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DESIGN METHODOLOGY FOR ZERO ENERGY PUBLIC BUILDINGS

Dissertation for the Achievement of the
Doctoral Degree of Philosophy in Architecture

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Dedicated To

My Mam and The Soul of My Dad

My husbandDr. Ahmed Abouzaid

My brothers and sister..... Mohamed, Amr, and Yasmin

My son and daughters..... Omar, Aliaa, and Fouad

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List of Abbreviations

ZEB	Zero Energy Building
NZE	Net Zero Energy
nZEB	Nearly Zero Energy Building
nZEPB	Nearly Zero Energy Public Buildings
ZEPB	Zero Energy Public Building
EISA	Energy Independence and Security Act
NZEB	Net Zero Energy Building
SHASE	The Society of Heating, Air conditioning and Sanitary Engineers of Japan.
EPBD	The Energy Performance of Building Directive
EISA 2007	The Energy Independence and Security Act of 2007
IECC	The International Energy Conservation Code
CEC	California Energy Commission
BEARS	The Building Energy Asset Rating System
GHG	Green House Gas
OERD	Office of Energy Research and Development
CEF	Clean Energy Fund
WWR	Window to Wall Ratio
PERD	Program of Energy Research and Development
PV	Photovoltaic
BIPV	Building Integrated Photovoltaic
BEE	Bureau of Energy Efficiency

MoHURD	Ministry of Housing and Urban-Rural Development (In China)
METI	Ministry of Economy, Trade and Industry
ECL	The Energy Conservation Law
HRV	Heat Recovery Ventilation
CAPBS	Climate Adaptive Public Building Shell
WTs	Wind Turbines
BCSs	Building control systems
AI	Artificial Intelligence
RFP	Request For Proposals
OPR	Owners Project Requirements
VIP	Vacuum Insulation Panels
PCM	Phase Change Materials
TF	Thin Film
SPG	Suspended Particles Glass
SPD	Suspended Particle Devices
BPS	Building Performance Simulation

CHAPTER 1 : Introduction

1.1 Introduction

1.2 Problem statement

1.4 Research aims and objectives

1.6 The research hypotheses

1.3 Scope of research

1.5 Research significance

1.7 The research methodology

1.1 Introduction

Construction is one of the sectors that known with the highest energy demands, it consumes 40% of total energy consumption world wide (Eehc Annual Report 2013/2014, 2015), and the numbers are even higher in Egypt, reached 52% of total energy sold in 2014 (Sbci, 2009) with an annual average growth rate of 5.2%. These increasing rates affect energy cost, exhaust national grid and will lead to troubles in Energy supplies in the future. Public buildings need energy in order to provide users with various services, all the electrical and technical systems use energy, so, its energy consumption has a great effect on total energy consumption.

Recently, zero energy public buildings receive a great concern worldwide. The Energy Independence and Security Act (EISA) at 2007 set a goal of Net Zero Energy (NZE) for all public buildings by 2030, further specified a Net Zero Energy target of 50% of U.S public buildings by 2040, and a net-zero standard for 100% of new and existing public buildings by 2050 (S, 2011). Egypt needs to start its action plan in this field to achieve zero energy goal at public buildings sector, it is essential to follow planned design methodology to guide architects, engineers, contractors and decision maker.

Researchers now have a new challenge to reduce buildings' energy demand without compromising user's comfort and design buildings able to face the climate change.

For more information about public buildings effectiveness, the number of public units is about 12 million and expecting to reach 17 million in 2030 (tea, 2011). Although, there are more than 4.8 million public units in the Egyptian building sector which represent 40% of the total buildings (Egyptian Electricity Holding Company, 2013/2014). Moreover, the public sector energy consumption will increase up to be 33% for the non-domestic sector in 2030 (L. Pérez-Lombard, 2008) represents the great potential of this sector in reducing the total energy demands.

This high energy demands of public buildings make it important to adopt the main aim of this scientific dissertation to reduce energy demand and target energy efficiency, save natural resources, help the economy, reduce greenhouse gas emissions and consequently decrease global warming. Also, intends to introduce an applicable design methodology for public buildings to be nearly zero energy buildings or totally zero energy buildings. And to

achieve Zero energy goal, the proposed methodology is based on three major phases are proposed and tested: the first targeted energy efficiency design, the second applied energy saving strategies and the third added renewable energy techniques. All these phases are considered equally important and complete each other.

1.2 Problem statement

There are critical questions need to be addressed before development of this research. How to design buildings that achieve zero energy? What are the design requirements to design zero energy public building in hot climate?

The buildings consume significant amounts of energy and recently they are major contributors to CO₂ emissions. Reducing building energy consumption is an important contribution to the overall global warming control.

This thesis explores energy consumption reduction strategies, integrates renewable energy resources and proposes a methodology for Zero Energy Public Building design, specially in Egypt and suitable for hot climates.

1.3 Research aims and objectives

The research main aim is to set an applicable methodology for designing zero energy public buildings in Egypt, in addition to, design an analytical model helps in analyzing successful examples of zero energy public buildings to recognize on the latest techniques and strategies that reduce energy demand in public building and integrate clean renewable energy resources.

1.4 The research hypotheses

The research hypotheses is that the proposed methodology for designing public buildings in hot climate -specially in Egypt- will achieve zero energy public building in fact. Further, the integration between environmental design strategies, new techniques, and renewable energy technologies will hit zero energy goal.

1.5 Scope of research

The scope of the study is studying energy reduction strategies related to public building specially in hot and arid climate and focusing on the design process to get highly energy efficient public building as a beginning, then enhance this efficiency by integrating renewable energy technologies. Also, using a simulating software Design Builder simulation program to check the ability of the proposed methodology. Research scope dose not include building construction phase or Co2 emissions measurements. Cost analysis for the energy production scenarios are also beyond this study.

The analytical study is based on analysing fifteen zero energy buildings case studies; all the buildings belong to public building categories. It should be noted that all the case studies are real and are selected because they are representing zero energy public buildings. The evaluation of these buildings examined the energy demand, building orientation, climate zone effect, building activity type, floor area, users' number, building envelop insulation, shadings, openings, service systems, types and performance and the renewable energy resources integrated into the building design.

1.6 Research significance

Reducing the energy demand of public buildings and integrating clean renewable energy resources result in immediate improvements in environmental quality and economic efficiencies in addition to contribute to better health.

The research helps to identify a new design methodology that affects on the public building architectural design, opens new horizons for architects to solve the environmental issues.

By using the latest architectural trends and technologies, architects can use the proposed design methodology and mitigate the energy consumption problem in designing zero energy public buildings.

A significant question rise from this research is whether it is possible to establish methodology for public building design in hot climate? And will it deliver zero energy performance likely to be experienced? To identify the most appropriate solutions for public buildings is primary target of this research, also, presenting guidelines for zero energy public building.

By achieving the vision of zero energy public buildings, this research will suggest the pursuit of multiple design strategies including the development of new technologies, practices of international programmes and policies, integration of renewable energy into public building designs, and the adoption of innovative strategies for using energy and resources.

All countries need to set future vision to achieve zero energy goal in the building sector generally, and for public building particularly, to reduce the energy demands and increase the use of existing developed technologies which play a key role in achieving the zero energy goal.

Earlier improvements in energy performance of integrated equipment and systems in the public buildings have not produced the expected energy reduction. Advanced technologies is needed to support the design performance improvements. Additional energy reduction of 20% to 40% can be achieved by integrating advanced technologies in the public building design. (Griffith, 2007)

1.7 The research methodology

The research methodology embraces a mixed strategy that is needed to investigate different components of study. It comprises literature review, data collection, analysis, as well as applying the methodology on the analyzed case studies to detect the applicability. The following research methodology adopted the theoretical method, the comparative method, analytical method and deductive method as shown in (Figure 1-1), more details as following:

The Theoretical Approach: the literature review is divided into three different parts complete each other and they are:

- First part is about public buildings and includes public buildings definitions, classifications, energy consumption, international zero energy programmes, policies, and strategies, zero energy building certifications, and the importance of achieving zero energy public building.
- Second part is about reducing energy demand in public building and includes a brief about climate effect on public buildings design, also, the factors that affecting on energy use in the public building and the new environmental building technology and techniques that can be applied

on the public building design to help in reaching to zero energy public building.

- Third part is about the public buildings mechanical systems and the renewable energy technologies that can be integrated on the public building, the public building control systems and the build-design team that responsible for designing zero energy public building.

The Analytical Approach: this approach aims to reach to zero energy public building efficient design methodology. So, this part works first on designing an analytical model extracted from the theoretical study and using it in analyzing some successful existing zero energy public building. Then analyses the case studies data to extract the design methodology that used in their designs.

The Applicable Approach: (Simulation) this part works on testing the proposed ZEPB design methodology by designing public building located in Egypt through using the proposed design methodology and use “Design Builder” software to simulate energy performance after completing of each phase. Then calculations and results of each phase are compared to find out the efficiency of the proposed design methodology.

Conclusions and recommendations: this part concludes the zero energy public building design guidelines and the recommendations. (Figure 1-1) clarify the research structure.

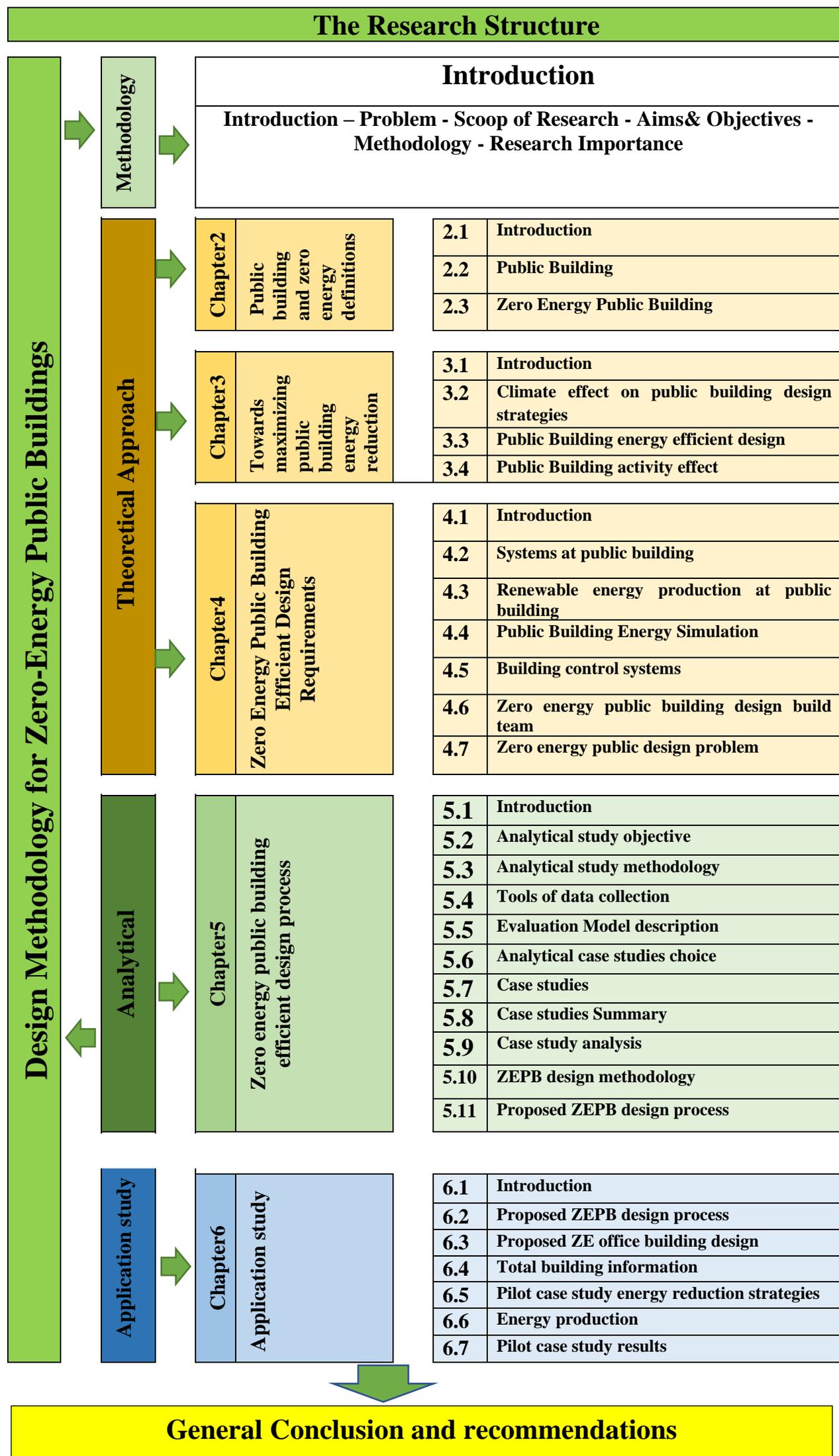


Figure 1-1: The research structure

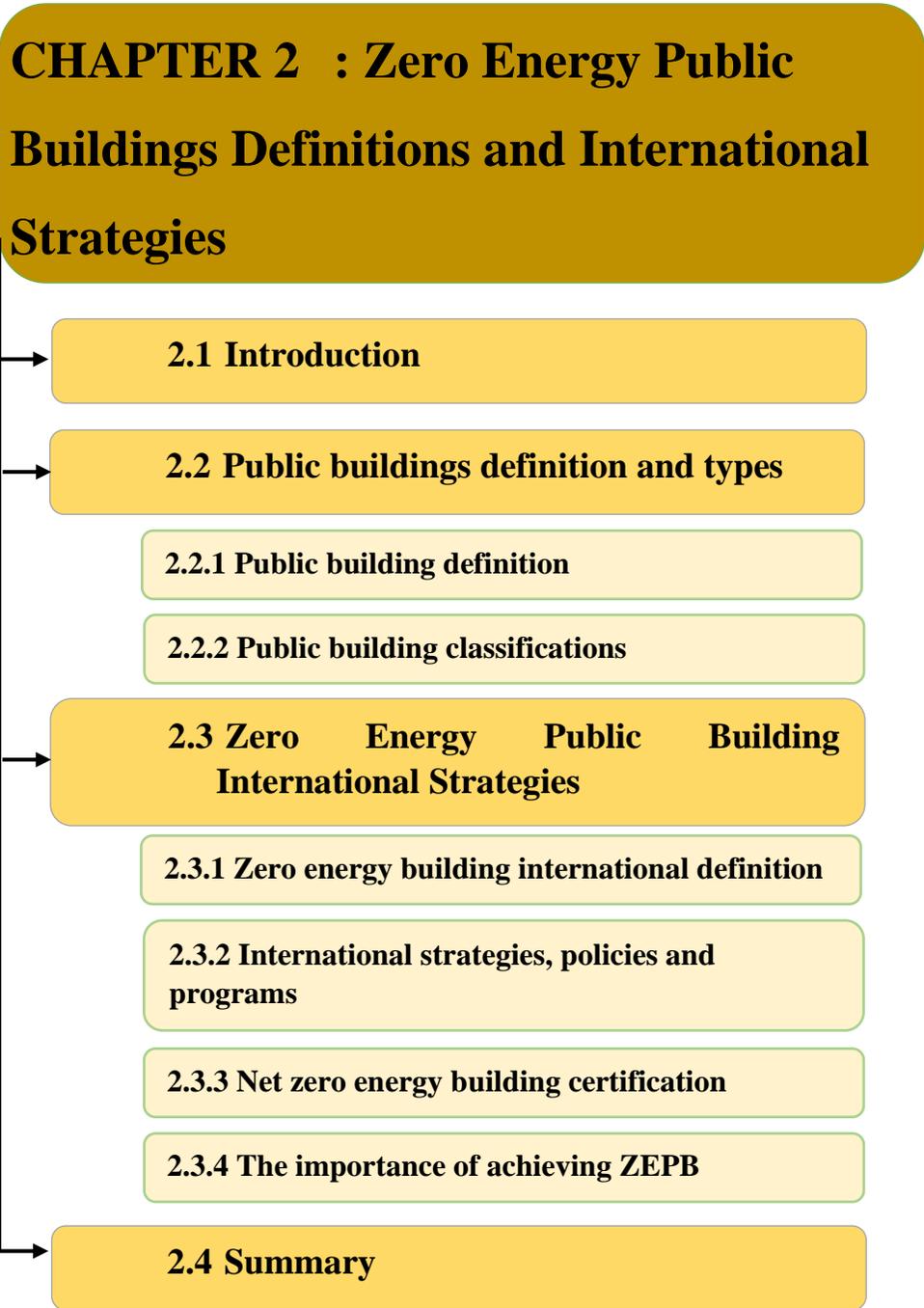


Figure 2-1: Chapter 2 structure

2.1 Introduction

Public building energy consumption is a great part of the total building sector energy consumption and the need to achieve zero energy public building (ZEPB) is essential. This chapter focuses first on defining the public buildings and its different classifications, then, releasing the definition of zero energy building (ZEPB) for significantly reducing the energy demand to achieve Zero energy public building (ZEPB), in addition to, realising the importance and the benefits of achieving zero energy public building(ZEPB), also, going through some of the international polices and programs towards zero energy public building(ZEPB), finally, recognising on the international organizations that certify the public building is a zero energy, the requirements to get these certificates, and how these organizations follow the building usage to be certain that the building will continue to be zero energy.

2.2 Public buildings

Public buildings have to be identified to determine the meaning of public and specify the public buildings classifications that the research is working on.

2.2.1 Public Building Definition.

United States government defines “public buildings” as buildings that funded through tax money by the U.S. government or state or local governments. All types of governmental offices are considered public buildings. Public buildings generally serve the purpose of providing a service to the public (bizfluent.com, 2017), Europe countries define ‘public buildings’ in several different ways: The Czech Republic defines “public building” as all buildings that are not apartments or are non-residential, Finland defines “public building” as those buildings which provide public services, France defines “public building” as a building that is occupied by a governmental body, and United Kingdom defines “public building” as a building that is: “occupied by a public authority and frequently visited by the public” (consultation, 2015), and United Arab Emirates defines “public buildings” as the non- residential buildings, privet or government buildings. (Majd Fayyad, 2017), Thus, The public building that this research is working on can be defined as any non-residential building, no matter it owned by government or people.

2.2.2 Public Buildings Classifications

Public building typology to certain types, depending on their character, purpose and specific content they are aimed for, as well as studying of their spatial and functional characteristics has special significance for studying the buildingship. Public buildings classifications are based on building typology. Also, public buildings zoning and energy codes are based on typologies of **use**, or **occupancy**, or **structure**, retail, **manufacturing**, etc. because the activities housed in a building mostly produce the same effects, such as noise, traffic, and pollution, while designers and architects are more likely the typologies of **form** such as bar building or high-rise building, towers..., etc. The public building **thermodynamic** nature of typological descriptions becomes clear with the new develop over time. (Lotka, 1922, p. 151)

Apart from classifying of the buildings according to their purpose and content, which is in the literature often associated with the typology, there are main five classifications of public buildings according to their purpose, their position on the surrounding urban tissue, plan shape, floor area size and according to thermodynamic principals.

2.2.2.1 Public buildings classification according to the building purpose

- Governmental buildings, headquarters and administrative buildings
- Military buildings, Religious institutions, Medical institutions, Hotels
- Educational and scientific institutions - elementary schools, gymnasiums. (Figures 2-2,3,4,5)
- Cultural Institutions - theater, reading rooms, libraries and museums
- The buildings for special purposes - railway stations and covered markets. (Mirjana R., 1997)



Figure 2-2: White house, government building (advocate.com, 2019)



Figure 2-3: European Scientific research centre (tedxtallinn.org, 2019)



Figure 2-4: Hilton hotel (hilton.com, 2019)



Figure 2-5: San Joaquin County Administration Building (novumstructures.com, 2019)

According to public building purpose, building activity, working hours and user number are specified and its energy consumption can be calculated.

2.2.2.2 Public buildings classification according to their position on the surrounding urban tissue

Public buildings can be classified according to the standpoint of their position towards the surrounding urban tissue and based on the data about the location (1997). Public buildings can be distinguished into three basic groups as shown in (Figure 2-6):

1. Free-standing public buildings with all four sides free
2. Built-in buildings from one side.
3. Built-in buildings from two sides.

This classification can help in identifying the public building situation and how many facades can be efficiently designed towards designing zero energy building.

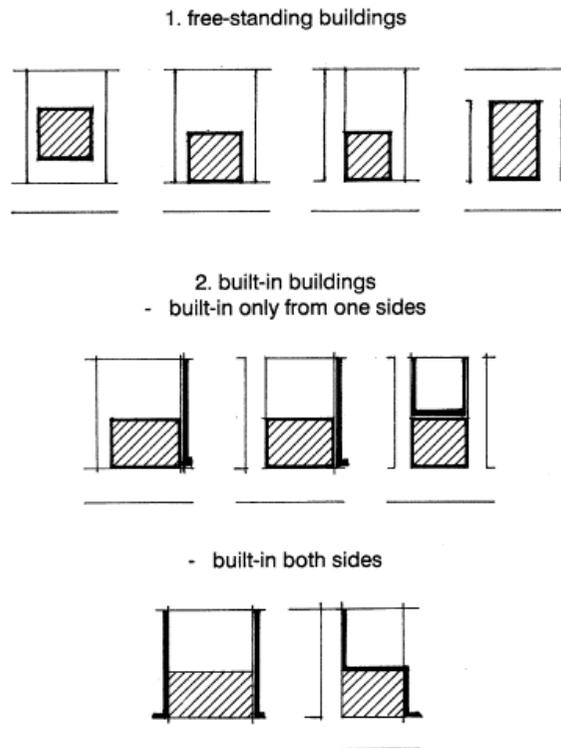


Figure 2-6: Classification of the buildings in relation to their position, Source: Mirjana R. B., Basic Typology of The Public Buildings Presented on The Examples Built in Belgrade in Period Between 1830 -1900, Facta Universities, Series: Architecture and Civil Engineering Vol.1, No 4, 1997 pp. 509 - 524

2.2.2.3 Public Buildings Classified According to The Shape of The Plan:

In some cases of public buildings their basic shape is a result of certain functional and technological requirements which referred to, primarily, purpose and content (Mirjana R., 1997). Building plan can be rectangular plan, nearly square plan, composite plan or buildings whose plan is adjusted to the corner position.

This public building classification and the different plan shape has to be as a result of environmental and climate interaction to reduce the public building consumption.

2.2.2.4 Public buildings classification according to the floor area size

Public building classification according to floor area is:

- Large public buildings (total floor area is more than 20 thousand square meters).
- Medium buildings with floor area between 10 and 20 thousand square meters.
- Small buildings are less than 10 thousand square meters (Li Yuana, 2016).

