POLTECNICO DI TORINO
MASTER DEGREE COURSE IN ARCHITECTURE CONSTRUCTION CITY

Thesis

# NEARLY ZERO ENERGY BUILDING
# IN ALKHOBAR, SAUDI ARABIA
## A Residential Building


Realtore : Prof.ssa Valentina Serra
Politecnico di Torino, Italy

Candidato : Fareal Aiad

Correlatore: Prof.ssa Anna Laura Petrucci
Dar Al Uloom Univesity, AlRyadh
Saudi Arabia


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## Riassunto

Il concetto di edifici a energia quasi zero è ormai conosciuto in Italia e altrettanto in Europa. La necessità di costruire edifici energeticamente efficienti si è affermata in Europa già negli ultimi decenni del secolo scorso, in conseguenza della crisi energetica degli anni ‘70. È proprio in quel periodo che si è definito il concetto di sviluppo sostenibile e diffusa la sensibilità al tema del risparmio energetico.
Dagli anni Settanta ad oggi sono state compiute molte ricerche che hanno reso dell’idea una vera e propria realtà . Sono state emanate normative finché si è arrivati ad ultime definizioni sul tema, con l’obbligo di costruire, dal 2020, solo edifici a energia quasi zero.

L’obiettivo di questo studio invece sarebbe dimostrare la fattibilità di questa tipologia di edifici a energia quasi zero in un ambiente e clima totalmente diverso rispetto a quello europeo ormai largamente testato.

In vista delle nuove future piani dei stati arabi del golfo “GCC” ( Il Consiglio di cooperazione del Golfo) nel medio oriente i quali prevedono città più sostenibili, l’Arabia Saudita è stata scelta come un paese su cui compiere questo studio. Infatti sarebbe lo stato che registra il consumo energetico più alto tra tutti gli stati del “GCC”. In particolare è stata scelta la città del Al Khobar in quanto è in forte crescita edilizia e si affaccia sul Golfo Persico ,per cui presenta un clima caldo-umido caratterizzante in gran parte l’area circostante.

È stata scelta la tipologia edilizia residenziale in quanto è il settore che registra quasi il 52% del consumo energetico del paese. Perciò era essenziale studiare la cultura dell’ abitare saudita in quanto presenta degli aspetti caratterizzanti dovuti alla forte influenza della religione islamica. Infatti il concetto di “Privacy” viene approfondito e osservato nella sua applicazione nella distribuzione spaziale della casa saudita, sia in quella tradizionale che in quella contemporanea.

La sfida composizionale presente nel progetto residenziale è stata quella di realizzare appartamenti che soddisfino le esigenze culturali della società saudita. Infatti, la tipologia multipiano presente sul territorio è in gran parte indirizzata agli stranieri e i singoli lavoratori. I cittadini tendenzialmente sceglievano la tipologia monofamiliare, fin quando ultimamente si è registrata la tendenza dei giovani sauditi a scegliere la tipologia appartamentale per ragioni economiche.

Il progetto prevede un complesso di cinque piani sviluppato su 1640 $m^2$ di 890 $m^2$ di costruito, rispettando le normative edilizie dello stato Saudita che prevede il limite di costruzione sul 60% dell'area ad Al Khobar. L'edificio è ad alte prestazioni energetiche infatti si è dato un forte interesse alla stratigrafia dell'involucro esterno andando a diminuire il più possibile l'U value e usufruendo delle capacità termiche dei materiali PCM (phase change material) che sfruttano il fenomeno della transizione di fase per assorbire i flussi energetici entranti, immagazzinando un'elevata quantità di energia e mantenendo costante la propria temperatura, e che in quel caso studio progettato in ambiente caratterizzato da un clima caldo sarebbe una buona soluzione.

Viene utilizzata anche in progetto il Mashrabyya ( balaustra in legno), un elemento tipico del luogo rivista in stile contemporaneo , per sfruttare le sue prestazioni igrotermiche in clima umido come Al Khobar e per dare un tocco arabo all'edificio. Per l'analisi delle prestazioni energetiche dell'edificio, viene utilizzato Wufi Plus Software, uno strumento di simulazione di calore e umidità nella famiglia di software WUFI. Simula l'ambiente interno ed è quindi adatto per calcolare il comfort e il consumo di energia negli edifici. Poiché le simulazioni sono basate sul clima specificato dall'utente e sulla ventilazione definita dall'utente, HVAC e carichi interni, le simulazioni possono rappresentare accuratamente la situazione. Considerando le strategie passive messe in atto nella progettazione dell'edificio, la richiesta energetica del progetto risulta più bassa del 52,3% ( 84,06 kWh/$m^2$y) rispetto all'esigenza energetica tipica di un edificio residenziale (176,5 kWh/$m^2$y - Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province)

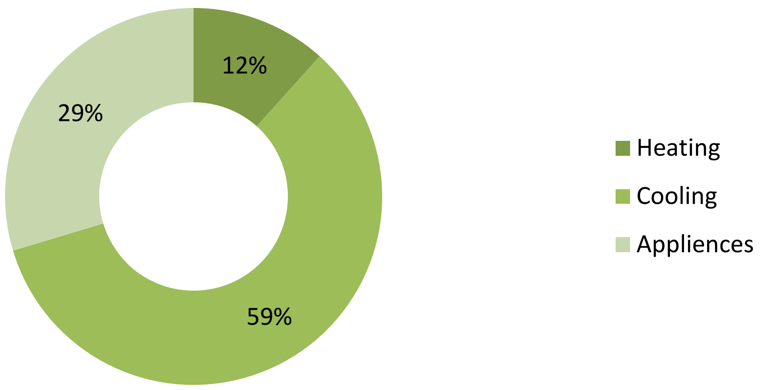
In seguito viene dimensionato l'impianto photovoltaico da installare sulla tettoia da 906 $m^2$ progettata sull'edificio. Vengono valutati due casi:

- Impianto a pannelli in posizione ottimale a 24° verso sud, considerando la distanza da lasciare tra gli array, andrebbe a coprire il 44% dell'esigenze energetiche.
- Impianto a pannelli posizionati in orizzontale a 0° andrebbero a coprire il 94% dell'esigenze energetiche .

Di conseguenza viene scelta l'integrazione dell'impianto fotovoltaico nella tettoia, pannelli fotovoltaici posizionati a 0°, come soluzione progettuale efficiente.

| | | | | |
|---|---|---|---|---|
| Heating | 39.763,70 | kWh /y | 9,81 | kWh/m$^2$y |
| Cooling | 200.055,40 | kWh /y | 49,34 | kWh/m$^2$y |
| Appliences | 100.998,00 | kWh /y | 24,91 | kWh/m$^2$y |
| Total Energy Need | 340.817,10 | kWh /y | 84,06 | kWh/m$^2$y |

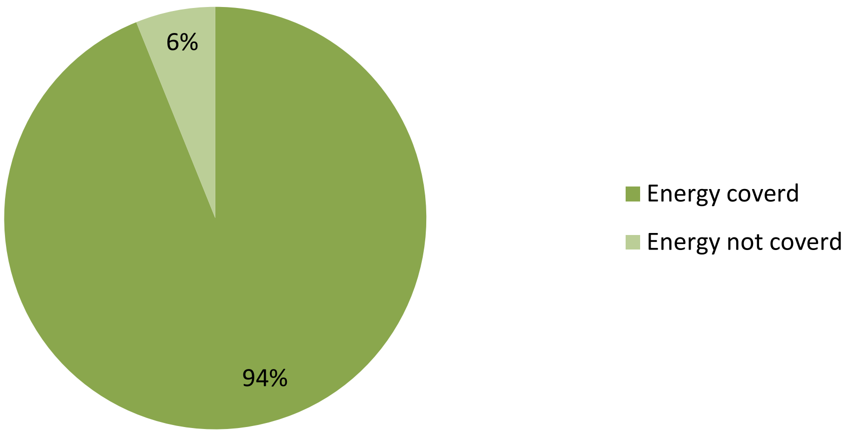
## nZEB Al Khobar Energy Needs




| | | |
|---|---|---|
| PV panel Ey 0° | 604 | kWh /m$^2$y |
| | | |
| Canopy Area | 906 | m$^2$ |
| Panel Area | 1,71 | m$^2$ |
| Total N°panels | 530 | |

| | | | |
|---|---|---|---|
| Energy need | 340.817,10 | kWh/y | 100% |
| Energy coverd | 320.014,04 | kWh/y | 94% |
| Energy not coverd | 20.803,06 | kWh/y | 6% |

## nZEB Al Khobar Energy Production



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nZEB : nearly ZERO ENERGY BUILDING

KSA: Kingdom of Saudi Arabia

UAE : United Arab of Emirates

PV Panels : Photovoltaic Panels

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## Abstract

According to the “BP Statistical Review of World Energy 2017”, Saudi Arabia was the world’s 10th largest consumer of total primary energy in 2016. It can provide itself completely with self- produced energy and the main source of energy production are the Fossil Fuels. The total consumption of electric energy per year is an average of 8,889 kWh per capita, and the energy needs are going to grow faster in future because the fast population growth, the high economic growth and the low energy prices. The buildings residential, governmental and commercial in KSA consume 80% of the electricity generated in the country, while AC represents more than 70% of this consumption, followed by lighting and appliances. This study aims to demonstrate the feasibility of a nearly Zero Energy multi-layer residential building in AlKhobar, a main city in the Eastern Province on the coast of the Persian Gulf, characterized by a hot and humid climate.

This study will analyse the current energy situation of the country and specifically of the city in case.

Afterwards, in view of a residential project, it will be necessary to get closer and learn more about the culture of local living. In this sense, the Saudi home will be analyzed and the concept of privacy, which largely infuences the aspects of Saudi living and housing, will be studied in depth: It is a society that tends to choose to live in types of single family houses, but lately, for economic reasons, young people are looking for apartments that conciliate their cultural needs with economic ones. In fact, an annual rent of a single-family villa is as expensive as buying an apartment. One of the challenges, that will be faced in this project, is to adapt a multi-layer residential building to the users’ needs so that it can become their choice. In this case, the main features to satisfy would be: privacy, spaciousness and typical internal distribution.

Furthermore, the research will present how much the Saudi Arabia has rich potential for solar energy due to its position and will proved the PV panel high power potential in Al Khobar city . The nZEB project, will adopt some technological material choices and passive strategies, considering as much as possible the materials present on the Saudi market, to improve the passive performance and the energy efficiency of the building. The passive strategies and choices are: using PCM (phase change material) , increasing the insulation thickness, Installing double glazing windows, reusing a traditional element “Mashrabyya “ (wooden baluster) taking advantage of its environmental functions, using solar protection devices, installing a canopy over the roof and scheduling the HVAC system according to the periods in need.

The model for an energy simulation will be developed within the WUFI PLUS software, which allows to simulate the progress, the efficiency of the materials and the energy demand for heating and cooling of the building within a year.
Having obtained the result of the simulation regarding the cooling and heating energy needs and adding the energy needs of household appliances, the photovoltaic system will be sized to be installed on the roof.
Having obtained the result of the simulation regarding the cooling and heating energy needs and adding the energy needs of household appliances, the photovoltaic system will be sized to be installed on the roof.

# Introduction

The Middle East region is facing a unique set of natural, operational, political, economic and social challenges in efforts to adopt sustainability. The rapid development and increasing population in these countries have led to an increased consumption of fossil fuels, water, and other non-renewable natural resources, impact on the environment. It has abundant sources of renewable energy resources, namely solar and wind that can be effectively used to build a sustainable environment. In fact a huge part of the Middle East lies within the Global Sun Belt, the area around the world that gets the most sunlight and the least rainfall. These climatic conditions can generate and supply terawatts of solar electricity, offering a global source of renewable energy.

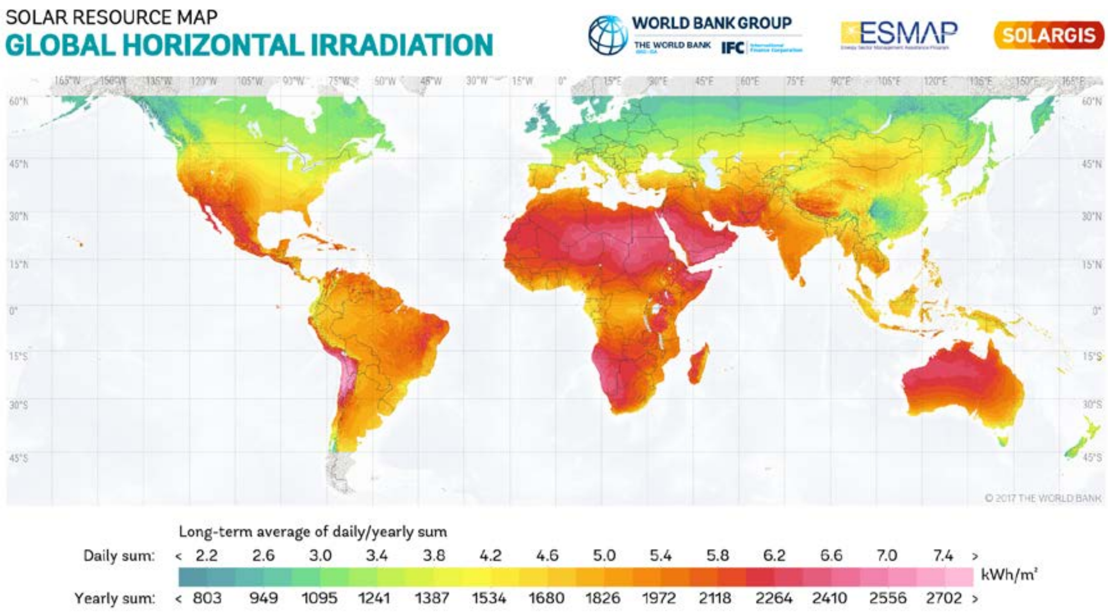



Figure 1 - Global solar irradiation map that shows the global sun belt on the middle east area.
Source : www.solargis.com

Though the Middle East countries have significantly contributed to the carbon emissions, over the past decade they have taken positive steps towards addressing the core environmental issues and improving sustainability situation in their respective countries.

The UAE, Saudi Arabia, Kuwait, and Qatar are investing in a number of renewable energy schemes and aiming to achieve 30, 15, and 20 percent of their power generation respectively from renewable energy sources by 2030.

The increased investments by the Middle East countries in sustainable develop-

The increased investments by the Middle East countries in sustainable development projects such as the introduction of the Green Building Regulation and the use of renewable energy and recycling strategies will help preserve the natural resources and reduce the carbon footprint, fostering sustainability in this region.

## 0.1 Green Building Councils

Green Building Councils are independent, non-profit organisations made up of businesses and organisations working in the building and construction industry. As members of World GBC, they work to advance green building in their own countries, as well as uniting with other Green Building Councils to achieve environmental, economic and social goals on a larger, global scale.

Chapter 1

# GCC STATES and SUSTAINABILITY

The GCC states that adhere to the green building council are Qatar (2009), UAE (2006), Kuwait (2009).
Countries like Qatar and UAE have come up with their own green building rating system to incorporate socio-economic, environmental and cultural aspects in modern architecture.

## 1.1 2030 GCC VISION

The GCC ( Gulf cooperation council) region has long been known for a profusion of oil, making its countries economically wealthy. However, it has also made the economy reliant on a single source. In 2014, the oil market saw an unexpected plummet that has given many nations a reason to diversify income. From here, Vision 2030 emerges to expand nations' economy through various industries.
An essential part of these visions is to focus on human wealth, as it is an investment that guarantees high returns for the entire nation. Education and fair opportunities will not only aid the GCC countries but will also give rise to a future generation of ambitious individuals.
Bahrain, KSA, and the UAE ( 2021 Vision) have come to realize that tourism has been a massive contributor to the local economy. Future trends suggest that the industry will continue rising in the years to come. Therefore, there is a move towards adding new projects and improving on current ones. A growth in tourism will also release the countries from an oil-dominated economy to a booming and diverse one.

### 1.2 UAE (United Arab Emirates)

For instance, the government of the United Arab Emirates has recently announced its objective of building a sustainable nation and making sustainability one of the core themes of the EXPO 2020. Similarly, Estidama ('sustainability' in Arabic) is the first organic sustainability framework in the Middle East that imposes green building code under the pearl rating system.
The Presidency of Meteorology and Environment (PME), Saudi Arabia too announced a decree asking all the organizations to meet the air, water, and noise pollution standards approved by the nation's Council of Ministers.

### 1.2.1 Pearl Rating System (UAE)

The Pearl Rating System (PRS) is the green building rating system for the emirate of Abu Dhabi designed to support sustainable development from design to construction to operational accountability of communities, buildings and villas. It provides guidance and requirements to rate potential performance of a project with respect to Estidama (sustainability). First launched in 2010. There are three rating systems:

- Pearl community rating system
- Pearl building rating system
- Pearl villa rating system

592 buildings and 10 719 villas has been rated. Only one building has achieved a five Pearle Rating.
The Pearl Rating System has various levels of certification. Ranging from one to five pearls. A minimum certification of one pearl is required for all new development projects within Abu Dhabi. The Pearl Rating System is organized into seven categories where there are both mandatory and optional credits. To achieve a 1 Pearl rating, all the mandatory credit requirements must be met.

### 1.2.2 Masdar City (Abu Dhabi, UAE)

The Masdar City in Abu Dhabi is expected to be the world's most sustainable eco-city. Designed by the British architectural firm " Foster and Partners". The city relies on solar and other renewable energy.
This city is expected to show how other cities how can adapt rapid urbanization through the efficient utilization of energy, water, and waste. The water and energy demand of the city's building is 40 percent lower than that of the average building in Abu Dhabi. It aims to be a commercially viable city offering the highest quality of life, including employment generating land uses, residential areas, parks, plazas and neibourhood amenities. It attract clean tech companies of all sizes as types test, commercialise and deploy energy technologies.
The Masdar city master plan offers multiple clean tech mobilities options such as the personal rapid transit : an internal electronic driverless mode of movement. While two major networks are planned to pass through the Masdar City : the Metro and the Light Rail Transit.
Ongoing growth will eventually se 52 000 people living, whilst 40 000 jobs and student placement will be offered.
Masdar City has made commitments under the Estidama building rating system, targetin a minimum rating of 3- Pearls for all buildings and 4- pearls for its public areas.


Figure 2 - Location of The Masdar City in UAE.

Figure 3 – Rendering of The Masdar city by Foster and Partners.

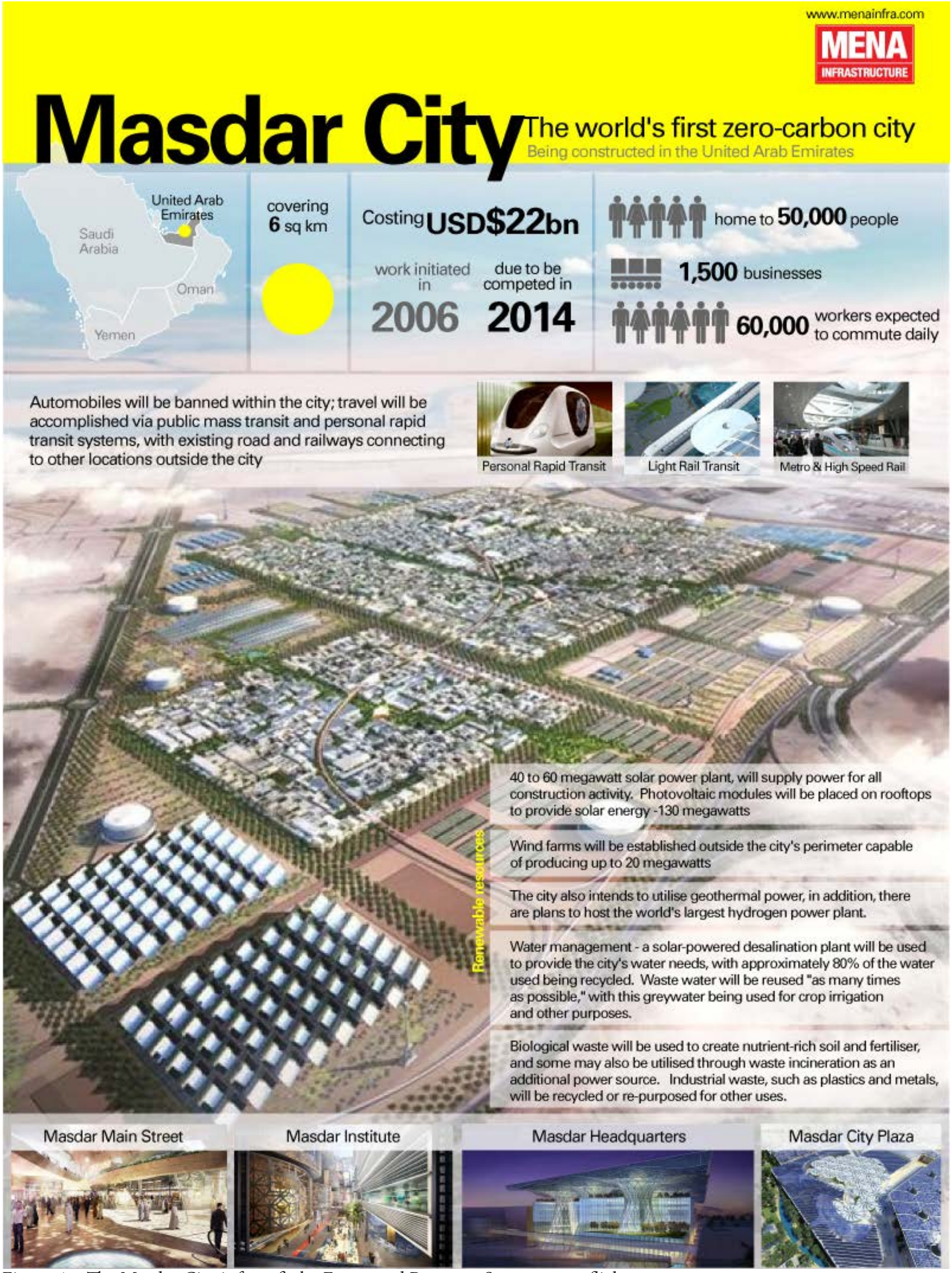



Figure 4 - The Masdar City infografic by Foster and Partners. Sourse: www.flicker.com

## 1.3 Qatar

Qatar has launched in October 2008 the " Qatar National Vision 2030" with the aim to transform Qatar into advance society capable of achieving sustainable development. The plan's development goals are divide into four central pillars: economic, social, human and environmental.
For environmental development provides the adoption of new technologies that reduce the energy consumption and conducting environmental awareness campaigns to promote a more sustainable attitudes.

### 1.3.1 Solar Energy in Qatar

There is great scope for small, medium as well as large scale solar power projects in Qatar. The Global horizontal irradiance is 2140 kWh/ $m^2$ per year which makes it well suited for solar photovoltaic systems. In addition to solar PV , it has good potentials for concentrated solar power CSP as it has a direct normal irradiance value around 2 008 kWh/ $m^2$y. CSP can provide stable energy supply for continuous operation of desalination plants, based on thermal or membrane processes, in Qatar. Leading CSP technology companies are talking a keen interest in Qatar solar market and rapid developments are expected future years.
Kahrama, the state electricity and water utility, is spearheading efforts to transform Qatar into a regional solar hub. Kahramaa's first solar power facility, setuped in Duhail over 100,000 $m^2$ area. In operation from 2016 generating capacity of 15MW and has a target to generate capacity of 200MW soler power at 60 sites across the country by 2020. To make up for Qatar space, the company planes to install solar panels on roofs.

### 1.3.2 Global Sustainability Assessment System (Qatar)

The Global Sustainability Assessment System (GSAS), formerly known as the Qatar Sustainability Assessment System (QSAS), was developed in 2010 by Gulf Organization for Research and Development (GORD) in collaboration with T.C. Chan Center at the University of Pennsylvania. GSAS aims at creating a sustainable urban environment to reduce environmental impacts of buildings while satisfying local community needs.

