooling:
113.310 kWh/year

2. Extra mass building

The standard building is adjusted with extra thermal mass. Two simulations are done, one with walls that are 1 meter thick and another with 1,5 meter thick walls. The glazing is the same as the standard building and is 30% of the walls.

The energy use for heating and cooling of the building with 1 meter walls is 103.540 kWh/year. The energy use for heating and cooling of the building with 1,5 meter walls is 94.759 kWh/year.

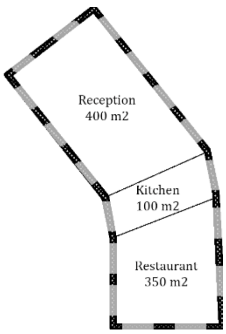


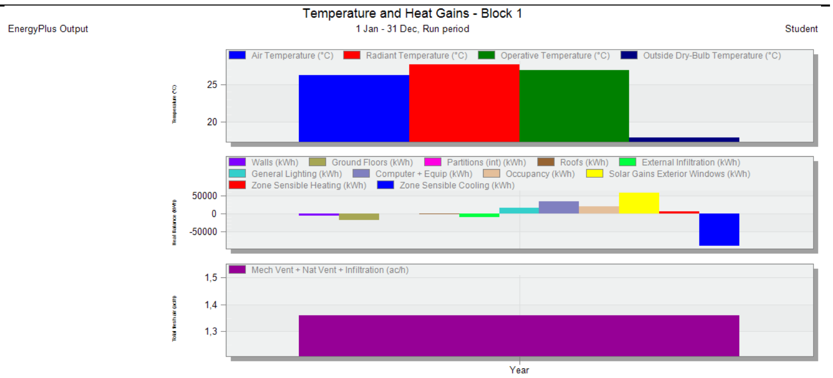


Air Temperature (°C)	26,09
Radiant Temperature (°C)	27,70
Operative Temperature (°C)	26,90
Outside Dry-Bulb Temperature (°C)	17,88
Walls (kWh)	-5,97
Ground Floors (kWh)	-17,88
Partitions (int) (kWh)	-0,00
Roofs (kWh)	-1,56
External Infiltration (kWh)	-11,30
General Lighting (kWh)	17,62
Computer + Equip (kWh)	38,54
Occupancy (kWh)	22,16
Solar Gains Exterior Windows (kWh)	59,80
Zone Sensible Heating (kWh)	6,34
Zone Sensible Cooling (kWh)	-97,20
Mech Vent + Nat Vent + Infiltration (ac/h)	1,36

Walls 1 meter thick

Energy use for heating and cooling:
103.540 kWh/year





Air Temperature (°C)	26,16
Radiant Temperature (°C)	27,67
Operative Temperature (°C)	26,91
Outside Dry-Bulb Temperature (°C)	17,88
Walls (kWh)	-5436,21
Ground Floors (kWh)	-17815,42
Partitions (int) (kWh)	-0,51
Roofs (kWh)	-1570,55
External Infiltration (kWh)	-10181,85
General Lighting (kWh)	15864,33
Computer + Equip (kWh)	34741,73
Occupancy (kWh)	19641,73
Solar Gains Exterior Windows (kWh)	57288,64
Zone Sensible Heating (kWh)	6080,57
Zone Sensible Cooling (kWh)	-88679,34
Mech Vent + Nat Vent + Infiltration (ac/h)	1,36

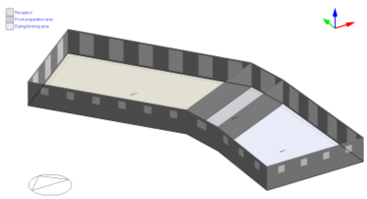
Walls 1,5 meter thick

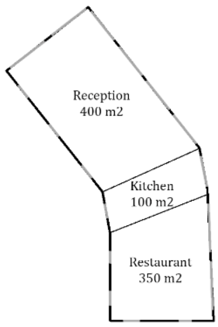
Energy use for heating and cooling:
94.760 kWh/year

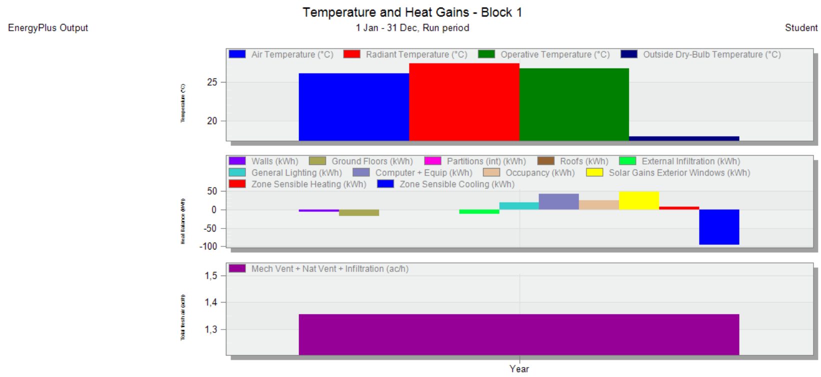
3. Windows adjusted to orientation

Now the windows from the standard building are adjusted. Windows on the south and west side of the building ensure that the building heats up because of the sun. Therefore, the windows on the south and west side are made smaller. Only 8% of the façade is glazing. However, to ensure enough sunlight in the building, the windows on the north and east side are made bigger. 40% of these facades is glazing.