This classification will help in identifying which type of floor area size is easier in achieving the zero energy goal at the analytical part in this research.

2.2.2.5 Public buildings classification according to the thermodynamic principles

Thermodynamics is the science of the relationship between heat, work, temperature, and energy. Thermodynamics deals with the transfer of energy from one place to another and from one form to another. This typology expands the kinds of available environmental public buildings design and they can be classified into:

- Maximum power.
- Energy concentration hierarchies.
- Co-cycling of materials.
- Mix between more than one type. (William W., 2016, p. 200)

2.3 Zero Energy Public Buildings strategies

several countries realize the environmental impact of building energy consumption and work hard to target zero energy building on a long term plan, specially the Governmental organizations, non-profit's, and industry stakeholders who have developed their own definitions of ZEB in the absence of an international standardized definition and lack of unified building performance measures that could advise ZEB policies and programs. In this part zero energy definitions are studied, and international strategies, programs and planes are outlined, in addition to represent zero energy public building certifications.

2.3.1 Zero Energy Building definitions

Zero Energy Public Building (ZEPB) is defined as very high energy performance building (A. Hermelink, 2013, p. 447), where the energy needs are reduced to the minimum and equal (Wells, 2018) to the energy generated by the renewable energy (Brambilla, 2018) on the building on monthly or annual basis and consider in the design the thermal comfort. From technical level, Zero Energy Building (ZEB) is a measure of a building's energy performance, whereby it produces as much or more renewable energy as it uses over the course of a year in operation (Hinge, September 2018). Also, the ZEPB can be defined as building where Equal energy generation to usage (Wells, 2018). As well as, Net Zero Energy Building (NZEB) is defined as buildings with outstanding performances and a very low energy needs, which should be covered by renewable sources (Brambilla, 2018).

And for better understanding to the principal behind the emerging definitions of ZEBs, it is important to review the existing ZEB definitions for leading countries that targeting ZEB and have action plans to reach their goal, like United States, Canada, China, Japan, Korea, and United Arabic Emirates.

The Zero Energy Building (ZEB) definition of United States is described at the National Renewable Energy Laboratory (NREL) as “**An energy efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy**” (DOE, National Renewable Energy Laboratory (NREL), September 2015), while the New Buildings Institute (NBI) its Zero Net Energy (ZNE) definition is: “**The amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building**” (California Energy Commission, JULY 20, 2011).

In Canada, the NSERC Smart Net-zero Energy Buildings Strategic Research Network (SNEBRN) define the net zero energy building (NZEB) as “**Building that in an average year, produces as much energy (electrical plus thermal) from renewable energy sources as it consumes**” (SNEBRN, 2012).

In China, the passive nearly zero energy buildings is defined as “**The buildings with the best envelope thermal insulation performance and air tightness, makes full use of natural ventilation, natural lighting, solar radiation and other technologies such as the passive method of getting energy from indoor non-heating source, minimizes the demands of heating and air**

conditioning and accomplishes the harmony and comfortable indoor environment” (The Ministry of Housing and Urban-Rural Development (MoHURD), November, 2015), and this definition was the first step to define ZEB, therefore, the Net Zero Energy Building NZEB is defined as **“The energy calculation period should be one year, with the end-use energy as the performance indicator, the energy generated from the building and nearby renewable energy system are higher than the energy consumption of the building itself”** (Xu Wei, Zhang Chicong, November 2014, p. 36).

Japan Net Zero Energy Building definition according to SHASE¹ is defined as: **“A building that consumes zero or nearly zero energy on an annual net basis by reducing primary energy consumption in the building as a result of enhanced energy efficiency performance of the building and facilities, neighboring buildings, on-site utilization of renewable facilities, networking of buildings, on-energy, and so on”** (Xu Wei, Zhang Chicong, November 2014, p. 72).

In Korea, Zero Energy Building” is defined as **“A building that maximizes thermal insulation performance to minimize energy consumption and uses renewable energies to provide energy self-sufficiently.”** (Xu Wei, Zhang Chicong, November 2014, p. 112).

At Europe, the European Commission definition for Nearly zero-energy buildings NZEB is **“A building that has a very high energy performance with the nearly zero or very low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby”** (europa.eu, 2019), there is not yet an official definition to define ZEB.

A nearly Zero Energy Building (nZEB) in the United Arab Emirate UAE is defined as **“A highly energy efficient building with a site EUI less than 90 kWh/m²/year and covers a significant portion of its annual energy use by renewable energy sources produced on-site or off-site”** (Majd Fayyad, 2017, p. 7).

From all the previous definition the Zero energy public building (ZEPB) can be conclude as:” **A public building that designed with high energy efficiency and has renewable resources to produce energy, and the total**

¹ SHASE: The Society of Heating, Air conditioning and Sanitary Engineers of Japan.

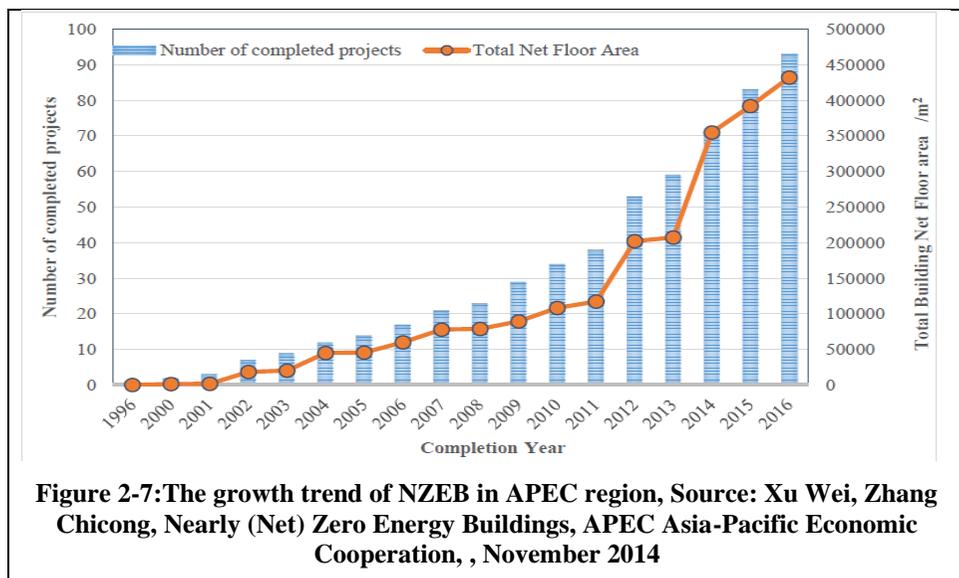
building energy consumption is less than or equal the total amount of renewable energy produced on an annual basis” (Author).

2.3.2 The importance of achieving ZEPB

Nowadays buildings responsible of consuming nearly a third of the world’s energy use and this percentage is expected to rise compatible with population growth. Building sector - residential and public – consume approximately 40% of primary energy use. (Eehc Annual Report 2013/2014, 2015)

If the current trends continue, buildings sector may consume more than industry and transport compinged. (U.S. Department of energy, 2009)

The major difference between ZEB and current buildings is the reductions in energy use and this difference requires a fully innovative and integrated technical design. The studies show the rapid growth trend at the last few years because of realizing the importance of achieving ZEB (Banerjee, May 2015), the following shows the growth trend for ZEB (Figure 2-7).²



This growth trend of NZEB shows the worldwide awareness, and motivation in solving the environmental problems associate with building sector growth. Even so, all the countries need to move faster in achieving the zero energy

² After investigating 100 projects statistical results shows that a rapid growth trend occurred in 2012 with 15 projects completed, and the amount of large scale nZEB projects began to rise in 2013 with 5 projects more than 5,000 square meters.

vision and set national goals to reduce the energy demands. Zero energy building design process has advantages and disadvantages (Banerjee, May 2015) and they are as shown in (Figure 2-8).

Even the initial ZEB costs can be higher than the traditional buildings, but it separates the ZEB owners from future energy price increases, the total cost is reduced due to enhance building energy efficiency and the cost is payed back by time. Also, few designers or builders have the necessary skills or experience to build ZEBs, but by sharing the successful experiences more designers and builders will be experts in ZEB field. Furthermore, without an optimized thermal envelope design, ZEB can oversize renewable energy systems to fill the energy gap, so energy simulations are essential to optimize thermal envelop design. Sometimes electricity grid is not developed to receive extra energy produced by ZEB in summer months, so smart grid needs to be integrated.

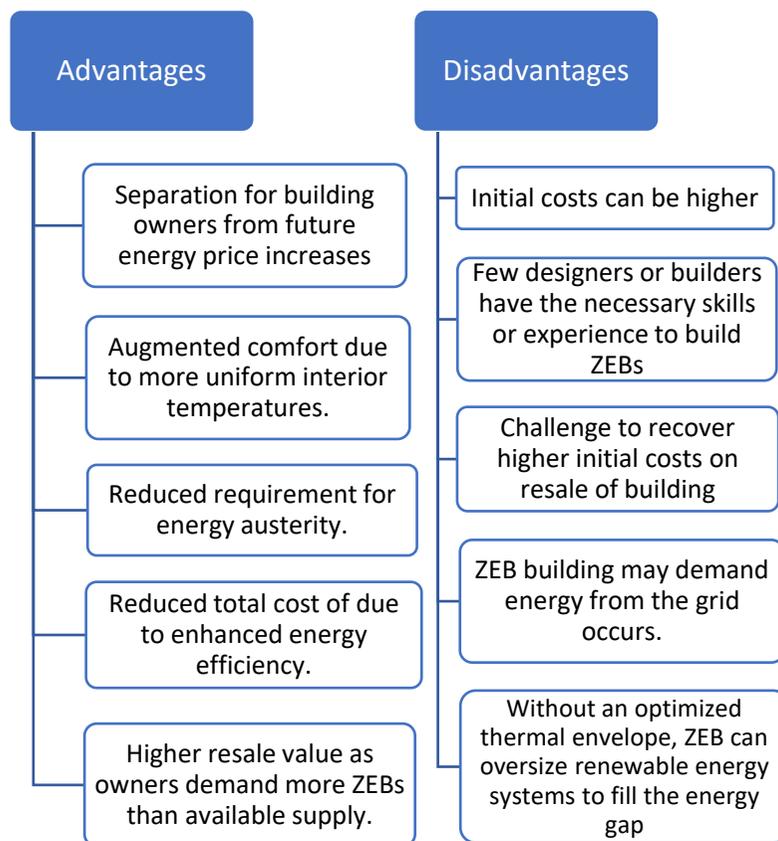


Figure 2-8: Advantages and disadvantages of zero energy buildings, Source: Reshmi Banerjee, Importance of Net Zero Energy Building, International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163

2.3.3 International Strategies, Policies and programs towards ZEB

Since the energy consumption of buildings sector cause more and more worldwide attention, NZEB is starting at a rapid developing stage, and list of countries set policies and energy codes to enhance energy efficiency in the public building sector (Sharifi, 2013), many countries are racing in this field to apply it first but the leading countries in researches and applications about controlling building energy consumption are Canada, China, Japan, Korea and United States, by proposing many programs and adapted applicable Policies.

2.3.3.1 United States

In United States, polices to promote ZEPB are taken according to the right of the public building ownership and they are divided into Federal building and commercial building.

Table 1-1: Public building ownership at U.S

Federal buildings.	Commercial building
<p>The federal government enacted to the Executive Order³ to meet Energy Efficiency Guiding Principles. The timeline and means for achieving the stated goal of zero net energy federal buildings can be summarized as follows:</p> <ul style="list-style-type: none"> • All planning for new Federal buildings should achieve Net Zero Energy by 2030. • Net Zero Energy goals are to be incorporated into the process of buying or leasing new government properties. 	<p>The Energy Independence and Security Act of 2007 (EISA 2007) led Commercial Building Energy Alliances to establish specific goal for commercial buildings (Cassidy R, 2011):</p> <ul style="list-style-type: none"> • Net zero energy use in all new commercial buildings constructed by 2030. • Net zero energy use in 50% of commercial building stock by 2040. • Net zero energy use in the commercial building stock by 2050.

³ The Executive Order no.13514, which is an executive order titled Federal Leadership in Environmental, Energy, and Economic Performance that U.S. President Barack Obama issued on 5 October 2009.

In addition to follow the International Energy Conservation Code (IECC) which is the most widely adopted energy code in the United States. It offers an international forum for energy professionals to discuss performance and prescriptive code requirements. (newbuildings.org, 2018)

In 2012, the California Energy Commission (CEC) developed the Building Energy Asset Rating System (BEARS) that is a tool allows for an easy auditing process that can help owners further financially justify their energy investments and identify target areas for upgrades. (newbuildings.org, 2018)

2.3.3.2 Canada

Almost one third of Canada's greenhouse gas (GHG) emissions are attributed due to building energy consumption. Buildings also consume about 53% of Canada's electricity consumption, therefore, Canada started in an official roadmap for the public building sector addressed towards NZEB (Government of Canada, 2007) which includes: (Figure2-7)

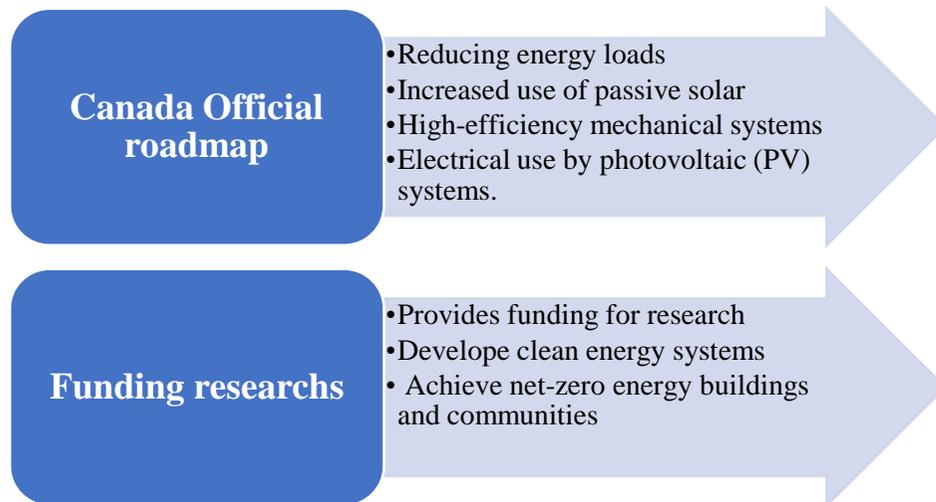


Figure 2-9: Canadian plans towards ZEPB, Source: Natural Resources Canada (NRCan) 2006. Energy Use Data Handbook, 2007, edit by Author.

The funding programs administrated include Clean Energy Fund (CEF) are:

- Eco ENERGY Innovation Initiative in 2011.
- The Energy Innovation Program (EIP) in 2016.
- Program of Energy Research and Development (PERD).

2.3.3.3 China

In China the modernization and urbanization increased rapidly the buildings energy consumption, but there are achievements in reducing the energy consumption of public buildings and heating energy consumption in severe cold area and improving the proportion of renewable energy's application since 1980 (Yang L, 2014) (Cai WG, 2009). Now, the building energy consumption is reduced and improved occupants living environment. The energy saving work is a collaboration between the central government and the local government as shown in (Table 1-2):

Table 1- 2: China working plan towards ZEPB

Central government	Local government
<p>Was responsible for planning the roadmap which include:</p> <ul style="list-style-type: none"> - Since 2006, issued a series of measures about BEE⁴ in the ‘‘Eleventh Five-Year Plan period’’. - The Passive Ultra-Low Energy Green Building Technical Guide^{5,6}. - Encourage the scientific research, series of publications were conducted Under the encouragement of MoHURD⁷. - Passive Ultra-low Energy building Certification were granted to announce the outstanding design, construction and operation starting from December 2016. 	<p>Adopted important economic incentive policies of public building energy efficiency including:</p> <ul style="list-style-type: none"> - Special fund for energy efficiency of government office buildings and large-scale public buildings. - Special fund for demonstration of renewable energy application in building, - Subsidy fund for building integrated photovoltaic (BIPV), - Subsidy for city-level demonstration of renewable energy application, - Financial subsidy for promotion of high efficiency lighting products.

4 BEE: Bureau of Energy Efficiency

5 Ministry of Housing and Urban-Rural Development (MoHURD), November 2015

6 It is considered as China's first Ultra-low energy building technical guidance.

7 MoHURD: Ministry of Housing and Urban-Rural Development

Working on Ultra-low energy public buildings considered the first step to NZEB, while The Nearly Zero Energy Building Technical Standard was launched in October 2016 and the Standard is published in 2019 which considered the first official NZEB standard in China.

2.3.3.4 Japan

Japan worked towards net zero energy buildings using renewable energy technology in 2009. The Ministry of Economy, Trade and Industry (METI) has also created guidelines and standards for Net Zero Energy Building. (IEA, 2016)

The Japanese government believes that energy efficiency policies for each sector should be complemented with policies to promote lifestyle changes and that the general awareness should be increased and released:

(1) Energy Conservation Law: The Energy Conservation Law (ECL) was enforced in Japan in 1979 after the second oil crises and has subsequently been revised several times (Energy Conservation Center, 2013).

(2) Action Plan and Roadmap of ZEB: “Committee on Realization and Generalization of ZEB” started in 2009 to examine the roadmap of Zero Energy Building (ZEB) by proposed the standard for new buildings by 2030 to realize ZEB (Figure 8).

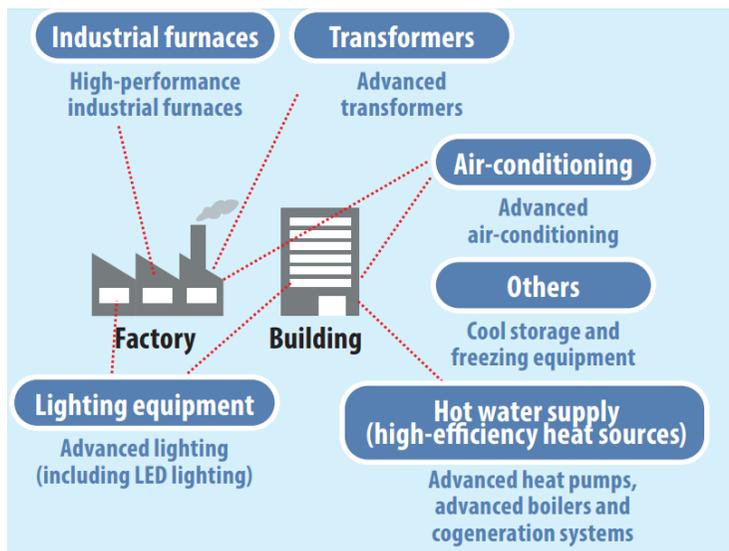


Figure 2-10: Japanese energy efficiency strategies for public buildings, Source: Japan’s Energy Plan, The Ministry of Economic Trade and Industry (METI) ,2015

2.3.3.5 Korea

Korea tried to reduce 80% of cooling/heating energy in building sector by 2017 (Green Growth hold, November 5th, 2009). On July 2014, Activation Plan of ZEB was issued by Ministry of Land, Infrastructure and Transport set up the future roadmap toward ZEB step by step.

Korea developed three kinds of zero energy buildings (Xu Wei, Zhang Chicong, November 2014, p. 112) as follow:

- **Low-rise Zero Energy Building:** A building that can provide energy required in cooling, heating, lighting and ventilation, self-sufficiently within the corresponding site.
- **High-rise Zero Energy Building:** A building that can provide energy required in cooling and heating within the corresponding site. It needs to maximize the renewable energy system installations to provide the energy required in cooling and heating self-sufficiently, and the shortages can be covered by other renewable energy installations from nearby schools, parks, etc.
- **Zero Energy Building Town:** Expand the range of zero energy from individual buildings to district units, and enforce the development targeting new towns and municipalities.

2.3.3.6 Europe

In Europe, The Energy Performance of Buildings Directive (EPBD) had a recast started in 2010 to reach with all the new buildings to be nearly zero energy buildings nZEB by 2020, and the nZEB implementations are:

- Member States at EPBD have to ensure that new buildings occupied and owned by public authorities are NZEBs after 31 December 2018 and that all new buildings are NZEBs by 31 December 2020. (European Union, 2016)
- The necessary measures had been taken to ensure that new and existing buildings meet minimum energy performance requirements, considering the use of high efficiency alternative systems.

- EU countries have their own national plans to achieve nearly zero-energy buildings.⁸

The following (Figure 9) show EPBD timeline for nZEB implementation.

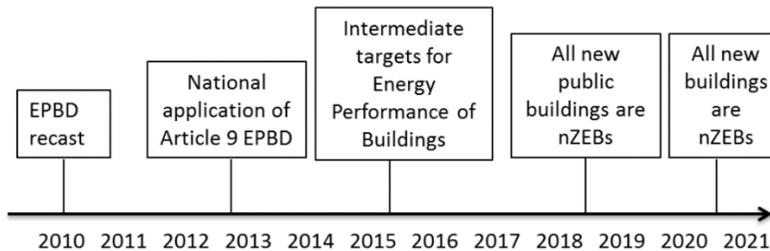


Figure 2-11: Timeline for NZEBs implementation for EPBD recast,

Source: <https://ec.europa.eu/energy/en/content/eu-countries-nearly-zero-energy-buildings-national-plans-0>

2.3.3.7 United Arab Emirates

According to UAE Vision 2021, the strategies that aim to construct sustainable environment are “Plan 2021” and “Abu Dhabi Plan 2030”. Dubai aims to reduce 30% of its energy consumption by 2030 and increase the share of clean energy to 75% by 2050 (Majd Fayyad, 2017, pp. 11-17). And to achieve this vision, several implementations are done as following:

- For better understanding the performance of existing buildings, the government launched enterprises to evaluate these buildings’ energy performance.
- As part of Dubai’s commitment to Building Efficiency Accelerator, the energy performance of 100 buildings in three focus groups (hotels, malls and schools) had been evaluated under the UN Program ‘Sustainable Energy for All’.
- The Ministry of Energy will provide data to government users to track production and consumption.
- The electricity tariffs had been increased in recent years in several Emirates including Abu Dhabi, Dubai and Sharjah to direct consumers’ attention to their energy spending and thereby raises awareness on the importance of reducing buildings’ energy consumption.

⁸ Each EU country vision in this site, <https://ec.europa.eu/energy/en/content/eu-countries-nearly-zero-energy-buildings-national-plans-0>

- The Shams Dubai program was launched to encourage households and building owners to install photovoltaic systems and connect them to the public grid under a net metering billing mechanism.