In addition to addressing regional aspects of sustainability, GSAS/QSAS also developed a standalone building energy standard to support Qatar's building energy ratings. Qatar has incorporated QSAS into Qatar Construction Standards 2010 and it is now mandatory for all private and public sector projects to get GSAS certification.

Chapter 2

# SAUDI ARABIA

Officially the Kingdom of Saudi Arabia is a country in Western Asia constituting the bulk of the Arabian Peninsula. With a land area of approximately 2,150,000 km$^2$. Polulation: 32 938 000.
It is the largest state in the Middle East, bordered by Jordan and Iraq to the north, Kuwait to the northeast, Qatar, Bahrain, and the United Arab Emirates to the east, Oman to the southeast and Yemen to the south. It is separated from Israel and Egypt by the Gulf of Aqaba. It is the only nation with both a Red Sea coast and a Persian Gulf coast, and most of its terrain consists of arid desert, lowland and mountains. Saudi Arabia is the largest by size, population and economy in the Middle East as of October 2018 and the 18th largest in the world. Petroleum was discovered on 3 March 1938 and followed up by several other finds in the Eastern Province. Saudi Arabia has since become the world's second largest oil producer behind the U.S. and exporter, controlling the world's second largest oil reserves and the sixth largest gas reserves. The kingdom is categorized as a World Bank high-income economy with a high Human Development Index and is the only Arab country to be part of the G-20 major economies.

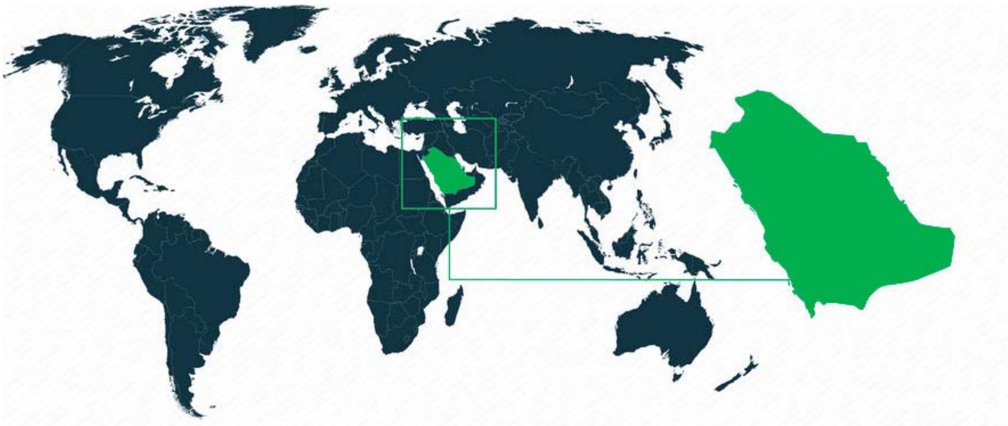


Figure 5- Saudi arabia position on world mapOKsource:www.vectorstock.com

## 2.1 The primary Energy in Saudi Arabia

According to the BP Statistical Review of World Energy 2017, Saudi Arabia was the world's 10th largest consumer of total primary energy in 2016 at 266.5 million tons of oil equivalent, of which about 63% was crude oil and petroleum liquids-based. Natural gas accounted for nearly all of the remaining 37% of consumption. Domestic consumption growth has been spurred by the economic expansion in the wake of historically high oil-related revenues that persisted until mid-2014. Further, large fuel subsidies, which reportedly cost the Saudi government an estimated $61 billion in 2015, have led to demand growth of about 7% per year between 2006 and 2016. Despite crude oil revenues falling from historic highs in 2014, Saudi Arabia's energy consumption has grown steadily mainly as a result of the subsidies.

Saudi Arabia is the largest consumer of petroleum in the Middle East, particularly in the area of transportation fuels and direct crude oil burn for power generation. Although transportation demand is substantial and growing, an increasing share of crude oil demand is attributable to direct crude oil burn for electric power generation, which can reach as high as 900,000 b/d during summer months. Crude oil and petroleum liquids reserves in the country remain plentiful, but Saudi Arabia is looking to diversify its mix of fuels for electric power generation, focusing on natural gas, nuclear, and renewable energy solutions.

Total Primary Energy Production, 2016

| Ranking | Country | Quadrillion Btu |
|---|---|---|
| 1 | China | 108.181 |
| 2 | United States | 84.262 |
| 3 | Russia | 59.156 |
| 4 | Saudi Arabia | 29.412 |
| 5 | Canada | 21.179 |
| 6 | Iran | 17.019 |
| 7 | India | 16.285 |
| 8 | Australia | 15.918 |
| 9 | Indonesia | 15.159 |
| 10 | Brazil | 11.626 |
| 11 | Qatar | 10.141 |
| 12 | United Arab Emirates | 9.977 |
| 13 | Norway | 9.642 |
| 14 | Iraq | 9.561 |

Figure 6- Total Primary Energy Production 2016. Source: U.S Energy information administration. www.eia.org

Total Primary Energy Consumption, 2016

| Ranking | Country | Quadrillion Btu |
|---|---|---|
| 1 | China | 136.244 |
| 2 | United States | 97.524 |
| 3 | Russia | 31.485 |
| 4 | India | 29.011 |
| 5 | Japan | 19.523 |
| 6 | Canada | 14.676 |
| 7 | Germany | 13.523 |
| 8 | Brazil | 12.617 |
| 9 | Korea, South | 12.287 |
| 10 | Iran | 11.25 |
| 11 | Saudi Arabia | 10.843 |
| 12 | France | 9.902 |
| 13 | United Kingdom | 8.085 |
| 14 | Mexico | 7.915 |
| 15 | Indonesia | 7.198 |
| 16 | Italy | 6.576 |
| 17 | South Africa | 6.033 |
| 18 | Australia | 5.917 |

Figura 7- Total Primary Energy Consumption 2016. Source: U.S Energy information administration. www.eia.org

Total Petroleum and Other Liquids Production, 2017

| Ranking | Country | Thousand Barrels Per Day |
|---|---|---|
| 1 | United States | 15647 |
| 2 | Saudi Arabia | 12090 |
| 3 | Russia | 11210 |
| 4 | Canada | 4958 |
| 5 | China | 4779 |
| 6 | Iran | 4695 |
| 7 | Iraq | 4455 |
| 8 | United Arab Emirates | 3721 |
| 9 | Brazil | 3363 |
| 10 | Kuwait | 2825 |
| 11 | Mexico | 2260 |
| 12 | Venezuela | 2077 |
| 13 | Nigeria | 2015 |
| 14 | Norway | 1979 |
| 15 | Qatar | 1974 |
| 16 | Kazakhstan | 1880 |
| 17 | Angola | 1707 |

Figure 8 – Total Petroleum and other liquids Production 2016. Source: U.S Energy information administration. www.eia.org

## 2.2 Electric Energy Consumption in Saudi Arabia

The total consumption of electric energy per year is 292,80 billion kWh. It's an average of 8,889 kWh per capita (www.worlddata.info). The KSA can provide itself completely with self- produced energy and the main source of energy production are the Fossil Fuels.

| Electricity | total | Saudi Arabia per capita | Compared to Europe per capita |
|---|---|---|---|
| Own consumption | 292.80 bn kWh | 8,889.37 kWh | 5,437.14 kWh |
| Production | 318.00 bn kWh | 9,654.44 kWh | 5,848.09 kWh |
| **Crude Oil** | **Barrel** | **Saudi Arabia per capita** | **Compared to Europe per capita** |
| Production | 10.46 m bbl | 0.318 bbl | 0.005 bbl |
| Export | 7.27 m bbl | 0.221 bbl | 0.004 bbl |
| **Natural Gas** | **Cubic meters** | **Saudi Arabia per capita** | **Compared to Europe per capita** |
| Own consumption | 102.30 bn m³ | 3,105.82 m³ | 822.75 m³ |
| Production | 102.30 bn m³ | 3,105.82 m³ | 444.60 m³ |

Figure 9 - https://www.worlddata.info/asia/saudi-arabia/energy-consumption.php

Carbon footprint

| | CO2 emissions in 2014 | Saudi Arabia per capita | Compared to Europe per capita |
|---|---|---|---|
| total | 601.05 m t | 18.25 t | 5.39 t |
| › of which diesel + gasoline | 413.23 m t | 12.55 t | 2.22 t |
| › of which natural gas | 159.26 m t | 4.84 t | 1.31 t |
| › other sources | 28.56 m t | 0.87 t | 1.86 t |

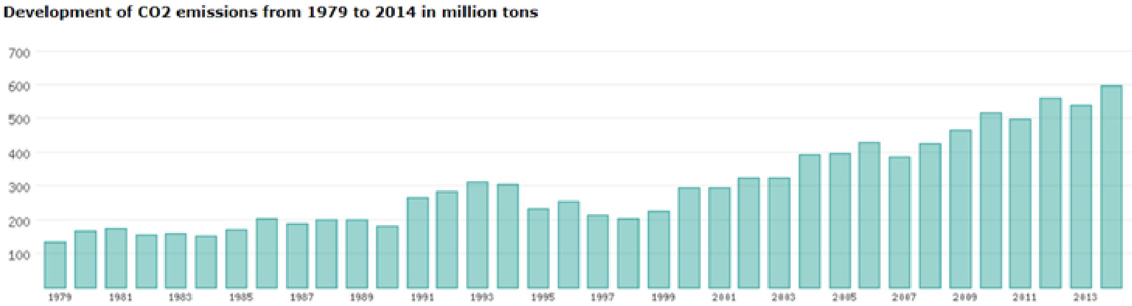



Figure 10 - https://www.worlddata.info/asia/saudi-arabia/energy-consumption.php

| Energy source | total in Saudi Arabia | percentage in Saudi Arabia | percentage in Europe | per capita in Saudi Arabia | per capita in Europe |
|---|---|---|---|---|---|
| Fossil fuels | 604.27 bn kWh | 99,9 % | 48,9 % | 18,345.66 kWh | 8,014.87 kWh |
| Nuclear power | 0.00 kWh | 0,0 % | 7,6 % | 0.00 kWh | 1,247.99 kWh |
| Water power | 0.00 kWh | 0,0 % | 24,1 % | 0.00 kWh | 3,946.70 kWh |
| Renewable energy | 604.88 m kWh | 0,1 % | 15,7 % | 18.36 kWh | 2,571.37 kWh |
| Other energy sources | 0.00 kWh | 0,0 % | 3,8 % | 0.00 kWh | 624.58 kWh |
| Total production capacity | 604.88 bn kWh | 100,0 % | 100,0 % | 18,364.02 kWh | 16,405.51 kWh |

Figure 11 - Energy source Saudi Arabia compared to Europe https://www.worlddata.info/asia/saudi-arabia/energy-consumption.php

## 2.3 Usage of renewable energies

In 2015, renewable energies accounted for around 0.0 percent of actual total consumption in country. The following chart shows the percentage share from 1990 to 2015:

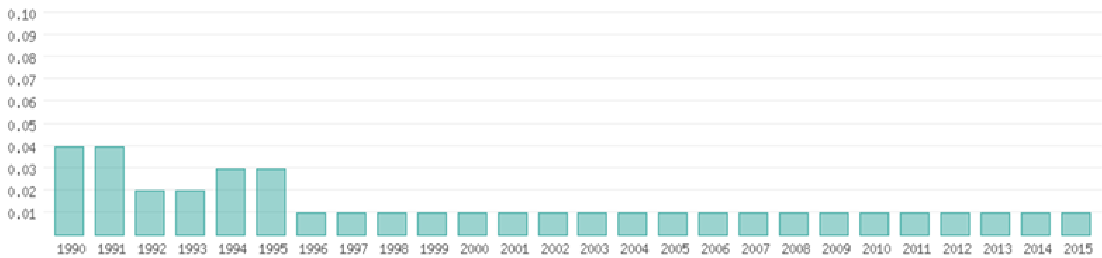



Figure 12 – Saudi Arabia Usage of renewable Energy percentage from 1990 to 2015 https://www.worlddata.info/asia/saudi-arabia/energy-consumption.php

## 2.4 Saudi Energy Efficiency Center

The Center was established by the Council of Ministers Resolution on 1st November 2010 to transfer the National Program for Energy Management and Conservation in King Abdul-Aziz City for Science and Technology to a permanent national center. It aims at rationalizing the production and consumption of energy in order to increase efficiency in the Kingdom and unifying efforts in this field, whether governmental or non-governmental, preserving the Saudi wealth of energy sources in a way that supports the national economy and forces.
The energy needs of the country are going to grow faster in future for different reasons:

- Fast population growth
- High economic growth
- Low energy prices

## 2.5 Energy consumption in the building sector

The building construction sector in KSA is the largest and fastest growing market in the GCC States. It is estimated that 2.32 million new homes are to be built by 2020 in order to meet the demand of growing population. According to the Ministry of Municipal and Rural Affairs (MoMRA) majority of the licenses issued for construction in the KSA were for residential buildings. The buildings residential, governmental and commercial in KSA consume 80% of the electricity generated in the Kingdom, while AC represents more than 70% of this consumption, followed by lighting and appliances. The annual report of Electricity & Cogeneration Regulatory Authority (2011) has mentioned that the energy consumption in the building sector reached more than half of the sold electricity (residential-51.2%, commercial sector-13.6% and governmental-13.4%).

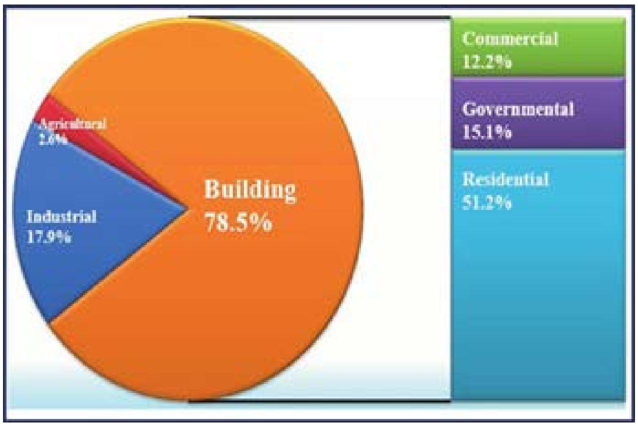



Figura 13 –Energy Consumption by Sector in Saudi Arabia
Source SEEC & K.A.CARE, 2013

According to the Ministry of Water and Electricity, the total electricity sold to the residential sector for the year 2011 was 109.261 GW h (i.e. approx. 50% of the total energy sold in KSA). A study conducted by SEEC revealed that lighting consumption rate in some commercial buildings exceeds 30% of the total consumed energy for the optimal lighting usage.

The Kingdom faces many challenges in the energy efficiency efforts in buildings. The SEEC mentions few of these challenges as follows:

- As high as 70% of residential buildings are not thermally insulated.
- Average electricity bill for 65% of consumers is less than 100 SAR (Saudi Arabian Riyal) per month, so there is no motive to rationalize consumption. Moreover, these low bills do not encourage investment in energy efficiency in buildings.
- The lack of awareness of energy efficiency leads buying low efficiency devices, in addition to restricted motives to replace low energy efficiency products by high efficiency ones.
- Weakness of supervision and product control standards, as there are no mechanisms to supervise products.
- Until few years ago there were not specifications, standards, or mechanisms to control insulation and lighting products.

### 2.5.1 Saudi government Measures

The rapid increase in energy consumption needs an immediate and serious strategy in order to reduce building consumption until sustainable sources for energy generation are found. The strategy take into consideration and focus on the residential sector since it represents the majority of energy consumed in the nation.

In view of the 2030 vision that expects a program towards more sustainable cities, the Saudi government has taken two important measures in the last years:

- A Gradual increase of the electricity tariffs to enhance for a more conscious consumption.
- Issued a building regulation: "SAUDI STANDARDS, METROLOGY AND QUALITY ORGANIZATION " has proceeded to publish in 2014 the first " Thermal Transmittance Values for Residential Buildings" standards. In fact creating more high-performance homes in Saudi Arabia will significantly reduce the increasing consumption of electricity and consequently of fossil fuel.

### 2.5.1.1 Electricity tariffs

From January 2018 the Saudi Arabia's Electricity and Cogeneration Regulatory Authority (ECRA) has announced new electricity tariffs as part of plans to gradually increase prices . Under the new electricity prices, consumption tariffs for residential, commercial, agricultural, healthcare, private education and charitable institutions were increased. Specifically, residential consumption of between 1 and 6,000 KW/h per month is costing 18 halalas ( cents ) per KW/h instead of 5 halalas for first 2000 kilowatt per hour (kWh) of electricity consumption per month , and rising to 30 halalas for consumption above 6,000 KW/h instead of 20 halalas.

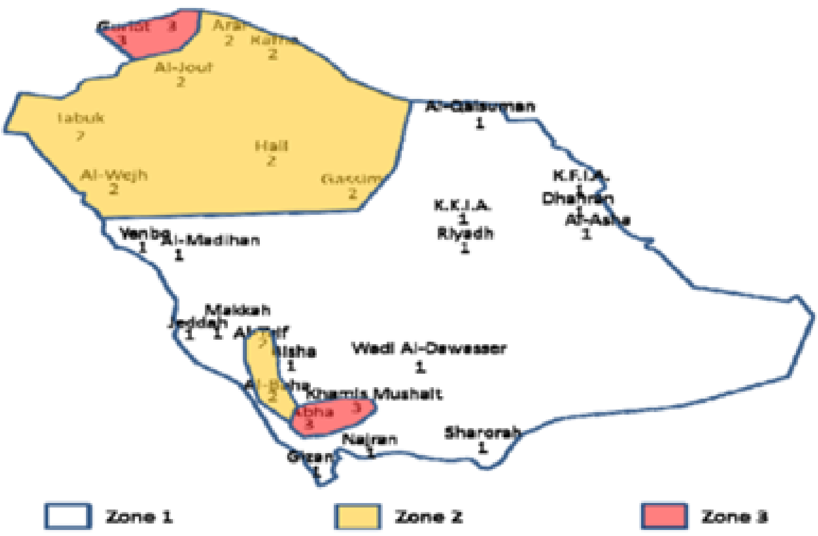
Creating more high-performance homes in Saudi Arabia will significantly reduce the risks associated with the increasing consumption of fossil fuel and the $CO_2$ emissions. This approach could be achieved through two major steps. First, creating buildings that are more efficient in order to minimize the energy consumed. Second, relying on sustainable sources of energy in order to cover the homes energy demand.

### 2.5.1.2 Saudi Arabia Standards

In the sustainable direction the "SAUDI STANDARDS, METROLOGY AND QUALITY ORGANIZATION " has proceeded to publish in 2014 the first

" Thermal Transmittance Values for Residential Buildings" standards.

The values listed in Table 1 are applicable to these buildings only until January 1, 2017. Beyond January 1, 2017, the values listed in Table 2 shall be applicable to all low rise / residential buildings.




## Table 1 – The thermal transmittance (U-Values) for low-rise / residential buildings

| Opaque Elements | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Roofs | 0.31 | 0.37 | 0.42 |
| Walls | 0.53 | 0.61 | 0.7 |
| Opaque Doors –All Assemblies | 2.84 | 2,84 | 2,84 |
| Vertical Glazing , 25% of wall | | | |
| All Assemblies | 2.67<br>SHGC - 0.25 | 2.67<br>SHGC - 0.25 | 2.67<br>SHGC - 0.25 |
| Skylight with Curb , Glass , % of Roof | | | |
| 0% -3% All Types | 4.26<br>SHGC- 0.35 | 4.26<br>SHGC- 0.35 | 4.26<br>SHGC- 0.35 |

## Table 2 – The thermal transmittance (U-Values) for government buildings

| Opaque Elements | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Roofs | 0.20 | 0.24 | 0.27 |
| Walls | 0.34 | 0.4 | 0.45 |
| Opaque Doors –All Assemblies | 2.84 | 2.84 | 2.84 |
| Vertical Glazing , 25% of wall | | | |
| All Assemblies | 2.67<br>SHGC- 0.25 | 2.67<br>SHGC- 0.25 | 2.67<br>SHGC- 0.25 |
| Skylight with Curb , Glass , % of Roof | | | |
| 0% -3% All Types | 4.26<br>SHGC- 0.35 | 4.26<br>SHGC- 0.35 | 4.26<br>SHGC- 0.35 |

Figura 14- Thermal Transmittance Values for Residential Buildings, SAUDI STANDARDS, METROLOGY AND QUALITY ORGANIZATION SASO, SAUDI STANDARD DRAFT No. 28793/2014 .

Source: https://www.saso.gov.sa/en/pages/default.aspx

Chapter 3

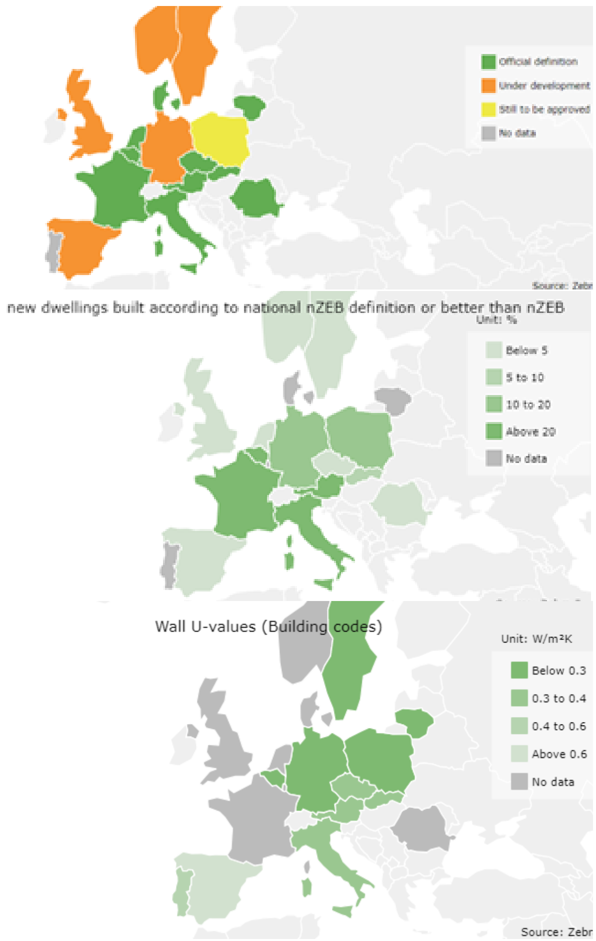
# The nearly ZERO ENERY BUILDING

## 3.1 Nearly Zero Energy Building definition

A nZEBs is defined as a building with a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby.
According to ZEBRA 2020 NEARLY ZERO-ENERGY BUILDING STRATEGY 2020 Strategies, for a nearly Zero-Energy Building market transition in the European Union, After 31/12/2020 all new buildings are nZEBs (after 31/12/2018 for public buildings). Therefore, The UE Member States shall draw up national plans for increasing the number of nZEBs and develop policies and measures to stimulate the transformation of buildings that are refurbished into nZEBs. Among others, the national plan would include:

- A detailed application in practice of the definition of nearly zero-energy buildings including a numerical indicator of primary energy use expressed in kWh/m$^2$ per year
- Intermediate targets for improving the energy performance of new buildings, by 2015
- Information on the policies and financial or other measures for the promotion of nZEBs.

According to CA EPBD report (2015), about 40% of the Member States (MSs) do not yet have a detailed definition of the nZEB in place. About 60% of the MSs have laid out their detailed nZEB definition in a legal document, but a few of them emphasise the draft status of the definition, or that the definition might be updated later on.



It is interesting to note the different values in different states shown in the bar chart in comparison with a passivehaus value.