The energy use for heating and cooling of this building is 103.400 kWh/year.







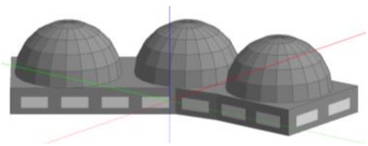
Air Temperature (°C)	26,20
Radiant Temperature (°C)	27,51
Operative Temperature (°C)	26,85
Outside Dry-Bulb Temperature (°C)	17,88
Walls (kWh)	-6,96
Ground Floors (kWh)	-17,42
Partitions (int) (kWh)	0,00
Roofs (kWh)	-1,18
External Infiltration (kWh)	-12,79
General Lighting (kWh)	19,57
Computer + Equip (kWh)	42,77
Occupancy (kWh)	24,38
Solar Gains Exterior Windows (kWh)	48,07
Zone Sensible Heating (kWh)	8,19
Zone Sensible Cooling (kWh)	-95,21
Mech Vent + Nat Vent + Infiltration (ac/h)	1,36

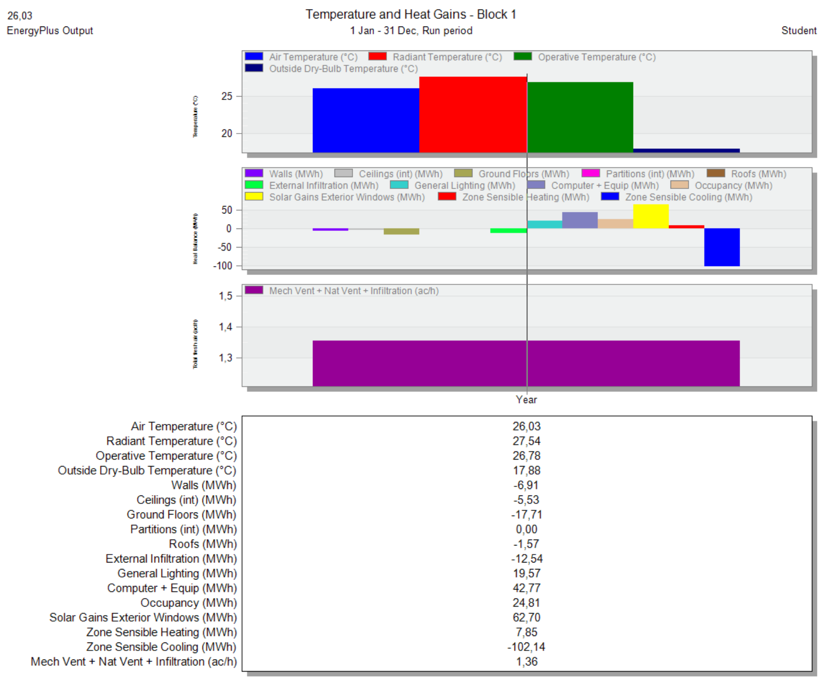
Energy use for heating and cooling:
103.400 kWh/year

4. Domed roof

Besides the mass and the windows also the roof can be adjusted. For this building the impact of the domed roofs is calculated. Three domes are placed on top of the building. The domes will minimize the building from heating up during the day while maximizing the cooling during the night.

The energy use for heating and cooling of this building is kWh/year.





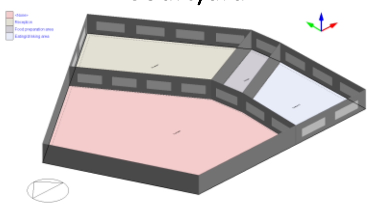
Energy use for heating and cooling:
109.990 kWh/year

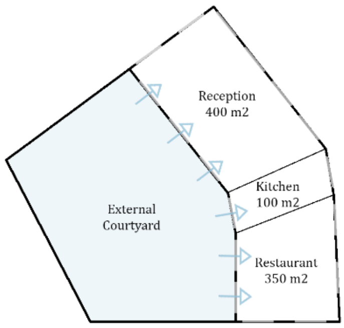
5. Courtyard added to the built form

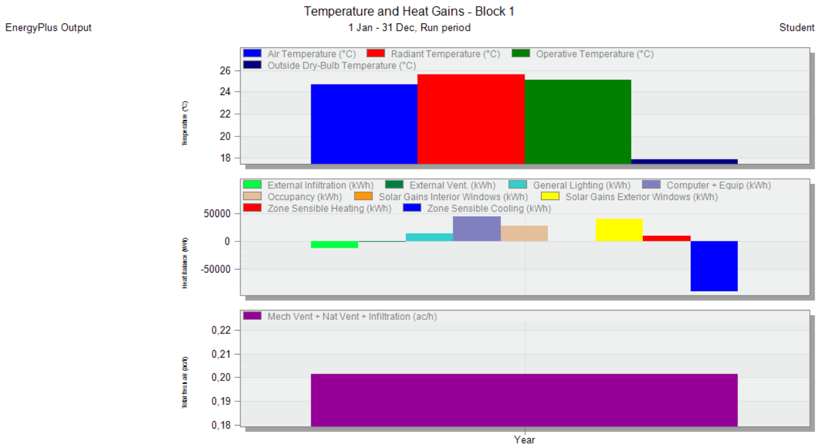
The standard building is now expanded with a courtyard. This courtyard can provide a lower air temperature which can cool the building. Therefore, the assumption is that less cooling will be needed in this building.