As a step towards this vision at November 2019, the Dubai Chambers of Commerce and Industry has announced that the University of Dubai is the first LEED Certified net zero energy building in region. (Oommen, 2019)

2.3.4 Zero Energy Public Building certifications

Zero Energy building is a main goal for many public buildings all over the world. Such buildings depend on exceptional energy reduction and on site renewable generation to meet their heating, cooling and electricity needs. Many buildings that pretend to be Zero in fact are not, because actual Zero Energy buildings are still rare so many rating systems appeared to improve the quality of energy efficiency and resources in buildings such as LEED, BREAM, ENERGY STAR (Sharifi, 2013, p. 73–87). In Egypt, there exist green pyramid rating system, but it was still under construction and Egyptian energy efficiency code which unenforceable until now. But now, there are international programs that verifies net zero energy public building performance and certify them as following:

2.3.4.1 The International Living Future Institute Certification

The International Living Future Institute (ILFI) has launched the Net Zero Energy Building (NZEB) Certification program. Modeled in connection with the Living Building Challenge, the program's certifications are based at least 12 months of consecutive performance data (access.living-future.org, 2018).

Building needs to achieve the following points to be certified as Zero Energy Building:

- The total building's energy needs must be supplied by on-site renewable energy on an annual basis.
- Renewable energy for the program is defined as passive solar, photovoltaics, wind turbines, solar thermal, direct geothermal, water-powered microturbines, or fuel cells powered by hydrogen generated from renewable powered electrolysis.
- No combustion is allowed, and green tags or green power purchases are not recognized as compliance paths.

- Teams must supply a completed energy usage table with monthly information gathered from tracking systems that record energy consumed and produced, as well as energy bills for a continuous 12-month period.
- The building may not block access to, nor diminish the quality of fresh air, sunlight, and natural waterways to any member of society or adjacent developments.
- Teams must provide calculations or 3D diagrams demonstrating compliance with maximum shading allowances of adjacent properties.
- The building must contain design features intended solely for human delight and the celebration of culture, spirit, and place appropriate to its function.
- Educational materials about the performance and operation of the building must be provided to the public to share successful solutions and to motivate others to make change.
- Teams must conduct a survey of building occupants and users and hold at least one annual open day to educate the public about the building's systems and achievements.

The following table show the organizations, type of construction, building sector, and verification method in US and Canada. (access.living-future.org, 2018)

Table 2- 3: verification methods in US and Canada.

Countries	US and Canada
Organization(s)	International Living Building Institute, International Living Future Institute partners and the Canada Green Building Council
Type of program and construction	Voluntary, New and retrofit constructions
Building Sectors	Commercial, institutional, homes and multifamily housing
Performance areas	Sustainable site development, energy balance, rights to nature, beauty, renewable energy systems and life cycle assessment
Verification method	Measured

2.3.4.2 LEED Zero Energy

The Institute's Net Zero Energy Building Certification (NZEB) was the only program in the world that verifies net zero energy building performance until LEED Zero was released by USGBC⁹ in November 2018. It is a new program that addresses zero operations and resources in buildings. LEED projects can achieve Net Zero certification when they demonstrate any or one of the following: net zero carbon emissions, net zero energy use, net zero water use or net zero waste. In order to achieve any of these zero certifications, projects must be LEED-certified and must provide 12 months of performance data across any or all of these categories. (usgbc.org, 2018)

For over two decades, LEED has guided and pushed projects to aim for higher performance through integrated building strategies impacting energy.

LEED Zero Energy certificate is defined in LEED Zero Energy Guide as the certificate that recognizes buildings or spaces that achieve a source energy use balance of zero over a period of 12 months. (U.S. Green Building council, May 2019), it also verifies the achievement of net zero goals and signals market leadership in the built environment. And to obtain LEED Zero Energy certification, the public building must achieve a source energy use balance of zero for the past year. The net zero energy balance is based on the quantity of energy consumed and the quantity of energy generated by the project. (U.S. Green Building council, May 2019)

Source Energy Balance = Total Energy Consumed – Total Energy Generated
On-Site or Procured Off-site

⁹ USGBC is US Green Building Council

2.4 Conclusion

For reaching design methodology for zero energy public building, it is important to define public building and zero energy building, so the definitions and the conclusion of this chapter as following:

- The public buildings are defined as all non-residential buildings, and there are many classifications for public building according to building purpose or the building location or the shape of the plan or the floor area size.
- Also, zero energy building (ZEB) can be defined as building where equal energy generation to usage with outstanding performance, moreover, many countries set policies and programs to move the building sector towards ZEB goal and the leading countries in this field are United States, Canada, China, Japan, Korea, Europe, and from the middle east United Arabic Emirates.
- And now, there are many organizations follow the ZEB usage and give certificate to certify that the public building is zero energy building like Net Zero Energy Building Certification that has lunched by The International Living Future Institute and LEED Zero Energy that has lunched by US Green Building Council. And at November 2019, the Dubai Changers of Commerce and Industry has announced that the University of Dubai is the first LEED Certified net zero energy building in region.
- At the end of this chapter it focused on the importance of achieving zero energy public building goal and the advantages and disadvantages of this process.

After studying the definitions and classifications of public buildings and zero energy, it is important to recognize on the factors that maximize public building energy reduction as the ZEB technologies are summarized in three categories: passive energy-saving technologies, energy-efficient building service systems and renewable energy production technologies (Xiaodong Cao, June 2016) and this will be more detailed in the next two chapters.

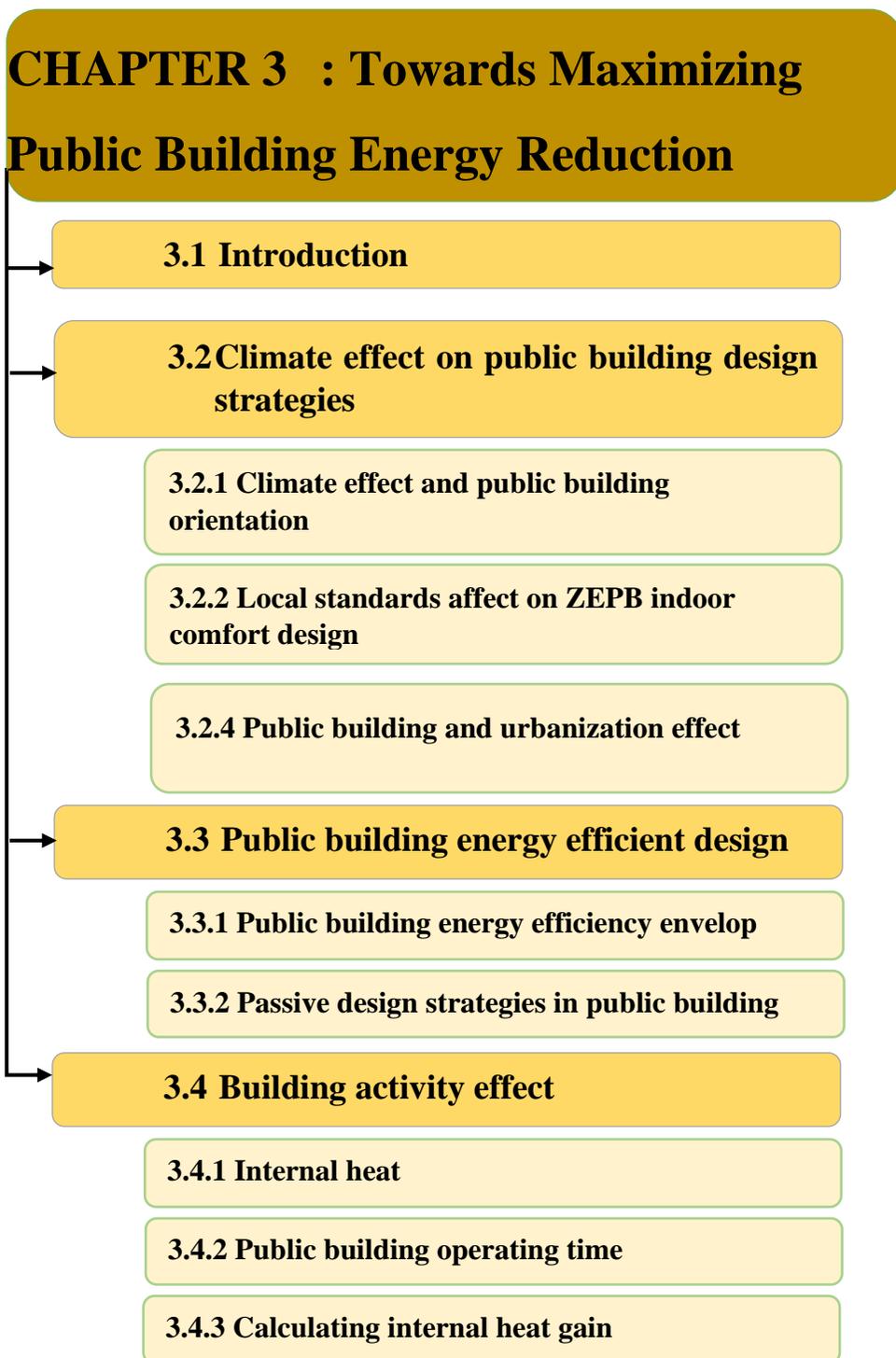


Figure 3-1 Chapter 3 structure

3.1 Introduction

While designing ZEPB, there are many factors and standards that need to be taken into consideration, it requires understanding the building energy needs and how to reduce its energy consumption to the minimum according to many factors like the climate zone where the building is located and the design strategies related to it, also, the energy efficiency at the building envelop or by using passive strategies, in addition to calculating the internal heat gain for the public building according to the working hours, number of occupants, equipment types,...etc. So, this chapter focus on climate effect on public building design and the various techniques and strategies that can be integrated into the design to achieve ZEPB goal and comfort zone for the users. In addition to studding the urbanization effect on the ZEPB design methodology. Also, explain passive design strategies for increasing the building efficiency, specially the building envelop which plays important role in achieving ZE goal. Also, public building activity, operating time, occupancy numbers, and equipment type need to be well studied and calculated its great effect on building energy consumption.

3.2 Climate effect on public building design strategies

Climate is a critical variable in the design of a NZEB projects. (William W., 2016, p. 80) How is the public building is oriented? Is the public building located on urbanized or rural area? And what is the comfort temperature in building location? Three important questions show the serious effect of climate on ZEPB. (Figure3-2)

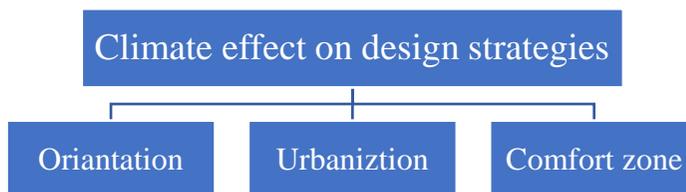


Figure 3-2: Climate effect on design strategies, Source: Author.

3.2.1 Climate effect and public building orientation

Public building orientation refers to the way a public building is situated on a site and the positioning of windows, rooflines, and other features to maximize

solar gain at the appropriate time of the year when required in cold climate and to minimize solar gain in a hot climate. Building orientation and openings play an important role in achieving thermal comfort and reduction of energy consumed in cooling, heating, lighting, or any other purposes. Orientation of building should be done for the climatic zone in which the building is situated. The purpose of public building orientation is to provide a comfortable working space throughout the year even under simple undesirable weather conditions and takes advantage of passive and active solar strategies; which use energy from the sun to heat and illuminate buildings. Egypt has a hot and dry summers with moderate winters, so this study will focus on public building orientation located in hot and dry climatic zones. (Rania E. Ashmawy, December 2017)

Generally, hot and dry climate occur at latitude between 15 degrees to 30 degrees on both the hemispheres, also, maximum daytime summer temperature goes high up to 45 degree centigrade and relative humidity as low up to 20%. (theconstructor.org, 2019) (Figure 3-3)

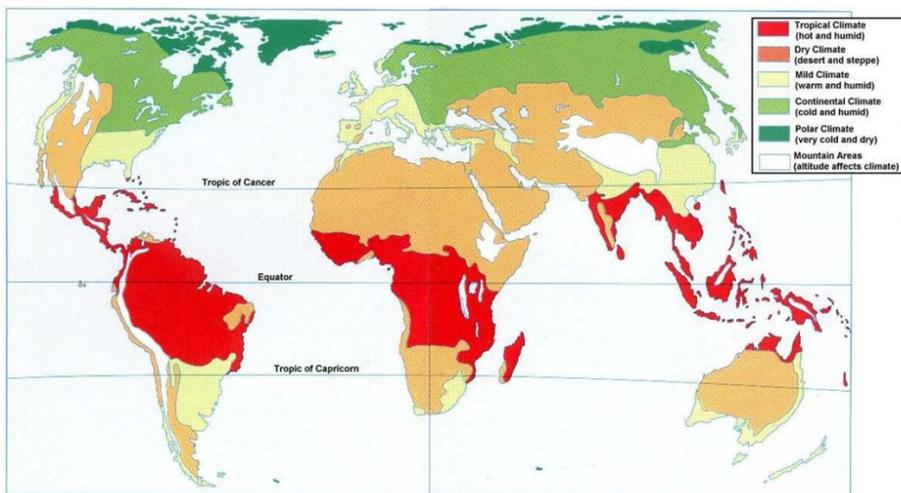


Figure 3-3: World Climate Type Map, Source:

<https://sites.google.com/a/lps.k12.co.us/science-rocks/home/world-climate-type-map>

3.2.1.1 Suitable building orientation in hot and dry climate

A studied orientation greatly influences the impact of the sun and wind on the building. Orienting the largest dimension of the building north and south will reduce a building's solar exposure, the windows should face the prevailing wind; which will maximize cross-ventilation of the rooms.

Public buildings must be responsive to solar orientation on the site. The sun is at a low angle during the winters and to the south of east-west axis. During summer, its path is at a high angle and slightly north to the east west axis. The alteration in path affects solar radiation penetration patterns during different seasons and consequently, heat gain and loss in a building. (Figure 3-4)

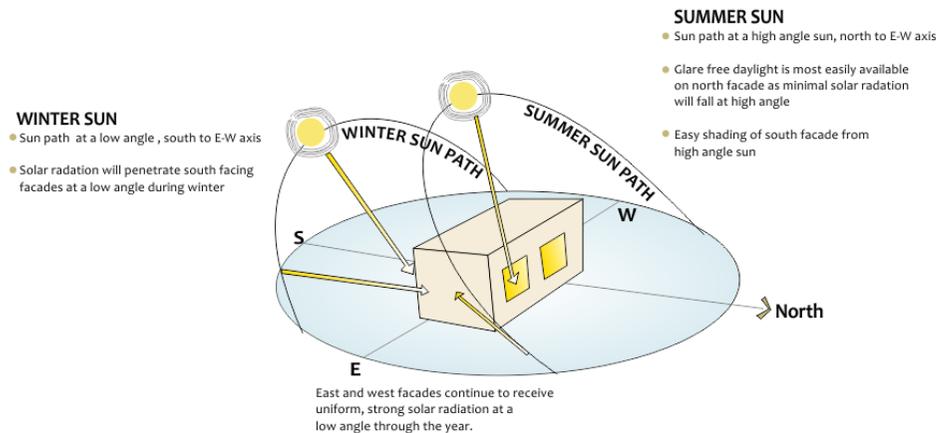


Figure 3-4: Sun path during summer and winter, Source:
<http://www.nzeb.in/knowledge-centre/passive-design/form-orientation/>

Also, proper orientation of a building will provide occupants comfortable working spaces throughout the year and even under several weather conditions. However, it is found that a southern facade results in the least energy consumption because of lower heating loads in winter. Moreover, the western facade causes the highest annual energy consumption by 26% over the southern façade. And, it is found that the energy consumption for the facades North-South is lower than the energy consumption for the facades East-West by nearly 10%, which is reflected on reducing the annual energy consumption rates by about 13%. (Rania E. Ashmawy, December 2017)

3.2.1.2 Form and orientation of public building in hot and dry regions

The building form determines the volume of space inside a building that needs to be heated or cooled. (Figure 3-5)

- More compact the shape, the less wasteful it is in gaining/losing heat.
- In hot & dry regions, building's shape needs to be compact to reduce heat gain and losses. (Bilqis Aisyah, February 2016)

- The surface to volume (S/V) ratio of the building should be as low as possible to minimize heat gain.
- Mutual shading of built forms and compact forms i.e. forms with low surface area to volume (S/V) ratio and low perimeter to area (P/A) ratio are ideal for extreme climates. Compact forms gain less heat during daytime and lose less heat at nighttime. (Beta Paramita, 2010)

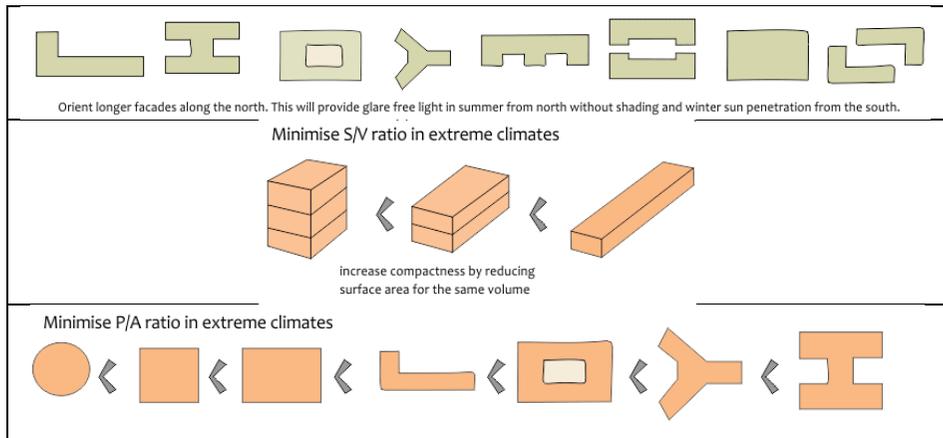
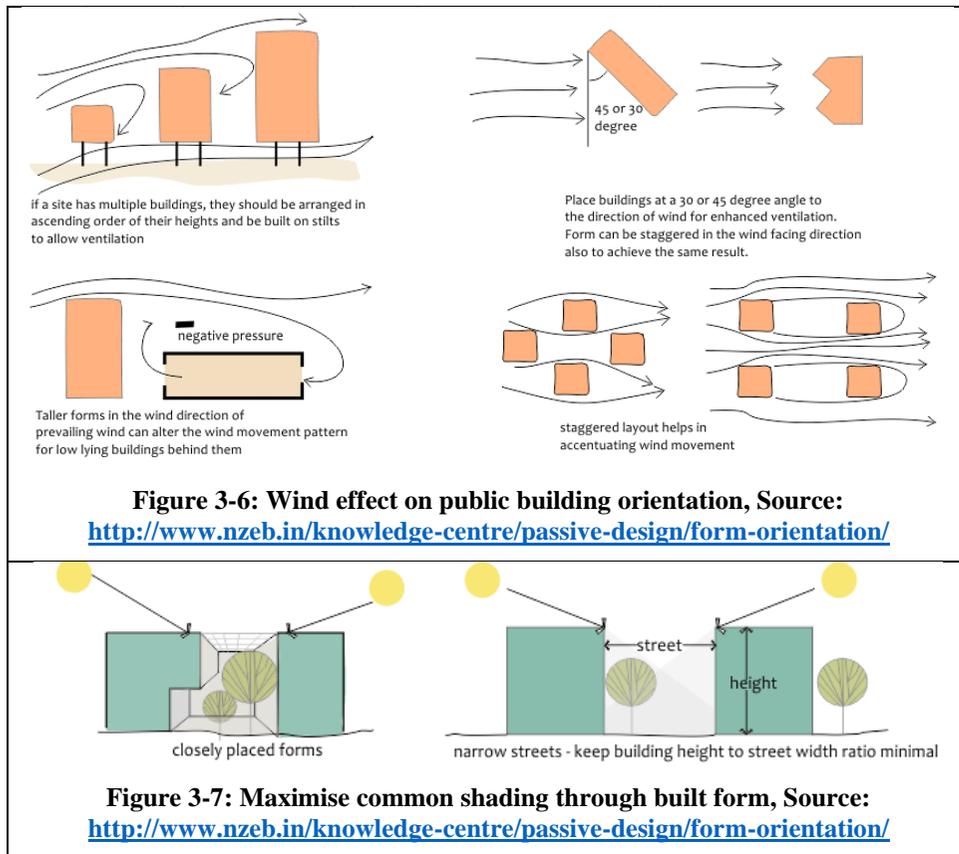


Figure 3-5: public building better form orientation, Source:
<http://www.nzeb.in/knowledge-centre/passive-design/form-orientation/>

3.2.1.3 Wind and orientation of public building in hot and dry regions

- Public buildings should be oriented with their longer axis (north – south) aligned perpendicular to the prevailing winds to facilitate maximum air-flow and cross ventilation through the building (Abbaszadeh, 2015).
- Public buildings can be oriented at an angle between 0° to 30° or 45° with respect to the prevailing wind direction. (Figure 3-6)
- In case of multiple public buildings on a site, they must be arranged to avoid built forms falling in the wind shadows created by other buildings on the site and to take advantage of prevailing wind. (Petr Hanzlik, 2005)
- Buildings that feature a courtyard, orienting the courtyard 45° from the prevailing wind maximizes wind flow into the courtyard and enhances cross ventilation in the building. (Figure 3-7)



These design considerations for suitable orientation, form, and interaction to wind are considered in designing the form of proposed zero energy public building at the practical study at chapter 6.

3.2.1.4 Thermal comfort basis

In Climate Consultant Software, various parameters are analysed which are responsible for climate change. Climate Consultant helps us in designing climatic data like temperature, humidity, dew point, sky cover range, wind velocity, psychrometric chart etc. (Ashwani Kumar, 2018)

A psychrometric chart is a graph of the physical properties of moist air at a constant atmospheric pressure. It expresses how various properties relate to each other and is thus a graphical equation of state. (Daniela de C. Lopes, 2009)

Psychrometric Chart in Climate Consultant software is one of the most powerful design tools. It shows dry bulb temperature across the bottom and moisture content of the air up the side. This vertical scale is also called absolute

humidity and can be shown as the humidity ratio in pounds of water per pound of dry air (or grams of water per kilogram of dry air), or as the vapour pressure. The curved line on the far left is the saturation line (100% Relative Humidity line) which represents the fact that at lower temperatures air can hold less moisture than at higher temperatures (Figure 3-8).