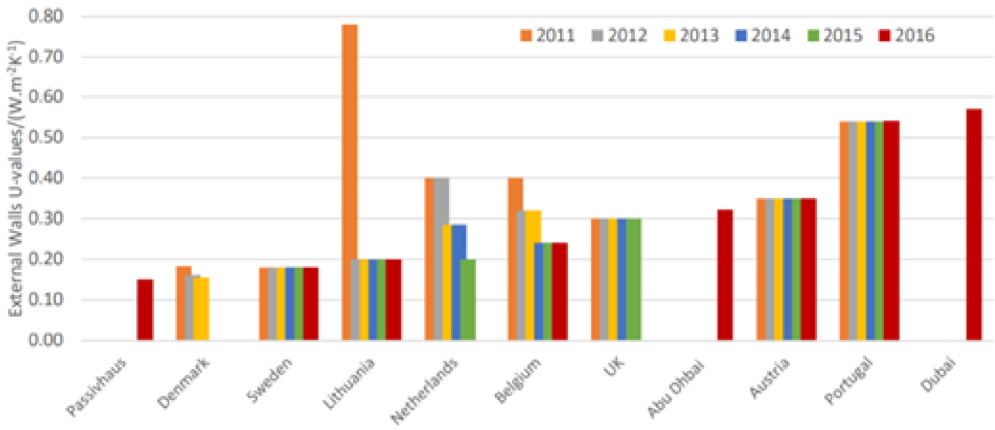



Figura 15- External wall U- Values of some European countries. The Abu Dhabi, Dubai and Passivhause external wall U-Value requirements are also shown. Suorce: Zebra

However, since the NZEB concept was initially developed for cold climates, it will not have the ability to be directly implemented in hot and arid climates, and studying its principles adapted to hot and arid climates would therefore be the ideal approach to achieving net-zero energy homes in Saudi Arabia.
There are three  following study case of NZEB residential buildings developed in the GCC area characterized by hot and arid a climate.

## 3.2 GCC nZEB Case Studies

The principle of effectiveness of a nZEB is actually based on an energy efficient building, which is a concept that has always existed in the middle east in general and of the GCC region in particular. As a matter of fact its principles have been used in the vernacular architecture from a long period of time. The design of vernacular houses was evolved in a response to socio-cultural and climatic conditions. In fact houses were constructed in the GCC region with great focus on passive design strategies to prevent heat providing the needed ventilation, natural light and privacy. Courtyards, thick mud/baked bricks walls, small opening to outside and compacted layout are some of the main passive strategies used in the old traditional house design of the region (Al-Hinai, et al., 1993). After the discovery of the oil in the region, the availability of electricity, new construction materials, and new technologies, it became necessary to achieve comfort by cooling system. In the way a modern life style, substantial social and climatic architectural features, such as the courtyard, were neglected in the new house design (Abdu-Majid, et al., 2012). In the 21 century the region was more influenced from the West in the building sector even if such design strategies need more energy for cooling due to high level of heat gain, poor insulation and larger exposed envelop area making the house susceptible to solar radiation (St.Clair, 2009). This inefficient design strategies with low energy prices in the region have led to a high energy consumption.

During the last few years GCC states have taken initiatives to reduce energy consumption and encourage the construction of buildings with low energy demand. Research and experimentation initiatives have begun on the feasibility of energy-efficient buildings in both of public and residential sectors. In the public building sector the project of Euro University (2005 )in Bahrein by the German "Obermyer Planen + Beraten" studio is considered one of the first projects in the region that takes into consideration the realization of an efficient envelope as well as a photovoltaic system for the electricity production and a water purifier. While the few cases tested and implemented in the residential sector are typical single-family dwelling located in Oman, Qatar and Saudi Arabia.

### 3.2.1 SQU Ecohouse-Oman

Oman, similar to other neighbouring countries, is also foreseeing the benefits of the design and construction of energy-efficient buildings. It became necessary to examine the feasibility of the existing low energy building design and construction strategies in order to adapt what is found to be appropriate or suggest new ones that suit the Omani conditions. The first step in this direction has been taken by The Research Council (TRC) in Oman who introduced The Oman Eco-House Design Competition in 2011. A significant aspect of this competition is that it aims at not only design, construct and operate an energy-efficient house in Oman but requires competitors to involve youth in this process in order to enhance public awareness and built national capacity of sustainability issues in the Omani building sector. In total five Omani universities has participated in the competition. We review here Sultan Qaboos University's Eco-house. This house is one of the first research-based attempts to design, built and operated an energy-efficient house in Oman based on collaboration between academic, governmental and industrial local bodies. The house feature a compacted form with two-story with around 280 $m^2$ built up area and a total height of 8.6 m. The house was designed to fulfil the living pattern of the modern Omani family while respecting social norms. The house uses references from the vernacular architecture to emphasis the depth of the Omani architecture and its historical and traditional roots. The typology of traditional houses was studied and the idea of the courtyard as climatic and social element was revisited to inform the design. The resulted design included two courtyards, north and south courtyards, which render the building form into H-form creating better air flow in the building while enhancing the indoor-outdoor connectivity. Several passive strategies were used.

Figure 16 - Images of SQU Ecohouse-Oman . Source- www.ecohouse.com

A carefully designed shading system was developed and supported by a double-shell system where a perforated second structure is introduced outside the main building in order to provide protection from direct solar radiation. This created a shaded cavity between the two shells where air current cools the in-between air and reduces heat gain in the main building. Optimized oriented courtyards, differences in air temperature and pressure, and carefully designed window openings were teamed up to maximize nature ventilation. Landscaping was also utilized to moderate the microclimate of the site, provide shading in the needed directions, and control air currents. With these strategies, the project aims to achieve comfort by natural ventilation alone for four months (Anon., 2014).

Figure 18 - Images of SQU Ecohouse-Oman .
Source- www.ecohouse.com

Figure 18 - Images of SQU Ecohouse-Oman .
Source- www.ecohouse.com

On a construction level, the externals walls were well insulated and consist of three layers: external layer of 100mm thermal blocks, 50mm insulated cavity, external layer of 100mm thermal blocks. The roof is fully shaded and incorporates also a 100mm thermal insulation layers. With the above mentioned strategies, it is anticipated that 40% of energy consumption will be saved in the Ecohouse when compared to its business-as-usual counterpart. Energy simulation of the house suggests that the Ecohouse will consume 155 kWh/m$^2$y, whereas, its business-as-usual counterpart requires around 250 kWh/m$^2$y. Although this value is higher than the required value by the Passive House Institute which is 120 kWh/m$^2$y, the primary energy consumption of the Eco-house could be improved by including energy recovery systems, LED lights and more efficient cooling system (Anon., 2014). The roof

The roof top of the house is equipped with 156 $m^2$ of 20 kW-peak PV panels that supplies all the power needed by the house during day time and provide shading to the roof to reduce solar gain. The PV panels orientation was optimized at 23.5° from horizon to provide maximum energy (Anon., 2014). The house, after completion, will be occupied by a local family and monitored for energy efficiency, energy balance, and liveability.

### 3.2.2 Baytna- Qatar

The Baytna villa is probably the first energy-efficient house experiment in the region. The house is being undertaken by Qatar Green Building Council as the technical and scientific adviser and in partnership with several industrial and governmental bodies. The significance of this project lies in the fact that the project consists of two identical villas in terms of size, spatial arrangements and comfort requirements.

Figure 19-20 – Source: https://www.constructionweekonline.com/article-24193-site-visit-baytna-project-barwa-city

They differ in the design specifications as one of them was design based on passive house strategies with solar panels whereas the other is designed in a similar way to its conventional villas in Qatar to act as a control case. This allows a comparison between the two houses in terms of energy consumption, CO2 emissions, cost effectiveness, comfort levels, and occupants satisfaction. The energy efficient villa was designed according to the Passive House Institute standards in order to achieve at least 50% reduction in annual operational energy consumption, water usage, and CO2 emissions when compared to its conventional twin house. The project aims to achieve this reduction with no more than 20% additional capital cost of the capital cost of the conventional house. The house has the following “green” features (Amato & Skelhorn, 2014):

- Wall construction: 370 mm extruded polystyrene insulation and 200 mm masonry wall (compared to 150 mm external /100 mm internal concrete block with 50 mm air gap in the twin conventional house).
- Triple glazed windows and doors. Skylight in atrium with louvres that open/close with sun angle.
- PV array with a peak power of 34 kW.
- Black and grey water recycling.

### 3.2.3 SABIC – Home of Innovation, Ryadh, KSA

The Home of Innovation Demonstration Home at the Home of Innovation facility at Riyadh Techno Valley, King Saud University exemplifies the best in current sustainable home design. In addition to this Project being a Nearly Zero Energy Building (NZEB), Home of Innovation has also achieved LEED Platinum rating, the highest level of recognition by the U.S Green Building Council (USGBC). Thus, making this project the First LEED Platinum Certified Homes project in Saudi Arabia and the Middle East.

Figure 21-22 – Sabic, Ryadh. source : https://www.greenbuildermedia.com/design/2016-green-home-of-the-year-award-winner-extreme-measures extreme-measures

The Demonstration Home showcases a full assortment of the latest commercially available technologies yielding net zero energy use, water conservation and environmentally responsible building materials and techniques to light the path for sustainable home building around the globe.Solar PV system has been designed to be Grid Connected with Battery Back-up. Operational Principle of the system is such that power generated from the Solar PV system will fully charge the battery bank, and export the surplus to the Utility Grid.

The home features a 28-kWh rooftop solar array, a bank of 88 lithium-ion solar batteries that stores surplus electricity for power outages. Saudi Arabia does not yet offer net-metering, but the house is ready when it does.

The project introduced insulated concrete forms (ICFs) for the home's structural/thermal envelope. Combined with additional air sealing and high-performance fenestration, ICFs reduced the home's overall energy load by at least 30 % compared to conventional building practices and enabled the optimization and further energy savings of heating, ventilating, and air conditioning equipment and appliances.

Although a new and innovative technology for construction in Saudi Arabia, ICFs are a logical evolution from the prevailing use of concrete block.

Chapter 4

# SAUDI RENEWBLE ENERGY POTENTIALS

Its feasibility in Saudi Arabia is granted because of  it is location between 17.5˚N and 31˚N in latitude, and 36.5˚E to 50˚E in longitudes,  with relatively high potential of both solar radiation and sunshine hours as a result of its unique location and climate.  In this way renewable energy in general and solar energy in particular. However, despite the availability of substantial renewable energy resources, the electricity generation in the KSA depends mainly on fossil fuel resources. These renewable energy resources are yet to be tapped. Since 1970s, many studies have shown the potentials of solar and wind energy in the country but these technologies have not been exploited in a meaningful way. The geographic location of the KSA is ideal  to profit by solar energy. According to the Saudi Solar Radiation Atlas, the country annually receives around 3 245 sunshine hours accounting for a solar radiation figure of over 2 200 kWh/m². The Photovoltaic power potential is clearly high compared to Europe as it shown in solargis Photvoltic potential map.

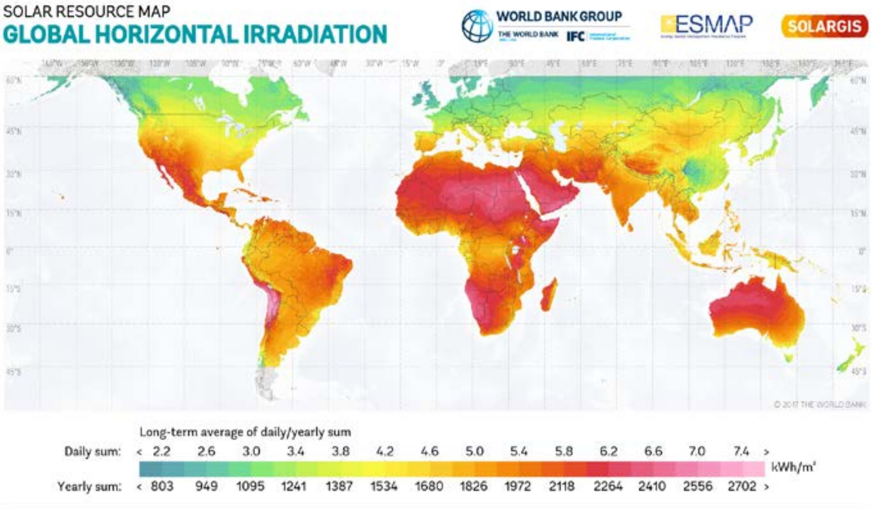



Figure 23 - Global horizontal irradiation map that shows the global sun belt on the middle east area.

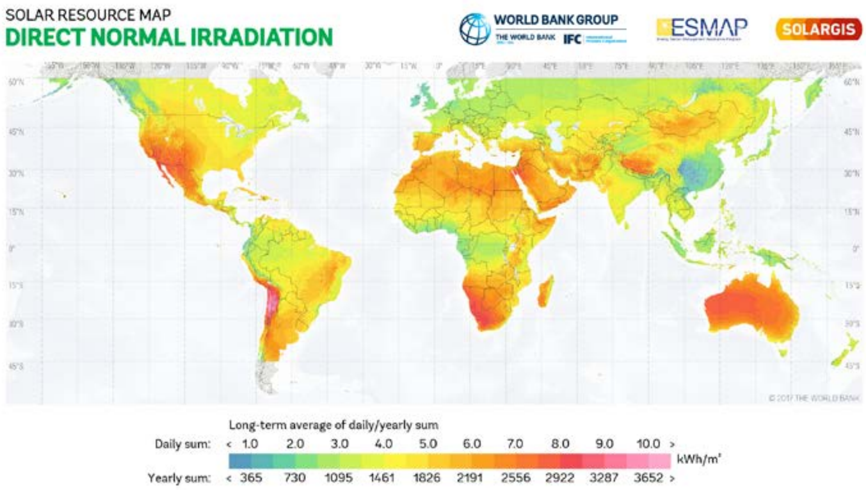



Figure 24 - Direct normal irradiation map that shows the global sun belt on the middle east area.

Source : www.solargis.com

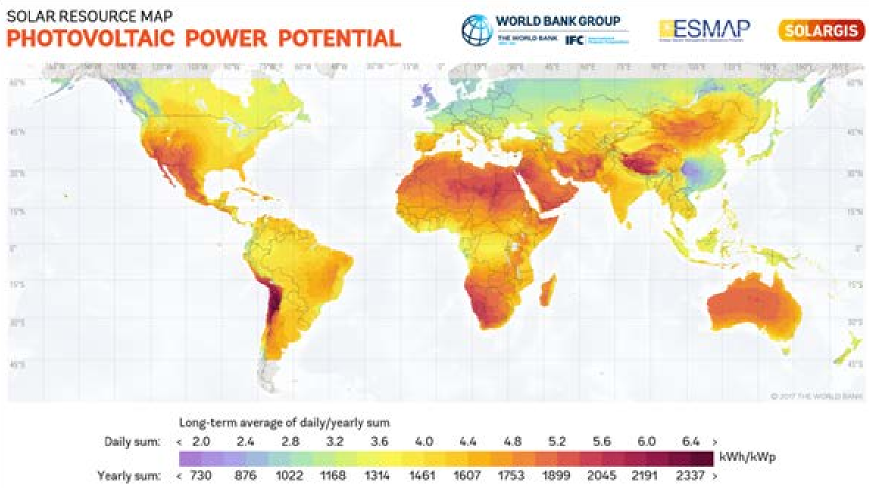



Figure 25 - Photovoltaic power potential map that shows the global sun belt on the middle east area.
Source : www.solargis.com

Chapter 5

# SAUDI HOUSING

In view of a residential project it was necessary to analyse The Saudi housing and to do a special focus  in Eastern Province.
The Kingdom of Saudi Arabia has seen vast changes between its past and present in various aspects of life. the culture of the place has a tribal background strongly influenced by the Islamic religion. In fact in ancient times nomad tents were divided into three sections – the men's part called the Al-Rabba'a, the women section is called the Muhramm and the third section is used for cooking. A division that has carried on in their traditional houses and in some way even in contemporary homes. The improved economy, government policies, and communication have positively impacted the residents' lifestyle. The most notable is the continuous support that the country has provided to its residents through various housing programs. This is why housing in Saudi Arabia is turning out to offer such great in-house real-estate opportunities for the nationals. In this way, under Vision 2030 & National Transformation Program, housing is the biggest area of expenditure with over SR 5 billion committed to the cause. The most highly sought-after property types are actually  4+  bedroom villas and 3+ bedroom apartments.
Housing in Saudi Arabia has been perpetually transforming, as the evolution of contemporary needs always results in modifications.

Here are a few fun facts to understand the housing circumstances:

- Large Arab families tend to require larger houses.
- Most of the families like to reside in large villas.
- The middle-class tends to live in large apartments.
- The poorer residents tend to live in small houses and smaller apartments in the shabbier neighborhoods that aren't as well maintained.
- Generally, the indigenous population of KSA (especially the middle and lower class families) are given low-cost loans for long span installments. This loan is even tapered off in some states for the poorer families if they aren't repaid within a particular time limit.

According to the 2018 census, the Saudi population counts 33 423 660 of which 12 645 033 (38%) are foreigners. This high presence of foreigners certainly had affected the types of houses and the criteria of choice which justifies the diffusion of the apartments typology. Although lately many Saudis choose the apartment typology as long as it respects their cultural needs, furthermore they have a decidedly lower cost than the single-family house type ( Villas). It could be a kind of a Saudi social housing.
Therefore it is worth noting a strong transformation of the traditional Saudi house while maintaining some cultural pillars:

- Privacy
- Spaciousness
- Typical internal distribution

*"We have our own factors, values and principles as the Saudi society and we try to make progress according to our own needs."*
*Crown Prince Muhammad Bin Salman*

## 5.1 Saudi traditional House

Physical representation of privacy needs in traditional houses in the Eastern region of Saudi Arabia. Information related to this house was found i the book Potentiality of the Traditional House (Naim, 1998). The traditional Islamic-Arab house layout separate the house between what is public, semi-public and private areas of the house. The design of the house is for the interior while the outside walls are generally featureless, which discourage strangers from looking inside.
The example is of a traditional courtyard house located in the Eastern region of Saudi Arabia. Through this example, the user lifestyle patterns will be explained in relation to the functional spaces and social use. That is to reflect the spatial utilisation to serve the social and personal needs of users.
This house has:

- A countryard around which the house is developed
- Only one exterior access to the house
- Consists of two vertical levels accessed by three stairs allocated in different location of the house.

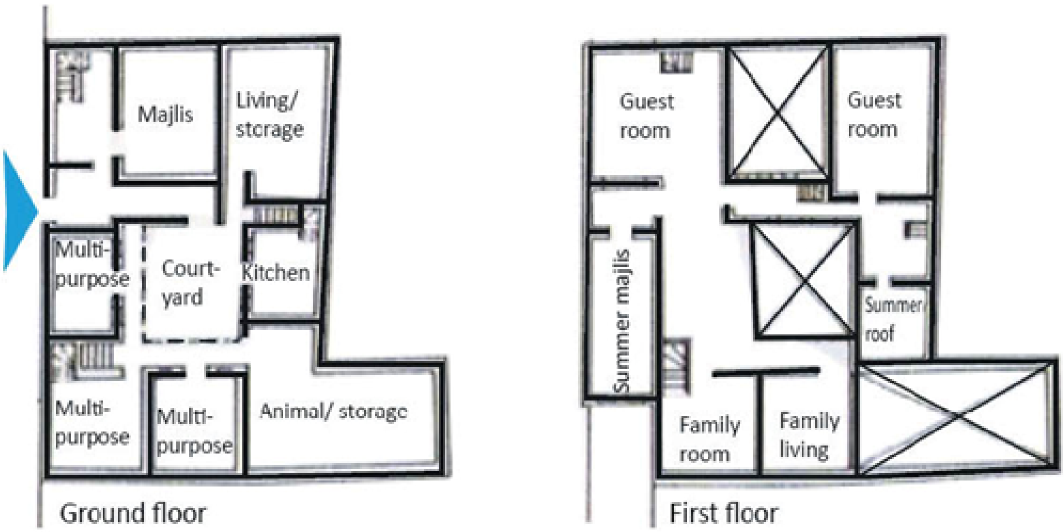



Figura 26 - The traditional coutryard house. Source: article " the visual representation of the concept of privacy in the eastern region of saudi arabia's houses design: a comparative study of the traditional and contemporary "

That architectural typology developed around a courtyard with external walls almost devoid of openings, recalls the Roman Domus and not only but also the first Renaissance Palazzi in Florence which sought to reconcile the traditions with the urban needs of the new cities.

The way this house was designed providing the users with control over the visitors and other members, who access the courtyard and who are only welcomed into the Majlis, formal living room. Also this central functional space has access (visual and physical) to other spaces of the house: living spaces; vertical circulaton; storage; and the space dedicated for the animals. The central courtyard overlooks three multi-purpose rooms that act as bedrooms and guest living spaces, for male and female guests. The other three spaces of the house have different functons: one is designed to welcome more visitors, while the other two spaces are more dedicated to the owners of the house where they access the kitchen space and animal stable. This house has three vertcal circulaton elements, one for the use of visitors and the other two for the different family members of the house. The stairs located to the main entrance direct visitors accessing it to the dedicated guest room on the second level, while the other two stairs direct family members to the sittng areas on the second level. On the ground floor, a small space was dedicated to the kitchen and is close to the stairs and with direct access to the courtyard, giving it access to other living spaces of the house, ground and first level.

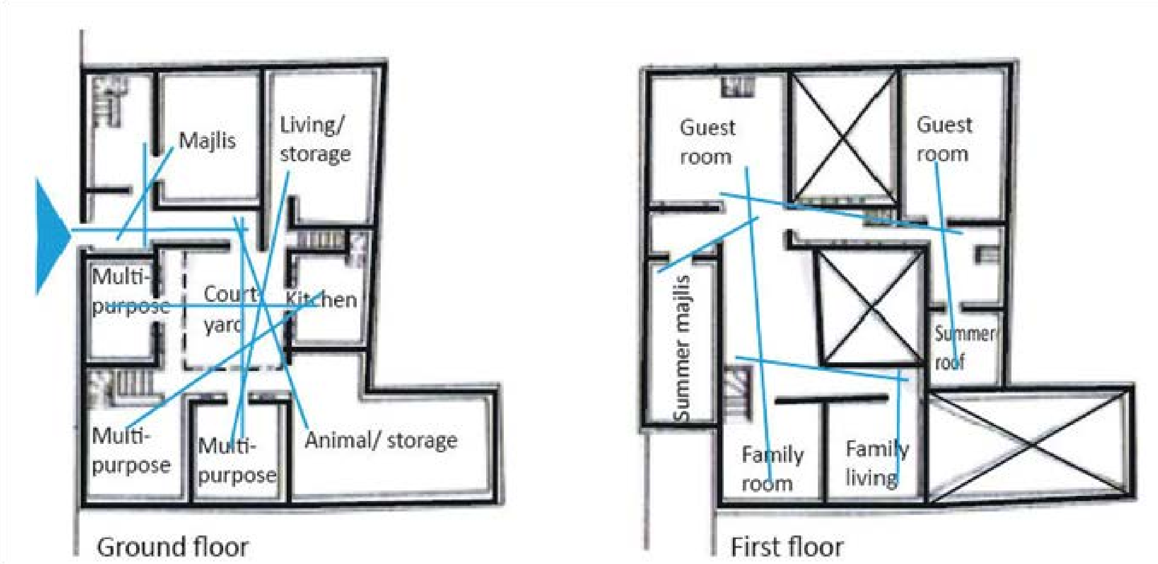



Figura 27- The traditional coutryard house. Source: article " the visual representation of the concept of privacy in the eastern region of saudi arabia's houses design: a comparative study of the traditional and contemporary "

## 5.2 Privacy

Literature referred to privacy as the person's state of existence: being safe; feeling secure; comfortable; and in control (Newell, 1995; Pedersen, 1982; Westin, 1967). Privacy is a universal concept influenced by cultural factors (Altman, 1977). Italian Renaissance house designs considered the house interiors to be the place of women, where it is private, while men are to go and domain public spaces by working and socializing (Weddle, 2001). Even the architecture of the Florentine palazzi supports this idea. The palazzi have "forbidding facade to the street ... an interior courtyard where family functions took place." Meanwhile in China, the house privacy was with owners control over their belongings and information (Ying-Keung, 2000). The situation is not different in Arabian countries, where the interiors are the domain of women and they control its appearance and accessibility (Abu-Gazzeh, 1996; Kries & Vegesack, 2003).