The energy use for heating and cooling of this building is 97.450 kWh/year.

Courtyard



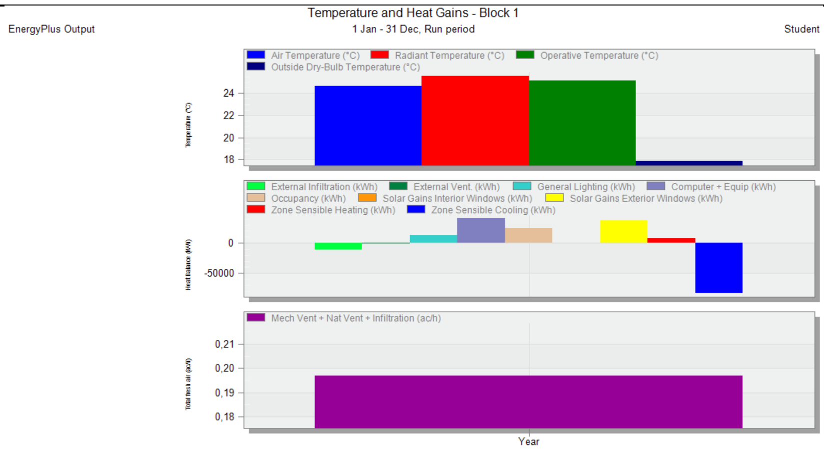




Air Temperature (°C)	24,64
Radiant Temperature (°C)	25,57
Operative Temperature (°C)	25,11
Outside Dry-Bulb Temperature (°C)	17,88
External Infiltration (kWh)	-11966,88
External Vent. (kWh)	-1571,76
General Lighting (kWh)	13109,50
Computer + Equip (kWh)	42851,17
Occupancy (kWh)	26301,47
Solar Gains Interior Windows (kWh)	128,77
Solar Gains Exterior Windows (kWh)	38842,98
Zone Sensible Heating (kWh)	8967,58
Zone Sensible Cooling (kWh)	-88482,32
Mech Vent + Nat Vent + Infiltration (ac/h)	0,20

Energy use for heating and cooling: 97.450 kWh/year

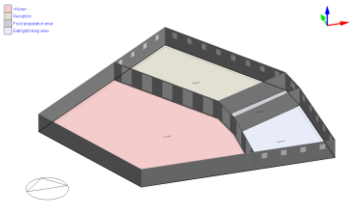
Courtyard + mass

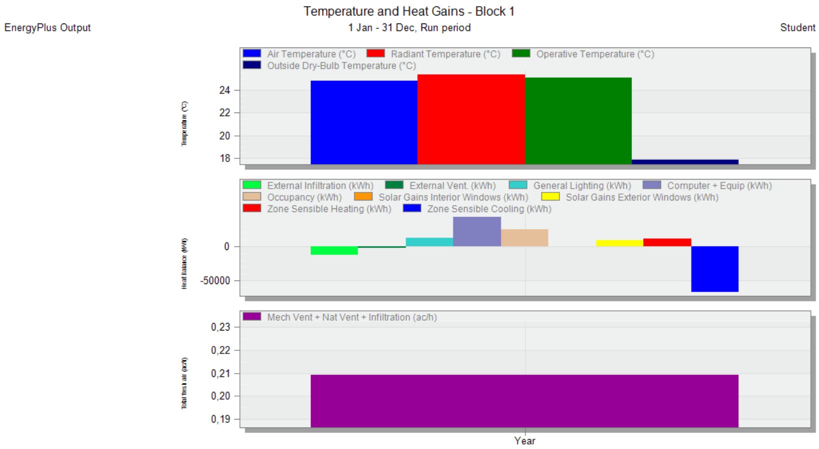


Air Temperature (°C)	24,66
Radiant Temperature (°C)	25,55
Operative Temperature (°C)	25,10
Outside Dry-Bulb Temperature (°C)	17,88
External Infiltration (kWh)	-11342,90
External Vent. (kWh)	-1539,96
General Lighting (kWh)	12303,04
Computer + Equip (kWh)	40550,48
Occupancy (kWh)	24380,32
Solar Gains Interior Windows (kWh)	116,11
Solar Gains Exterior Windows (kWh)	37482,68
Zone Sensible Heating (kWh)	8228,90
Zone Sensible Cooling (kWh)	-82596,78
Mech Vent + Nat Vent + Infiltration (ac/h)	0,20