Every hour in the climate data file is shown as a dot on this chart. Some dots may represent more than one hour, for example when a given temperature and humidity occurs more than once in any month. A given hour's dot might meet the criteria for more than one strategy zone, in which case it is counted in the Percentage of Hours for both zones, which is why the percentages add up to more than 100%. (Ashwani Kumar, 2018)

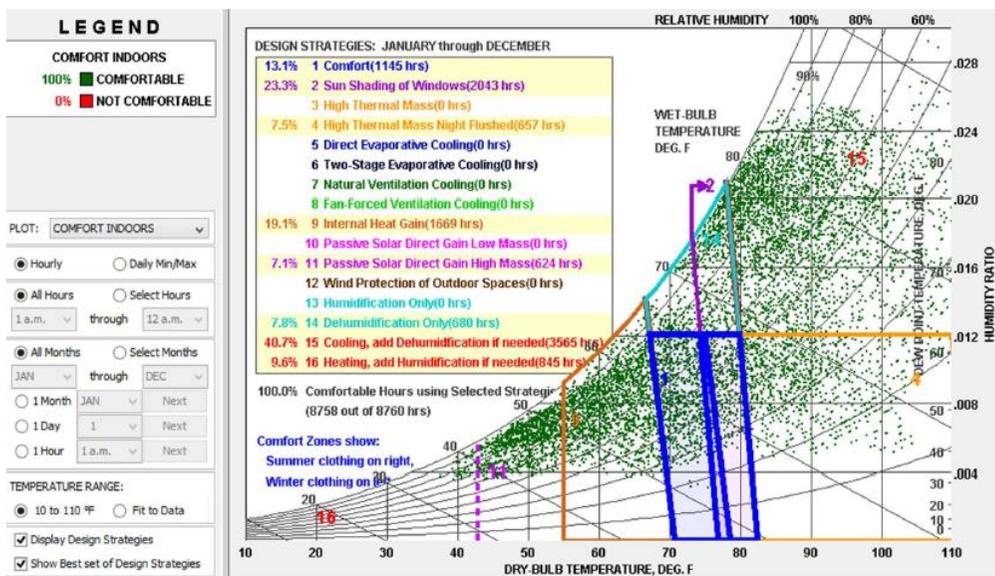


Figure 3-8: Psychrometric Chart in Climate Consultant software, Source: (Ashwani Kumar, 2018)

As shown in this figure the best eight Design Strategies are proposed in above Psychrometric chart. Also, this depicts that 40.7% cooling and 9.6% heating is required in that area particularly. (Ashwani Kumar, 2018)

3.2.2 Local standards effect on ZEPB indoor comfort design

Achieving Comfort zone is very important element in ZEPB design process, by taking care of the conditions that would make most people comfortable and releasing that the luxuries of one generation become the necessities of the next.

(William W., 2016) and the local standards that affect on ZEPB indoor comfort design are in (Figure 3-9).

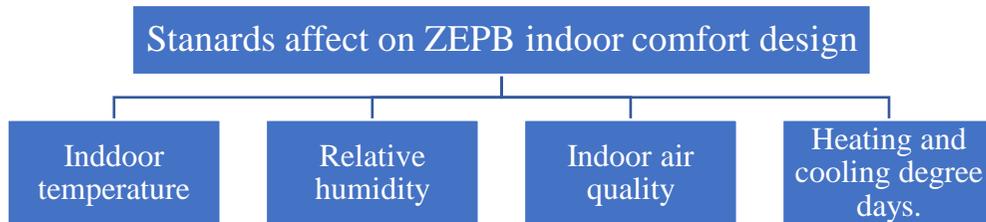


Figure 3-9: Factors effect on ZEPB indoor comfort design, Source: Author

3.2.2.1 Indoor temperature

Indoor environment of NZEB projects have great differences among various nations. Each NZEB typical design should follow local design specifications and standards. Commonly, most of the indoor design temperature is 25-26 °C in summer and 18-20 °C in winter (Xu Wei, 2017). (Figure 3-10) shows the minimum and maximum indoor temperature for cooling and heating in different countries.

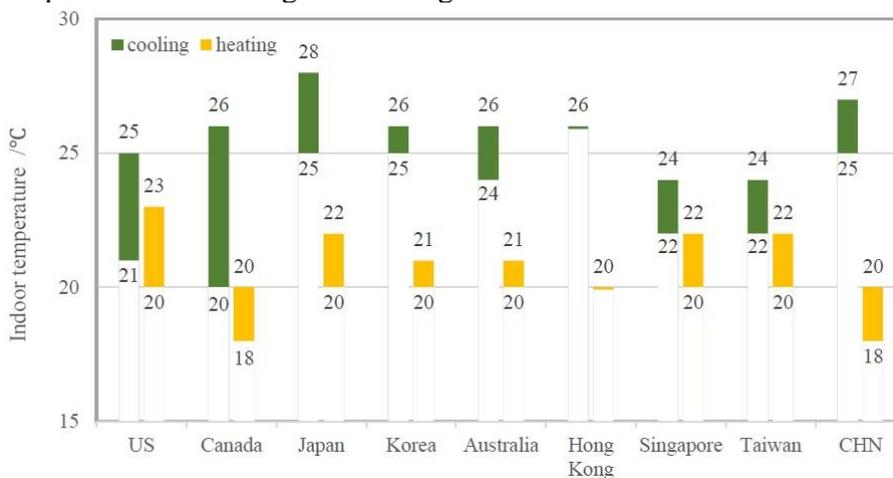


Figure 3-10: Indoor temperature setting in many countries, Source: Xu Wei, Zhang S., APEC 100 Best Practice Analysis of Nearly/Net Zero Energy Building, Asia Pacific Economic Cooperation, 2017, p.29

Taking Energy Saving as the priority, Japan has put significant effort in cutting down building energy consumption. Some of the office indoor temperature are set to 28 °C to reduce cooling demand and use radiant cooling system as the comfort compensation.

3.2.2.2 Relative humidity

Compared to indoor temperature, the relative humidity of indoor air is also a crucial factor of body comfort, especially for hot and humid climate zones. For high temperature, humidity region, the more rigid humidity requirement, the lower temperature of the chilled water at traditional HVAC system and meanwhile, the higher cooling demand. (Xu Wei, 2017)

Indoor relative humidity minimum and maximum values, at winter or summer, are shown in (Figure 3-11) for different countries. All these standards have to be considered in zero energy design.

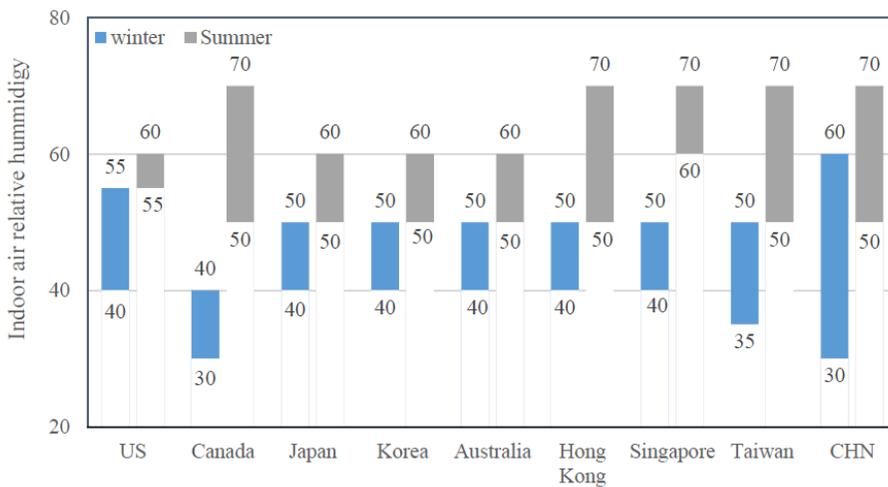


Figure 3-11: Indoor relative humidity, Source: Xu Wei, Zhang S., APEC 100 Best Practice Analysis of Nearly/Net Zero Energy Building, Asia Pacific Economic Cooperation, 2017, p.29

3.2.2.3 Indoor air quality

Indoor air quality is a measure of the healthiness and comfort of air in buildings. Modern public buildings tend to have high concentrations of occupants and materials that can compromise healthy IAQ unless enough solutions are applied. Pollutants in the air are normally categorized as gaseous, particulates, or microbial. In large scale public buildings, such as shopping centre and office building, the composition of pollutants is usually very complex. For now, the worldwide recognized CO₂ concentration standard is not higher than 1000 ppm (Xu Wei, 2017). There are several indoor air quality

standards like ISO 7730 and ASHRAE 55 and 62.1 (Tamara Bajc, October 2015), they specify the following:

- ISO 7730¹⁰: International standard 7730 determines the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) as a function of the activity and clothing. The PPD and PMV express warm and cool discomfort for the whole body. The limits for the light, mainly sedentary activity during the winter period are given in standard. The operative temperature shall be between 20°C and 24°C. The relative humidity shall be between 30 and 70%.
- ASHRAE Standard 55¹¹: This standard defines the thermal environmental conditions for human occupancy. It describes the metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, humidity and position of the measuring equipment. Operative temperature or PPD, PMV shall be measured or calculated at a height of 0,6 m level above the floor for seated occupants and at the 1,1 m level for standing occupants.
- ASHRAE Standard 62.1¹²: gives ventilation criteria for acceptable IAQ when the mechanical ventilation system is designed. According to this standard, minimum ventilation outdoor air rate in breathing zone for office space per person is 2,5 l/s/pers, while the outdoor air rate per area is 0,3 l/s/m². Maximal allowed CO₂ concentration for offices is 700ppm higher than outdoor air level. Typical CO₂ concentration level in outdoor air is between 300 and 500 ppm, so maximal recommended CO₂ concentration for offices is from 1000 to 1200 ppm. (Tamara Bajc, October 2015)

3.2.2.4 Heating and cooling degree days.

The first step during the design process which is commonly used to estimate energy consumption in the thermal design of the building is calculating Heating Degree Days (HDD) and Cooling Degree Days (CDD). (Tamara Bajc, October 2015)

¹⁰ ISO 7730 International Standard: Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

¹¹ ASHRAE standard 55: Thermal environmental conditions for human occupancy.

¹² ASHRAE standard 62.1: Ventilation for acceptable indoor air quality.

However, the various base temperature that adopted during the HDD and CDD calculation show different HDD and CDD values. (Xu Wei, 2017) as shown in (Table 4)

Table 4: Base temperature of heating and cooling Economy

Base temperature that adopted in HDD/CDD calculation		
Countries	Temperature adopted in HDD/ °C	Temperature adopted in CDD/ °C
United States	20	23
Canada	20	23
China	18	26
Japan	18	26
Korea	20	23
Europe ¹³	22	7°C below the outdoor temperature
United Arab Emirates ¹⁴	22.5	25.5
Egypt ¹⁵	22.2	25.6

At CDD the central heating was developed to save labor and increase productivity, but it quickly became a regular service and now mandated by law (in cold climates), with the comfort zone written into regulations. (William W., 2016)

In Egypt, buildings are characterized by low levels of insulation which leads to a very poor thermal performance and low indoor air quality. (S. Attia, 2012) For example, Cairo consumes 74% of the used electricity towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones. (Attia, 2013) This studies shows the importance of solving the thermal comfort features and proves and the importance of enhancing public building insulation efficiency to save significantly the used energy.

¹³ European climate zones and bio-climatic design requirements, Project report, BEAR-ID, NOBATEK, September 2016, p.12

¹⁴ Hanan A. I., Indoor Air Quality in UAE Office Buildings and Their Effects on occupants' Health, Comfort, Productivity and Performance, MSc Sustainable Design of the Built Environment, the British University of Dubai 2015

¹⁵ M. M. Mahdy, M. Barakat, Thermal Behaviour Assessment For The Different Building Envelope Parts In Egypt Under Climate Change Scenarios, Journal of Engineering Science and Military Technologies, Volume (1) - Issue (2), Egypt, 2017, p.75

3.2.3 Public building and urbanization effect

Dense building developments, heat emissions, human activities, etc., have a great impact upon the local climate of a city, there is great difference in temperatures between urban and rural areas and this is called as urbanization effect or the urban heat island (UHI) effect, which develops when urban cooling rates are slower than rural ones. (Figure 3-12)

High density of industrial centers and urban population is also a problem and has led to 5-11 °c increase in temperature compared with adjacent regions (Koosha Kalhor, 2015) due to many factors:

- High capacity of the buildings in the urban area, lead to absorb and store more of the sun's energy.
- High density of buildings in urban areas block the view of the sky and reduce the heat release back to space.
- Dense development in urban areas especially tall buildings, which trap air into street canyons and reduce wind speeds within the city.
- Building material store solar heat and release it at night.
- Long wave radiation is reflected from walls back to street level.
- Man-made heat emissions by buildings, air conditioning, transportation and industries in urban areas.
- Lack of vegetation areas in urban spaces.

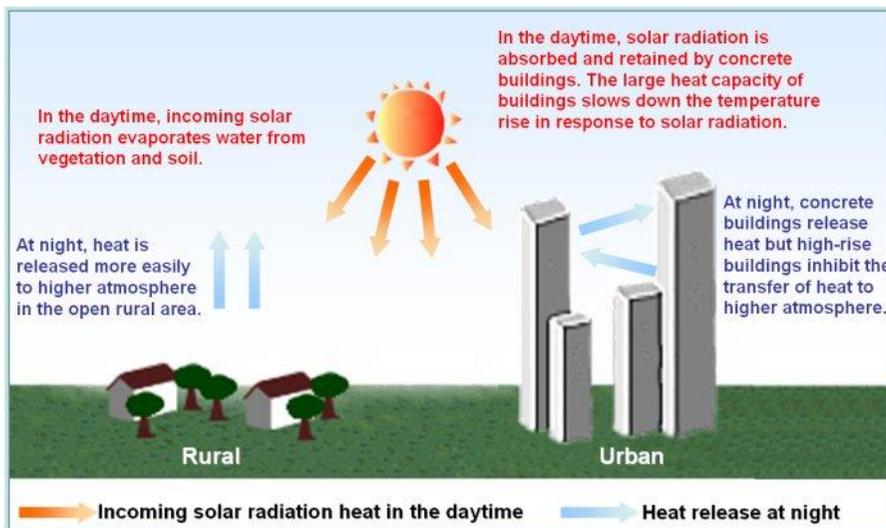


Figure 3-12: Sketch explain the difference between urban and rural area, Source: https://www.hko.gov.hk/climate_change/urbanization_e.htm

Generally, the UHI can be felt in areas where urbanisation has been more intense- such as the central business district (CBD). In Egypt, urbanization increased by 30% during the years from 1990 to 2009. (Koosha Kalhor, 2015)

3.3 Public Building energy efficient design

Saving the building from the external environmental effects make it easier to reach thermal comfort and reduce energy consumption. So, efficient design process at hot and dry climate saves energy by keeping building cooler in summer as well as warmer in winter and protects exterior walls from weather damage and corrosion.

Factors that increase public building energy efficiency envelop like wall section design, glazing and opening control, roof insulation, and more need to be carefully studied, in addition to applying on the building design the passive strategies for heating, cooling, ventilation, daylighting and shading to reach high energy performance building.

3.3.1 Public building energy efficient envelop

The building envelope is the front line of the building's interface with the exterior environment and climate. And it plays a critical role in the implementation of passive strategies, also, it should be integrated with decisions about orientation and massing, as well as with mechanical and electrical system design. The public building envelope must balance the needs for passive strategies with the need for the performance from a thermal energy perspective. So, the high performance building envelope is the first step and the critical element towards ZEPB building design. (Hootman, 2013.)

Zero energy public building envelope selectively filter the climate and adjusting temperature, humidity, moisture, wind, and sunlight as well as the different aspects of the envelope that influence heat exchange: lossiness, thermal mass, time constant, transparency, and shading. (William W., 2016, p. 80)

To save energy while keeping interiors in the comfort zone range, the building envelope has two basic routes of energy exchange: (Figure 3-13).

- 1- Heat transfer through the many components of the building envelope, driven by the temperature difference between the interior and exterior.
- 2- Penetration of sunlight through windows, which converts to heat when it strikes interior surface.

Because environmental conditions are so variable, at hot arid regions, the high temperature throughout the year is reaching the highest rates in the summer (about 42°C). It also noted that the temperature difference between day and night is significantly high (up to 20°C). The humidity drops to the lowest rates because of the high rate of evaporation. The concentration of solar power reaches 5 kW/m²/day. (Ahmad Kandeel, January 2013)

The task of the building envelop is dynamic, modifying, and stabilizing the available energy flows. (William W., 2016, p. 84) And the time that determines how quickly the building warms up, whether from sunlight, the heat given off by people, or other sources doesn't depend on building size -large or small- because buildings can have the same value of response to temperature change (Figure 3-14).

As for the largest external area of a building walls, openings, and roofs are where most heat losses occur. High performance envelope reduces heat loss in cold weather and keep out heat in hot weather. So, each element will be studied in detail to save energy, starting from fabrics U-value¹⁶, openings, shadings design, to roofs.

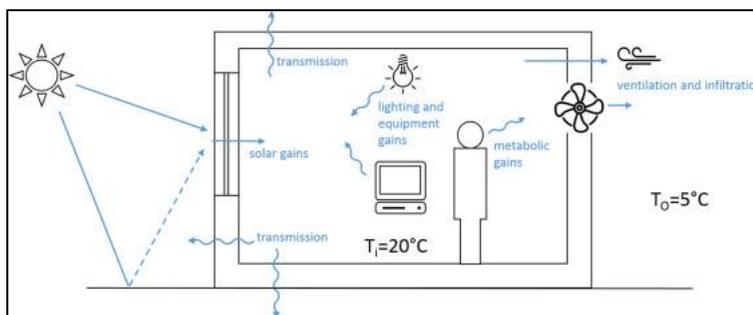


Figure 3-13: Heat transfer at the building, Source: Stijn V., Amaryllis A., Thermal inertia in buildings: A review of impacts across climate and building use, Renewable and Sustainable Energy Reviews, Volume 82, Part 3, February 2018, Pages 2300-2318

¹⁶ U-value: is the rate of transfer of heat through a structure (which can be a single material or a composite), divided by the difference in temperature across that structure. The units of measurement are W/m²K.

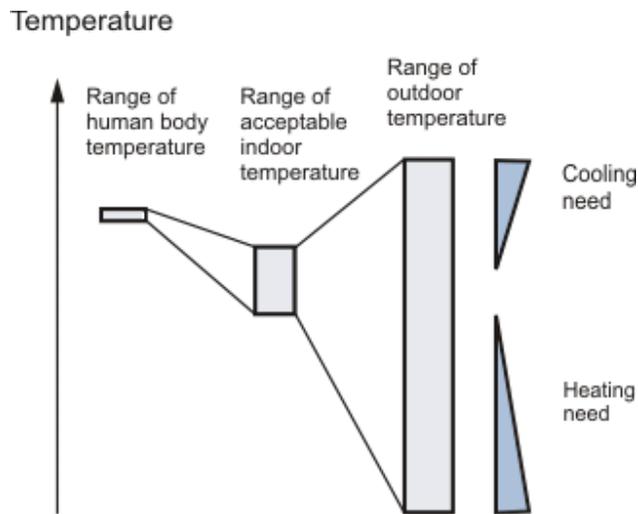


Figure 3-14: High thermal resistance of insulating layers reduces temperature amplitudes felt on the human skin, Source: <http://www.thermopedia.com/content/603/>, BUILDINGS AND HEAT TRANSFER, access on February, 12th, 2019

The thermal transmittance U is calculated as the inverse of the total thermal resistance R_T (Equation 1), which is simply obtained as the sum of internal and external surface resistances R_{si} , R_e and the thermal resistance of each layer of the assembly R_i . (Arregi Goikolea, 2018) Energy simulation programmes calculate it too.

Equation 1: The thermal transmittance U

$$U = \frac{1}{R_T} = \frac{1}{R_{si} + \sum R_i + R_{se}}$$

3.3.1.1 Factors that affect envelop efficiency

The heat transfer coefficient in various parts of the building envelope, shading coefficient, and air tightness requirements for different building climate division had been specified. (Durkay, 2013) However, the thermal performance of the building envelope of public building has not yet fully meet energy efficiency standards and the building envelope hasn't been taken energy-saving measures.(Figure 3-15)



Figure 3-15: Envelop efficient quality factors, Source: Author.

3.3.1.1.1 Thermal Insulation for public building envelope

Insulation systems are used widely in public building as a solution to reduce the rate of heat transfer through the roofs and sidewalls. Insulation is used also on chilled water piping, HVAC ducts and equipment for thermal, sound, condensation and process control. (Insulation Institute , 2016)

More insulation does not necessarily mean better performance. Optimum economic thickness of insulation can be defined as the thickness of insulation for which the cost of the added increment of insulation is just balanced by increased energy savings over the life of the project. Thermal insulation does not always have the same thermal effectiveness for all types of buildings, its effectiveness and economic value can be determined (Al-Homoud, 2004) through the following:

- The public building type and function have an important role in determining the impact of envelope thermal insulation on the thermal performance of buildings.
- Using proper treatment of building envelopes, can significantly improve thermal insulation performance.
- Walls and roof insulation are recommended for buildings in all climates for more thermally comfortable space with less energy requirements.
- Air sealing is must prior to insulating, caulk and seal all sill plates, band joists, penetrations, joints and other areas where air infiltration might occur. (Figure 3-16)



Figure 3-16: Air Sealing is a Must, Source: Building Insulation: A Performance Comparison for Today's Environmental Home Builder & Renovation Project, Handbook, Naima, Canada, 2010

3.3.1.1.2 Public building envelope airtightness

The strategy is to make the public building envelope as airtight as possible to reduce heating and cooling, and then to ventilate the building using a mechanical system. Envelope airtightness can be defined as “the resistance to inward or outward air leakage through unintentional leakage points or areas in the building envelope”. (Limb, 1992) Envelope airtightness can be measured by using a fan pressurization test or known as blower door equipment (Figure 3-17) or Large-Building Airtightness Test Fan (Figure 3-18) for public building (nist.gov, 2019).