One of the major social challenges facing sustainable housing in Saudi Arabia is achieving privacy. It is crucial in the design of a Saudi house, and the concept of privacy is perceived from three different areas as stated by Daneshpour (2011), between the neighbours dwelling as well as the street, between the sexes and privacy between individual family members . Abu-Gazzeh (1996) states, "The concept of privacy has become a subject of growing concern for people, architects, urban designers, landscape architects and social scientists involved in development projects in Saudi Arabia".The house design should separate private and public life, maintaining their independence. It's to point out the importance of gender separation where it is fundamental to most people's educational, social and political activities. To incorporate this fundamental requirement in housing design, the housing designer should divide the house into three areas:

- **Private** areas for the inner family members such as the father and
- the mother.
- **Semi-private** areas for the whole famil, such as the living room.
- **Public** guest zones for men and guests.

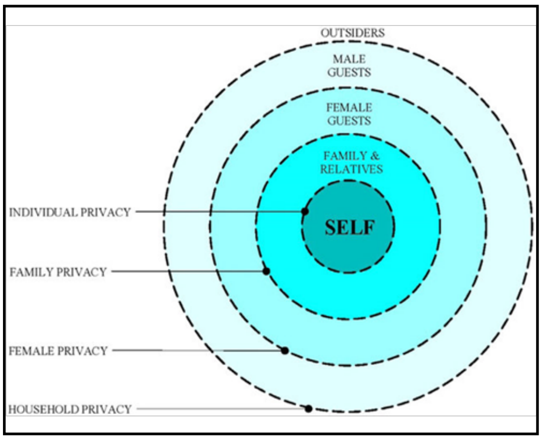



Figure 28- Layers of privacy in traditional Muslim's home, Architectural Patterns of Privacy in Saudi Arabian Housing, mcgill Thesis, school of Architecture, Author : Bahammam,

A typical contemporary Saudi home is designed to be as far away from the public's eyes as possible. The ideal home is a self-contained villa away from the eyes of neighbours. High walls typically surround houses. This is why in any Saudi street the typical skyline would be of high fences surrounding homes, such that the design of the house might not even be noticeable, except from within the boundaries of the fence.

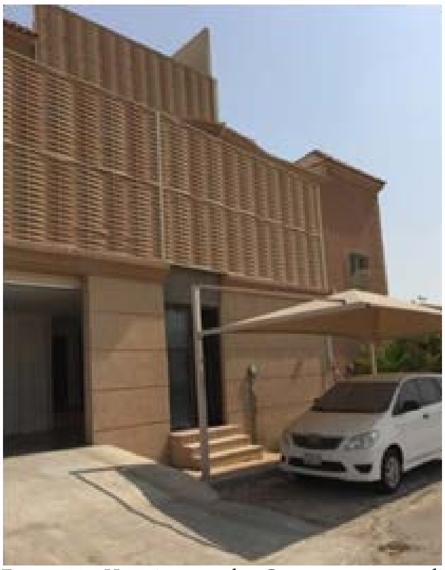


Figure 29 -How is seen the Contemporary saudi house from an outside point of view, surrunded by high walls and fencies

Figure 30 -What is hidden behind the haigh walls in the private area.


Figure 31-32-33-42 - DWifferent examples of houses in Al Khobar city.

There are essentially two kinds of entrances – a large gate for the car entrance followed by a driveway along with several (around 3-4) doorway entrances for the actual residents of the home.
Here's the breakdown of all the entrances:

- one for the residents,
- one for female guests,
- one for male guests
- an occasionally a backdoor in the kitchen.

Moreover, you'll find a separate entrance for the suite areas if the home is actually designed on a grand scale.

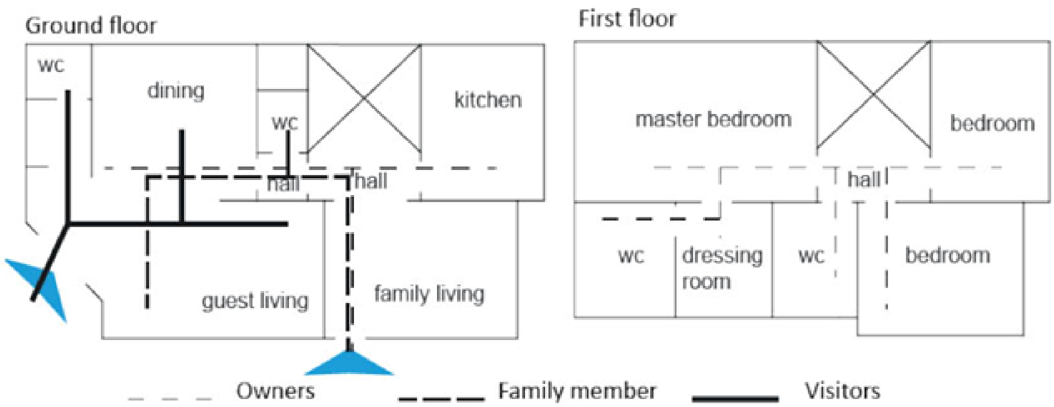



Figure 35 - The Contemporary house. Source: article " the visual representation of the concept of privacy in the eastern region of Saudi Arabia's houses design: a comparative study of the traditional and contemporary"

Different users access the functional spaces provided of this contemporary house:

- Owners
- Different family members
- Friends
- Other visitors

The analysis displays these different types and the spaces that they are allowed to access without over riding the privacy boundaries of the house owners. From the analysis, visitors are limited to the guest living and dining rooms, and an entrance is provided to ensure this limitation of access. There is a door that separates the guest living section of the house from the family and private section of the house. This separation creates two sections of the house on the ground floor. Also the visitors' sections is not accessed when no visitors are around, it is totally dedicated to them. Meanwhile, family members and close friends are allowed to access the family living space. Furthermore, it is apparent that the second fldoor is limited to the house owners, where the bedrooms are located.

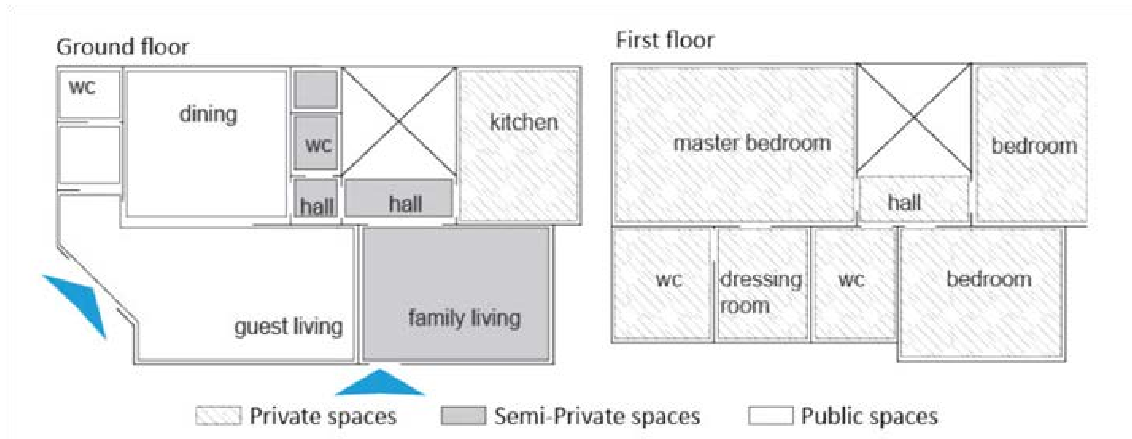



Figura 36- The Contemporary house. Source: article “ the visual representation of the concept of privacy in the eastern region of saudi arabia’s houses design: a comparative study of the traditional and contemporary”

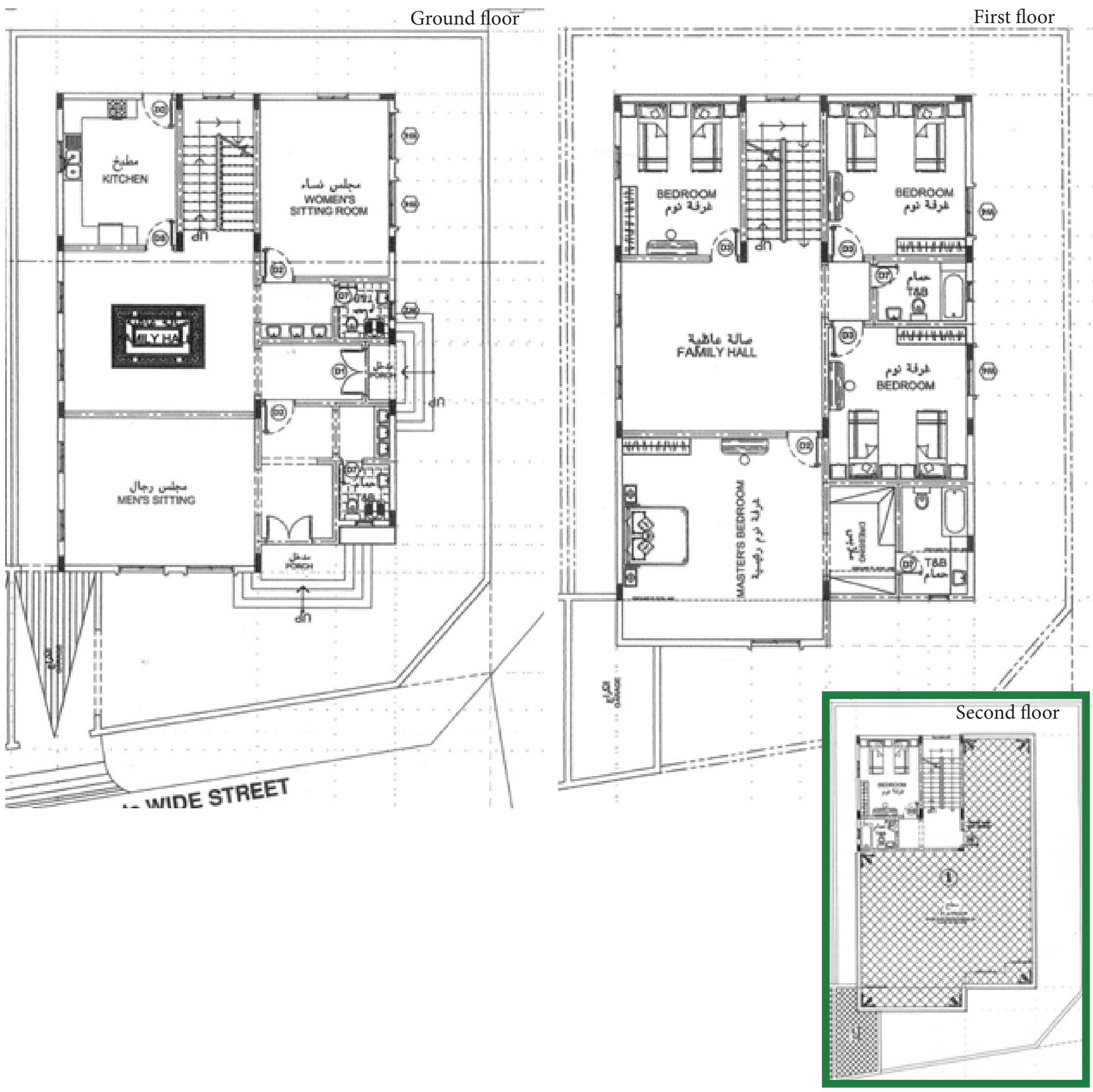



Figure 37 - An example of a Contemporary house in eastern province Ground Floor, First Floor and Second Floor. Source: Architect studio

## 5.3 Different contemporary types of housing in Al Khobar city

First of all, it's important to note that all units of housing in Al Khobar and almost Saudi Arabia in general, whether single-family houses or residential buildings, have an efficient urban planning. They are located in well-planned neighbourhoods with public gardens, government service buildings, market zones, sports complexes, and mosques. There are contemporary types of housing diffused in Al Khobar city adabted to their needs.

### 5.3.1 Rooftop apartment

The trend of rooftop apartments in Saudi Arabia started with the presence of foreigners who wanted to have an outdoor space of their own, given the cultural privacy of the Kingdom. Since it could be difficult for them to own houses, these rooftop apartment complexes in nice neighbourhoods seem like the best housing option for them. (Deniz Kaya, comelite-arch.com)

### 5.3.2 Penthouse Villas

Penthouse villas are an alternative living choice for Saudi nationals who cannot really afford an actual villa but are still looking for a residence with more than 3 bedrooms. This type of housing in Saudi Arabia is usually located at the top of a building. They can be either rented or bought by the nationals.

**5.3.3 Independent villas**

This is an individual housing unit type usually used by a family that wants to accommodate up to three generations. They're usually constructed on a 2,000 $m^2$ of land and the inside is designed to accommodate family members from all walks of life. Saudis value togetherness,but the culture also respects privacy. The villa usually features a very private design with 3-meter high exterior walls that keep the villa façade from showing too much. You'll find a small niche for cool water on the exterior of the wall built for thirsty passersby. These exterior walls are an integral part of the culture, not only demarcating the boundary of the property but also ensuring the privacy of the family.

This type of villa is extremely expensive, even for the nationals. You would usually find an additional room for the driver in Saudi homes, but due to recent laws that allow women to drive, this room might not be necessary anymore. (Deniz Kaya, comelite-arch.com)

**5.3.4. Detached Duplex**

Such types of houses are relatively newer in the kingdom, and seem like a smaller version of the villa. The land size of these units is usually 300 $m^2$ and they are definitely the more affordable housing typology. They typically consist of two units with a dead-wall between them.

They also have a boundary wall for privacy purposes, which has become a major part of the Arab and Islamic cultures. These duplexes are also designed according to the traditional majlis style housing with separate entrances for men and women. (Deniz Kaya, comelite-arch.com)

### 5.3.5 Palaces

Saudi royalty and capital owners like to spend their wealth on lavish residences that liken to actual palaces. Palaces are constructed on a land size of about 5000 $m^2$ or more and are the most luxuries type of housing in Saudi Arabia. They tend to be widespread in the capital at ryadh, but are also present in al khobar as holiday homes (Deniz Kaya, comelite-arch.com)

Chapter 6

# MASHRABYYAH

Mashrabiya is a kind of traditional element which are widely used in Saudi Arabia’s architecture built on the faced of the building.  Nowadays, Its design gives to the modern contemporary architecture a strong Arabic connotation. The function of mashrabyya was is used to provide a private place and to shade the strong desert sunlight to keep the room cool. Therefore, it can be used in the contemporary architecture and use its passive features as a window, curtain, air conditional and refrigerator at the same time to maximise the passive cooling. Mashrabyyas were also introduced used in mosques because of its function: suppresses the string sunlight to keep the room cool and which are also conducive to prayer and meditation.

Figure 38,39 - Mashrabya in traditional Saudi Building. Source: www.pinterest.it

Figure 40-41 - Mahrabya in contemporary architecture. Source: www.pinterest.com

Mashrabiya is the prominent window that overlooks the street or the courtyard of traditional Arab houses. It was diffused in the  Eastern Province Houses because of its hygrometric characteristics that help to face air  humidity . In the past, Mashrabiya was the name given to space which is enclosed with wooden lattice openings where jars of drinking water were put to cool (Fathy, 1986). Later, the name Mashrabiya was only given to the lattice screen which is made of wooden balusters with a circular section as a perfect condition to provide smoother airflow which contributes to the evaporation factor. This screen was completely hand-made and the design of the balusters was varied in different artistic ways.

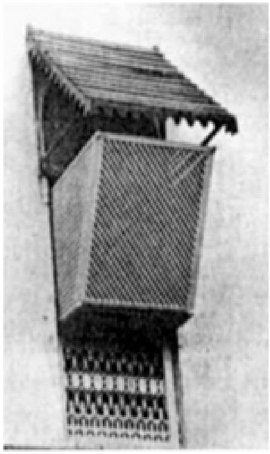


Figure 42 - An old Mashrabiya in Cairo, Egypt 1640's . Source: Ashi, 2010

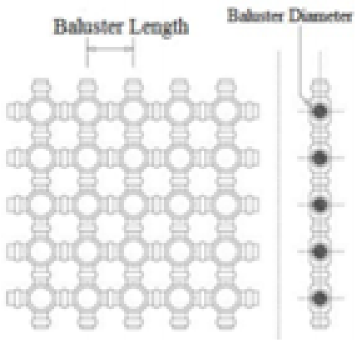



Figure 43 - Traditional Mashrabiya typology . Source: Samuels, 2011

The word Mashrabiya came from an Arab root meaning a place where the jars of drinking water were being put to cool, and Mashraba is the noun form of a verb in Arabic "yashrab " meaning "drink". The history of Mashrabiya is dating back to the period when Arabs entered to Egypt, but when it first became used in particular, it is difficult to pinpoint because of the ever-evolving nature of architecture. The Mashrabiya began to flourish during Tulunid era (868- 905) where they used a wood in their buildings, and Arab manufacturers benefited at the beginning of the industry, from the experience of the Copts, who were excellent wood workers. The growth of this construction continued during the Abbasid era (750-1258), especially during the time of the Ayyubid (1171-1250).
Thereafter, during the Mamluk era (1250- 1517) the Mashrabiya industry grew and flourished artistically.

The privacy requirement was an important value of the Islamic religion, so the Mashrabiya had widespread popularity throughout history, especially during the Islamic Ottoman era (1517- 1805) and it also continued later in various Arab regions, helping to adorn the streets, by giving it a beautiful artistic character (Maspero, 1974).

Mashrabiya spread to the cities of Syria, Arabian Gulf, Lebanon, Sudan, Iraq and in the Maghreb countries, as well as to India, Pakistan, Iran and Spain. And the spread of it in these countries coincided with the Egyptian periods. There are some countries which neglect the Mashrabiya heritage, for example: Saudi Arabia due to many factors , for example, the result of cursory modernization, the growth of globalization, and the abandonment of vernacular traditions. Concurrent with this was a changing economic structure, which was born of the industrial revolution that made small craft-based manufacturing redundant.

## 6.1 Functions of Mashrabyya

Mashrabiya did not provide only a decorative and aesthetic element, but also it was designed to perform many environmental functions like adjustment of lighting, humidity and air flow control, reducing the heat, and playing an essential role in securing privacy, as Architect Hassan Fathy asserted. Mashrabiya is able to control when and how much direct daylight could enter the building during summer or winter according to the parameters of Mashrabiya design which the architect determines:

- It limits the solar gain by shading the inner spaces during the hot summer.
- Decreases internal heat gain during winter.
- Allows for a good amount of light to enter during summer.
- Decrease the humidity in the air.

And even if there is a need to block direct sunlight in the troublesome times, the users still need enough natural internal light for regular daily activities. Mashrabiya is an important element that allows ambient light to pass through spaces without letting in direct sunlight. While with regard to glare, it doesn’t raise the temperature of the room, but it causes an optical inconvenience. To solve this problem Mashrabiya is one of the best effective choices. In this case, the architect has to choose a Mashrabiya with a circular section for the balusters as the main condition (Fathy, 1986).

Mashrabiya is used to ensure air circulation inside the building, air is pulled into the room through the small interstices of the Mashrabiya in the lower part and hot air is ejected out through the large interstices of the upper part.

### 6.1.1 Humidity and Mashrabeya

The air which passes through the wooden Mashrabiya loses some of its humidity by the absorption property of the wooden balusters; if they are cold, as usual at night, and when the Mashrabiya is heated by direct sunlight, this humidity is absorbed by the air which flows through the porous wooden Mashrabiya. This technique is efficient in making the dry air more moist in the heat of the day, humidifying and cooling it at a time when most needed.

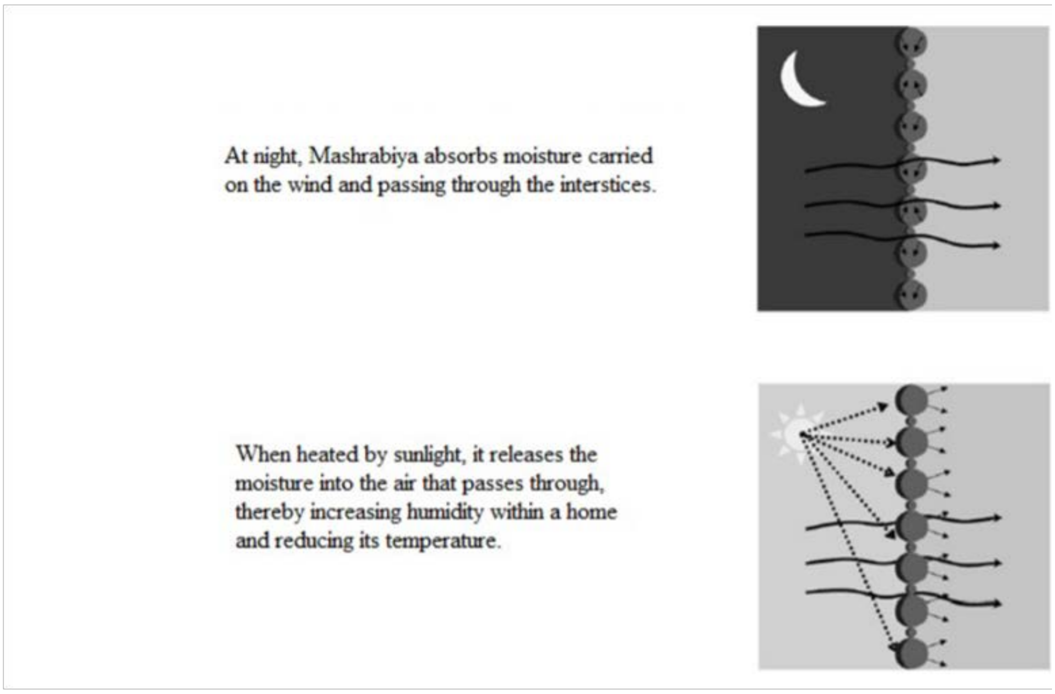



Figure 44. The cooling effect of Mashrabiya through the evapo-transpiration process (Source: Fathy, 1986, illustration by Gelil, 2014). Source: "An Evaluatve and critical study of Mashrabiya in contemporary architecture" Thesis by HIBA ALOTHMAN.

With regard to the foregoing, it should shed light on the importance of the wood chosen for the construction of Mashrabiya, and take into account that new alternative materials should have properties which are more or less similar to wood, in relation to absorption and evaporation matters. Mashrabyya is considered as an important environmental component due to it works as a mediator between all of the techniques that adjust the temperature of buildings.

Chapter 7

# nZEB ALKHOBAR

## RESIDENTIAL BUILDING PROJECT

The cities of Saudi Arabia have the largest growth rates of cities in the Middle East, such that it has become a cause in shortage of housing for mid and low-income families, as is the case in other developing countries. Even when housing is found, it is not sustainable nor is it providing the cultural needs of those families.

## 7.1 Eastern Province "I-Sharqiyyah"

I-Sharqiyyah is one of the four main geographic regions of the country and comprises the principal petroleum-producing areas of Saudi Arabia. The wealth produced from extensive oil deposits, discovered in the 1930s, transformed Al-Sharqiyyah into one of the kingdom's most progressive regions. Many oilfields, including Al-Ghawār , are operated by the Saudi Aramco oil company. The impressive improvements in economic conditions brought by the discovery of oil in commercial quantities in the late 1930s and the increasing market demand worldwide during the 1970s catapulted the traditional society to lifestyles comparable to that in many developed societies. Between 1950 and 1992 the level of urbanization in Saudi Arabia increased from 10% to 75%. According to the 1992 census, the total population of the Kingdom was 16.93 million, of which Saudi nationals comprised 72.7%. Inevitably, the housing sector was the first to show the strain on urban services. The sharp increases in demand for new and "better" units meant the use of modern construction methods and the introduction of new design styles, paramount, the detached "Western" villa, and the multi-story apartment buildings.