Energy use for heating and cooling: 90.826 kWh/year

Courtyard + windows

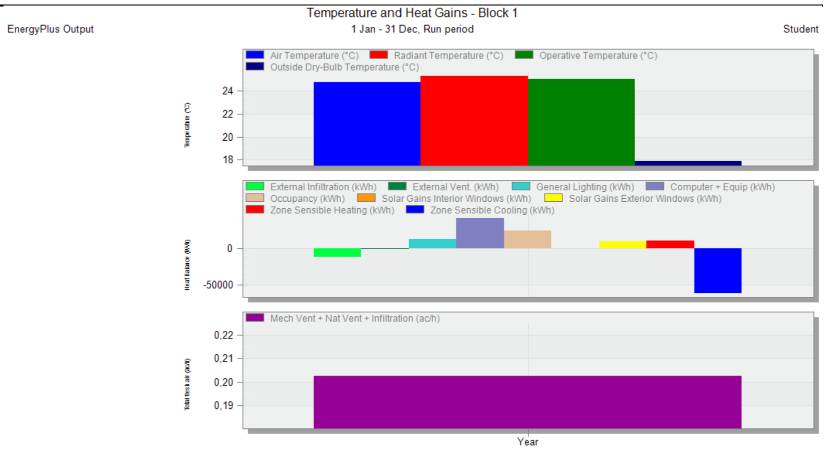




Air Temperature (°C)	24,76
Radiant Temperature (°C)	25,33
Operative Temperature (°C)	25,04
Outside Dry-Bulb Temperature (°C)	17,88
External Infiltration (kWh)	-12430,53
External Vent. (kWh)	-1976,59
General Lighting (kWh)	13201,18
Computer + Equip (kWh)	43160,09
Occupancy (kWh)	25645,76
Solar Gains Interior Windows (kWh)	60,36
Solar Gains Exterior Windows (kWh)	9175,21
Zone Sensible Heating (kWh)	11124,53
Zone Sensible Cooling (kWh)	-66791,05
Mech Vent + Nat Vent + Infiltration (ac/h)	0,21

Energy use for heating and cooling:
77.916 kWh/year

Courtyard + mass + windows



Air Temperature (°C)	24,75
Radiant Temperature (°C)	25,31
Operative Temperature (°C)	25,03
Outside Dry-Bulb Temperature (°C)	17,88
External Infiltration (kWh)	-11653,27
External Vent. (kWh)	-1871,36
General Lighting (kWh)	12303,04
Computer + Equip (kWh)	40550,48
Occupancy (kWh)	23683,82
Solar Gains Interior Windows (kWh)	54,40
Solar Gains Exterior Windows (kWh)	8839,96
Zone Sensible Heating (kWh)	10075,60
Zone Sensible Cooling (kWh)	-61557,40
Mech Vent + Nat Vent + Infiltration (ac/h)	0,20

Energy use for heating and cooling:
71.633 kWh/year

6. WINDCATCHER

The windcatcher is not modelled in DesignBuilder so an estimation is made for the energy reduction. The windcatcher will not have evaporative cooling to save on the water, so it will just get the higher air which is cooler. The effect of the windcatcher will probably be a bit less than the courtyard where some evaporation can take place because of the plants.

7. GROUND DUCTS FOR COOLING

Another method mentioned is the ground ducts which can be used for cooling. However, some calculations should be done to see if this is achievable. The building has three different facilities, namely:

Reception: 400 m^2
35 people

Kitchen: 100 m^2
10 people

Restaurant: 250 m^2
60 people

A duct at a depth of 3 meter with a ground temperature of 25 °C. (Climate Consultant, 2018) An outside temperature of 35 °C and an expected indoor temperature of 25°C. The three different facilities house another amount of people, so for every part a calculation will be made. A fresh air supply is needed of 25 m^3/h per person.

Diameter of the duct		
Reception	Kitchen	Restaurant
875 m^3/h	250 m^3/h	1500 m^3/h
$r = \sqrt{\frac{875\ /\ 3600}{2\pi}} = 0{,}19\ m$	$r = \sqrt{\frac{250\ /\ 3600}{2\pi}} = 0{,}11\ m$	$r = \sqrt{\frac{1500\ /\ 3600}{2\pi}} = 0{,}26\ m$

Length of the ducts

$$x = -\ln\left(\frac{Tin - Tsoil}{Tout - Tsoil}\right) * \frac{R^* * (v * r * pc)}{2}$$

Where:

Tin: 26 °C
Tout: 35 °C
Tsoil: 25 °C
R:* 0.1 m^2K/W
v: 2 m/s
r: Given above in m
pc: 1200

Reception 0,19 m

$$x = -\ln\left(\frac{26-25}{35-25}\right) * \frac{0{,}1 * (2 * 0{,}62 * 1200)}{2} = 171\ m$$

Kitchen 0,11 m

$$x = -\ln\left(\frac{26-25}{35-25}\right) * \frac{0{,}1 * (2 * 0{,}33 * 1200)}{2} = 91\ m$$

Restaurant 0,26 m

$$x = -\ln\left(\frac{26-25}{35-25}\right) * \frac{0{,}1 * (2 * 0{,}81 * 1200)}{2} = 224\ m$$

	Reception	Kitchen	Restaurant
Diameter	0,4 m	0,2 m	0,5 m
Length	171 m	91 m	224 m

However, the diameter of the ducts of the reception and the restaurant are too big to cool all air inside the duct with the ground temperature. Also, the length of the ducts is very long. Therefore, smaller, and more ducts will be used with a radius of 0,1 m.