Figure 3-17: Blower door equipment, Source: <https://obec.on.ca/events/2017/02/22/3-day-large-building-airtightness-testing-training>



Figure 3-18: Large-Building Airtightness Test Fan, Source: <http://www.infiltec.com/inf-g54s.htm>

An airtight public building has several positive impacts when combined with an appropriate ventilation system (Building Energy Codes, September 2011) whether natural or mechanical because it will lead to:

- Lower cooling bills due to less heat gain, with potentially smaller requirements for heating and cooling equipment capacities.
- Better performance for the ventilation system.
- Fewer airflows and thus increased thermal comfort
- Substantial energy savings by tightening building envelopes

3.3.1.1.3 Thermal bridging at public building

THERMAL bridge is a part of a building envelope with different geometry or thermal conductivity or fabric thickness. Thermal bridging causes additional heat losses that can degrade the building envelope thermal performance and therefore should be minimized. (Małgorzata O’Grady, 2018) Thermal bridging happens in the

building envelope when a material component transfers heat through itself at a greater rate than surrounding components, the thermal performance of a building's envelope can be greatly affected by thermal bridging, or high heat flow through walls, roofs and other insulated building envelope components (Figure 3-19). Additional heat flow due to thermal bridging at interface details, such as shelf angles or the interface between windows and walls, slabs, parapets and glazing transitions (Figure 3-20), can be sources of significant heat flow through the building envelope (Arregi Goikolea, 2018). The solution is determining the thermal bridge places and increase the U-value by 13.5% and 26.2 %. (Małgorzata O'Grady, 2018)

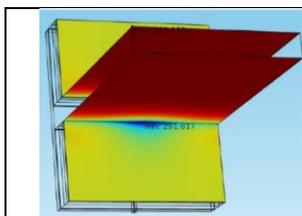


Figure 3-19: Thermal bridging heat flow by passing the insulation through the slab, Source: (Arregi Goikolea, 2018)

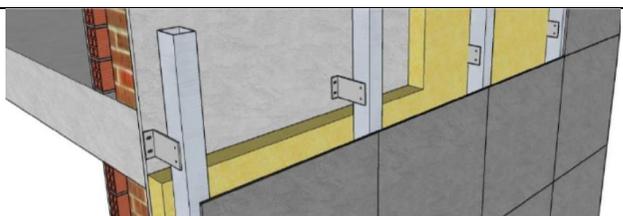


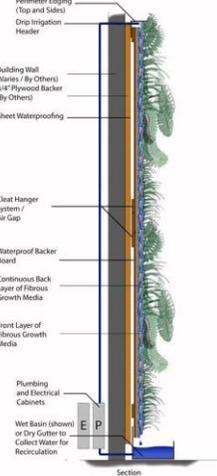
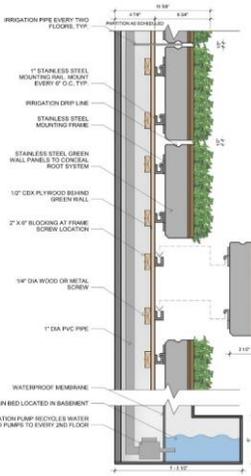
Figure 3-20: Auxiliary structure of ventilated façade assembly over existing external wall construction, Source: (Arregi Goikolea, 2018)

3.3.1.2 External walls and wall section design

External walls are the most significant elements in the building envelope. They receive a large amount of sunlight during the day, also, they often occupy the largest area in the building envelope, and they play the main role in resisting heat transfer from exterior space to interior space. The common types of external walls in public buildings include cast in site reinforced concrete (RC) walls, precast concrete walls, green walls and masonry brick walls. (Ahmad Kandeel, January 2013)

And for integrating green walls in public buildings (Michael B. McCullough, June 2018), provides environmental health benefits. They are based on the application of climbing or hanging plants along the wall. Plants can grow upwards the vertical surface, like traditional examples, or grow downward the vertical surface, in case they are hanged at a certain height. (Maria Manson, 2015) Green walls types are continuous system (Figure 3-21, 22) and modular system (Figure 3-23, 24), each system is shown in table 5.

Table 5: Green walls types and advantages

Continuous system	Modular system
 <p>Figure 3-21: Continuous green wall, Source: https://www.researchgate.net/figure/Continuous-green-I</p>	 <p>Figure 3-22: modular green wall, Source: https://www.researchgate.net/figure/Modular-living-wall-with-edible-plants</p>
 <p>Figure 3-23: continuous green wall sec, Source: https://www.pinterest.es/pin/359443614003656892/?lp=true</p>	 <p>Figure 3-24: modular green wall sec, Source: https://www.pinterest.es/pin/359443614003656892/?lp=true</p>

The wall section need to be designed to match the local standard of external wall U^{17} -value, for example at U.S. It is 0.88, at Canada is 0.4, at China 0.6, at Japan 1.46, and at Korea is 0.49 (Xu Wei, 2017) standard limited value. Nearly all the public building projects that looking to reach with there design to be ZEPB should reach a much lower U-value for external walls. Choosing proper insulation is critical. And to calculate the u-value of the building construction need to know each element Thermal Resistance¹⁸ (Virginia Gori, 2014). The

¹⁷ Tables of U-Values can be found in book: Energy Conservation in Buildings: A Guide to Part L of the Building Regulations, pp.78-102

¹⁸ R Thermal Resistance: is defined as a measure of the opposition to heat transfer offered by a particular component in a building element.

U Value is the reciprocal of the R Value and either can be calculated from the other ($U=1/R$ or $R=1/U$). (Rui Miguel de Sousa, 2014) And to improve the wall R value, using insulation layers is essential. There are many types of wall insulations, but the most popular in market are in table 6.

3.3.1.2.1 Fibre Glass Insulation – Batts, Rolls or Blown-in

Fibre glass batts are available in pre-cut sizes that fit standard wall cavities. They can also be easily cut to fit any size cavity and small spaces, its R-value of up to 4.3 per inch. (Figure 3-25)

3.3.1.2.2 Stone Wool and Slag Wool Insulation

They are available in pre-cut sizes and also easily cut to fit any size cavity and small spaces. Stone and slag wool can be either blown-in using a mechanical blowing machine or poured in place, its R value of about 3.14 to 4.00 per inch. (Figure 3-26)

3.3.1.2.3 Cellulose Insulation

Dry loose-fill cellulose insulation is installed in walls with blowing machines. It takes normal drying time of 24-48 hours, R-value of approximately R-3.5 per inch. (Figure 3-27)

3.3.1.2.4 Spray Foam Insulation (SPF)

Spray foam is usually installed by a specialty spray-foam contractor, when the foam insulation is sprayed, it coats the surface and quickly expands as it solidifies, R-value of about R-3.7 per inch. (Richard T. Bynum, 2001, p. 131) (Fig 3-28)

3.3.1.2.5 Vacuum insulation panels

Vacuum insulation panels are enveloped into a multilayer film. VIPs have the lowest thermal conductivity rate, and they allow for significant space economy. But they are relatively fragile, their performance significantly decreases with time, R-value about R-10 to R-30 per inch. (Sultan Sanat Alotaibi, 2013)

3.3.1.2.6 Aerogel insulation

Aerogel manufacturers have mainly focused on cost reduction. (Bjrn Petter Jelle, 2015) (Figure 3-29) Aerogel is an artificial, spongy ultralight material derived from a gel, in which the liquid component of the gel has been replaced with a gas and produced a solid material with extremely low density and low thermal conductivity. It is the most low-density solid material and has several unique physical properties as thermal insulation, R-value about R-20 per inch. (Bozsaky, 2016)

Table 6: Walls insulation types

	
<p>Figure 3-25: Fiberglass Insulation</p>	<p>Figure 3-26: Stone Wool Insulation</p>
	
<p>Figure 3-27: Cellulose Insulation, Source: Building Insulation: A Performance Comparison for Today 's Environmental Home Builder & Renovation Project, Handbook, Naima, Canada, 2010</p>	<p>Figure 3-28: Spray Foam Insulation , Source: Building Insulation: A Performance Comparison for Today 's Environmental Home Builder & Renovation Project, Handbook, Naima, Canada, 2010</p>
	
<p>Figure 3-29: Aerogel insulation, Source: https://www.researchgate.net/publication/281970746_Aerogel_Insulation_for_Building_Applications</p>	<p>Figure 3-30: installing VIP on wall, Source: https://www.buildingcentre.co.uk/specific/manufacturer/kevothermal-ltd/product/vacuum-insulation-panels</p>

3.3.1.3 Glazing and openings

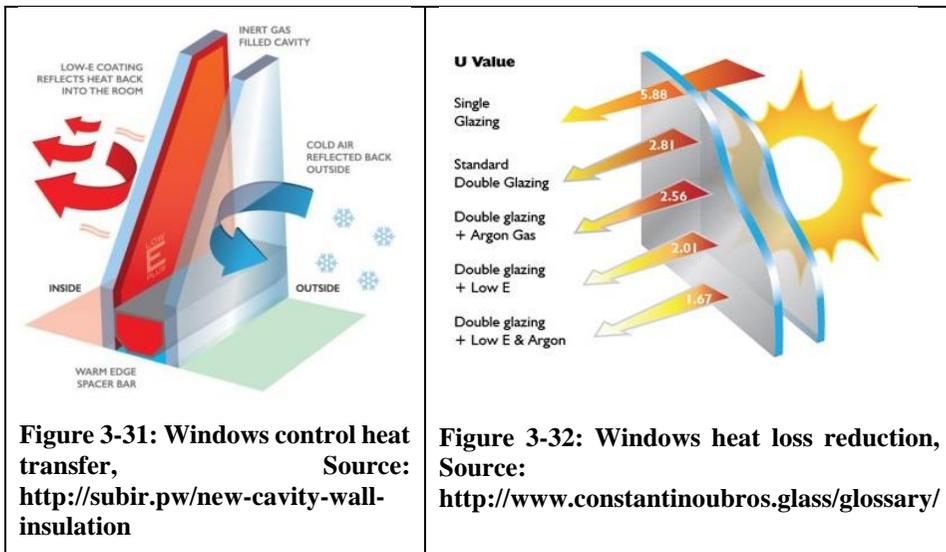
It is difficult to make windows and doors have the same heat transfer capacity as walls and roofs. Openings, specially windows have an important impact on building energy consumption. They are reason for 5% to 10% of the total energy consumed in buildings (Xu Wei, 2017). Comparing with walls, windows are multiple functions element in the building because they should control the entry of daylight, protection, ventilation, and at the same time, have to provide good insulation.

The standard window U-value at U.S. is 3.4, at Canada is 2.8, at China 2.6, at Japan 2.9 and at Korea is 3.4, One of the challenges for windows is to optimize the heat flow depending on the season (Xu Wei, 2017).

Openings effective strategy for public buildings experience both hot and cold climates is to adjust their properties between the seasons; in summer the windows are shaded during the day and opened at night when its cooler, and in winter the windows are directed to capture sunlight, with the envelope closed tightly to retain the heat. (Figure 3-31)

Improving openings cross section gives a significant improvement of energy efficiency to the whole public building and great reduction in energy consumption. Using opening with double glazing glass and fill with argon gas will be adopted at designing zero energy units to reduce the amount of heat transmitted into the building. Also, using high performance glazing with low-E coating on the inner side of the inner pane helps reflect heat back into the building. Windows cross section design control heat transfer from outside to inside, as shown in the figure the standard double glazing much more effective than single glazing, by adding argon gaze or extra coating layers, U-value is better and more effective as shown in (Figure 3-32).

The dimensions of the energy-efficient window have a low impact on the heating load but are very effective for the cooling load. Also, heat losses are very low when the building envelope is well insulated and triple-glazed windows had been installed. And it is recommended to use large windows at the northern facade and have desirable light conditions. However, when using large southern windows, the ventilation rate needs to be increased and shading devices should be utilized. (Persson, et al., 2006)



For all climates, the optimum WWR in a building with good insulation is 23.5% for a building with poor insulation it was 25.9%. In different conditions, the optimum glass area can be doubled due to the configuration effect of the envelope characteristics and electrical lighting. (Marino, et al., 2017).

For using daylight, the window area should not be less than 10% of the floor area, although the optimum window size for daylight may not be the same as the optimum value for energy (The National Board of Housing Building and Planning, 2019).

The opening position of a window area is highly important and by installing a window in the optimal location, the amount of energy loss through the thermal bridge decreases by 50% (Misiopcecki, et al., 2017).

In hot and arid climate, the building with 20–40% windows on the north facade had the minimum energy consumption. The southern front of the building, 20% and 30% windows had the minimum annual energy consumption. On the east and west facades, 30–50% windows had the minimum annual energy consumption. (Jalil Shaeri, April 2019)

To minimize overall heat gain/loss, one must reduce the window-to-wall ratio and use window glazing materials with low U-values. There have been recent advances in energy-saving glazing technologies such as vacuum glazing, low-emissivity (low-e) glazing and dynamic glazing. (A. Shehabi, 2013)

There are many glass types for openings as following:

3.3.1.3.1 Luxfer prism glass

one of the successful openings design in the early twentieth century, by using prismatic optics, Luxfer glass was redirecting daylight horizontally into rooms. This technique was extending and sometimes doubling the depth of the space that receives useful illumination. (Figure 3-33)

The physical size and configuration of contemporary public buildings dramatically restricts the amount of daylight possible, most interior spaces is too far from an opening. So, the most of contemporary buildings reduce the penetration of daylight that modern light sources are virtually the only choice. (William W., 2016, p. 107)

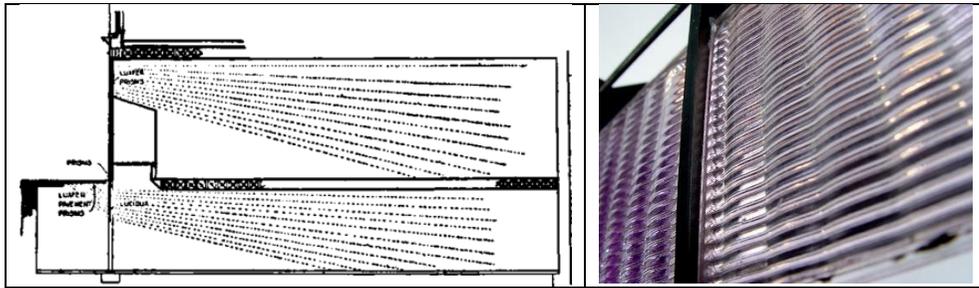


Figure 3-33: Luxfer prism glass redirect incident daylight into the interior, Source: <https://chestofbooks.com/architecture/Construction-Superintendence/Luxfer-Prisms.html>, access on February, 17th, 2019

3.3.1.3.2 Electrochromic glass

It is a self-tinting dynamic glass technology that darkens gradually and dynamically when heated by direct sunlight or darkens gradually upon light sensor or by electrical switch (Figure 3-34). (smartfilmsinternational.com, 2019)

3.3.1.3.3 Photochromatic glass:

Photochromic materials change their transparency in response to light intensity. Photochromic may be useful in conjunction with daylighting, allowing adequate light through for lighting purposes, while cutting out excess sunlight that creates glare and overloads the cooling system. (Figure 3-35) (Jelena Savić, 2013)

3.3.1.3.4 Suspended particles glass

It is a type of window that uses small light absorbing microscopic particles known as suspended particle devices (SPD) to make it transform from clear to dark in a matter of seconds. In an SPD window, millions of these SPDs are

placed between two panels of glass or plastic, which is coated with a transparent conductive material.

When electricity meets the SPDs via the conductive coating, they line up in a straight line and allow light to flow through, once the electricity is off, they move back into a random pattern and block light. When the amount of voltage is decreased, the window darkens until it's completely dark after all electricity is taken away. (Figure 3-36, 37) (Harary, 2000)

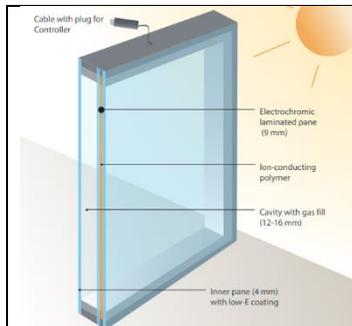


Figure 3-34: Section in Electrochromic glass, source: <http://smartfilmsinternational.com/wp-content/uploads/solar/SFI-Electrochromic-brochure.pdf>



Figure 3-35: Photochromic glass, source: (Jelena Savić, 2013)

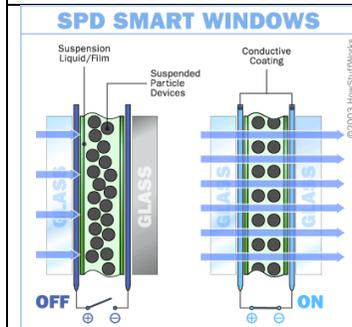


Figure 3-36: Section in Electrochromic glass, source: <https://home.howstuffworks.com/home-improvement/construction/green/smart-window2.htm>



Figure 3-37: SPG glass on and off mode, source: <https://www.glassappsource.com/smartglass/switchable-smart-glass-quality-smart-glass.html>

3.3.1.4 Public building Roof types

Roof as a part of the public building envelope has a great effect on heat transfer and radiation due to its large exposed area to sun and solar radiation.

Nearly all the projects that looking to reach with there public building design to be ZEPB should reach a much lower U –value for external roofs than the local standards. For example, the standard roof U-value at U.S. is 0.83, at Canada is 0.9, at China 0.55, at Japan 1.2 and at Korea is 0.35. (Xu Wei, 2017)

The choice between roof types depends on the interaction with the environment, on the climatic conditions and on the resources available or current technology. And there are five formal type of the roofs (Golzar Y., 2013): Pitched roofs, Flat roofs, Curved roof, Roof/ faced system, Green roofs and Other roofs, each one has many techniques to be isolated. (Figure 3-38)

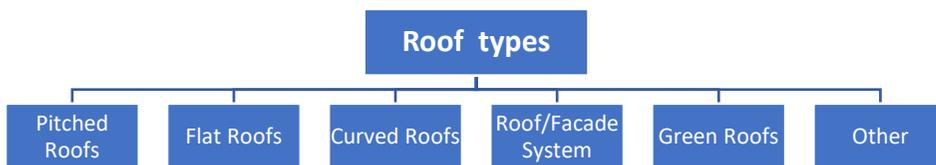


Figure 3-38: Roof types, Source: author.

3.3.1.4.1 Pitched Roofs

Pitched roofs are composed of a covering material and a structure, they have evolved toward a separation of the layer that provides protection from the rain and the layer that provides thermal protection (Figure 3-39), with a ventilation space between them that dries any moisture and acts as a thermal regulator. (Figure 3-40)



Figure 3-39: Pitched roof layers, Source:<http://savinggraciehorsescue.com/what-is-a-pitched-roof/pitch-contemporary-art-websites-what-is-a-pitched-roof/>

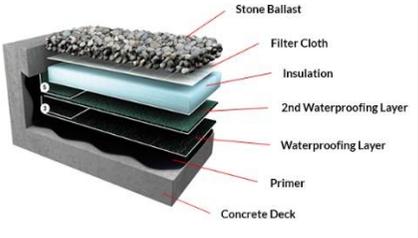


Figure 3-40: Public building with pitched roof, Source:<https://www.archdaily.com/catalog/us/products/12312/8-advantages-of-pitched-roofs-cupa-pizarras>

3.3.1.4.2 Flat roofs

Flat roofs are classified as in table 7 into; Bitumen cold or warm roofs (Figure 3-41), Inverted roofs (Figure 3-42), Walk-on roofs (Figure 3-43), Inverted roofs with a protective finish of gravel or insulating slabs, liquid membrane roof (Figure 3-44), Green roofs, Industrial roofs (Figure 3-45), and Parking roofs. (Figure 3-46)

Table 7: Flat roof types

 <p>A photograph showing a construction site for a bitumen roof. Large rolls of dark, fibrous bitumen membrane are being unrolled onto a flat concrete surface. The membrane is laid out in parallel strips.</p>	 <p>A 3D cutaway diagram of an inverted roof assembly. From top to bottom, the layers are: Stone Ballast (a layer of gravel), Filter Cloth, Insulation (a thick, light-colored layer), 2nd Waterproofing Layer, Waterproofing Layer, Primer, and Concrete Deck.</p>
<p>Figure 3-41: Bitumen roof</p>	<p>Figure 3-42: Inverted roof</p>
 <p>A photograph of a modern walk-on roof. The roof is paved with light-colored tiles and features a central area with a wooden deck, small trees, and a covered walkway. Several people are walking on the roof.</p>	 <p>A photograph showing a worker in a yellow safety vest applying a white liquid membrane to a flat roof. The worker is using a hose to spray the material, which is being applied in a large, smooth area.</p>
<p>Figure 3-43: Walk on roof</p>	<p>Figure 3-44: Liquid membrane roof</p>
 <p>A photograph of a large industrial building with a long, low-profile roof. The roof is covered in corrugated metal sheeting. A person is visible walking on the roof surface.</p>	 <p>A photograph of a parking roof on a city building. A silver SUV is parked on a concrete surface with white parking lines. The background shows a city skyline with several skyscrapers.</p>
<p>Figure 3-45: Industrial roofs</p>	<p>Figure 3-46: Parking roof</p>

3.3.1.4.3 Curved roof

Modern curved roofs most take advantage of the flexibility of metal roofing materials. Metal sheeting can be bent in such a way that it allows for curved surfaces, curved peaks and gently tapered roof edges. (build.com, 2019)

Orientation of the roof curve in relation to building climate zone, in hot and dry weather it can be used to reduce the thermal load in the building and can help in maximise the natural light distribution which led to reduce artificial lighting demand as shown in (Figure 3-47).



Figure 3-47: Example on Curved roof, United world college, Dilijan,
Source: <https://zinc-greenroof.com/references/united-world-college-dilijan>

3.3.1.4.4 Roof/façade system

In some public buildings the roof forms the outer skin of the building, with no separation between where the roof ends and the I begin. The roof fulfils its requirements and acts in turn as a façade, like a single skin that wraps the building completely. (Figure 3-48) For these roofs, easily malleable such as metal plate is used to crate the appropriate forms. (Golzar Y., 2013)



Figure 3-48: Example on Roof/façade system , Zaha Hadid's Heydar Aliyev Centre, Baku,
Source: <https://www.homedit.com/12-curved-roof-buildings-that-will-blow-your-mind/>

3.3.1.4.5 Green Roofs

These are also known as landscaped roofs. The thickness of the soil should be proportional to the size of the vegetable species that wish to

plant (Figure 3-49). Using Green roofs can reduce heat transfer through the roof and ambient temperatures on the roof surface, so it can be utilized as a good insulation to the roof no matter the roof pitched or flat or curved as shown in (Figure 3-50) the figure shows also the component of the used green roof.