The Nearly zero energy building project is located in Al-Khobar city (26°17'N - 50°12'E) , one of the three main cities in the Eastern Province (I-Sharqiyyah), on the coast of the Persian Gulf, the others are Dammam and Dhahran . They are part of the Dammam metropolitan area, the 3rd largest metropolitan area in Saudi Arabia with an estimated population of over 4,100,000 as of 2012.

## 7.2 AL Khobar Climate

Saudi Arabia has four climatic divisions :

- Hot - Humid climate
- Composite - East coast climate
- Up land climate
- Hot - Arid climate

Al Khobar is located in the composite- east coast climate, characterized by a humid and high temperature during summer : temperature reach a maximum of 43 °c with a relative humidity about 66% that rises especially during the early evening hours. In the winter season, the weather is slightly pleasant with a breeze blowing from the Arabian Gulf: temperature reach a minimum of 5 °c during evening hours of December. It is important to notice that winter months are characterized by a remarkable thermal excursion between day and night hours.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max Temperature °C ( °F) | 29 (84.2) | 28 (82.4) | 35 (95) | 37 (98.6) | 43 (109.4) | 45 (113) | 45 (113) | 46 (114.8) | 44 (111.2) | 40 (104) | 33 (91.4) | 28 (82.4) | 37.8 (100) |
| Average Temperature °C ( °F) | 15.5 (59.9) | 16.7 (62.1) | 20.6 (69.1) | 25 (77) | 30.6 (87.1) | 33.4 (92.1) | 35.2 (95.4) | 34.4 (93.9) | 31.9 (89.4) | 27.9 (82.2) | 22.3 (72.1) | 17 (62.6) | 25.9 (78.6) |
| Average Min Temperature °C ( °F) | 6 (42.8) | 8 (46.4) | 11 (51.8) | 15 (59) | 20 (68) | 24 (75.2) | 25 (77) | 26 (78.8) | 22 (71.6) | 18 (64.4) | 11 (51.8) | 7 (44.6) | 16.1 (61) |
| Average Sea or Water Temp °C ( °F) | 21 (70) | 18 (64) | 24 (75) | 27 (81) | 27 (81) | 27 (81) | 29 (84) | 31 (88) | 28 (82) | 27 (81) | 27 (81) | 25 (77) | 26 (79) |

Figure 45- Graphic Average temperature table . Source: www.dhahranclimatemp.com

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Relative Humidity (%) | 73 | 68 | 60 | 55 | 43 | 34 | 36 | 44 | 53 | 60 | 64 | 66 | 54.7 |
| Average Dew Point Temperature °C ( °F) | 10.7 (51.2) | 10.8 (51.4) | 12.6 (54.6) | 15.3 (59.6) | 16.6 (61.9) | 15.4 (59.7) | 17.9 (64.2) | 20.4 (68.7) | 21.1 (70) | 19.4 (67) | 15.2 (59.3) | 10.6 (51.1) | 15.5 (59.9) |
| Interpretation | Very comfortable | Very comfortable | Comfortable | Comfortable | Ok | Comfortable | Ok | Humid | Very humid | Humid | Comfortable | Very comfortable | Comfortable |

Figure 46–Relative humidity in relation with the Average Dew Point temperature and the interpretation of its relative feelings . Source: www.dhahranclimatemps.com

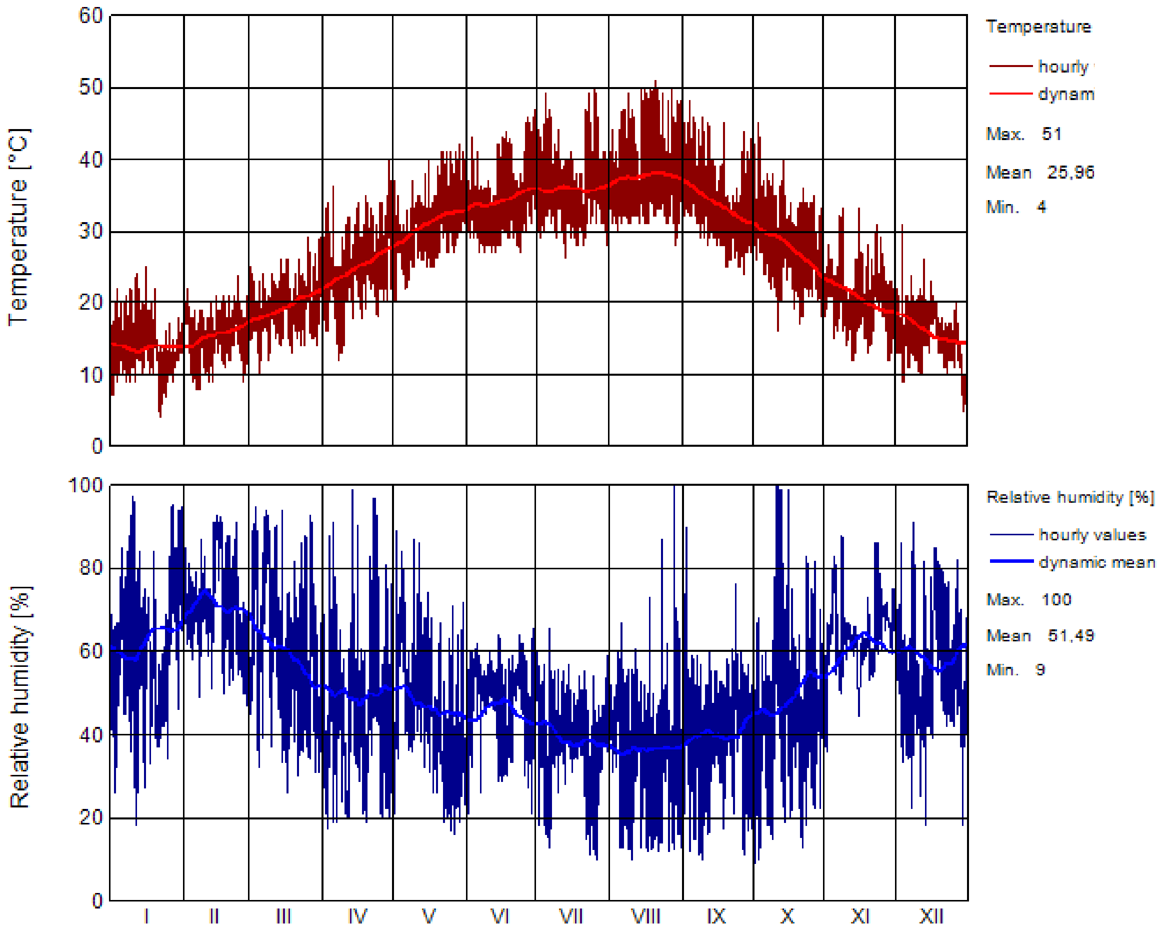



Figure46 - Graphic of daily average temperature and relative humidity in AlKhobar during 2012. Source: Wufi Plus analysis & The General Authority for Meteorology and Environmental Protection.

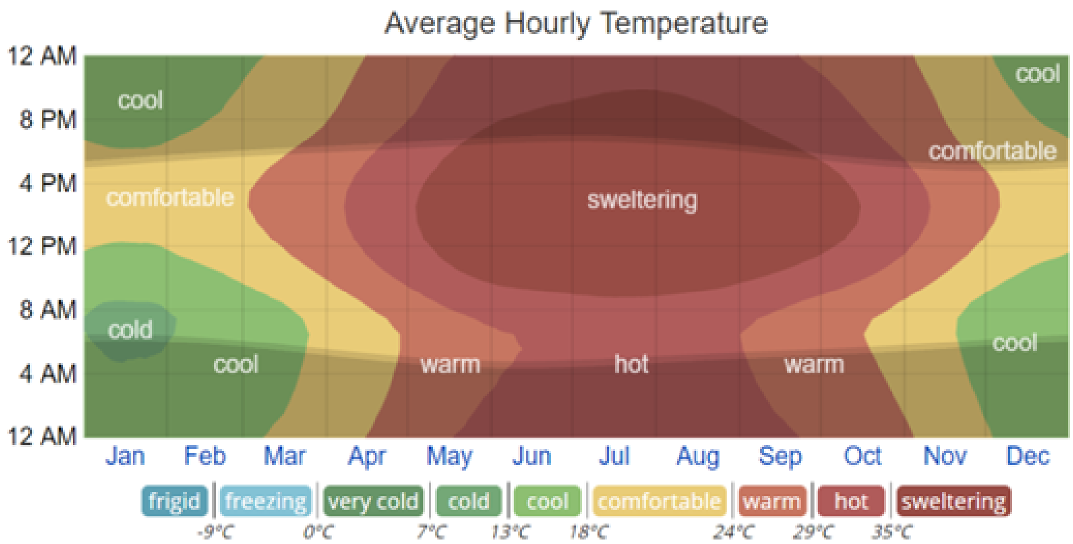



Figure 46 - The average hourly temperature, color coded into bands. The shaded overlays indicate night and civil twilight. Source: www.weatherspark.com

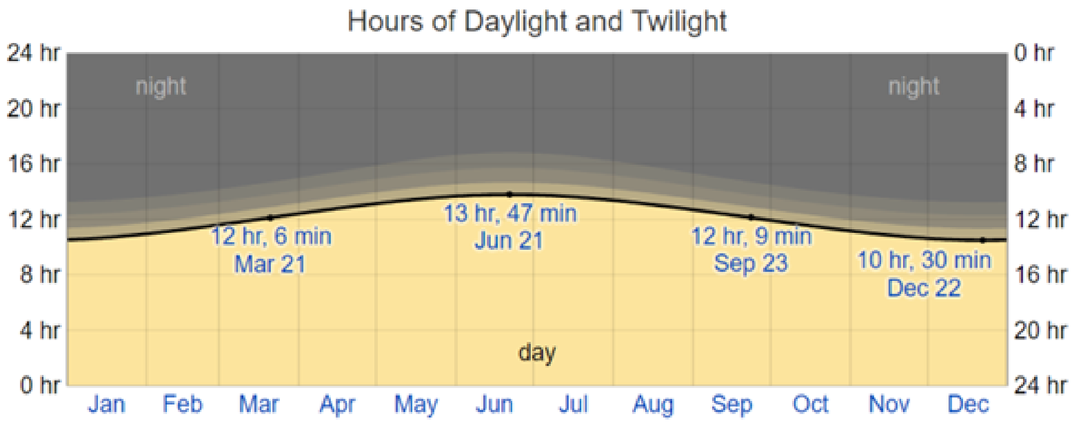



Figure 47- Daylight hours. Source: www.weatherspark.com

Al Khobar has dry periods in January, February, March, April, May, June, July, August, September, October, November and December.

On average, January is the most rainy.

On average, July has the least rainy days.

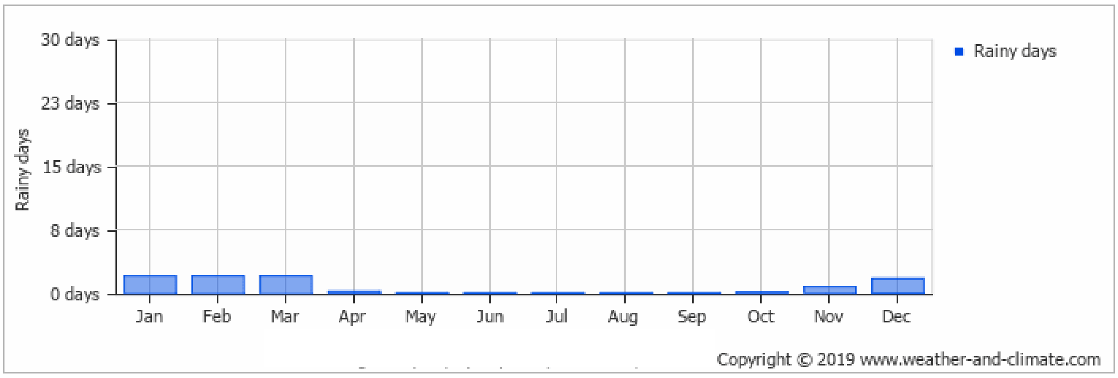



Figura 48- The monthly average percipitation over the year in Al Khobar

On average, the most wind speed is seen in December.

On average, the least wind speed is seen in September.

The mean monthly wind speed over the year in Al Khobar, Saudi Arabia (meters per second).

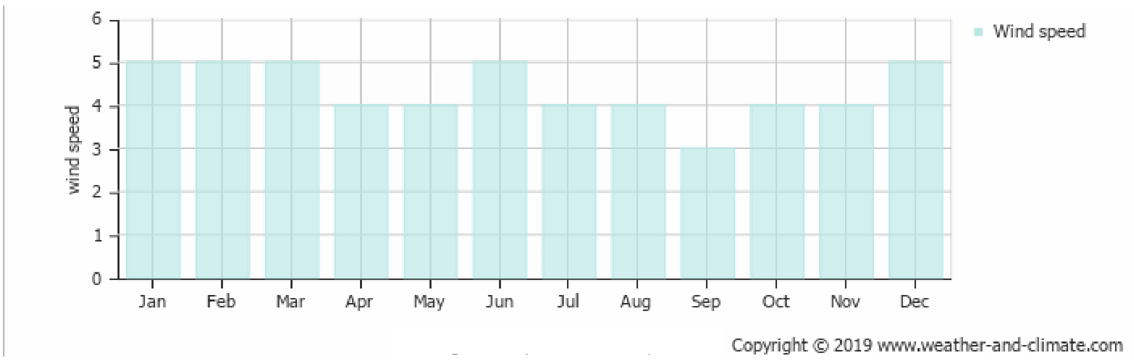



Figura 49- The monthly average wind speed over the year in Al Khobar

## 7.3 Al Khobar Energy Consumption

In “Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province” survey is calculated that the average consumption of an apartment is about 176.5 kWh /m2y. The 67% is a energy consumption for a cooling need as is described in the pie chart.

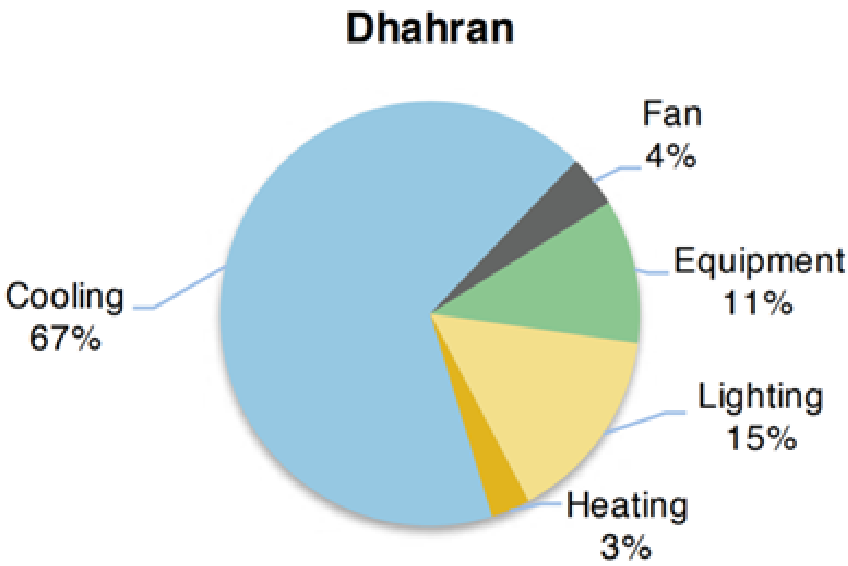



Figura 50 - Source: “Evaluating Building Energy Efficiency Investment Options for Saudi Arabia” Kankana Dubey, Nicholas Howarth and Moncef Krarti

The results of the survey conducted on 128 dwellings indicate that the annual energy consumption for varies from 27 to 401 kWh/m² whereas the average value is calculated to be 176.5 kWh/m². The energy consumption for 43% of all dwellings is between 125 and 174 kWh/m² .

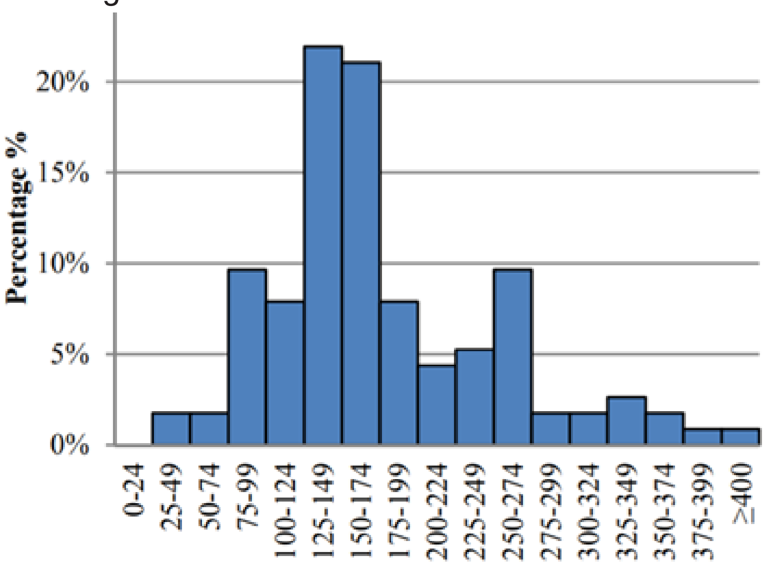



Figure 51- Percentage of Energy consumption. Source: “Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province”

The average of annual energy consumption for apartments, traditional house, and villas is respectively, 196.5, 156.5 and 150 kWh/m². It is observed that the energy consumption for apartments is higher than the other types. The survey results also reveal that the annual energy consumption per square meter especially for apartments and traditional houses decreases when the conditioned area increasing and vice versa.

This also disadvantaged due to the fact that apartments built for rent don't benefit the owner's interest in using efficient systems to improve the building passive performance with an advanced envelop.

The survey results indicates that in Dhahran region the use of thermal insulation started almost 20 years ago and none of the dwellings built over the last five years is un-insulated. While the use of double gazing system has increased during last ten years, the single-glazing system is still being applied.

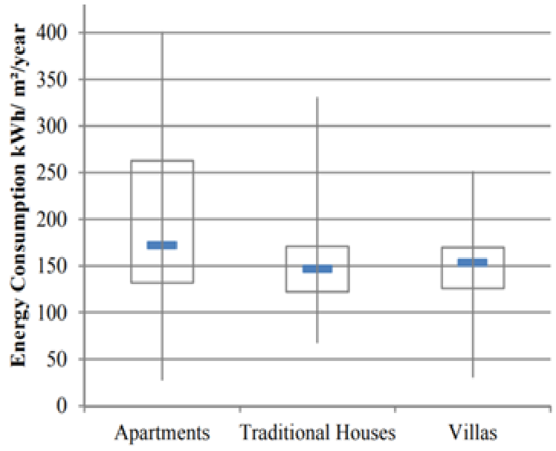



Figure 52- The energy consumption by dwelling types. Source: "Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province"

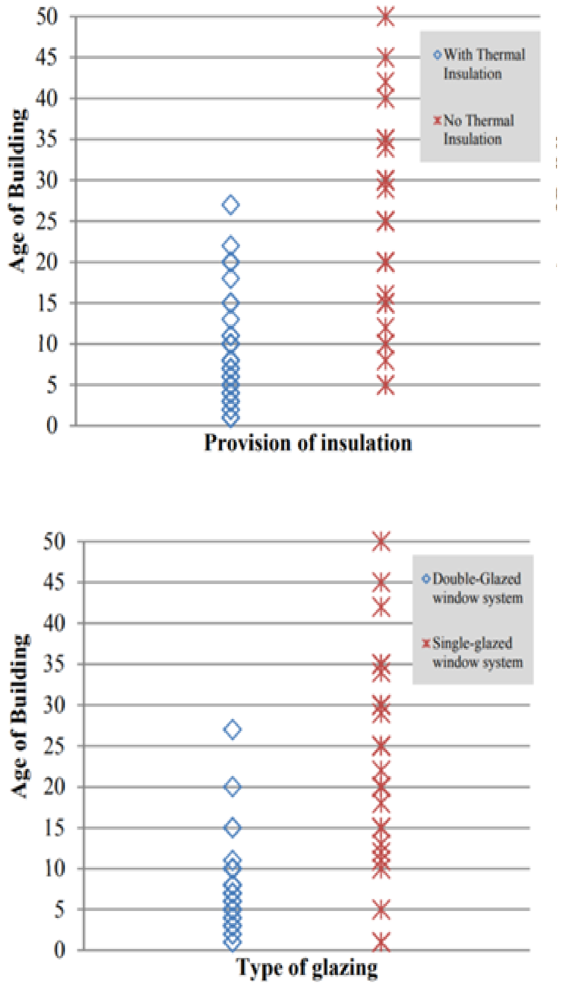



Figure 53 - Source: "Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province"

## 7.4 The design choices for an efficient nZEB in Al Khobar

The multi- storey nZEB building is designed respecting the contemporary Saudi housing and culture characteristics analysed before. In fact it is characterized by :

- The presence of a Majles: which is a separated setting area dedicated for male visitors with a separated guest toilet, that to grantee the privacy and separation between semi public and private area.
- The smallest apartment unit is 135 $m^2$.
- The necessary presence of a living area, a master room with dressing area and a bedroom toilet , and a maid room in the 200 $m^2$ apartments.
- The setting of the "mashrabiya", a typical element of the place, interesting for its hygrometric and privacy features .

Moreover, it is necessarily important to respect the "Saudi building Code". In view of a Nearly zero energy building project it is necessary to do a detailed analysis of the climate.

### 7.4.1 The multi-storeys residential nZEB AL Khobar design

The compositional project is a multi-storey residential building located in the city of Al Khobar, developed on an area of 1640 $m^2$ of which 890 $m^2$ area built, that is 54 % of the total area which respect the 60% limit set by the "Saudi building code".

The building is developed over four floors divided into four apartments and a fifth re-entrant level divided into two apartments which use the covered roof. The ground level host the parking lot as per regulation which provides a parking space for each residential unit, a nursery, a playground and four rooms reserved for drivers.

The roof is covered with canopy and host a barbeque area, in addition to the areas reserved for the residential units, on the top level. All bathrooms and kitchens have openings on air duct, while all rooms are windowed with a minimum area equal to 10% of the room area as imposed by "Saudi building code". The distribution plans are designed respecting the characteristics of Saudi Housing of privacy, spaciousness and typical internal distribution (well described in chapter n°5) .

The residential building host three types of housing :

- Apartment : there are 15 units of which 8 are 210 $m^2$ “Type A” , 4 are 195 $m^2$ “ Type B” and 3 are 135 $m^2$ “Type C”
- Roof top apartment “Type D” : there is a 257 $m^2$ unit with both a 50 $m^2$ and 80 $m^2$ roof top balcony.
- Pentahouse ville “Type E”: There is a 293 $m^2$ unit with a 142 $m^2$ private roof top balcony.

All units respect the cultural need of separation between private, semi-private and public area ( paragraph 5.2) as is better described in the unit in example figure 54.


Figure 54- The project rispect the cultural needs of plan distribution.