Diameter of the duct		
Reception	Kitchen	Restaurant
875 m^3/h	250 m^3/h	1500 m^3/h
r = 0,1	r = 0,1	r = 0,1
$x = 2 * 3600 * \pi * 0{,}1^2 = 226\ m^3/h$ So the air supply is 226 m3/h in a duct with a radius of 0,1 m		
875 / 226 = 3,9	250 / 226 = 1,1	1500 / 226 = 6,6
4 ducts are needed	1 duct is needed	7 ducts are needed

With a length of:

$$x = -\ln\left(\frac{26-25}{35-25}\right) * \frac{0{,}1 * (2 * 0{,}1 * 1200)}{2} = 27\ m$$

In summer the ducts can provide an indoor air temperature of 26 °C with an outdoor temperature of 35 °C. In winter the ground temperature is around 10 °C, while the air temperature is also around 10 °C. Therefore during winter the ducts will not work for heating.

Figure 1 shows the ground ducts needed for the entrance building. The restaurant needs most ducts, the space between the ducts is 1 meter.

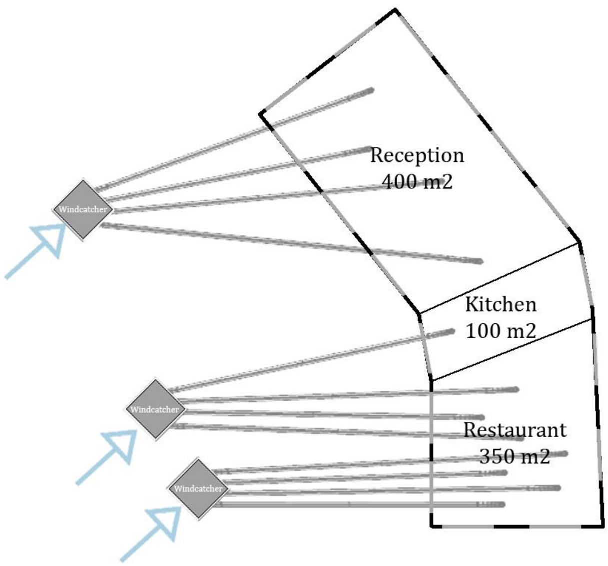
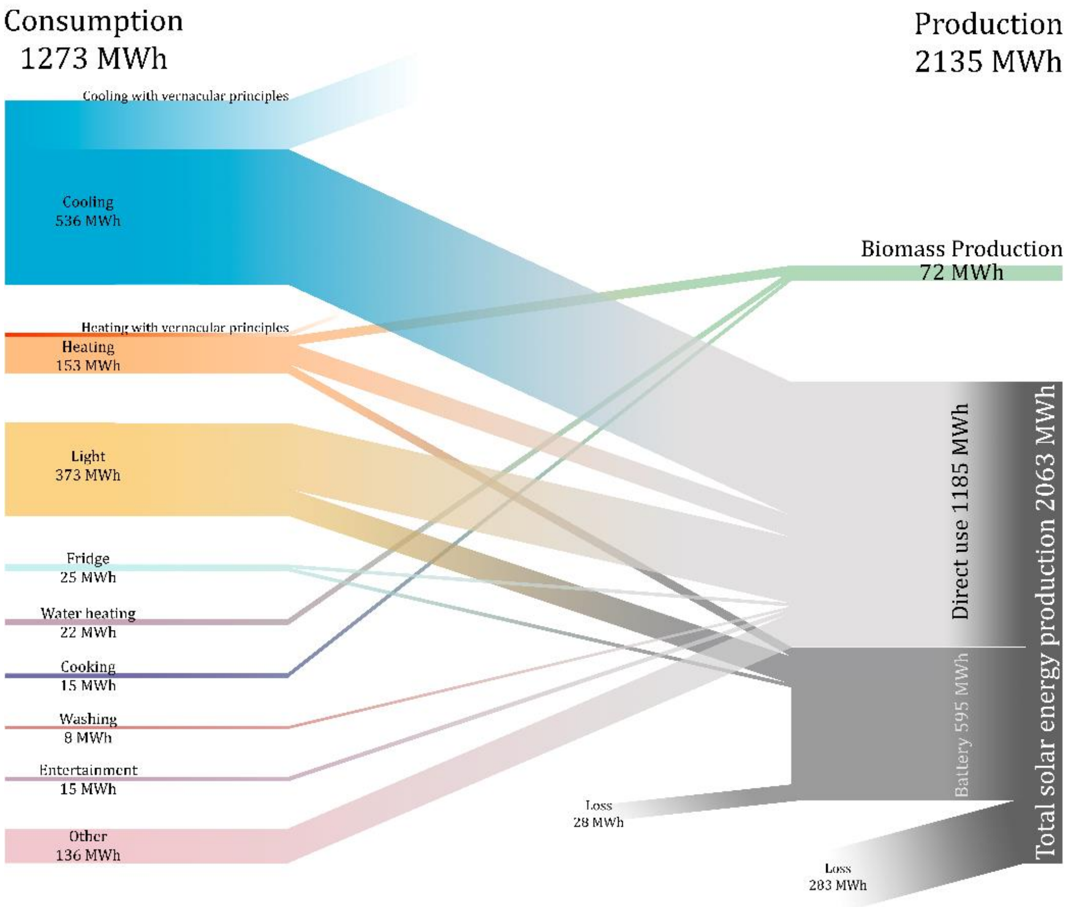