A recent study showed that a green roof system covering an area of 10000 m² helped reduce the annual cooling needs of an Athens 374 office building by 19%. (P. Karachaliou, 2015)

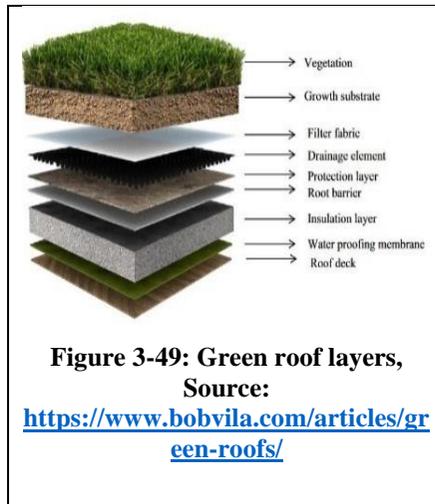


Figure 3-49: Green roof layers,

Source:

<https://www.bobvila.com/articles/green-roofs/>



Figure 3-50: Green roof Meydan shopping centre, Istanbul, by Foreign Office Architects, Source:

<http://www.singleply.co.uk/portfolio-items/meydan-shopping-centre/>

Green roofs may conflict with the installation of renewable energy systems. In this situation, hybrid photovoltaic (PV) green roofs appear to be a new solution that provides the benefits of both green roofs and PV electrical generation. (Vijayaraghavan, 2016)

3.3.1.4.6 Other Types of Roof

There are roofs with different characteristics that do not fall within the general classification, due to their geometric complexity. Care must also be given to waterproofing. A wide variety of materials and forms create the identity of each scheme. (Figure 3-51, 52)



Figure 3-51: The Peter B. Lewis Building designed by Frank Gehry,
Source:http://blog.cleveland.com/architecture/2012/11/the_10-year_old_peter_b_lewis.html



Figure 3-52: Royal Ontario Museum, Toronto, Source:
<https://raber.info/justdphoto-deconstruction-architecture-house.html>

3.3.1.5 Dynamic interactive envelope

Zero energy public buildings require more advanced and innovative solutions to reduce energy consumption, the traditional public building envelopes are static and not flexible and has not internal capability to react to changing boundary conditions. On the other hand, climate adaptive public building shell (CAPBS) has an adoption ability to the changing environment based on both passive design and active technologies, where CAPBS can be defined as; a climate adaptive building shell has the responsive ability by changing some of its functions, features, behavior and shape over time as a response to changing requirements and variable boundary conditions to improve the overall public building performance. (Maris Zamovskis, 2016)

The performed dynamic façade simulation showed a decrease of approximately 4°C indoors when the dynamic module is fully efficient at (21st June at 12 p.m.). Furthermore, the lux level is always within the comfort range for a public building (500-2000 lux) during both winter and summer scenarios. Moreover, the uniformity of distribution of daylight illuminance across the entire space is another associated advantage, giving interesting insights into potentials for architectural façade design. For example, to optimize the indoor comfort while calibrating the outline of a dynamic façade module, horizontal louvres of the adaptive façade can be used while they are moved by its absorption of energy. (J. Gaspari, 2019)

Dynamic interactive public building envelopes that respond to outside conditions and the needs of the people inside. Citing examples of public buildings with mechanical louvers as in (Figure 3-52, 53).



Figure 3-53: Al Bahr towers , Abu Dhabi ,
Examples on dynamic public building envelopes,
 Source: <https://www.urbangreencouncil.org/content/news/author-talk-russell-fortmeyer-shares-insights-dynamic-building-envelopes> ,



Figure 3-54: Examples on dynamic public building envelopes, Source: <https://www.pinterest.com/pin/525513850249889373/?lp=true>

3.3.2 Passive design strategies in public buildings

Implementation of passive energy saving technologies is a fundamental way to improve building energy efficiency. ‘Passive design’ is design that takes advantage of the climate to keep a comfortable temperature range in the building. Passive design reduces or eliminates the need for auxiliary heating or cooling. (Almusaed, 2011) The building type and operation determine which strategies will have the best overall impact on energy performance. There are many passive design strategies, but for ZEPB design the most important strategies are passive heating, passive cooling, passive ventilation, and passive day lighting (Figure 3-55).

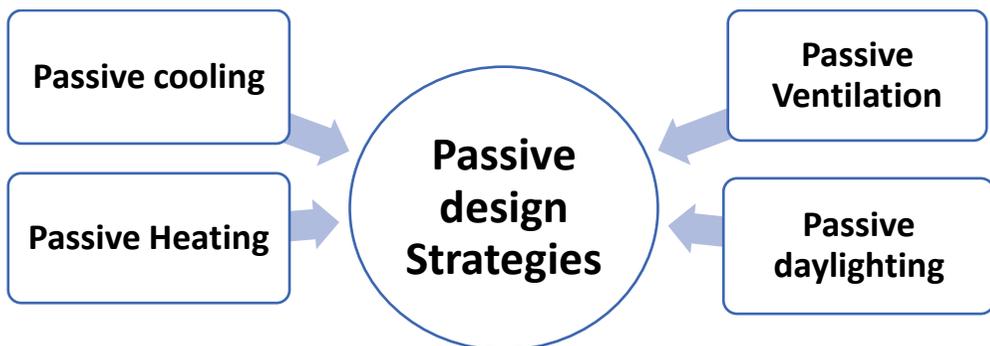


Figure 3-55: Passive design strategies, Source: Author

3.3.2.1 Passive Heating

Passive heating systems correspond to an environmentally friendly method of a human healthy building. There is no electricity consumed with electric fans and no emissions produced with burning fossil fuels. The only passive way to add free thermal energy on a public building is using building design to harness solar radiation and increase the internal heat gains. Passive solar heating combines a well-insulated envelope with other elements that minimize energy losses and harness and store solar gains to balance the energy requirements of the supplemental mechanical heating and ventilation systems.

Elements that contribute to building passive solar heating as explained are building orientation, building shape, internal space planning, high performance windows, window to wall ratio, shadings, building envelop insulation, and thermal mass, these elements can be concluded in (Figure 3-56).

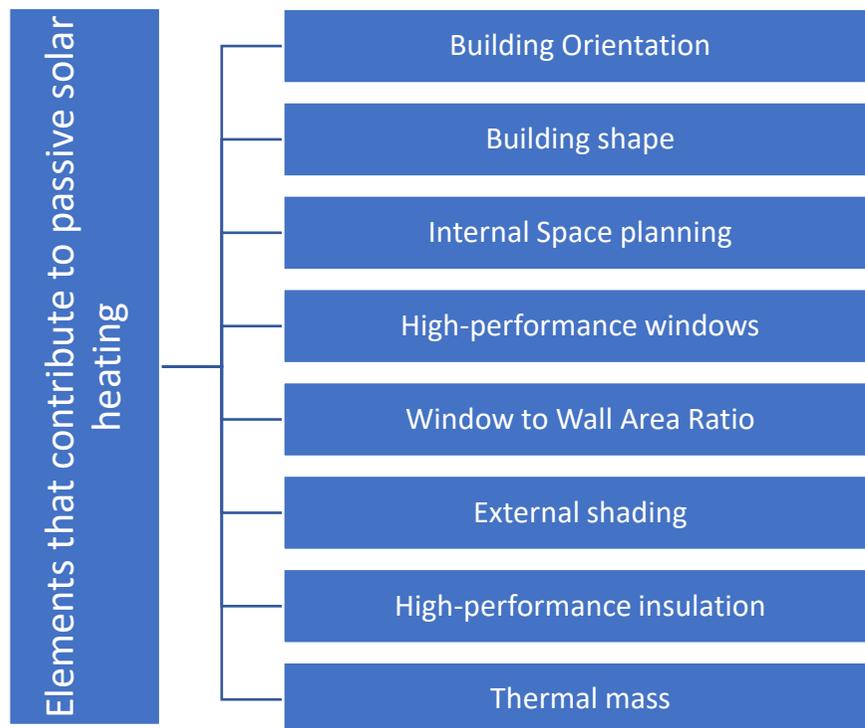


Figure 3-56: Elements that contribute to passive solar heating, Source: Author

3.3.2.2 Passive Cooling

Passive cooling techniques can reduce the peak cooling load in buildings, also, reducing the size of the air conditioning equipment and the period for which it is generally required. (Kamal, 2012) Passive cooling strategies prevent the building from overheating by blocking solar gains and removing internal heat gains (e.g. using cooler outdoor air for ventilation, storing excess heat in thermal mass) (Lévy, December 2018). There are several elements that contribute to passive cooling, like building orientation and shape, shadings, double façade, window to wall ratio, wind catchers, windows design, nocturnal cooling and more as shown in (Figure 3-57).

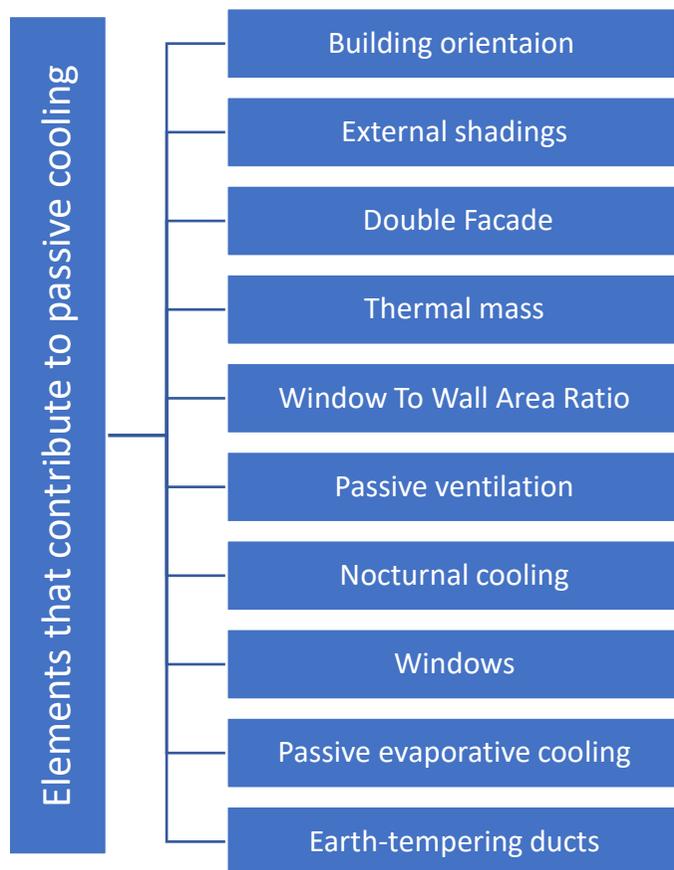


Figure 3-57: Elements that contribute to passive cooling, Source: Author.

The Nocturnal cooling uses overnight natural ventilation to remove heat accumulated in the building mass during the day. The cooler nighttime air flushes and cools the warm building structure/mass. This cooling system is

grouped into the air-cooling system and the water-cooling system. (Kevin N. Nwaigwe, 2010)

Ground cooling techniques are based on earth-to-air heat exchangers (EAHE) which is an underground cooling system with a network of pipes buried at a reasonable depth below the earth's surface. Ventilated air is cooled through recirculation in the underground pipes. In hot and dry climate conditions the total yearly energy output of an EAHE system with an air velocity of 5 m/s is 1290.53 kWh. (T.S. Bisoniya, 2015)

Also, shadings is important element in public building passive cooling, for controlling sun penetration to inside the public buildings it is important to provide exterior shading as a part of the envelope design. This shading devices can be attached to the building or can be achieved by the articulation and disposition of the building floors to create overhangs. (Kamal, 2012) Shading system was predicted to save 5.3% of total primary energy, improve the useful daylight level and reduce the excessive daylight level. (Xiaodong Cao, June 2016)

Exterior shading is preferred over interior shading as it is important to keep the solar radiation/heat from entering the building because interior or blind shadings block the glare of the sun, but still allow the heat to enter the interior space. (Figure 3-58)

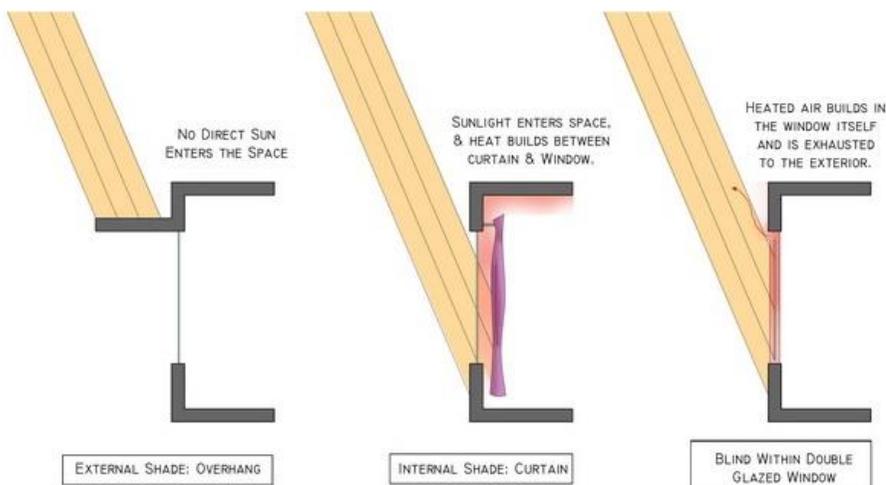
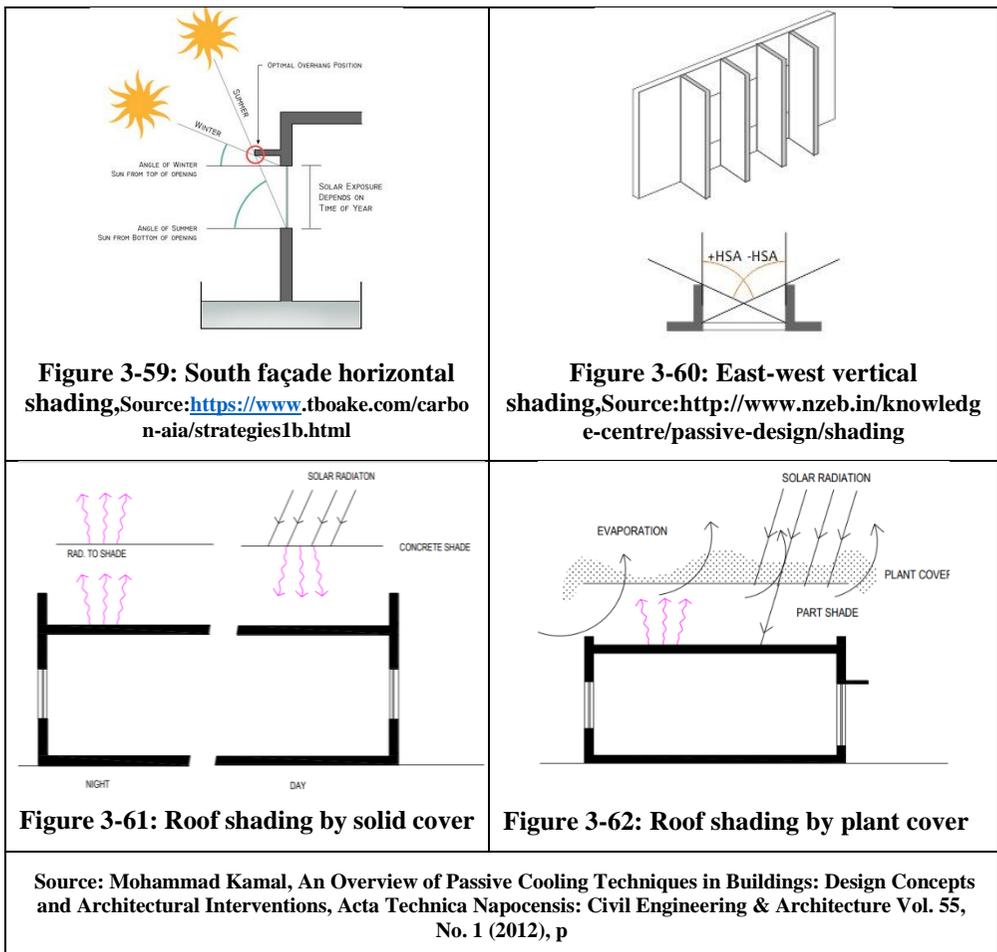


Figure 3-58: Difference effect between exterior and interior shading, Source: <https://www.tboake.com/carbon-aia/strategies1b.html>

Building facades are different in shadings treatment, each façade is different, and varies by orientation. (Kamal, 2012)

- The north façade: does not require shading because in the summer months in the early morning and late evening, no sun penetration occurs. It is best to increase as much as fenestration on the north as there will be very little solar heat gain and much direct heat loss from this side.



- The south façade: Shading devices are normally designed as horizontal projections above the windows. Such shading devices can be designed to eliminate sun penetration in the summer and allow for complete sun penetration during the winter when such is desired for passive heat gain (Figure 3-59).
- The east and west façades: Shading devices are normally designed as vertical projections (Figure 3-60).

Roof shadings: it is an especially important method of reducing heat gain. Roofs can be shaded by solid or plants, but disadvantage of this system is that

it does not allow escaping of heat to the sky at night-time, this can be solved by adding removable shading. (Figure 3-61, 62)

Also, Photovoltaic cells can be attached to the vertical or horizontal shadings in the south façade with an inclination to work on reduce sun heat penetration to the building in addition to generating energy. As shown in (Figure 3-63, 64)



Passive thermal energy storage is another practical approach for building thermal control that primarily relies on latent heat storage and release by a building's thermal mass or phase-change materials (PCM). (M. Kenisarin, 2016) One of the new techniques in passive heating and cooling is using phase change material, phase change materials (PCM) is the thermal energy storage materials can be used in any latent energy storage system. Phase change materials (PCM) are substances that absorb and release thermal energy during the process of melting and freezing (Figure 3-65). When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. PCM system store energy in the form of heat, so can be used to raise or lower temperatures. If needed the technology can store winter cold to provide summer coolness, just as well as summer heat for winter warmth. PCM used in building sector to keep living spaces comfortably and reduces heating and cooling costs. (Figure 3-66, 67)

It is suggested that integrating PCMs with nighttime ventilation can achieve greater energy efficiency. Thus, PCM are more effective in office buildings that are unoccupied during the night. (E. Solgi, 2016)



Figure 3-65: Phase change material working process, source: https://www.alibaba.com/product-detail/Phase-Change-Material-PCM-ball-for_1695288505.html



Figure 3-66: Installing PCM sheets in ceiling, source: <https://www.homebuilding.co.uk/phase-change-materials-a-new-form-of-solar-energy/>



Figure 3-67: Installing PCM sheets in walls, source: <https://www.homebuilding.co.uk/phase-change-materials/>

3.3.2.3 Passive ventilation

Passive ventilation is an essential element of the passive systems which depends on natural resources like outer air movement and pressure difference, consider part of passive cooling. Buildings can be designed to enhance these natural air flows and take advantage of them rather than work against them.

At public buildings with different methods of construction and large volume-to-surface ratio means of ventilation is mandatory and incorporated in the air-based heating and cooling systems. In 2010, Ventilation fans in public buildings accounted for 9% of the operating energy and the fresh air itself for 15% of the heating load. (DOE, 2012)

The passive elements that contribute to natural ventilation are building orientation and shape, openings size, buffer spaces, internal space planning, wind catchers and atriums as shown in (Figure 3-68).

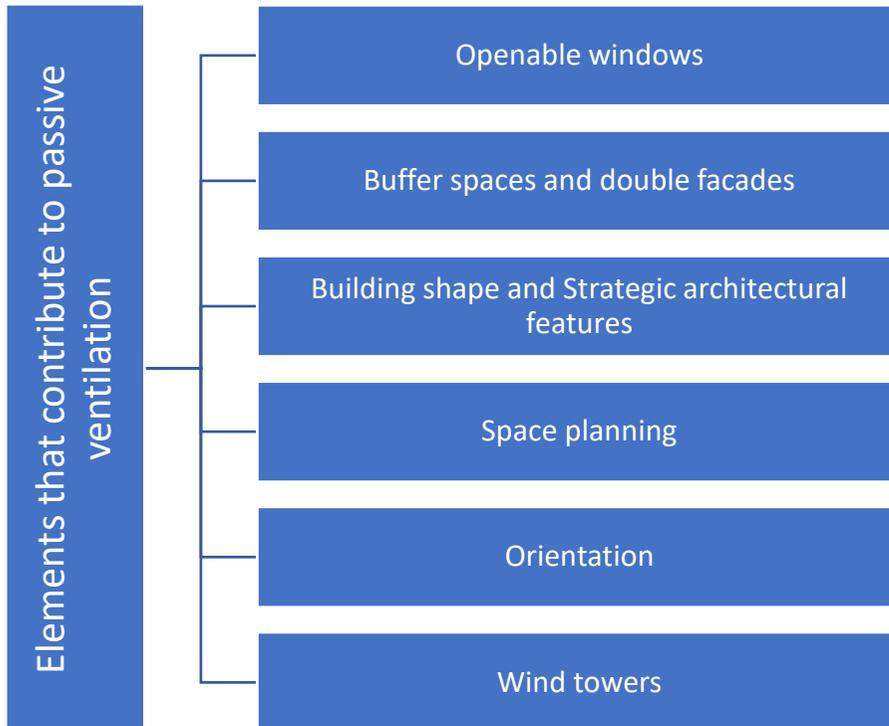


Figure 3-68: Elements that contribute to passive ventilation, Source: Author

Many passive ventilation elements are explained before, but a wind catcher does not, so, at wind catcher or wind tower the passive ventilation happens when the hot ambient air enters the tower through the openings in the tower, gets cooled, and then becomes heavier and sinks down. (Kamal, 2012)

At (Figure 3-69) an example of public building has integrated more than one passive ventilation techniques; the natural ventilation starts from the window louver which catch the preferable wind in and exit from the atrium top opening.

In a study it was found that ventilation system could save between 13 and 44 kWh/m² from cooling net energy per year. The savings in electrical energy from using a fan were approximately 4 kWh/m² per year. (T. Schulze, 2013)

There are many types of ventilation systems used in public buildings as air-based system, water based system, and plant based system, more details are shown in Table 8.