## Type A: Apartment 210 m²

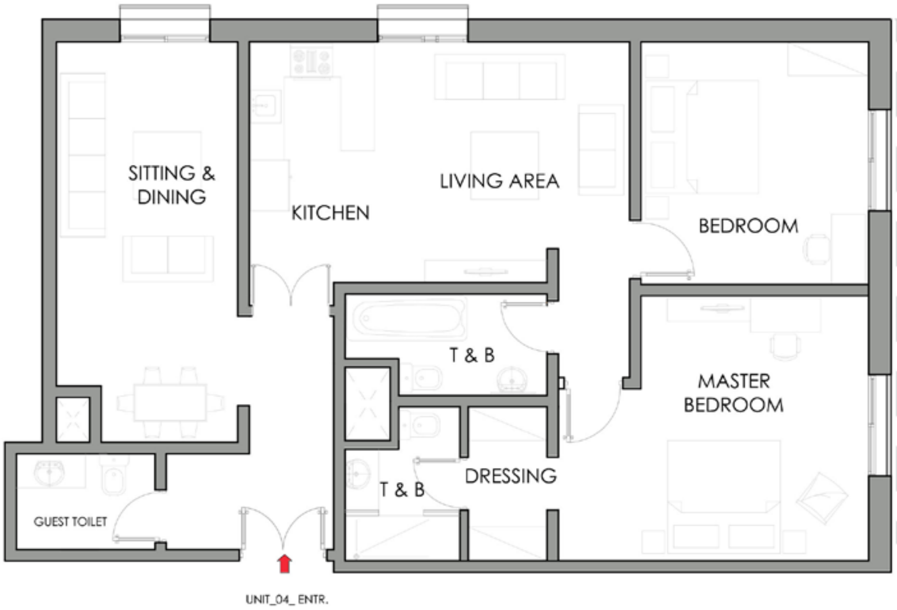
Plan out of scale


## Type B: Apartment 195 m²

Plan out of scale

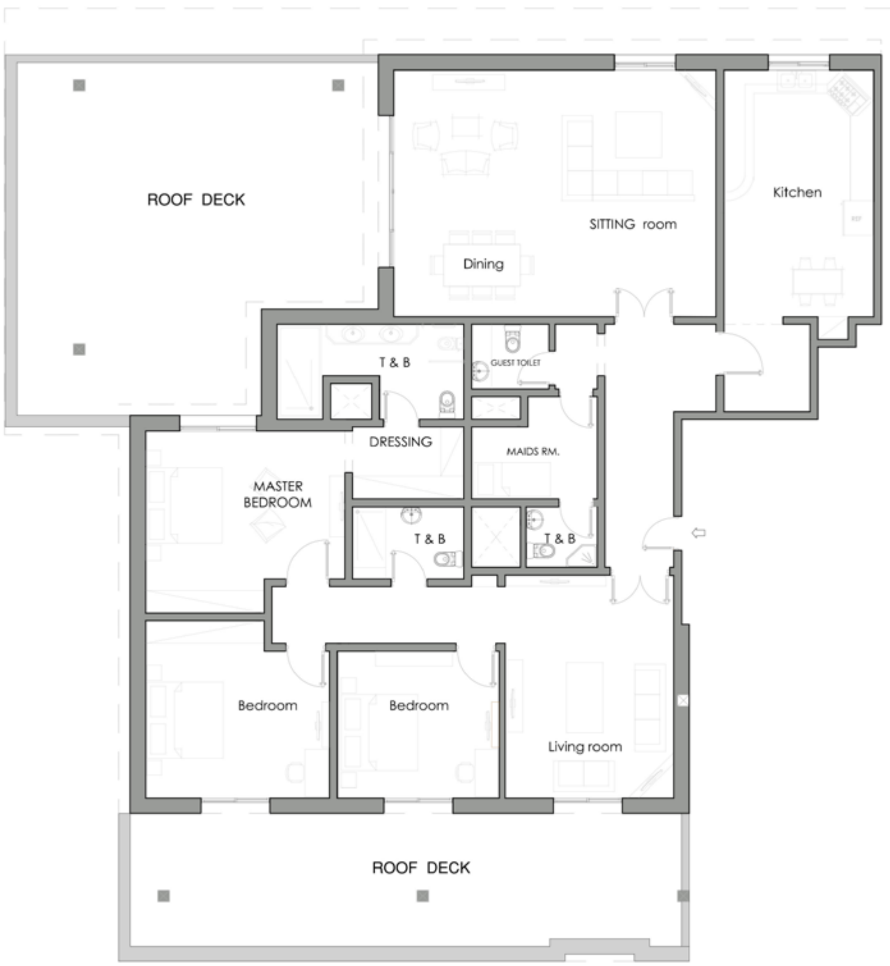
## Type C: Apartment 135 m²

Plan out of scale



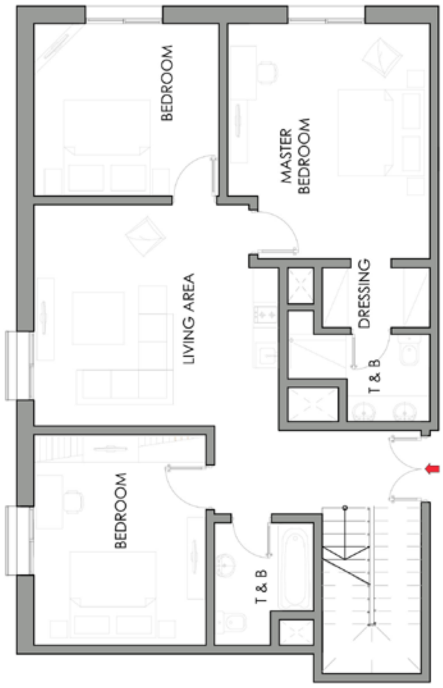

## Type D: Roof top apartment 257 m²

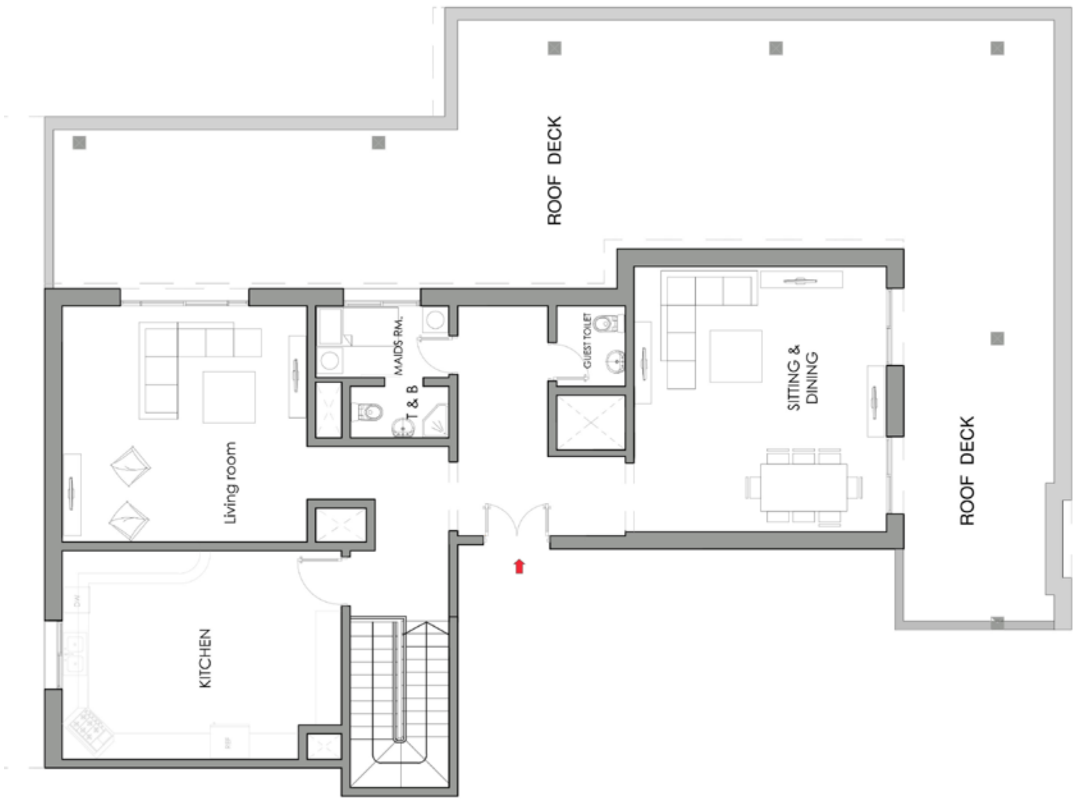
Plan out of scale



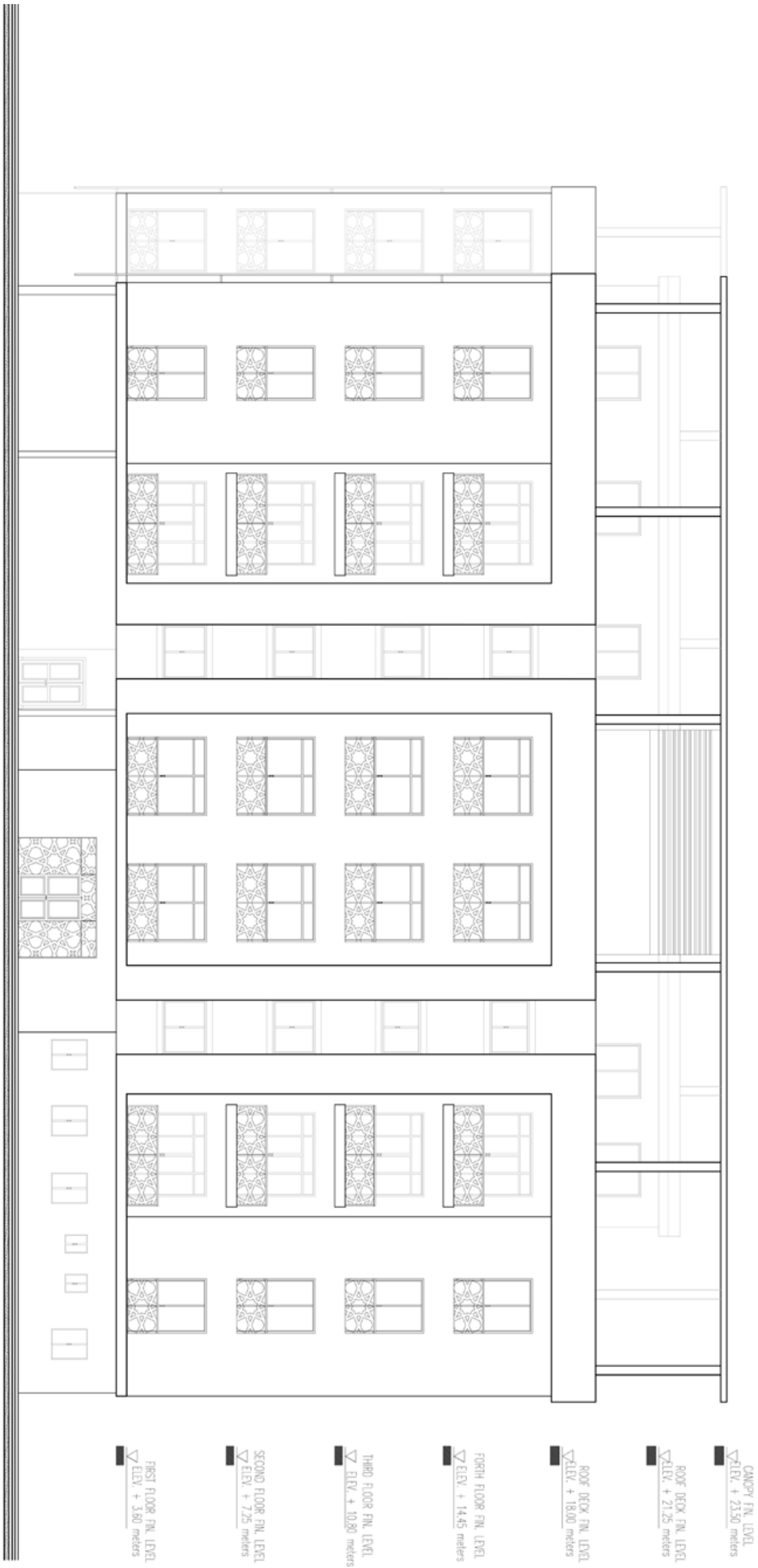
## Type E:
## Pentahouse villa  293 m²

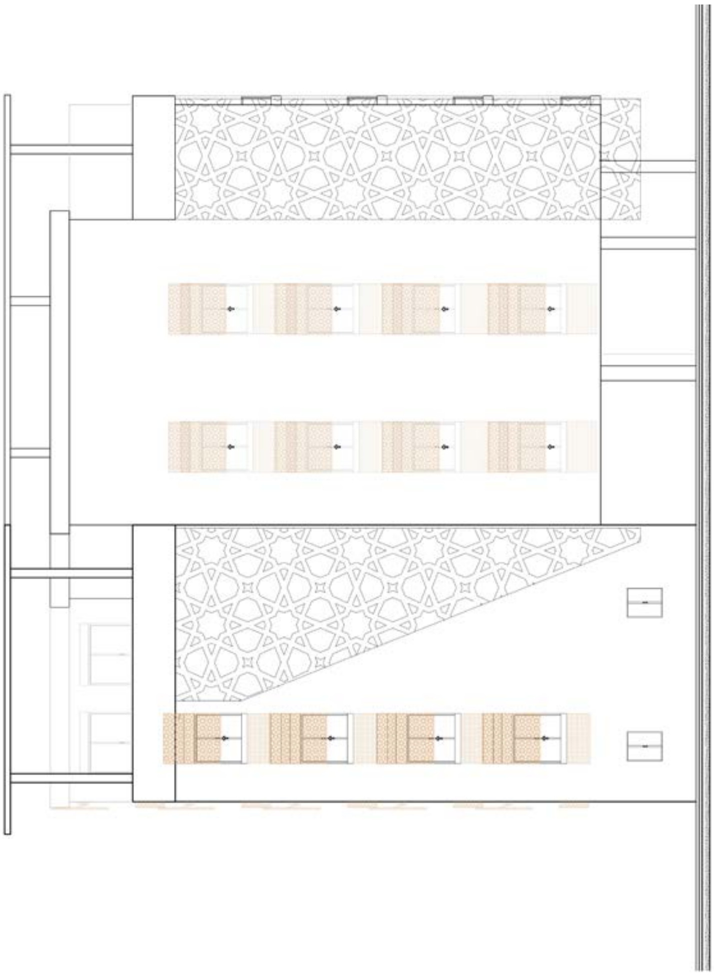
Plan out of scale



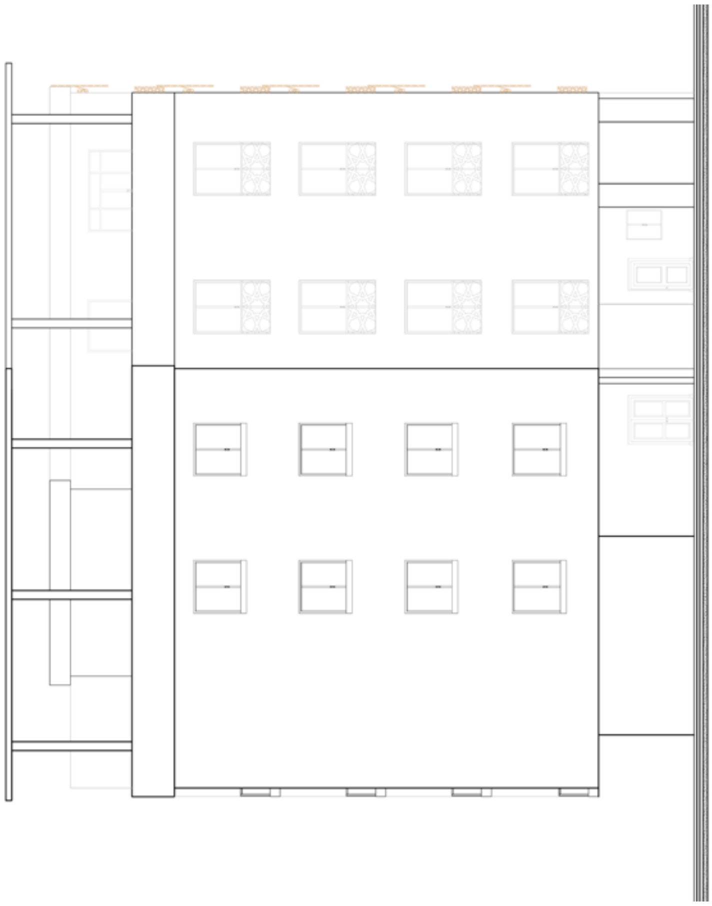



NE elevation

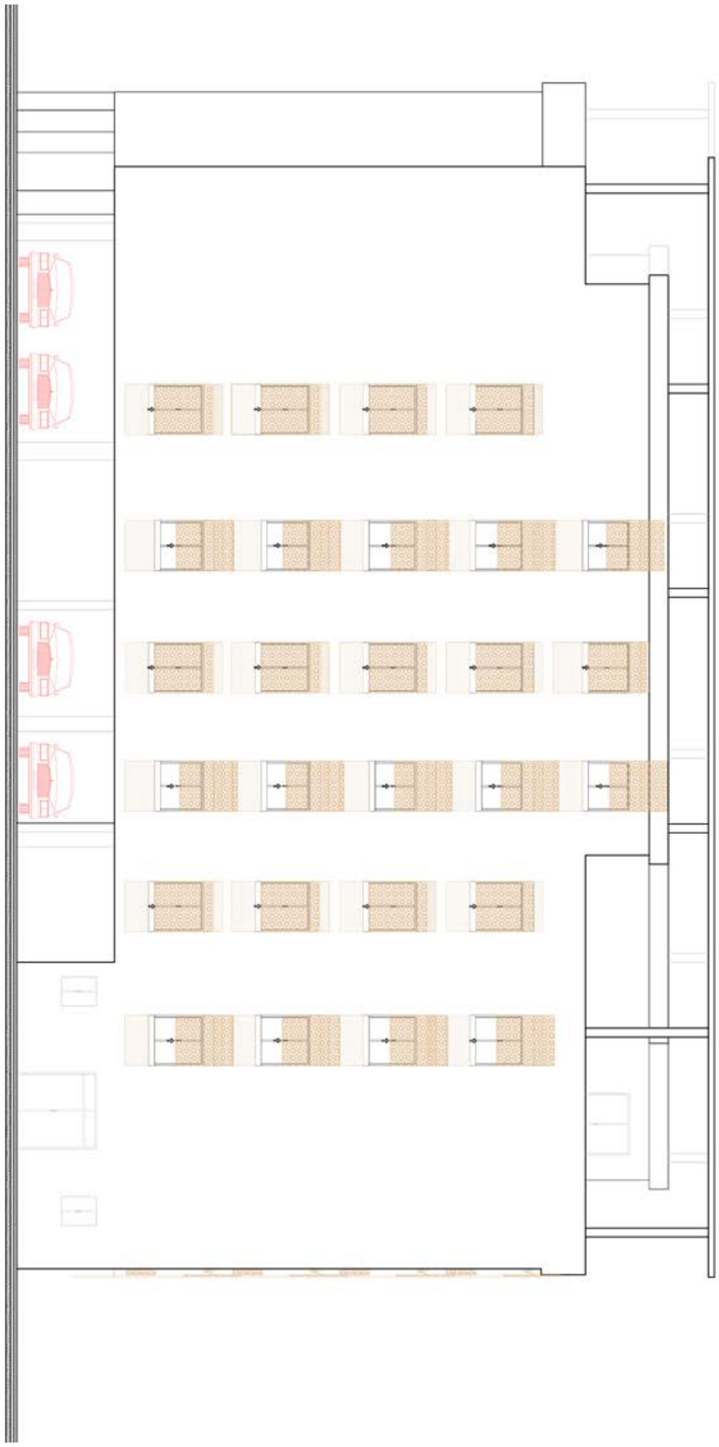




SE elevation



NW elevation



SW elevation

### 7.4.2 Passive building Strategies and Materials

For an efficient nZEB building it is necessary to reduce the consumption, studying a high performance building. To improve its envelop it is important to study a high- efficient stratigraphy for the external wall , roof and windows. The nZEB project, will adopt some technological material choices and passive strategies, considering as much as possible the materials present on the Saudi market, to improve the passive performance and the energy efficiency of the building.
The passive strategies and choices are :

- Using PCM ( the phase changing material) in external wall and roof stratigraphy.
- Increasing the insulation thickness with high performance.
- Installing double glazing windows
- Reusing a traditional element " Mashrabyya " (the wooden balusters) for its environmental functions like solar shading, humidity and air flow control, and reducing the heat as well as it guarantees privacy.
- Using Solar protection devices.
- Installing a canopy over the roof to reduce its solar exposure factor.
- Scheduling the heating and cooling system according to the periods in need, taking advantage of the building passive performance in periods characterized by a comfortable climate.

7.4.2.1 PCM (Phase Change Material)

Phase change materials are substances that have the ability to pass from solid to liquid state and vice versa, in a range of temperatures to be used for the accumulation of power.  The phase shift begins as much as the temperature rises to the melting point. During the phase transition, which requires a high level amount of energy, the material is kept at a temperature close to the melting point. In solidification phase takes place the reverse process, with the release of thermal energy and the passage to the solid state. In this way, since 1970s, studies have analyzed the possibility of using phase change materials in the energy efficiency field as accumulator of thermal energy.

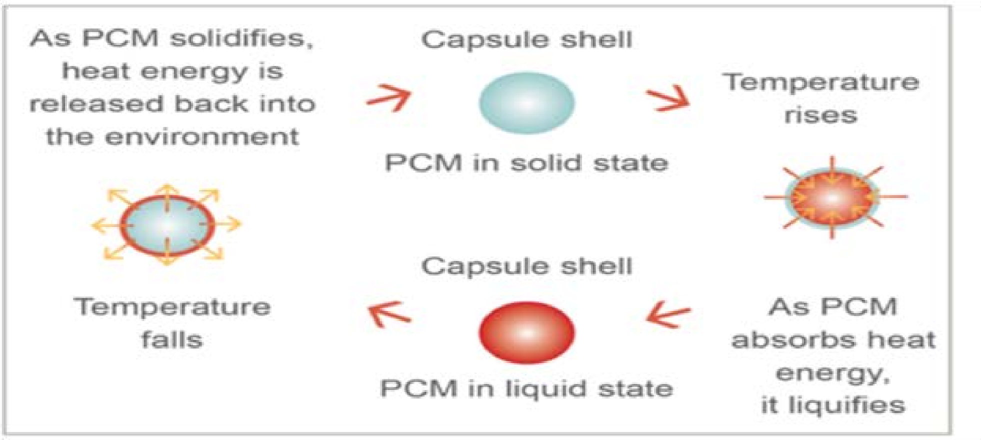



Figure 55- PCMs release heat energy by solidification process and absorb heat energy before liquefaction takes place. Source: Kosny and Kossecka (2013) International Journal of Sustainable Energy and Environmental Research, 2016, 5(4): 70-78

In the construction sector we find a large number of applications, both in the field of research scientific and industrial, both in experimental buildings. It is however possible to summarize the applications in:

- Walls or casing elements
- Passive and active solar systems
- Thermal accumulators
- Floor heating and cooling systems
- Air exchangers

The first possible application of phase change materials in the construction sector is within of the stratigraphy of the envelope: of this application there are several variants, by technology,
operation and benefits obtainable, but most of these with the objective of conferring thermal inertia. In AlKhobar nZEB case the material are


Figure 56- Prototype of polycarbonate alveolar panels to contain PCM, by Bruno Giampà e Gianluca Gindro, "Inerzia trasparente: definizione progettuale e validazione sperimentale di uncomponente di facciata in policarbonato alveolare e PCM" Politecnico di Torino ,2010

The first classification of materials used for thermal storage appeared in 1983 and was proposed (Abhat) . Based on chemical composition, a PCM can be classified as an organic, inorganic or eutectic compound.