Figure 1: Ground ducts for entrance building

The extended overview of the PVSyst outcome for the final energy balance.



In this part an overview of the PVSyst can be found where the new energy demand of the park is calculated. A part of the heating and cooling load is done by vernacular architecture principles, which reduces the energy demand of the park.

It is found that 2600 solar panels are needed and a battery storage of 84 m^3. The energy price will be 0,34 euro/kWh.

	kWh/year	Wh/year	Wh/day
Cooling	551.200	551.200.000	1.510.137
Heating	121.500	121.500.000	332.877
Light	372.385	372.385.000	1.020.233
Fridge	24.955	24.955.000	68.370
Water heating	21.390	21.390.000	58.603
Cooking	14.260	14.260.000	39.068
Washing	7.130	7.130.000	19.534
Entertainment	14.260	14.260.000	39.068
Other	136.320	136.320.000	373.479
Total	1.263.400	1.263.400.000	3.461.370

Stand alone system: Simulation parameters

Project : Park

Geographical Site	Āteshkadeh		Country	**Iran**
Situation	Latitude	28.92° N	Longitude	52.57° E
Time defined as	Legal Time	Time zone UT+3.5	Altitude	1657 m
	Albedo	0.20		
Meteo data:	**Āteshkadeh**	Meteonorm 7.2 (1998-2002), Sat=100% - Synthetic		

Simulation variant : **Simulation oud zonnepanelen**

Simulation date 25/06/19 10h46

Simulation parameters	System type	**Stand alone system with batteries**		
Collector Plane Orientation	Tilt	28°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
User's needs :	Daily household consumers	Constant over the year		
	average	3365 kWh/Day		

PV Array Characteristics

PV module Si-mono	Model	**AXN6M610T285**		
Original PVsyst database	Manufacturer	Auxin Solar		
Number of PV modules	In series	10 modules	In parallel	260 strings
Total number of PV modules	Nb. modules	2600	Unit Nom. Power	285 Wp
Array global power	Nominal (STC)	**741 kWp**	At operating cond.	699 kWp (40°C)
Array operating characteristics (50°C)	U mpp	301 V	I mpp	2320 A
Total area	Module area	**4230 m²**	Cell area	3703 m²

System Parameter	System type	**Stand alone system**		
Battery	Model	**Powerwall2**		
	Manufacturer	Tesla		
Battery Pack Characteristics	Nb. of units	2 in series x 300 in parallel		
	Voltage	101 V	Nominal Capacity	80400 Ah
	Discharging min. SOC	10.0 %	Stored energy	7357.4 kWh
	Temperature	External ambient temperature		
Controller	Model	Universal controller with MPPT converter		
	Technology	MPPT converter	Temp coeff.	-5.0 mV/°C/elem.
Converter	Maxi and EURO efficiencies	97.0 / 95.0 %		
Battery Management control	Threshold commands as	SOC calculation		
	Charging	SOC = 0.96 / 0.80		
	Discharging	SOC = 0.10 / 0.35		

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	2.1 mOhm	Loss Fraction	1.5 % at STC
Serie Diode Loss	Voltage Drop	0.7 V	Loss Fraction	0.2 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