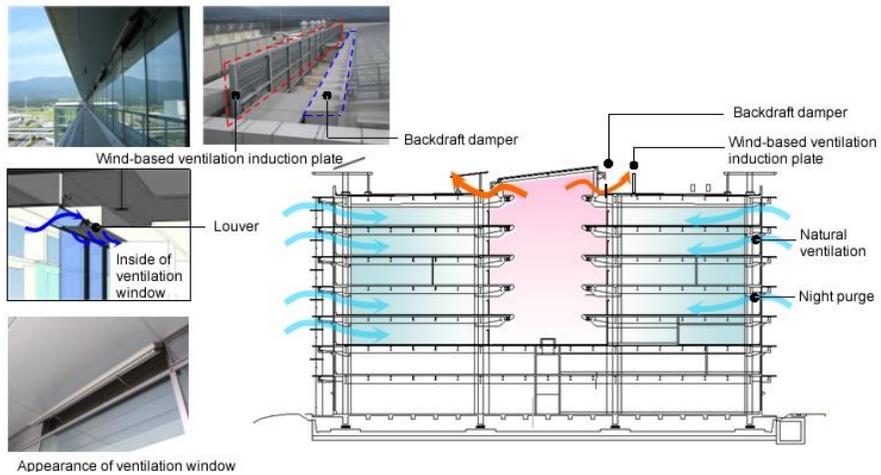
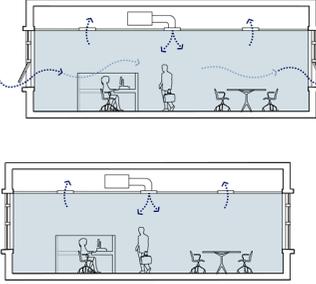
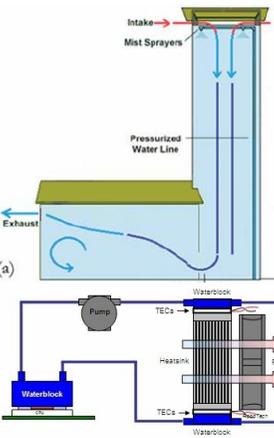
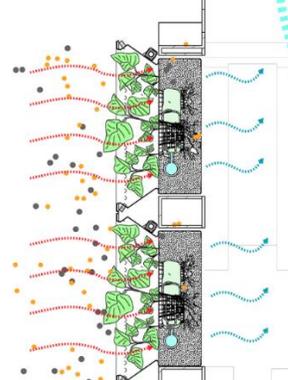


Figure 3-69: Conceptual diagram of natural ventilation in public building, Source: <http://www.ibec.or.jp/jsbd/O/tech.htm>, access on February, 17th, 2019

Table 8: Comparison between public building ventilation systems, Source: (DOE, 2012)

Air based systems	Water based systems	Plant based systems
Definition		
Natural ventilation is combined with the return conditioned air and then distributed with the supply air all over the public building.	Ventilation air has to be introduced independently, either through controlled openings in the envelope or dedicated fan powered systems	They are like gardens inside of the building atrium or internal green walls, these systems provide the building with conditioned return air
Properties		
Public buildings with these systems operate frequently to meet heating and cooling loads	Public buildings with water-based systems known as high performance buildings because conditioning systems rarely have to operate	This ventilation and filtration systems require more space because they operate with low power density light
usage		
Operable windows and wind catchers are application can be	Active and passive chilled beam systems are also water-based. This system is	This system is perfect ventilation system choice when the public building located in

<p>integrated to air based system ventilation This system is well suited for office buildings, schools, hotels and hospitals where individualized air conditioning for each room is needed. (Aynur, 2010)</p>	<p>preferred in hot and dry climate. Chilled beam systems are suitable in buildings with high sensible loads integrate with displacement ventilation or underfloor air distribution. (S. Weidner, 2009)</p>	<p>polluted environment with dusts, mists, bioaerosols, gases, and the building up of carbon dioxide from human respiration.</p>
 <p>Figure 3-70: Air based systems, source: https://www.cbe.berk.eley.edu/mix_edmode/aboutmm.html, access on February,20th, 2019</p>	 <p>Figure 3-71: Water based system , Sources: John Kaiser S. Calautit, Ben Hughes, Integration and application of passive cooling within a wind tower for hot climates, HVAC&R RESEARCH ,2014</p>	 <p>Figure 3-72: Section in plant based system, Source: https://innovaengineers.com/2018/02/09/plant-based-ventilation-systems/, access on February,17th, 2019</p>

Most public buildings are located in dense urban environments have no access to truly fresh air, relying on wind driven circulation to use various degrees of mechanical and chemical filtration to clean ventilation air and improve the quality of internal air.

3.3.2.4 Passive Daylighting

Passive daylighting design maximizes the use and distribution of natural daylight throughout a public building's interior to reduce the need for artificial lighting. The benefits of daylight not only supply energy savings but also

increases in work productivity and visual satisfaction. (Y. Chen, 2014) The features which contribute to a daylighting strategy are in (Figure 3-73, 74):

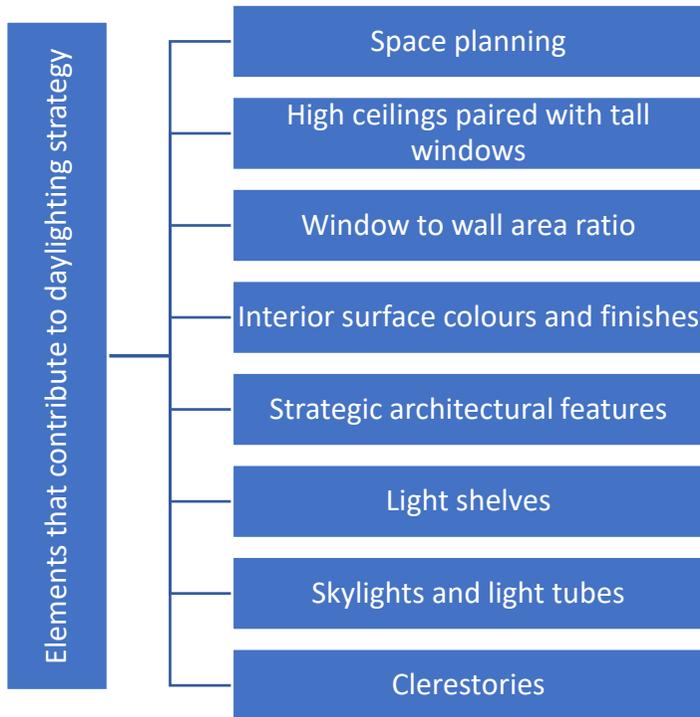


Figure 3-73: Elements that contribute to daylighting strategy, Source: Author



**Figure 3-74: Example on maximizing the use and distribution of natural diffused daylight, Salt Lake City Public Library, USA,
Source: <https://www.architecturerevived.com/salt-lake-city-public-library-utah-usa/>,
access on February, 17th, 2019.**

One of the most successful passive daylighting techniques is solar light tube which is an innovative daylighting technology is now gradually adopted in some of NZEB projects worldwide solar tube (or sun tunnel) (Figure 3-75).

Its advantages are:

- It is ecological system, where natural light is captured and directed through internally coated tube by highly reflective material.
- Minimizes the dispersion of the rays and allows a supply of light at considerable distances, without heat or cold transfer.
- An average of about 80% of working hours indoors can be performed with natural light, thus contributing directly to reducing energy consumption and consequently to improve the energy efficiency of buildings. (chatron, 2019)
- LED lighting integration in solar tubes, allowing efficient lighting 24 hours daily. During the day periods with sun the lighting of the entire space comes from the sun.
- Solar light tube advantages (Figure 3-76): lighting capability superior than a window, perfectly natural light with no thermic transfer (Cold and Heat), no need for cleaning or maintenance and UV radiation resistance, inserting solutions in 100% coverage reliable and secure.



Figure 3-75: Solar tube, Source: <https://www.chatron.pt/en/construccion/tubo-solar>, access February, 17th, 2019

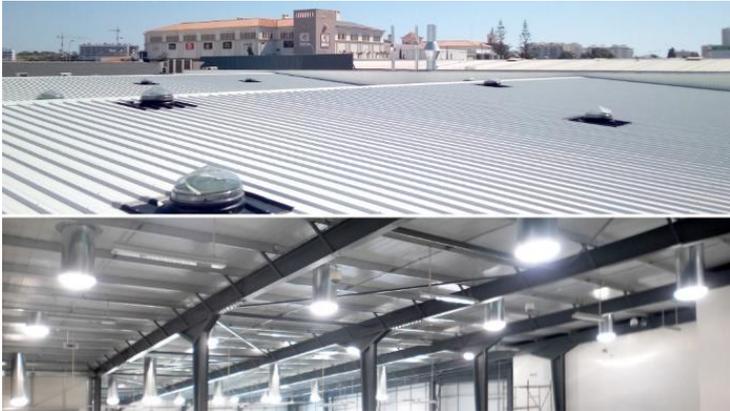


Figure 3-76: Solar tube application, Source:
<https://www.chatron.pt/en/construccion/tubo-solar>, access February, 17th, 2019

3.3.2.5 Applying passive strategies on public buildings design

Public buildings have different characteristics from residential buildings, such as higher internal heat gains from equipment and lighting, higher ventilation requirements, and different occupancy trends. (climatecolab.org, 2019) Specific passive approaches that will improve the overall energy performance of Public buildings in hot and dry climate include:

- High-performance insulation in the envelope with minimal thermal bridging, including exterior walls and roofs.
- Solar gain control using high-performance windows with low shading coefficient (tinted or reflective) or clear high-performance windows with a low-e coating in combination with operable external shading.
- Window to wall area ratio limited to <50%.
- Double facades with operable shading elements and operable windows to act as thermal buffer spaces, preheat ventilation air in the winter, and block solar gains and provide natural ventilation in the summer.
- Building shape and massing that enhances natural ventilation and daylighting, ideally with central atrium and ventilation towers.
- Thermal mass on the interior side of the insulation, located in the floors, external walls and walls between adjoining units (i.e., party walls).
- Passive cooling strategies, such as night-time ventilation to pre-cool spaces during summer.
- Air and moisture tight envelope.

3.4 Internal heat gain

Internal heat generates from the thermal energy from people, lighting equipment, devices and appliances that give off heat to the indoor environment. Whereas this is desirable in cold weather as it reduces the energy requirements for heating, in hot weather it increases the energy required for cooling. In office buildings, commercial stores, shopping centres, entertainment halls etc.. (UNIDO, 2009) the more people occupied or working into the public building, the more internal heat the building gain.

3.4.1 Building activity effect

There are many factors affecting public building energy consumption like; the building activity, number of occupied, the operating hours, building equipment, the form of cooling source, the age of construction, the form of heating source and the number of building stories. (Li Yuana, 2016)

3.4.2 Public building operating time

The operating time can be defined on the typical workday basis; by a start time, end time, working days per week and seasonal variation. In some cases, the load data associated with each zone were taken as the average for a specific zone or for the whole building. (Ashfaq A. Ch., 2007) Public building operating time used to be day time -8hours or 12hours- like schools or 24hours per week like hospitals. Furthermore, it is crucial factor in calculating public building energy consumption

3.4.3 Calculating internal heat gain according to Operating hours

The standard use of public buildings and the equivalent heat gain from appliances, lighting and occupants are provided in (table 8) which shows the building's number of occupied hours per 24-hour day, the number of days of use per week and the maximum heat gain from lighting and appliances and the maximum heat gain from occupants during the public building's occupied hours. The heat gain data do not include heat gain from the building's technical systems, which is calculated as part of the calculations made for the technical systems. (Minister of Economic Affairs and Communications regulation, 2014)

Table 9: Standard use of buildings and the corresponding maximum values of heat gain per square metre

Building's purpose of use	Occupied hours			Usage rate	Lighting ^a W/m ²	Appliances W/m ²	Occupants ^b W/m ²	Occupants m ² /person
	Hours	h/24h	d/7d					
Office building, library or research building	07:00-18:00	11	5	0.55	12	12	5	17.0
Commerce building or terminal	07:00-21:00	14	7	0.55	20	1	5	17.0
Accommodation building	00:00-00:00	24	7	0.5	8	1	4	21.3
Food service building or service building	12:00-22:00	10	7	0.4	20	4	14	6.1
Public building	08:00-22:00	14	7	0.5	14	0	5	17.0
Educational building ^e	08:00-16:00	8	5	0.6 ^f	15	8	14	5.4
Pre-school institution for children	07:00-19:00	12	5	0.4	15	4	20	3.8
Healthcare building	00:00-00:00	24	7	0.6	9	4	8	10.6

Source: Methodology for calculating the energy performance of buildings, Minister of Economic Affairs and Communications regulation, 2014

The data shown assume the use, in public buildings, of fluorescent lights or other lighting equipment of similar effectiveness. The internal heat gain from occupants only includes the sensible heat. To include latent heat, the relevant values must be divided by the factor 0.6.

Also, Lighting which is characterised by wattage lower than that given in (Table 8) like LED lighting units recommended to be used if it provides the same level of illuminance, and a separate calculation of illuminance in standard rooms is provided as part of the input parameters of the energy calculation.

The building's lighting is controlled on a demand basis, the number of use hours of the lighting is calculated using the occupied hours shown in (Table8).

And it is important to calculate the "usage rate" which means "the average use intensity of lighting and appliances and the average presence of occupants during the building's occupied hours". The maximum heat release value (usage rate =1) is used in the calculations of summertime indoor temperatures and cooling loads.

For energy manual calculation, the annual heat release Q [kWh/(m²y)] of lighting and appliances and the internal heat gain from occupants is calculated

using the following formula: (Minister of Economic Affairs and Communications regulation, 2014)

$$Q = kP \frac{\tau_d \tau_w}{24 \cdot 7} \frac{8760}{1000},$$

Where;

- k is the rate of usage;
- P is heat release W/m²;
- τ_d is the building's number of occupied hours per 24-hour day;
- τ_w is the building's number of days of occupancy per week.

For calculating the ventilation need, ventilation is held to start one hour before the building's start hour of use and to switch to the non-use-hours mode one hour after the end hour of use of the building (except for buildings which are used on a 24-hour basis).

3.5 Conclusion

This chapter focused on how to maximize public building energy reduction needs, and it can be concluded as following:

- The effect of climate on public building design strategies, specially at hot climate zone where Egypt is located, and the suitable building orientation is to the north to take benefit from the wind.
- For the building form can be concluded that compact forms gain less heat during daytime and lose less heat at nighttime and can reduce the solar thermal load
- Considering in the public building design the urbanization effect and achieving interior comfort zone for the building users.
- Working on public building energy efficient envelope through well designed wall and roof section, insulated openings.
- Considering in public building design the envelope efficient quality factors like airtightness, thermal bridging and thermal insulation.
- Including the passive strategies in the design, in heating, cooling, ventilation, daylighting and shadings, all these techniques to reduce the building energy consumption to the minimum.
- Consider the public building activity in the energy calculations, while internal heat gain, building operating hours and the number of elevators and escalators or any other building equipment can make a great deference.
- The zero energy building sector can take benefits from the new high efficiency technologies and integrate it in the building envelope and its insulation, in space heating and cooling systems, in water heating, in lighting, in appliances and occupants needs, and in indoor equipment. Many of these technologies that can transform regular building design to nZEB are already available.

For designing zero energy public building, there is an essential need for studding about systems at public building like lighting and mechanical systems and studding about renewable energy resource that can be integrated to the public building design, in addition to studding about public building control systems to control the energy consumption and production, also, recognizing on the ZEPB build team structure and missions. All these important points will be clarified in the next chapter.

CHAPTER 4 : Zero Energy Public Building Efficient Design Requirements

(Mechanical systems, renewable energy production, simulation software and design team)

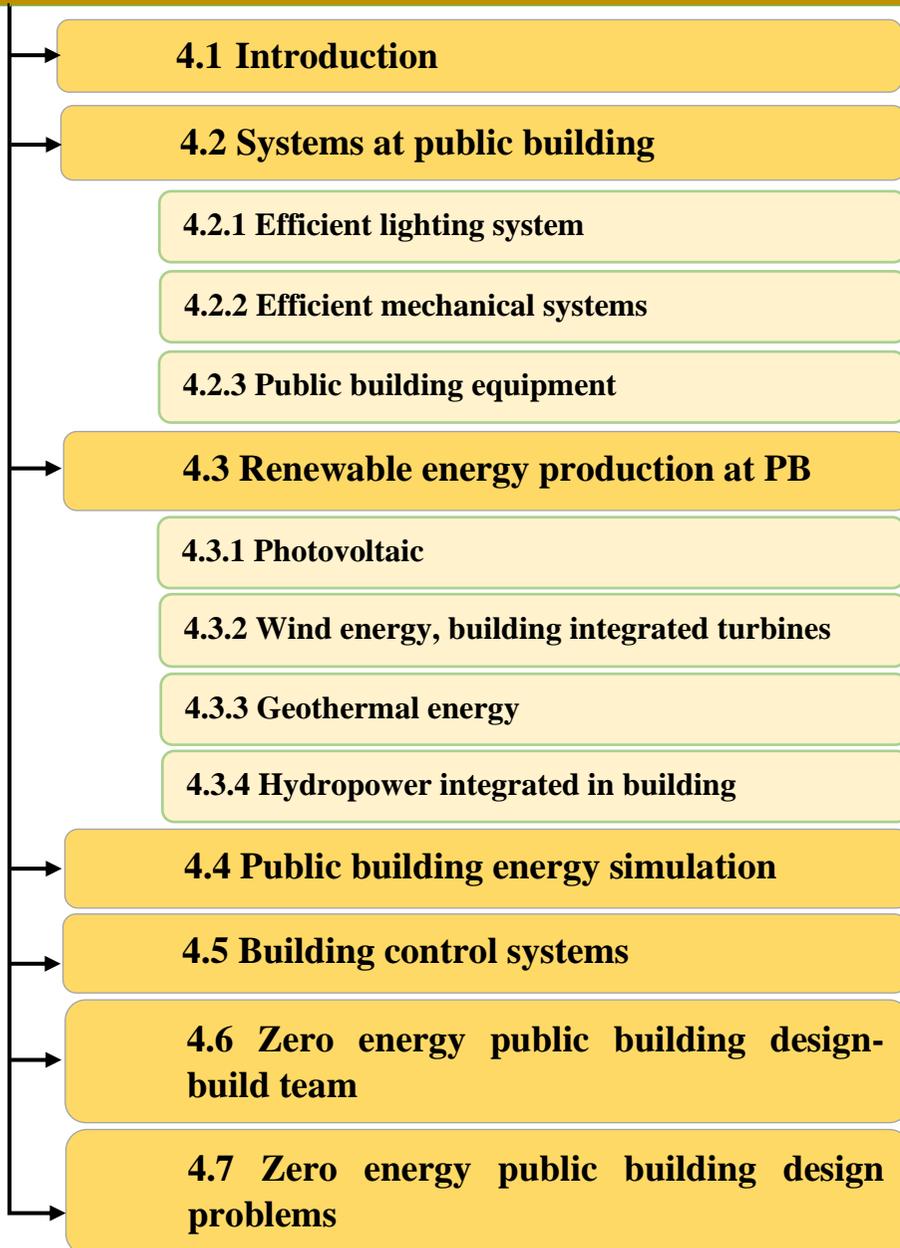


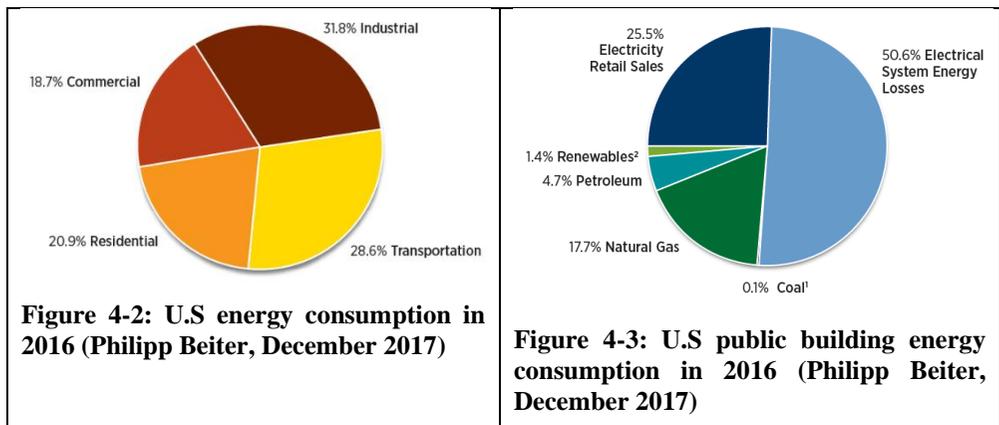
Figure 4-1 : Chapter 4 structure

4.1 Introduction

At the environmental design process some public building adapts elements such as green roof and photovoltaic panels, and other care about systems efficiency like insulated windows or recycled plastic lumber, but at zero energy public building design process all these elements has to be mixed in addition to caring about systems efficiency to reach the optimum energy design.

Cumulative global installed capacity of renewable electricity grew by 9.1% in 2016, which continued the steady growth of recent years 7.5% from 2006 to 2016).

The energy systems language helps designers better understand the building environmental behavior. U.S. public buildings represent 50.5% of total energy use (commercial and industrial sectors are combined) (Philipp Beiter, December 2017, p. 14) as shown in (Figure 4-2,3), the public building consume only 1.4% from its energy needs from renewable resources.



In Egypt, renewable energy generation increased to 13.5% in 2016, up from a growth rate of 1.9% in 2015, while solar electricity generation increased by 52.1%, wind electricity generation increased by 18.8%, and energy generation from hydropower increased by 6.7%, these numbers are good sign on moving toward the right direction. (Philipp Beiter, December 2017)

So, this chapter will focus on systems at public buildings (lighting and mechanical), renewable energy production (solar, wind, geothermal, and hydropower), and the controlling systems at public building.

4.2 Systems at public buildings

Technical systems and the building equipment are the great energy consuming at public buildings. Technical systems like; the heating and hot water systems which include the corresponding heat sources, the ventilation system, the cooling system, lighting and the systems which generate heat or electricity locally, any system has to be included in the energy calculation. (Minister of Economic Affairs and Communications regulation, 2014)

4.2.1 Lighting system

Lighting systems are significant consumers of electricity, particularly in office buildings. (M.-C. Dubois, 2011) For saving in lighting electricity energy, advanced lighting technologies and daylight harvesting strategies are used. Light-emitting diodes (LEDs) have the potential to become the predominant lighting technology in the next decade due to their long service life and good lighting efficacy. Integrating on/off and dimming controls with daylight save electricity up to 36.1% to 41.5%. (Y. Chen, 2014)

However, it should be noted that approximately 75–85% of the light electric power consumed by LEDs is still generated as convective heat, which may have a negative effect through increasing indoor cooling load. (B.-L. Ahn, 2014)

The recent improvements in LEDs maintain it the better choice. The latest LED replacement for the 60-watt lamp outperforms the compact fluorescent on almost every count, including the color of the light.

Heat is a by-product of light, it is an inseparable co-product of lamps, meaning that the investment of work and resources in the envelope is counted toward the delivery of light and heat. And, improved lighting is one of the most common strategies for reducing energy consumption, which involves replacing older, inefficient lamps with more efficacious ones that are operated with some form of automated controls. (William W., 2016, p. 109)

4.2.2 Mechanical systems

Energy consumption for space heating and cooling accounts for half of the total building energy use or more. For ZEPB, this part of energy can be reduced by using highly efficient heating and cooling systems integrated in the building design. The most used heating/cooling systems are:

4.2.2.1 HVAC system

HVAC (Heating, Ventilation, and Air Conditioning) systems are a big part of mechanical engineering for building systems and the one that affects energy usage the most (Broemel, 2016). HVAC systems account for almost half of building energy consumption and approximately 10-20% of total energy consumption in developed countries. HVAC ventilation systems is divided into mechanical by using fans or natural ventilation without fans. Also, HVAC types are divided into simple systems or complex system (Hart, 2016), and the difference between them in heating, cooling, and coverage in the next Table.