Organic materials, in turn, can be paraffinic or non-paraffinic. Typically, they can change their state several times without displaying any degradation. Salt hydrates and metals belong to a class of inorganic materials. The eutectic mixtures result from the combination of two or more organic and/or inorganic compounds, with the transition temperatures that can meet specific demands. (Mariaenrica Frigione , Mariateresa Lettieri and Antonella Sarcinella)

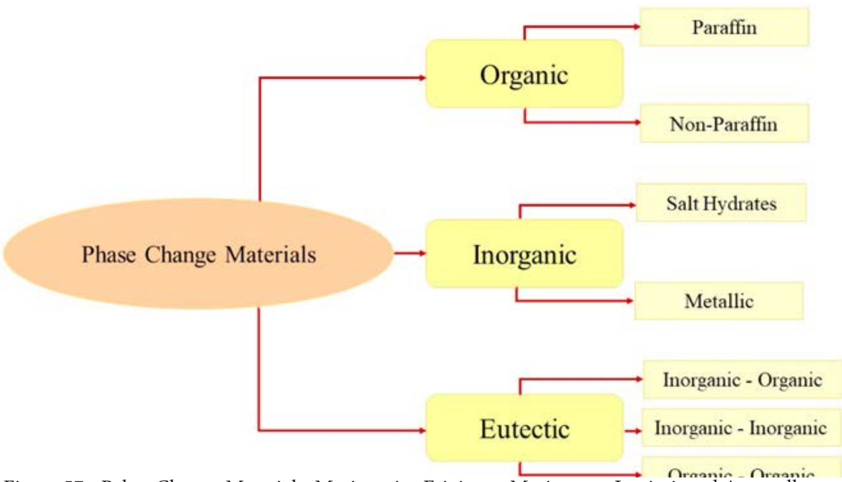



Figure 57 - Pahse Change Materials, Mariaenrica Frigione , Mariateresa Lettieri and Antonella Sarcinella, Phase Change Materials for Energy Efficiency in Buildings and Their Use in Mortars, april 2017

In the “hot” climatic areas, as Al Khobar situation, the applications were aimed at reducing the energy consumption of heating and to improve internal comfort, by increasing the given thermal inertia from a layer of PCM placed inside the stratigraphy, generally on the layer near the external coating. This application allows you to absorb most of the solar radiation it generates overheating of the building elements and producing a thermal load. When they are used in construction building, change phase occur from solid to liquid at 23-26°C. As PCM start to melt, they will absorb heat from the room so the room temperature will be stable. At night, PCMs will go back to its original solid state during ventilation. These valuable PCMs properties will significantly decrease cooling and heating energy demand if properly implemented and managed.

In a case study research on the application of PCM in a single family home in Al Khobar ( NET-ZERO ENERGY BUILDING – CASE STUDY AL KHOBAR CITY, SAUDI ARABIA Nader. A. Nader Rami S. Alsayed), the results analysis shows a 20% reduction of cooling load when utilizing PCMs materials in comparison to conventional ones.

### 7.4.2.2 The nZEB Al Khobar Envelop Stratigraphy

The latest regulations in force dictate a maximum u wall value of 0.34 (in Italy 0.26). It is a value that makes it difficult to achieve an efficiency from nZEB so it is necessary to go down considerably.

It is decided to make the project choices of materials which are available and in use on the site. In al Khobar it is used to build the external walls using 200 mm concrete bricks. In the last few years the insulation in the brick was integrated to reach the regulation satisfaction as much as possible. But in the case of nZEB it is not enough, so it was decided to use the cement brick without insulation and to add 160 mm thick stratigraphy of extruded polystyrene insulation that is available in their market. In addition is important the choice of Gypsum Board PCM (material elaborated on PCM paragraph).

U Ex.Wall = 0.143 W/m$^2$K
U roof = 0.148 W/m$^2$K
U double glaze window=1.89W/m$^2$K

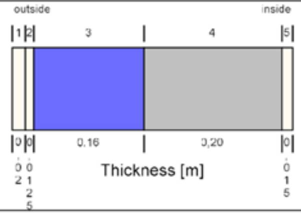
### 7.4.2.2.1 External Wall

Homogenous layers

Thermal resistance: 6,835 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0,143 W/m²K

Thickness: 0,408 m




| Nr. | Material/Layer (from outside to inside) | ρ [kg/m³] | c [J/kgK] | λ [W/mK] | Thickness [m] | Color |
|---|---|---|---|---|---|---|
| 1 | Cement Lime Plaster (stucco, A-value: 2.0 kg/m2h0.5) | 1900 | 850 | 0,8 | 0,02 | |
| 2 | Gypsum Board; PCM | 800 | 1200 | 0,2 | 0,013 | |
| 3 | Extruded Polystyrene Insulation | 28,6 | 1470 | 0,025 | 0,16 | |
| 4 | Concrete Brick | 2315 | 800 | 0,733 | 0,2 | |
| 5 | Interior Plaster (Gypsum Plaster) | 850 | 850 | 0,2 | 0,015 | |

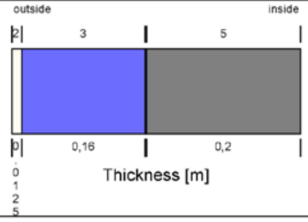
### 7.4.2.2.2 Warm roof

Homogenous layers

Thermal resistance: 6,594 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0,148 W/m²K

Thickness: 0,375 m




| Nr. | Material/Layer (from outside to inside) | ρ [kg/m³] | c [J/kgK] | λ [W/mK] | Thickness [m] | Color |
|---|---|---|---|---|---|---|
| 1 | PVC Roof Membrane | 1000 | 1500 | 0,16 | 10E-4 | |
| 2 | Gypsum Board; PCM | 800 | 1200 | 0,2 | 0,013 | |
| 3 | Extruded Polystyrene Insulation | 28,6 | 1470 | 0,025 | 0,16 | |
| 4 | PE-Membrane 0,2 mm (sd = 87 m) | 130 | 2200 | 1,65 | 10E-4 | |
| 5 | Concrete, C35/45 | 2220 | 850 | 1,6 | 0,2 | |

### 7.4.2.2.3 Window

Double Glazing: Low-e, low-solar 2, Frame: Insul. Fiberglass/Vinyl -

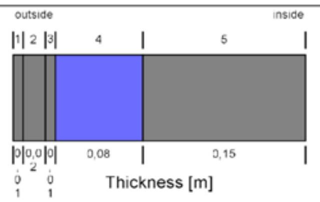
| | |
|---|---|
| Uw -mounted [W/m²K] | 1,89 |
| Frame factor | 0,7 |
| Solar energy transmittance hemispherical | 0,31 |
| Long wave radiation emissivity (mean glazing/frame) | 0,8 |

## 7.4.2.2.4 Ceiling over unheated environment

Homogenous layers

Thermal resistance: 3,334 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0,272 W/m²K




Thickness: 0,27 m

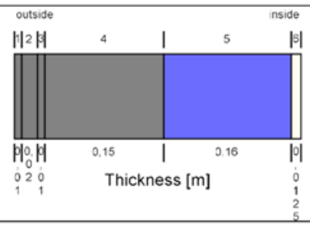
| Nr. | Material/Layer (from outside to inside) | ρ [kg/m³] | c [J/kgK] | λ [W/mK] | Thickness [m] | Color |
|---|---|---|---|---|---|---|
| 1 | Concrete Screed, top layer | 1890 | 850 | 1,6 | 0,01 | |
| 2 | Concrete Screed, mid layer | 1970 | 850 | 1,6 | 0,02 | |
| 3 | Concrete Screed, bottom layer | 1990 | 850 | 1,6 | 0,01 | |
| 4 | Extruded Polystyrene Insulation | 28,6 | 1470 | 0,025 | 0,08 | |
| 5 | Concrete | 2104 | 776 | 1,373 | 0,15 | |

## 7.4.2.5 Ceiling over heated environment

Homogenous layers

Thermal resistance: 6,597 m²K/W (without Rsi, Rse)

Heat transfer coefficient (U-value): 0,147 W/m²K



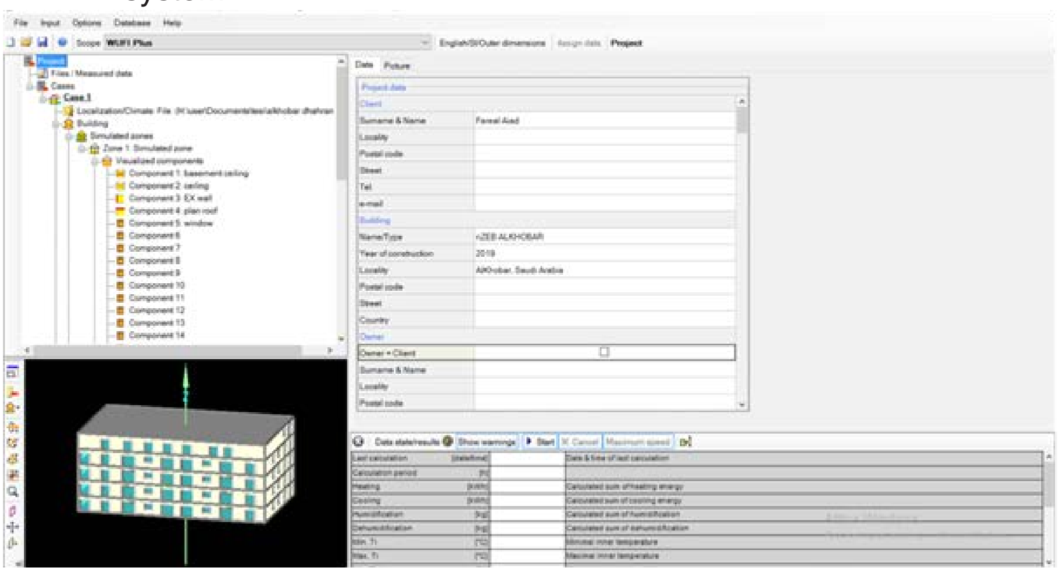

Thickness: 0,363 m

| Nr. | Material/Layer (from outside to inside) | ρ [kg/m³] | c [J/kgK] | λ [W/mK] | Thickness [m] | Color |
|---|---|---|---|---|---|---|
| 1 | Concrete Screed, top layer | 1890 | 850 | 1,6 | 0,01 | |
| 2 | Concrete Screed, mid layer | 1970 | 850 | 1,6 | 0,02 | |
| 3 | Concrete Screed, bottom layer | 1990 | 850 | 1,6 | 0,01 | |
| 4 | Concrete | 2104 | 776 | 1,373 | 0,15 | |
| 5 | Extruded Polystyrene Insulation | 28,6 | 1470 | 0,025 | 0,16 | |
| 6 | Gypsum Board; PCM | 800 | 1200 | 0,2 | 0,013 | |

### 7.4.3 WUFI plus Simulation

WUFI Plus is a heat and moisture simulation tool in the WUFI software family. In addition to simulating hygrothermal conditions in building components, WUFI Plus simulates the indoor environment and is therefore suitable for addressing comfort and energy consumption in buildings. Since simulations are based on user-specified climate and on user-defined ventilation, HVAC, and internal loads, the simulations can accurately represent the situation. Simulation of the interaction between building usage and system technology allows for integral assessment of indoor climate, thermal comfort, indoor air quality, and damage to components as a function of heating and cooling loads and the necessary effort to humidify/dehumidify.
Integrated modules for dynamic analysis of 3D bodies (thermal bridges) and for air exchange between conditioned zones and the outside further expand the capabilities of WUFI Plus.
The model for an energy simulation was developed within the WUFI PLUS V3.2.0.1 software, which allows to simulate the nZEB Al Khobar progress, the efficiency of its materials and the energy demand for heating and cooling of the building within a year. It takes into consideration, besides the design choices and the HVAC system, the climatic data of the location got from "The General Authority for Meteorology and Environmental Protection" in the Easter province.
Various simulations are carried out so that the optimal solution is reached:

- Simulation of the inner inner climate condition of the building
- Simulation of the building design conditions with an ideal HVAC system



#### 7.4.3.1 Simulation of the inner inner climate condition of the building

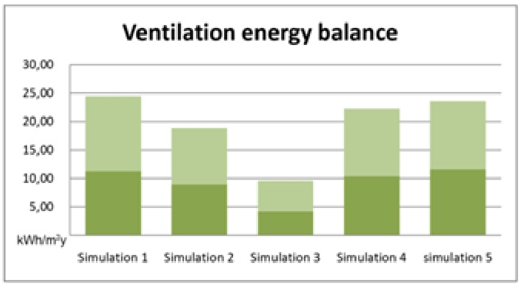
With wufi it is possible to analyze the passive performance of the building, evaluating the inner climatic conditions. The average duration of a simulation is 1 min 30 seconds. There are 5 simulations that present 5 different conditions by alternately combining ventilation with the presence or absence of solar shading device and thermal bridge.

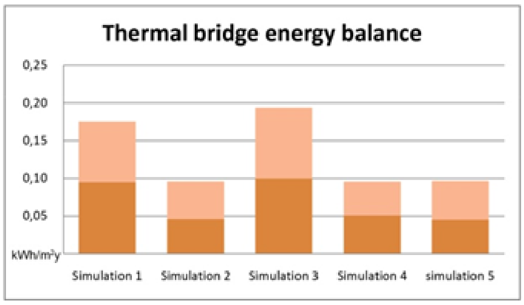
| | | | | | Results | Inner temprature | | Inner Relative humidity | |
|---|---|---|---|---|---|---|---|---|---|
| | Ventilation | Ventilation scheduled | Solar Shading Device | Thermal bridge | | min Ti | max Ti | min | max |
| Simulation 1 | 0,5/h | no | no | yes | | 12,8 | 37,9 | 15 | 100 |
| Simulation 2 | 0,5/h | no | no | no | | 12,5 | 39 | 15 | 100 |
| Simulation 3 | 0,2/h to 3/h all periods | yes | yes | yes | | 14 | 37,9 | 13,1 | 100 |
| Simulation 4 | 0,2/h to 3/h all periods | yes | yes | no | | 12,8 | 38 | 13 | 100 |
| simulation 5 | 0,2/h to 3/h mild period | yes | yes | no | | 14,6 | 37,8 | 12,8 | 100 |

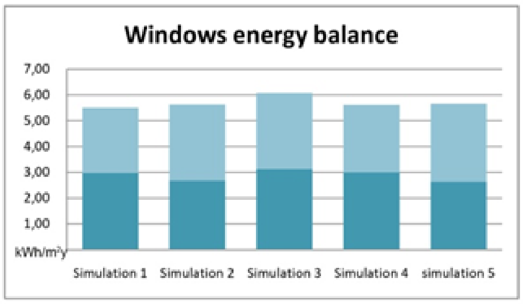
Comparing the simulation results, regard the min and max temperatures, the relative humidity and the resulting energy balance, some important considerations come up:

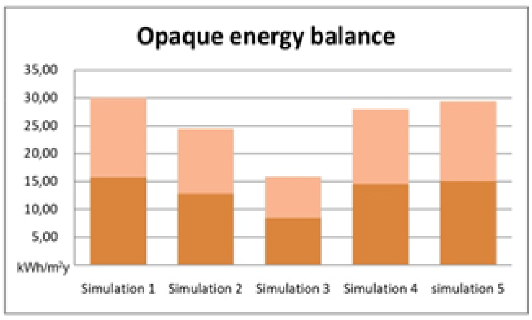
- A scheduled ventilation, increasing it in periods characterized by a mild climate and reducing it in the summer period, affects the inner temperatures and humidity by improving its conditions.

- The small thermal bridges do not affect a hot climate like the Khobar where the main problem is the heat and not the cold as in Europe make worse the inner climate conditions, indeed from the simulations it results that in the presence of the thermal bridge the maximum internal temperature is reduced and the min temperature rises.



### 7.4.3.2 Simulation of the building design conditions with an ideal HVAC system

Through simulation of the building design conditions with an ideal HVAC system on Wufi plus software, it is possible to analyse the energy demand to cover the heating and cooling of a hypothetical ideal hvac system. In this study the three most significant simulations are chosen to analyse, each presenting different situations to evaluate which could be best operating strategies for a lower energy consumption. The average duration of each simulation is 5 h 50 min.

| | Ventilation | Ventilation scheduled | Solar Shading Device | HVAC schedule |
|---|---|---|---|---|
| **Simulation 1** | 0,3/h | no | yes | no |
| **Simulation 2** | 0,2/h to 3/h | yes | yes | no |
| **Simulation 3** | 0,2/h to 3/h | yes | yes | yes |
| | | 15/3 to 14 /5 | | cooling : 15/11 to 15/3 |
| | | 16/9 -14/11 | | Heating :15/5 to 15/ 9 |

Results

| | Cooling E.need kWh/m$^2$ y | Heating E. Need kWh/m2 y | humidification kg | dehumidification kg |
|---|---|---|---|---|
| **Simulation 1** | 49,34 | 9,8071 | 7,87 | 45,73 |
| **Simulation 2** | 55,79 | 17,99 | 19,07 | 67,12 |
| **Simulation 3** | 32,89 | 6,54 | 19,07 | 67,12 |

Comparing the simulation results some important considerations come up:

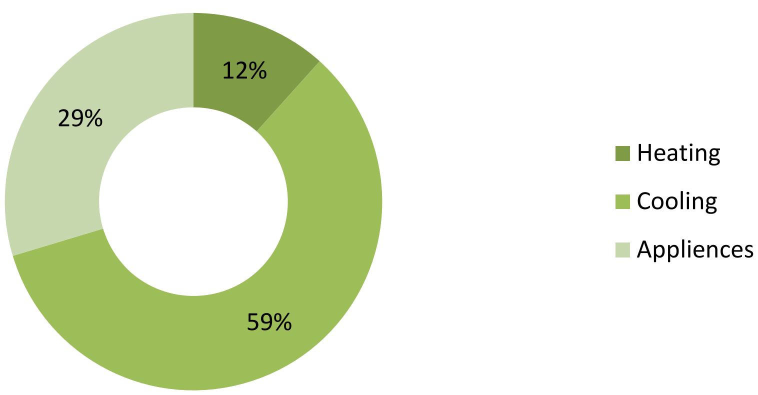
- The dehumification grows noticeably increasing ventilation, due to the humid climate characterizing the place
- Cooling and heating energy needs increse when increase the ventilation if the HVAC system is not scheduled.

In this study, case “simulation 1” is chosen to size the Phovoltaic System need to cover the total energy consumption of the nZEB Al Khobar.

Thanks to the passive strategies taken to improve the performance, it is able to reach an annual energy need for heating 9,81 kWh/m$^2$y and cooling 49,34 kWh/m$^2$ which is a total Energy need equal to 59,15 kWh/m$^2$y.
Regarding the energy need of household appliances per apartment is simulated with PV syst Software . From the analysis it comes out an household appliances energy demand equal to 24,91 kWh/m$^2$y.
Consequently the total energy need is equal to 84,06 kWh/m$^2$y instead of the average consumption 176,5 kWh/m$^2$y (Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province).
In the nZEB Al Khobar the Energy demand is reduced almost 52,3 % compared to a standard multi-storey building .

| | | | | |
|---|---|---|---|---|
| Heating | 39.763,70 | kWh /y | 9,81 | kWh/m$^2$y |
| Cooling | 200.055,40 | kWh /y | 49,34 | kWh/m$^2$y |
| Appliences | 100.998,00 | kWh /y | 24,91 | kWh/m$^2$y |
| Total Energy Need | 340.817,10 | kWh /y | 84,06 | kWh/m$^2$y |

**nZEB Al Khobar Energy Needs**



## 7.5 Photovoltaic Panels Power Potential in Al Khobar

At this point in the design of nZEB Alkhobar, having calculated the energy needs of the building. It proceeds with the estimation of the Phovoltaic panels system needed to cover the energy demand. A photovoltaic system would installed on a canopy over the roof, to grantee the maximum area availability and increase the shade factor on the roof as one of passive building strategies.

Solar photovoltaic systems or solar PV systems can be simply defined as power systems, which use photovoltaic technology to convert solar energy into usable electrical energy.

Its feasibility in Saudi Arabia is granted because of it is location between 17.5˚N and 31˚N in latitude, and 36.5˚E to 50 ˚E in longitudes, with relatively high potential of both solar radiation and sunshine hours as a result of its unique location and climate (Chapter 5).

The nZEB Al Khobar takes place Al Khobar area which has around 1800 kWh/m2 ( www.solargis.com) average annual of solar ,while the photovoltaic potential is about 1720 kWh/kWp (http://re.jrc.ec.europa.eu/pvgis/). Comparing it with Turin about 1400 kWh/m$^2$ average annual of solar irradiation and 1330 kWh/kWp photovoltaic potential (http://re.jrc.ec.europa.eu/pvgis/) the potential of location PV production is clearly visible.

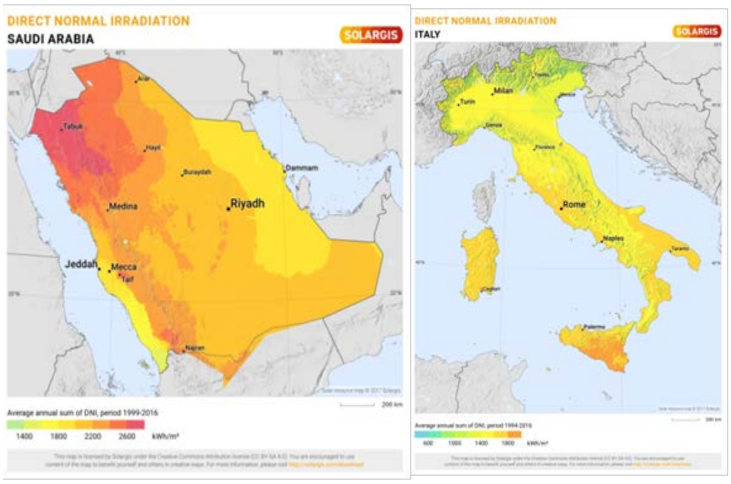



Figure 58- Saudi Arabia compared to Italy Direct normal irradiation.
source: www.solargis.com

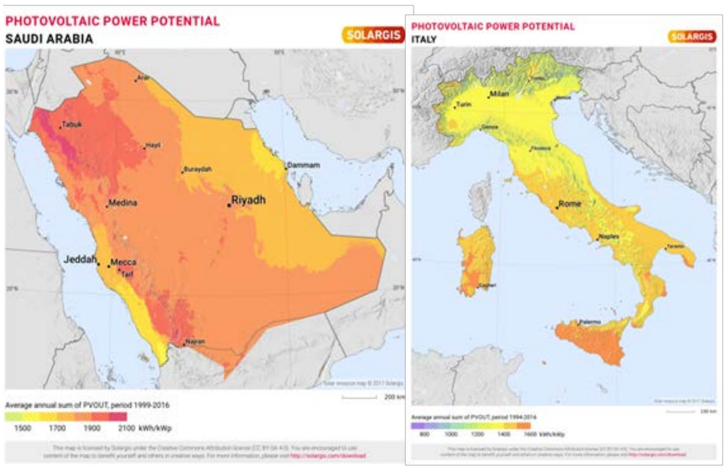



Figure 59 - Saudi Arabia compared to Italy Photovoltaic power potential.
source: www.solargis.com

### 7.5.1 Photovoltaic system in Nzeb Al Khobar

It is analysed to find out the percentage of potential energy product by PV panels system from the building's total canopy area using PVgis: a free online photovoltaic calculator tool to optimise light harvesting in vinticular .

A 375 Wp PV panel is chosen to be used in this study. It is "HyPro-mono half cell solar module 375 W" by SUNTECH, present on the Saudi market. The panel is 1.99 x 0.9 x 40 mm size and is going to be installed in the canopy over the roof ( example figure ) .

Then, the modules are drawn in AutoCAD twice assuming the following cases:

- PV panels are tilted with 24˚ optimal angle.
- PV panels are horizontal or flat with zero tilt angle.

Figure 60- example of A canopy which has an intgrated PV pnales system.