Stand alone system: Main results

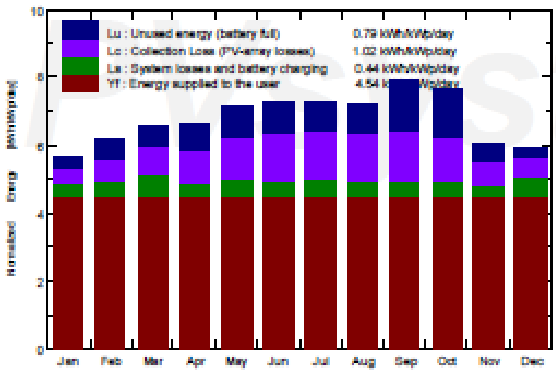
Project : Park

Simulation variant : **Simulation oud zonnepanelen**

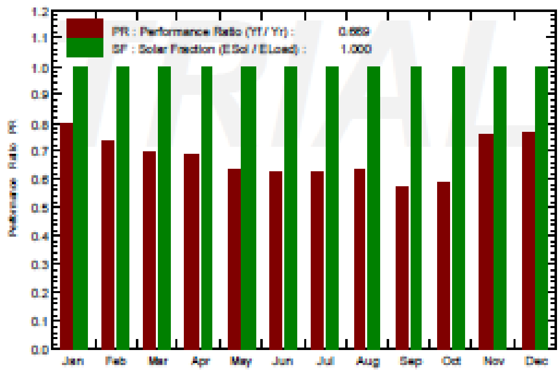
Main system parameters	System type	**Stand alone system with batteries**		
PV Field Orientation	tilt	28°	azimuth	0°
PV modules	Model	AXN6M610T285	Pnom	285 Wp
PV Array	Nb. of modules	2600	Pnom total	**741 kWp**
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA
Battery Pack	Nb. of units	600	Voltage / Capacity	**101 V / 80400 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1228 MWh/year

Main simulation results				
System Production	**Available Energy**	**1476 MWh/year**	Specific prod.	1992 kWh/kWp/year
	Used Energy	1228 MWh/year	Excess (unused)	212 MWh/year
	Performance Ratio PR	66.88 %	Solar Fraction SF	100.00 %
Loss of Load	Time Fraction	0.0 %	Missing Energy	0 MWh/year
Battery ageing (State of Wear)	Cycles SOW	90.5%	Static SOW	76.9%
	Battery lifetime	4.3 years		

Normalized productions (per installed kWp): Nominal power 741 kWp



Performance Ratio PR and Solar Fraction SF



Simulation oud zonnepanelen

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail MWh	EUnused MWh	E_Miss MWh	E_User MWh	E_Load MWh	SolFrac
January	119.8	171.8	113.0	7.62	0.000	104.3	104.3	1.000
February	131.7	169.3	108.7	12.34	0.000	94.2	94.2	1.000
March	175.6	197.6	124.3	12.99	0.000	104.3	104.3	1.000
April	195.1	192.7	119.3	16.43	0.000	100.9	100.9	1.000
May	238.7	214.7	128.7	20.71	0.000	104.3	104.3	1.000
June	243.9	211.0	124.6	21.06	0.000	100.9	100.9	1.000
July	247.3	217.7	126.9	18.66	0.000	104.3	104.3	1.000
August	225.8	216.0	126.1	18.74	0.000	104.3	104.3	1.000
September	212.4	230.9	136.0	32.54	0.000	100.9	100.9	1.000
October	186.3	233.1	140.3	32.78	0.000	104.3	104.3	1.000
November	127.5	177.0	111.6	11.27	0.000	100.9	100.9	1.000
December	119.7	180.3	116.7	7.27	0.000	104.3	104.3	1.000
Year	2223.8	2412.1	1476.2	212.41	0.000	1228.1	1228.1	1.000

Legends:				
	GlobHor	Horizontal global irradiation	E_Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E_User	Energy supplied to the user
	E_Avail	Available Solar Energy	E_Load	Energy need of the user (Load)
	EUnused	Unused energy (battery full)	SolFrac	Solar fraction (EUsed / ELoad)