#### 7.5.1.1 PV panels are tilted with 24˚ optimal angle

The optimal position for maximum Al Khobar energy production would be with tilted 24 ° angle in the south direction as analysed by the calculation made on PVgis. In fact in that case a panel would produce 640 kWh / m2y. The Canopy is 906 $m^2$.

| Fixed system: inclination=24°, orientation=0° | | | | |
|---|---|---|---|---|
| Month | $E_d$ | $E_m$ | $H_d$ | $H_m$ |
| Jan | 1.48 | 45.8 | 5.15 | 160 |
| Feb | 1.63 | 45.7 | 5.76 | 161 |
| Mar | 1.82 | 56.3 | 6.52 | 202 |
| Apr | 1.74 | 52.2 | 6.35 | 191 |
| May | 1.89 | 58.6 | 7.05 | 219 |
| Jun | 1.92 | 57.5 | 7.25 | 218 |
| Jul | 1.84 | 57.1 | 7.02 | 218 |
| Aug | 1.89 | 58.6 | 7.22 | 224 |
| Sep | 1.96 | 58.8 | 7.43 | 223 |
| Oct | 1.86 | 57.7 | 6.95 | 216 |
| Nov | 1.55 | 46.5 | 5.59 | 168 |
| Dec | 1.44 | 44.7 | 5.07 | 157 |
| **Yearly average** | **1.75** | **53.3** | **6.45** | **196** |
| **Total for year** | | **640** | | **2350** |

$E_d$: Average daily electricity production from the given system (kWh)
$E_m$: Average monthly electricity production from the given system (kWh)

Figure 61 - PVgis analysis for Al Khobar inclined panel with 24° tilt angle and south orientation.

Source: www.pvgis.com

Studying the arrangement of the inclined panels and considering that the distance between two PV arrays must be 3 times the height of panels. In this way, it is possible to install 233 panels with a total energy production equal to 149.008,61 kWh / y which would cover 44% of the Energy needs.

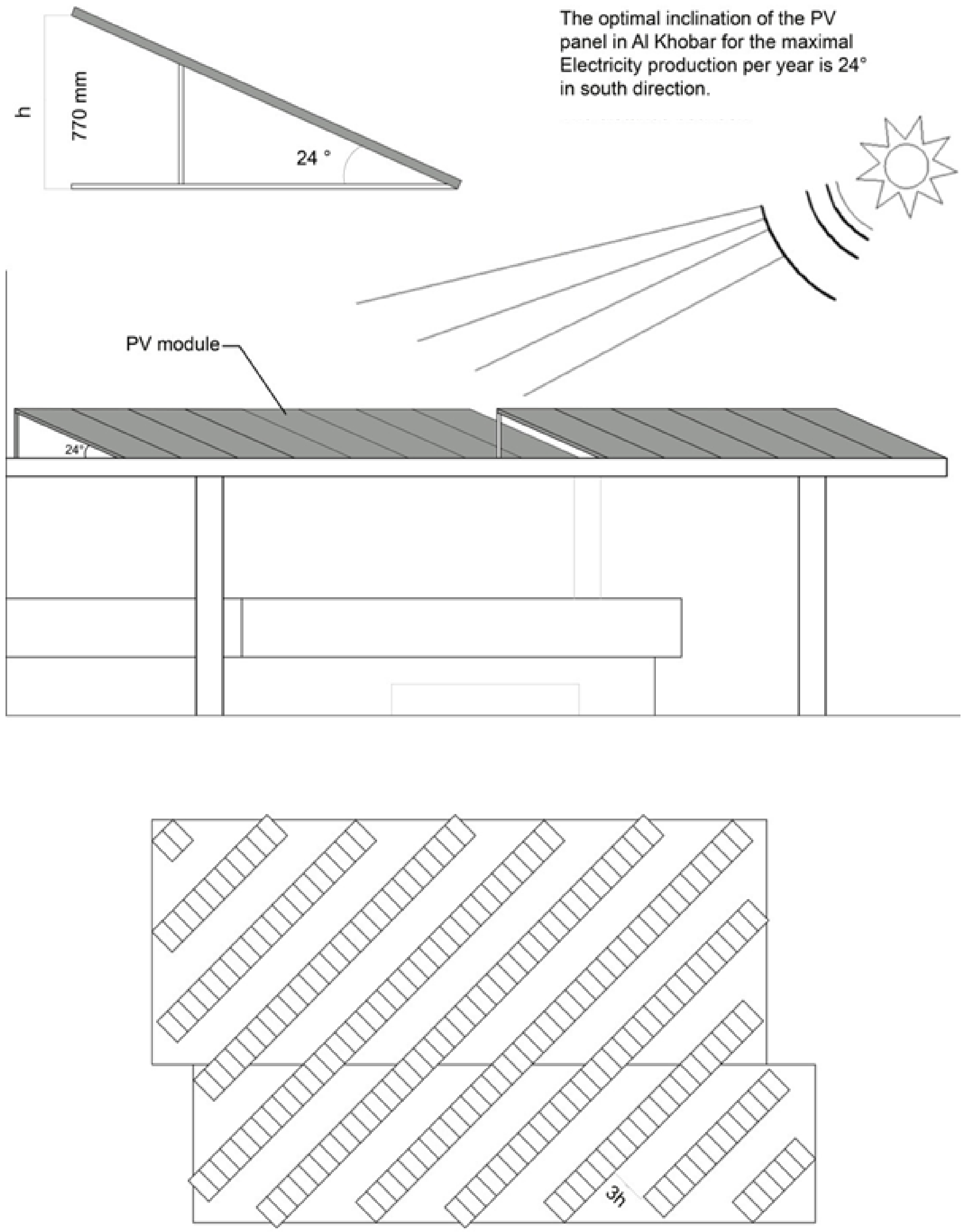



Figure 62-Autocad design showing the layout of the panels at 24° tilt angle in south orientation set on the canopy in project.

### 7.5.1.2 PV panels are horizontal or flat with zero tilt angle

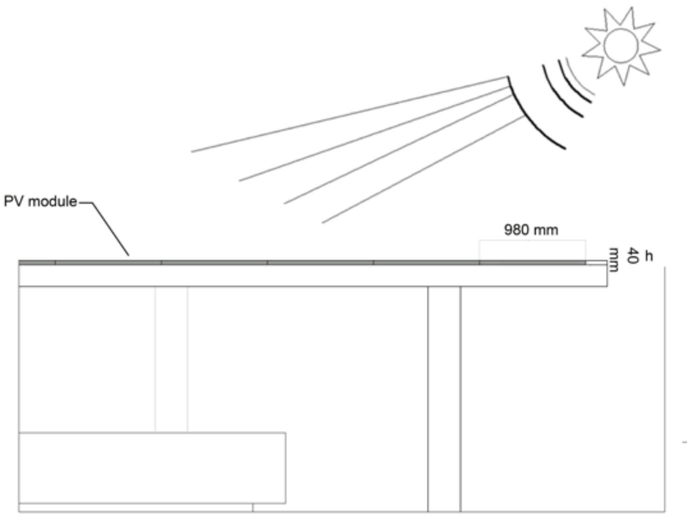
The PV panels module in horizontal 0° tilt integrated in the 906 $m^2$ canopy which can assume 530 module. The maximum electricity production of a 375 Wp PV panel module in Al Khobar with 0° tilt angle is 604 kWh / $m^2$y. The Canopy is 906 $m^2$. Studying the arrangement of the flat panels it is possible have a total energy production equal to 320.014,04 kWh / y, which would cover 94% of the building Energy Needs 340 817,10 kWh/y.

| Fixed system: inclination=0°, orientation=45° | | | | |
|---|---|---|---|---|
| **Month** | **$E_d$** | **$E_m$** | **$H_d$** | **$H_m$** |
| Jan | 1.13 | 34.9 | 3.93 | 122 |
| Feb | 1.36 | 38.2 | 4.77 | 134 |
| Mar | 1.69 | 52.2 | 6.01 | 186 |
| Apr | 1.77 | 53.0 | 6.42 | 193 |
| May | 2.06 | 63.8 | 7.66 | 238 |
| Jun | 2.17 | 65.1 | 8.21 | 246 |
| Jul | 2.04 | 63.2 | 7.76 | 241 |
| Aug | 1.97 | 61.2 | 7.51 | 233 |
| Sep | 1.86 | 55.8 | 7.01 | 210 |
| Oct | 1.58 | 49.0 | 5.85 | 181 |
| Nov | 1.17 | 35.2 | 4.23 | 127 |
| Dec | 1.05 | 32.7 | 3.71 | 115 |
| **Yearly average** | **1.66** | **50.4** | **6.10** | **185** |
| **Total for year** | | **604** | | **2230** |

$E_d$: Average daily electricity production from the given system (kWh)
$E_m$: Average monthly electricity production from the given system (kWh)

Figure 63 - PVgis analysis for Al Khobar for flat panel with 0° tilt angle.

Source: www.pvgis.com




Canopy elevation: 530 PV panels module with 0° tilt angle integrated in the canopy area 906 m².

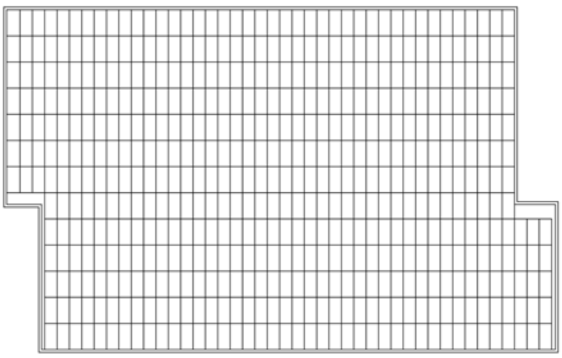
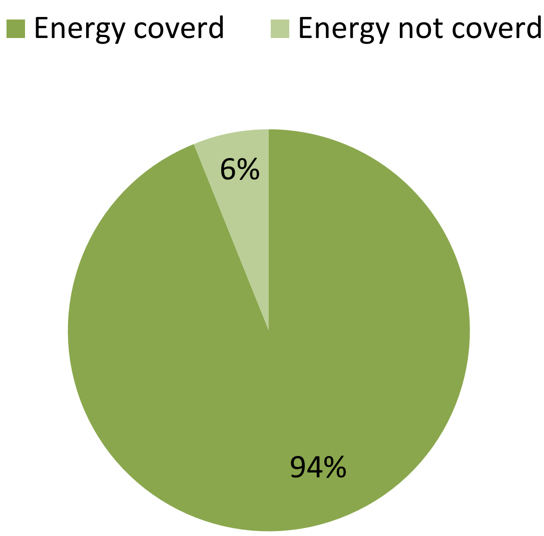


Figure 64-Autocad design showing the layout of the panels at 0° integrated in the canopy in project.

| | | |
|---|---|---|
| PV panel Ey 0° | 604 | kWh /m$^2$y |
| | | |
| Canopy Area | 906 | m$^2$ |
| Panel Area | 1,71 | m$^2$ |
| Total N°panels | 530 | |

| | | | |
|---|---|---|---|
| Energy need | 340.817,10 | kWh/y | 100% |
| Energy coverd | 320.014,04 | kWh/y | 94% |
| Energy not coverd | 20.803,06 | kWh/y | 6% |



Chapter 8

# CONCLUSION

According to the “BP Statistical Review of World Energy 2017”, Saudi Arabia was the world’s 10th largest consumer of total primary energy in 2016 and the energy needs are going to grow faster in future. The buildings residential, governmental and commercial in KSA consume 80% of the electricity generated in the country, of which 51.2% is used by residential buildings, and AC represents more than 70% of this consumption. Saudi Government has taken measures to face this huge growth in consumption but it is not enough to have more energy-sustainable cities

The Nealry ZERO ENERGY BUILDING concept could be an ideal solution to face the challenges associated with increasing of residential building energy consumption, specially due to the Saudi Arabia strong potentiality of renewable energy, in particular solar energy.

In this way, it was decided to design a residential building for a more sustainable choice and to meet the needs of the new generations in Al Khobar. It is a main city in promising growth from a constructive point of view in the Eastern Province, on the coast of the Persian Gulf, characterized by a hot and humid climate.

For the Saudi society that conceives the house as a single family building, the decision to design a multi-storey building was a compositional challenge, in which it was important to satisfy the cultural needs of privacy, spaciousness and typical internal distribution, in an apartment instead of a villa building typology. Although in the city of Al Khobar residential buildings are present but are meant more for foreigners families and single workers.

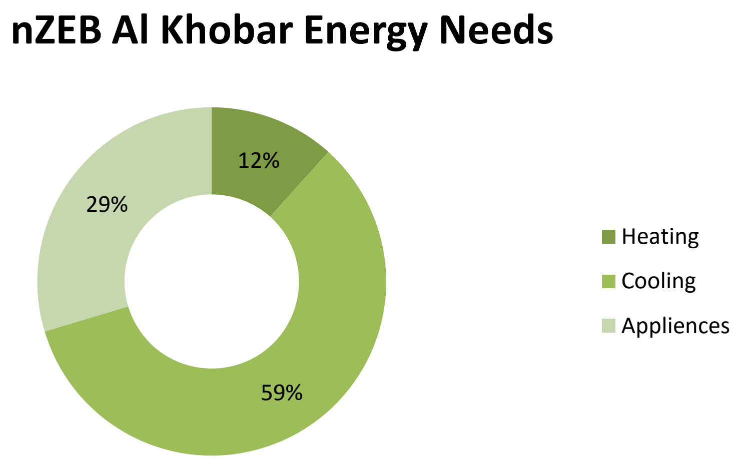
As far as the design of the nZEB was concerned, it was necessary first of all to create a building with high passive performance in order to reduce its energy demand. Some technological material choices and passive strategies, considering as much as possible the materials present on the Saudi market, was adopted: using PCM (phase change material) , increasing the insulation thickness, Installing double glazing windows, reusing a traditional element “Mashrabyya “ (wooden baluster) taking advantage of its environmental functions, using solar protection devices, Installing a canopy over the roof and scheduling the HVAC system according to the periods in need.

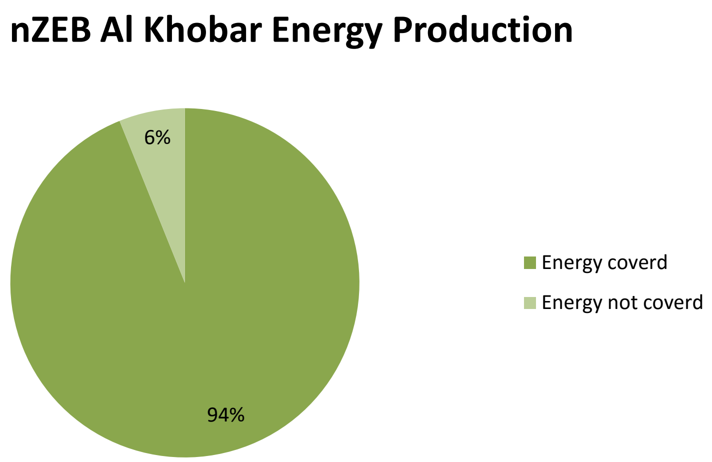
U Ex.Wall = 0.143 $W/m^2K$

U roof = 0.148 $W/m^2K$

U double glaze window=1.89$W/m^2K$

The model for an energy simulation was developed within the WUFI PLUS software, which allows to simulate the progress, the efficiency of the materials and the energy demand for heating and cooling of the building within a year. The passive strategies implemented allowed to reduce the m²y Energy demand (cooling need, heating need and household appliances need) by 52.3% (84,06 kWh/m²y) compared to a standard local residential building (176,5 kWh/m²y " Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province" ).
The photovoltaic system was sized to be installed integrated in a canopy on the roof. Using PVgis was possible to estimate the average energy produced annually in Al Khobar from a panel of 375 W with a size of 0.9x1.98 m. It comes out that a panel installed on the canopy on the building roof, at 0° tilt angle can produce 604 KWh /m2y. That means that for an area 906 m² the PV system could product 320.014,04 kWh / y, which would cover 94% of the building Energy Needs 340 817,10 kWh/y.
In this study the aim to prove the feasibility of a residential nZEB in a hot and humid climate such as Al Khobar was achieved thanks to the passive strategies and the solar energy potentiality by site.



**References**

Nearly Zero Energy Building

- *Almasoud, A.H., Gandayh, H.M.,* "Future of solar energy in Saudi Arabia", Journal of King Saud University – Engineering Sciences ,2014

- *Chaham Alalouch, Mohamed Salah-eldin Saleh, Saleh Al-Saadi,* "Energy-Efficient House in the GCC Region", 2016

-*Esam Elsarrag and Yousef Alhorr*," Towards Near Zero Energy Home", 2017

-*F. Alrashed, M. Asif,* "Prospects of Renewable Energy to Promote Zero-Energy Residential Buildings in the KSA", 2012

-*Farajallah Alrashed , Muhammad Asif,* "Trends in Residential Energy Consumption in Saudi Arabia with Particular Reference to the Eastern Province", School of Engineering and Built Environment Glasgow Caledonian University, Glasgow, UK, 2014

- *Farajallah Alrasheda, Muhammad Asifa,* "Climatic classifications of Saudi Arabia for building energy modelling", 2015

- *Haitham Feras Sawalha,* "Feasibility of rooftop solar photo voltaic (pv) system for kfupm buildings", may 2015

- *Hanan M. Taleb , Steve Sharples,* "Developing sustainable residential buildings in Saudi Arabia" A case study December 2009

- *Hanan M. Taleb,* "Towards Sustainable Residential Buildings in the Kingdom of Saudi Arabia", Conference On Technology & Sustainability in the Built Environment, University of Sheffield, UK

- *Kankana Dubey, Nicholas Howarth and Moncef Krarti,* "Evaluating Building Energy Efficiency Investment Options for Saudi Arabia" , October 2016

- *Lisa White,* "Passive building in Hot and Humid Climates", Passive House Institute , 9 th Annual North American Passive House Conference, US 2014

- *Mai hamad M A Fetais,* "Design of hybrid renewable energy system for near zero energy building in Qatar", Qatar university, college of engineering, June 2016

- *Mohammad A. Alshenaifi* “High Performance Homes in Saudi Arabia Revised Passivhaus Principles for Hot and Arid Climates”, May 2015

- *Mohammed Mumtaz A. Khan , Muhammad Asif and Edgar Stach,* “Rooftop PV Potential in the Residential Sector of the Kingdom of Saudi Arabia”, june 2017

- *Muhammad Asif, “*Urban Scale Application of Solar PV to Improve Sustainability in the Building and the Energy Sectors of KSA”, novmber 2017

- *Moncef Krarti, Kankana Dubey, Nicholas Howarth,* “Evaluation of building energy efficiency investment options for the Kingdom of Saudi Arabia”, 2017

- *Nadeem Javaid , Sardar Mehboob Hussain , Ibrar Ullah , Muhammad Asim Noor , Wadood Abdul, Ahmad Almogren and Atif Alamri,* “Demand Side Management in Nearly Zero Energy Buildings Using Heuristic Optimizations”, 2017

- *Omar Abdulmughni A Humaidan,* “Utilizing energy efficiency strategies to achieve a net-zero energy commercial building in the hot-arid region of mecca”, saudi Arabia, 2017

- *Stefano Pultrone, Barbara Totaro*, Analisi del Complesso Residenziale “Terracielo”, dipartimento di Architettura, Ingegneria delle Costruzioni e Ambiente Costruito progettazione di edifici a energia quasi zero (nzeb) , 2014

- *Yahya Wisam Al-Saeed and Abdullahi Ahmed, “*Evaluating Design Strategies for Nearly Zero Energy Buildings in the Middle East and North Africa Regions”, 29 September 2018

- Kingdom of saudi arabia saudi standards, metrology and quality organization saso saudi standard draft No. 28793/2014

- “Emirates GBC”, Defining Nearly Zero Enery Buildings in the UAE-2017

-“The Pearl Rating System for Estidama” Public Realm Rating System Design & Construction Version 1.0, December 2016

Phase Change Material

-*Abhat*, “A. Low temperature latent heat thermal energy storage: Heat storage materials”. Sol. Energy 1983, 30, 313–332

-*Bruno Giampà e Gianluca Gindro,* “Inerzia trasparente: definizione progettuale e validazione sperimentale di uncomponente di facciata in policarbonato alveolare e PCM” Politecnico di Torino,2010

- *Ding-Quan Ng a , Yen-Lin Tseng b , Yeng-Fong Shih b , Hong-Yuan Lian c , Yi-Hsiuan Yu*, “Synthesis of novel phase change material microcapsule and its application”, Polymer 133 pp 250-262, November 2017

- *J. Kośny Oak Ridge, E. Kossecka,* “Thermal balance of a wall with PCM-enhanced thermal insulation” Buildings and Materials Group, USA, pp 265-271

- *Luigi Giovannini , Francesco Goia , Valerio R.M. Lo Verso, Valentina Serra,* “Phase Change Materials in glazing: implications on light distribution and visual comfort. Preliminary results” , pp 357-366, 2016.

-*Mariateresa Lettieri and Antonella Sarcinella,* “Phase Change Materials for Energy Efficiency in Buildings and Their Use in Mortars”, april 2017

- *Nader. A. Nader, Rami S. Alsayed, “*Net-zero energy building – case study al khobar city”, saudi arabia 2016

- *Rami Mohammad Reda Saeed,* “Advancement in thermal energy storage using phase change materials”, 2018

Saudi Housing

- *Chair Prof, DrJosep Lluis Mateo, ETH Zurich,* "Middle East landscape- city-architecture", Park Books,2013

- *Faisal A Mubarak, "*Cultural adaptation to housing needs: a case study, riyadh, Saudi Arabia"

- *Gesa Schoneberg, "*Contemporary architecture in Arabia", Dom, 2008

- *Hiba Alothman* , "An evaluatve and critical study of mashrabiya in contemporary architecture", , 2017

-*Hiba Alothman , Ayten Özsavaş Akçay,* "A Theoretical Framework for the Evaluation from the Traditional Mashrabiya to Modern Mashrabiya", Journal of History Culture and Art Research, 6(3), 107-121. 2017

- *Mohamed Al Surf, Connie Susilwati, and Bambang Trigunarsayah,* "Analizing the Literature of the link between the conservative Islamic culture of Saudi Arabia and the Design of Sustainble Housing", pp 1-15, january 2012

- *Mohammed Al Surf, Connie Susilawati, Bambang Trigunarsayah, "*Integration of Saudi Arabia's Conservative Islamic Culture in Sustainable Housing Design", Proceedings of the 19th CIB World Building Congress, Queensland University of Technology, Brisbane Convention & Exhibition Centre, Brisbane, QLD, pp. 1-13, 2013

- *Maryam alkhateeb Tania Humphries-Smith Bob Eves*, "The visual representation of the concept of privacy in the eastern region of saudi arabia's houses design: a comparative study of the traditional and contemporary", rchidesign pp 739-750, July 2015

- *Udo Kulterman*n, "Contemporary Architecture in the Arab States", McGraw Hill , 1977

- *Zulkeplee Othmann , Rosemary Aird , Laurie Buys,* "Privacy, modesty, hospitality, and the design of Muslim homes: A literature review" Frontiers of Architectural Research , pp 12–23, february 2015

-"Saudi building code" first edition: january 2007 saudi building code national committee.

**Sitography**

- www.sciencedirect.com
-www.researchgate.net
- www.sbc.gov.sa
-www.worlddata.info/asia/saudi-arabia/energy-consumption.php
-www.weatherspark.com/y/104952/Average-Weather-in-Khobar-Saudi-Arabia-Year-Round
-www.worldgbc.org/
- www.sun-direction.com/country/saudi-arabia/
- www.suncalc.org
- www.solargis.com
- https://re.jrc.ec.europa.eu
- www.eamana.gov.sa/Pages/default.aspx
-www.greentechno.com/sustainability-leed-project-management-sabic-home-of-innovation-saudi-arabia/
- https://vision2030.gov.sa/en
- www.saso.gov.sa/en
-www.mdpi.com
- https://comelite-arch.com
- http://citeseerx.ist.psu.edu
-https://www.sciencedirect.com/science/article/pii/S0360544217308411
-https://www.seec.gov.sa/index.php
-https://www.kacare.gov.sa/en
-https://www.teknoring.com/guide/guide-architettura/guida-ai-pcm-i-materiali-a-cambiamento-di-fase/
-https://www.casaeclima.com/ar_8874__TECH-Ricerche-pcm--calore--rilascio-materiali-cambiamento-di-fase-PCM-sviluppi-di-applicazione-dalledilizia-al-solare.html