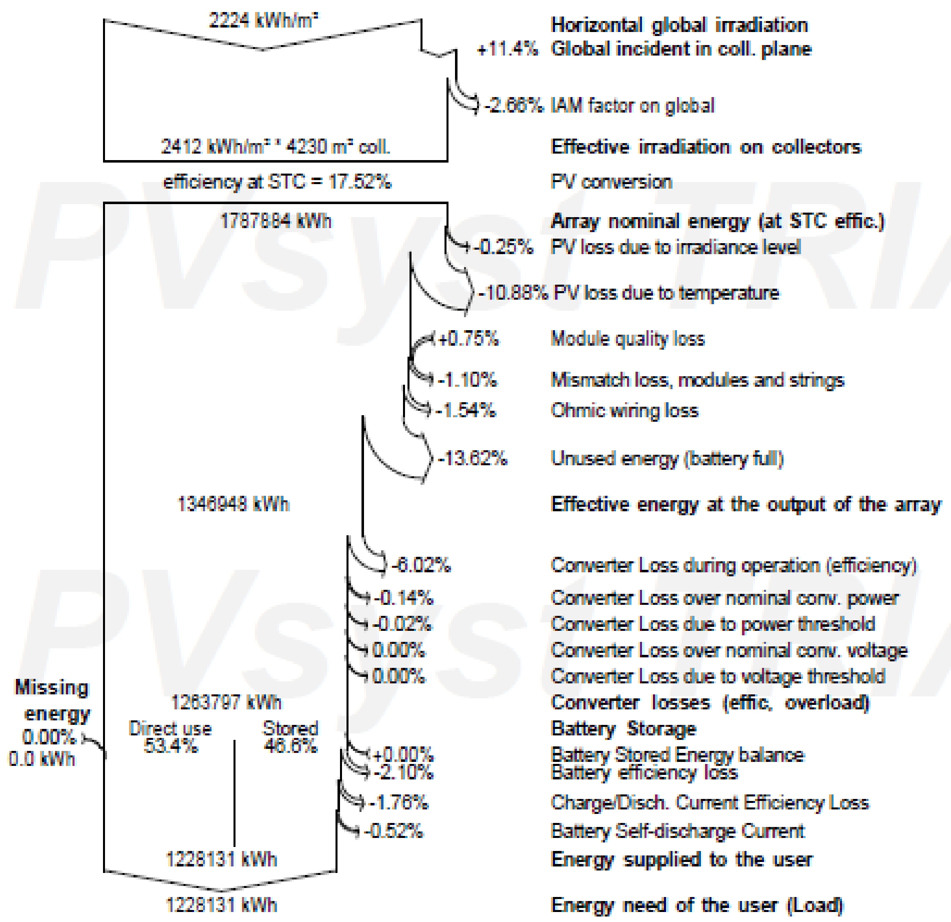
Stand alone system: Loss diagram

Project : Park

Simulation variant : **Simulation oud zonnepanelen**

Main system parameters	System type	**Stand alone system with batteries**			
PV Field Orientation	tilt	28°	azimuth	0°
PV modules	Model	AXN6M610T285	Pnom	285 Wp
PV Array	Nb. of modules	2600	Pnom total	**741 kWp**
Battery	Model	Powerwall2	Technology	Lithium-ion, NCA
Battery Pack	Nb. of units	600	Voltage / Capacity	**101 V / 80400 Ah**
User's needs	Daily household consumers	Constant over the year	Global	1228 MWh/year

Loss diagram over the whole year

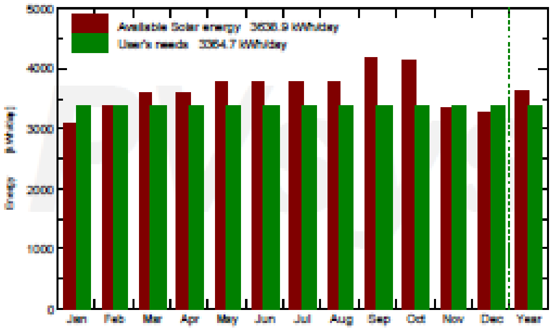


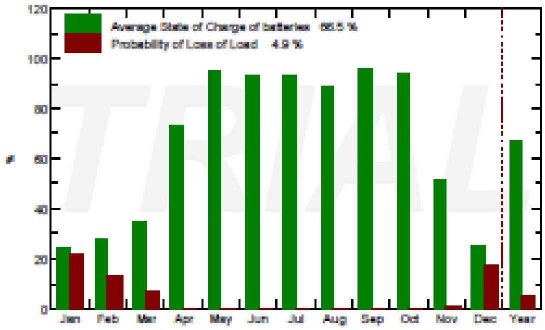
Stand-alone system presizing

Geographical Site		**Āteshkadeh**		Country	**Iran**
Situation	Latitude	28.92° N		Longitude	52.57° E
Time defined as	Legal Time	Time zone UT+3.5		Altitude	1657 m
Collector Plane Orientation	Tilt	29°		Azimuth	0°

System pre-sizing evaluation

Average use of energy	Daily	3365 kWh/day	Yearly	1228.1	MWh
Autonomy		2.0 days			
Loss-of-Load	Time fraction	4.9 %	Missing energy	29874	kWh
Battery system	Voltage	48 V	Capacity	*4938	Ah
PV array	Nominal power	665 kWp	Nominal Current	10653	A
Economic gross evaluation	Investment	2175378 EUR	Energy price	0.34	EUR/kWh





	Incid. kWh/m².day	PV avail. kWh	Demand kWh	Excess kWh	Missing kWh	SOC %	Pr. LOL %	Fuel liter
Jan.	5.8	96064.	104307	0.0	12301.	25	21.6	8200.9
Feb.	6.3	94323.	94212.	0.0	5454.5	28	12.8	3636.4
Mar.	6.7	110515	104307	0.0	3678.5	35	7.0	2452.4
Apr.	6.7	107145	100942	0.0	0.0	73	0.0	0.0
May	7.1	117359	104307	7105.9	0.0	95	0.0	0.0
June	7.1	113422	100942	8540.8	0.0	93	0.0	0.0
July	7.1	117498	104307	9905.9	0.0	93	0.0	0.0
Aug.	7.1	117297	104307	7620.9	0.0	89	0.0	0.0
Sep.	7.9	125599	100942	19781.	0.0	96	0.0	0.0
Oct.	7.8	127802	104307	18279.	0.0	94	0.0	0.0
Nov.	6.3	99862.	100942	259.5	391.0	51	1.0	260.7
Dec.	6.1	101319	104307	0.0	8048.1	26	16.9	5365.4
Year	6.8	*28213	*28131	71493.	29873.	66	4.9	19915.