Table 10: HVAC Types

Criteria	HVAC Simple system	HVAC Complex system
Heating	Gas, oil or electricity in a furnace to heat air	A boiler generates hot water or steam that is piped to heating coils
Cooling	Directly use refrigerant to cool or heat air	The refrigerant is in the chiller and chilled water goes to cooling coils
Coverage	Serve one zone	Serve multiple zones
Control	User direct control	Indirect control
Examples	Package Units  <p>Figure 4-4: Air conditioner (PTAC), Source:https://www.ajmadison.com/guides/air_conditioner/ptac/</p>	Unitary system  <p>Figure 4-5: Unitary air conditioner, Source:https://en.wikipedia.org/wiki/HVAC</p>
Use	Common in small scale public buildings	Common in Large scale public buildings
Consumption	Approximately 40% of total building consumption	Up to 70% of base building consumption.

The system type can be chosen to depend on space, temperature and humidity requirements, initial cost, operating cost, and maintenance cost. (Seyam, November 2018)

For example, An Alerton building uses an indirect-direct evaporative cooling (IDEC) system which conditions air without the use of compressors or refrigerants. The system draws fresh air from outside for each cycle. It integrates variable frequency drives which control the fan speed of the four air handling units, using minimal energy to operate. These units feed a total of 120 variable air volume zones. Demand-control ventilation allows the system to run only when necessary. (newbuildings.org, November 2018)

4.2.2.2 Displacement ventilation

Displacement ventilation is a room air distribution strategy where conditioned outdoor air is supplied at a low velocity from air supply diffusers located near floor level and extracted above the occupied zone, usually at ceiling height. For example, The Seoul Energy Dream Center where located in Korea, with floor area 3762 m², it represents sustainable architecture and center for renewable energy. The ground cooling system with the mechanical air heat recovery system together save 1600 kWh electricity for air condition with the efficiency at 72% of energy reduction (Figure 4-6,7).



Figure 4-6: The Seoul Energy Dream Centre, Korea, (Xu Wei, 2017, p. 48)

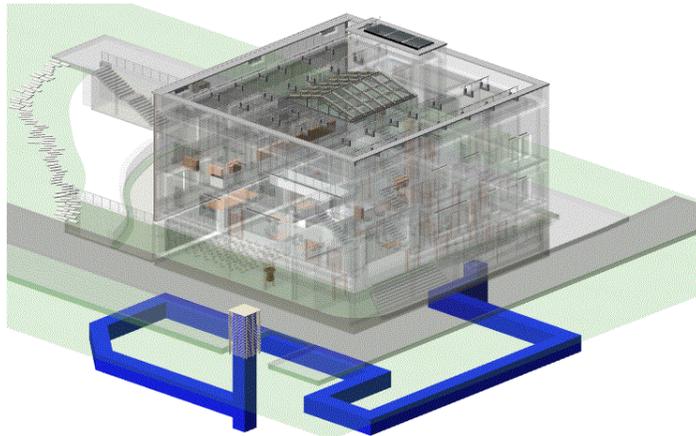


Figure 4-7: The ground cooling system and mechanical air heat recovery system at The Seoul Energy Dream Center, Korea (Xu Wei, 2017, p. 48)

4.2.2.3 Radiant technology in heating and cooling

Radiant heating has been successfully used in cooling systems for nearly 30 years. The radiant heating and cooling can offer lower energy consumption than conventional heating and cooling systems. More energy savings due to the lower amount of energy required to pump water as opposed to distribute air with fans. By coupling the system with building mass, radiant cooling can shift some cooling to off-peak nighttime hours.

Radiant heating/cooling systems must be integrated with structural components such as floor heating, chilled ceiling, and thermally activated building systems. Floor heating systems are typically applied in cold climates and chilled ceilings are widely used in mild or hot climates. (A. Binghooth, 2012)

Radiant cooling has lower first costs and lifecycle costs compared to conventional systems. For example, the Bullitt Center at US used highly efficient ground-source heat pump and in-floor radiant system heat the building extremely efficiently. Five heat pumps converts 11°C water from underground tubes to 35°C for heating the building with radiant heat system (Figure 4-8)

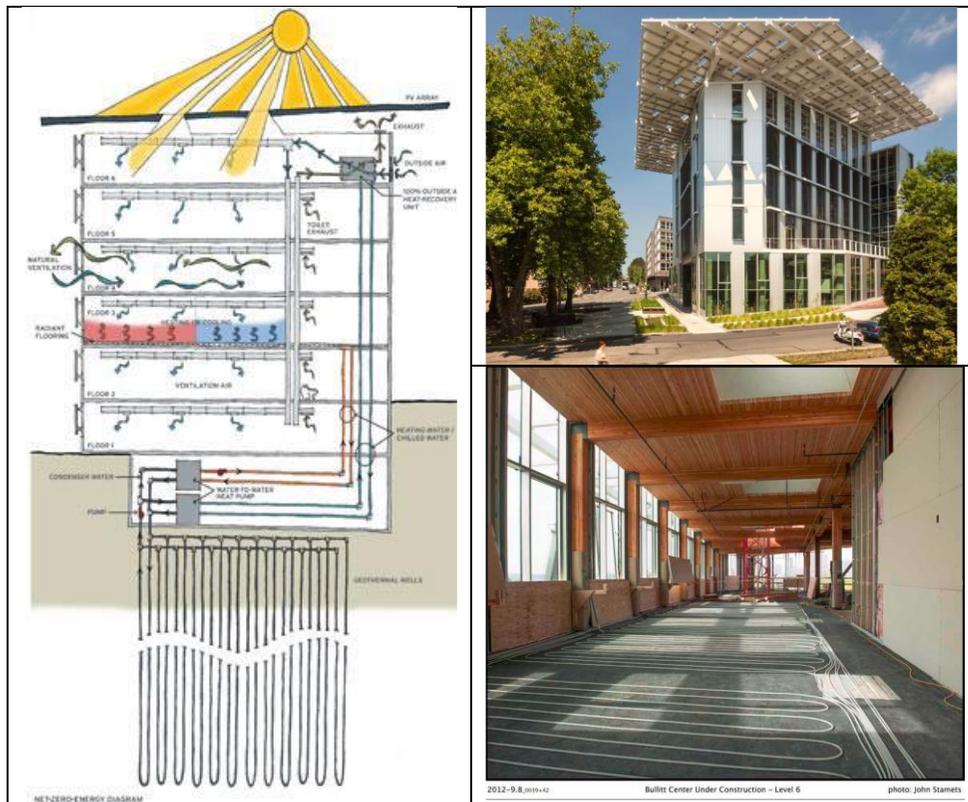


Figure 4-8: The high efficient GSHP and in-floor radiant system in the Bullitt Center, United States, (Xu Wei, 2017, p. 47)

4.2.2.4 Solar water heater

Solar heater is system that works on reducing the amount of heat that must be provided by conventional water heating, solar water-heating systems directly substitute renewable energy for conventional energy, reducing the use of electricity or fossil fuels by as much as 80%. (Dutton, 2018)

There are several types of solar water-heating systems, the basic technology is very simple. The solar water heater is composed by 2 components, the solar sensor and the heated water tank (Jean Cariou, August 2010), where, sunlight strikes and heats an "absorber" surface within a "solar collector" or an actual storage tank. (Figure 4-9)

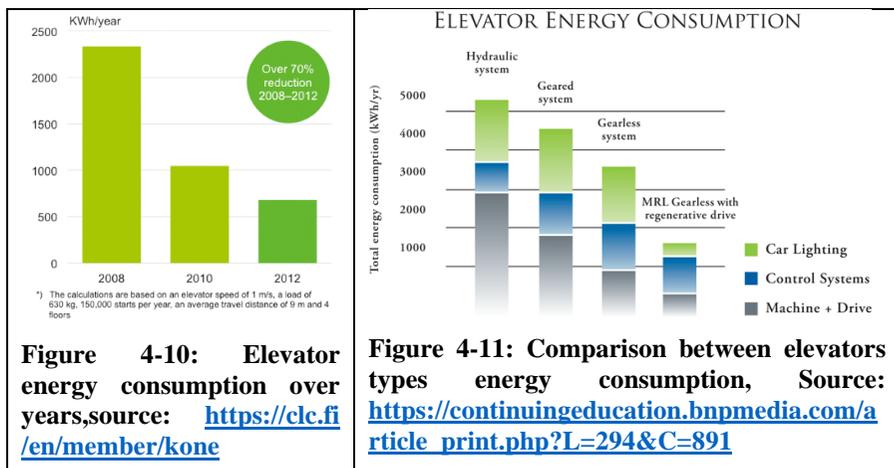


Figure 4-9: Solar water heater, <https://www.pushan.in/solar-waterHeating.php>, access on March, 9th, 2019

4.2.3 Public building equipment

Elevators and escalators are important equipment in public buildings and can consume between 5% and 15% of the energy needs for a building, depending on the type of building and its equipment provision. (Anibal de Almeida, 2010) Over 70% reduction in elevator energy consumption from 2008 to 2012, and it's even better now.

In elevators, energy is consumed in the light, control system, and driving machine, also, there are many types of elevators, and each type consume different amount of energy even for same load and speed. (Figure 3-76, 77)



Recently, elevators can be used in generating energy as the first case study in the analytical part.

4.3 Renewable Energy production at public buildings

Many countries are planning for all public buildings to be net zero by 2030, this can be achieved by producing as much energy onsite as they consume over a year as in California according to their Energy Code requirements.

Zero energy public building need to be designed as off Grid Connection building, by using renewable energy system that is energy generated from renewable energy sources like sun, wind, or other natural processes, and not connected to the utility grid. This system will have a battery bank to store the electricity for use when needed. There will be energy network which is a system for the transmission of energy and for the distribution of energy to consumers. (Minister of Economic Affairs and Communications regulation, 2014)

The availability of most renewable energy sources (i.e., wind, solar, tidal wave, hydro, etc.) tends to vary widely throughout the course of a day, season, year, even from one geographical location to another (PBL Netherlands Environmental Assessment Agency, 2015). A comparison of the global power capacities between different renewable energy sectors is listed in (Table 11). (Philipp Beiter, December 2017, p. 42)

Table 11: Comparison of the global power capacity between different renewable energy sectors (Unit: GW)

Order	Power capacity	Year		
		2013	2014	2015
1	Total Renewable power	1578	1712	1849
2	Hydropower	1018	1055	1064
3	Bio-power	88	93	106
4	Geothermal	12.1	12.8	13.2
5	Solar PV	138	177	227
6	Concentrating solar thermal	3.4	4.4	4.8
7	Wind power capacity	319	370	433

Source: Renewable Energy Policy Network for the 21st Century (Ren21). Renewables 2016 Global Status Report., (<http://www.ren21.net/status-of-renewables/globalstatusreport/>) [Accessed August 2016].

Globally, hydropower comprised 54% of cumulative installed renewable electricity capacity, followed by wind (24%), solar PV and CSP (15%), biomass (6%), and geothermal (1%) in 2016.

Renewable sources accounted for 26% of all electricity generation worldwide in 2016. Also, Global solar PV cumulative installed capacity increased by 33% in 2016. Wind installed capacity grew by 12% globally.

The top countries for renewable electricity installed capacity are China, United States, Brazil, Germany, and Canada as (Figure 4-12)

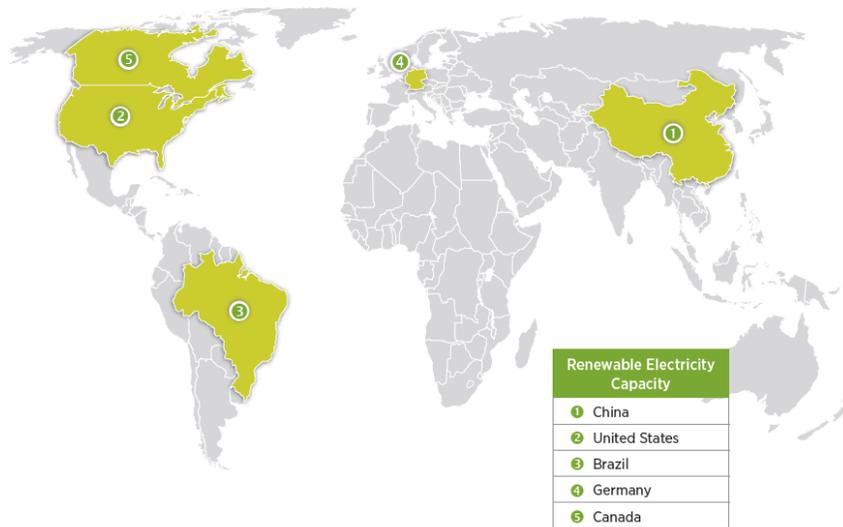


Figure 4-12: Top countries for renewable electricity installed capacity(2016), (Philipp Beiter, December 2017, p. 50)

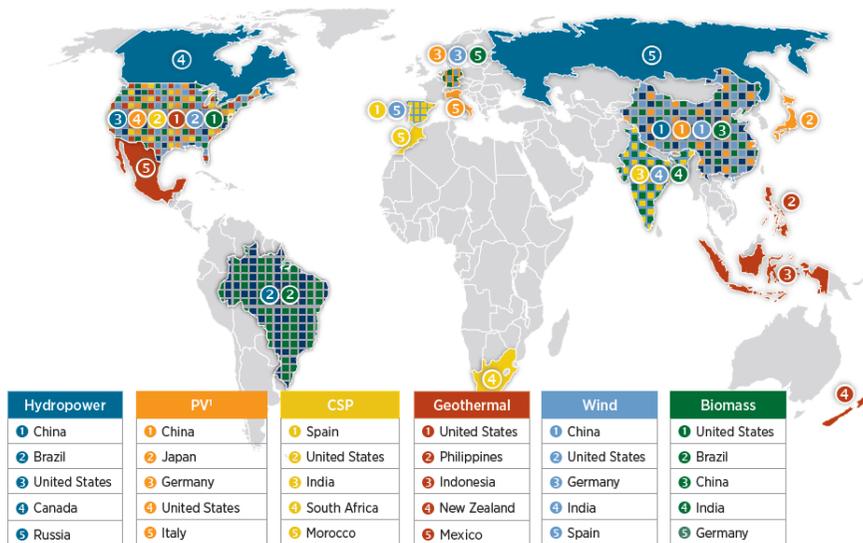


Figure 4-13: Top Countries with Installed Renewable Electricity Capacity by Technology (2016), (Philipp Beiter, December 2017, p. 51)

In 2016, China led the world in renewable electricity installed capacity. China also led in wind, hydropower, and grid-connected solar PV capacity. Spain led CSP installed capacity. The United States continued to lead geothermal and biomass installed capacity and was second in renewable electricity installed capacity as shown in (Figure 4-13). (Philipp Beiter, December 2017)

4.3.1 Photovoltaic Energy

The annual effective solar irradiance varies from 60 to 250 W m² worldwide, (Figure 4-14) shows the annual average intensity of solar radiation over the surface of the earth. In comparison, the sunniest places of the planet are found on the continent of Africa (Luqman M, 2015). Theoretically, the potential concentrated solar power (CSP) and PV energy in Africa is around 470 and 660 petawatt hours (PWh)¹⁹ (International Renewable Energy Agency, 2014).

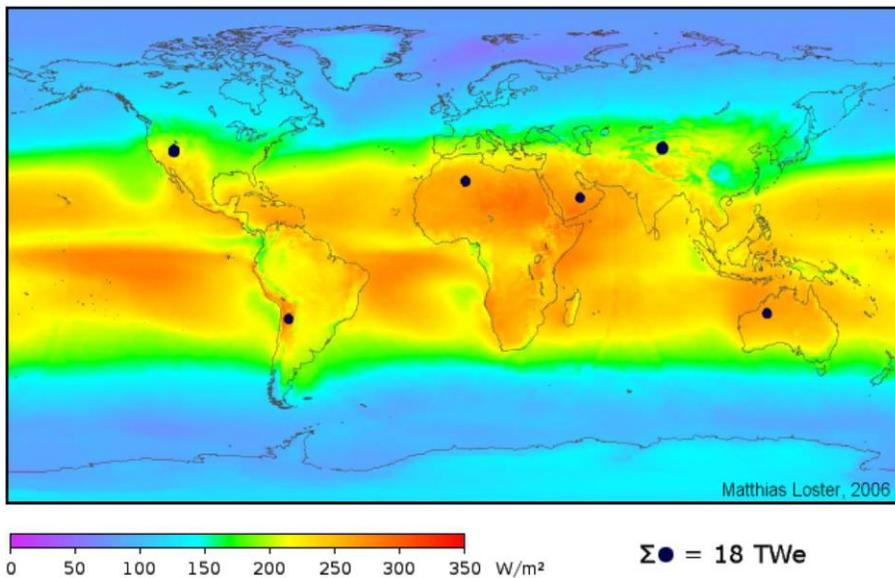


Figure 4-14: Annual average solar irradiance distribution over the surface of the Earth, Source: National Aeronautics and Space Administration. Plotted from satellite data supplied by NASA Clouds and the Earth's Radiant Energy System (CERES); 2014.

¹⁹ Petawatt (PW) is a derived metric measurement unit of power. The petawatt is equal to one billion million watts (1015W), source: <https://www.aqua-calc.com/what-is/power/petawatt>.

Currently, new technologies are being employed to generate electricity from harvested solar energy (Ehsanul Kabira, September 2017). The efficiency of solar power technologies has increased greatly in recent years (Renew Economy, 2015). This solar power can be converted to electricity by an electrical device called solar cell, or photovoltaic cell, by using the photovoltaic effect. PV or building integrated photovoltaic (BIPV) are the most widely used techniques to convert solar energy into electricity for ZEBs. (J. Khan, 2016) BIPV systems integrate PV modules with on-site building envelopes such as walls, rooftops and windows and can significantly increase total electricity output. When public building has limited rooftop area but large facade area, adopting semi-transparent BIPV windows is a good option.

4.3.1.1 Photovoltaic types and components

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

(Askari M. Bagher, 2015.)

There are many types of solar cells Based on the material used (Figure 4-15) but Multicrystalline solar cells are the most common type in PV market and consume most of the worldwide produced polysilicon and Monocrystalline Solar Cells - Polycrystalline Panels also known as Multicrystalline solar cells (Figure 4-16). (Askari M. Bagher, 2015.)

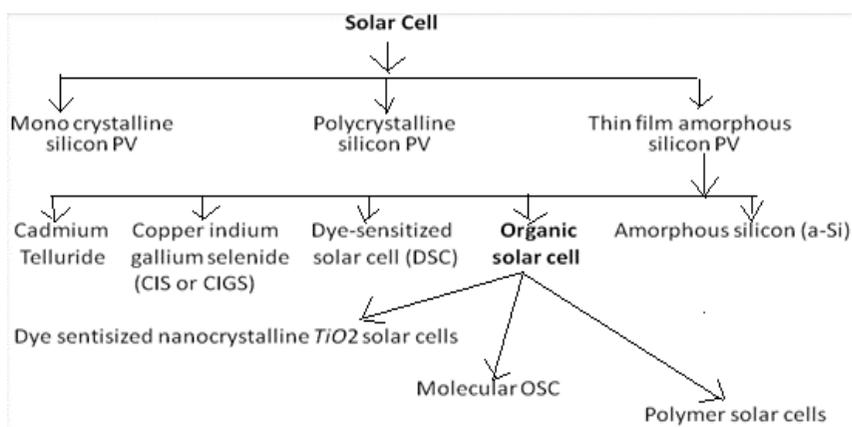
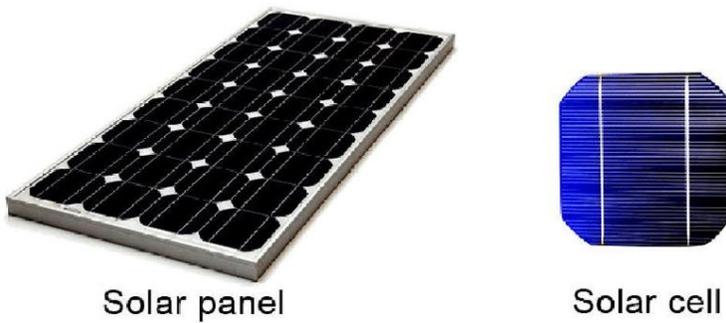


Figure 4-15: Solar cells types, Source: Rashmi Swami, Solar Cell, International Journal of Scientific and Research Publications, Volume 2, Issue 7, July 2012



Solar panel

Solar cell

Figure 4-16: Monocrystalline solar cell, Source:
https://www.researchgate.net/figure/Monocrystalline-Solar-Cells-Polycrystalline-Panels-also-known-as-multicrystalline_fig11_318654444

In many public buildings, PV glass modules are used to supply electricity to different offices or other parts of building by collecting solar energy from sun, convert it into electricity and allow offices to use their own electrical power for different purposes. (Askari M. Bagher, 2015.)

Photovoltaic glass (Figure 4-17) uses the same basic principle as solar panels, but it is transparent. Seeing through hardware (Figure 4-18) was developed at Michigan State University, which could collect as much solar power as current traditional rooftop modules. (BROWN, 2017)



Figure 4-17: Example on using PV glass as curtain wall,
 Source: <https://www.power-technology.com/features/featuresolar-windows-the-future-of-zero-carbon-buildings-4893224/>, access March 10, 2019

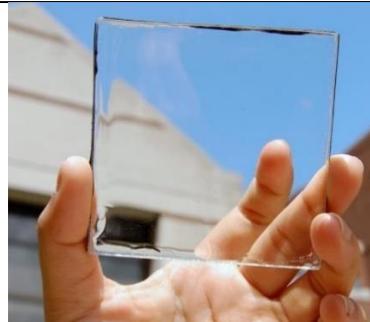


Figure 4-18: Transparent solar glass,
 Source: <https://www.pv-magazine.com/2017/10/26/new-transparent-solar-glass-developed-by-scientists-at-michigan-state-university/>, March 10, 2019

And a thin-film solar cell is a second generation of solar cell that is manufactured by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies. (Green, 2007)



Figure 4-19: Thin Film Flexible Solar PV panels, source: https://en.wikipedia.org/wiki/Thin-film_solar_cell



Figure 4-20: Thin Film solar panels after installation, source: https://en.wikipedia.org/wiki/Thin-film_solar_cell

4.3.1.2 Solar azimuth angle

The solar azimuth angle determines which compass direction the solar array is facing as shown in (Figure 4-19), and it can be defined as “the angle measured clockwise from the true north of the direction facing the PV array”. For example, fixed PV arrays are facing south, so, the azimuth angle is 180 degrees clock-wise from the north. In the southern hemisphere, the optimal azimuth angle is generally 0° i.e. facing true north. (Gevorkian, 2008)

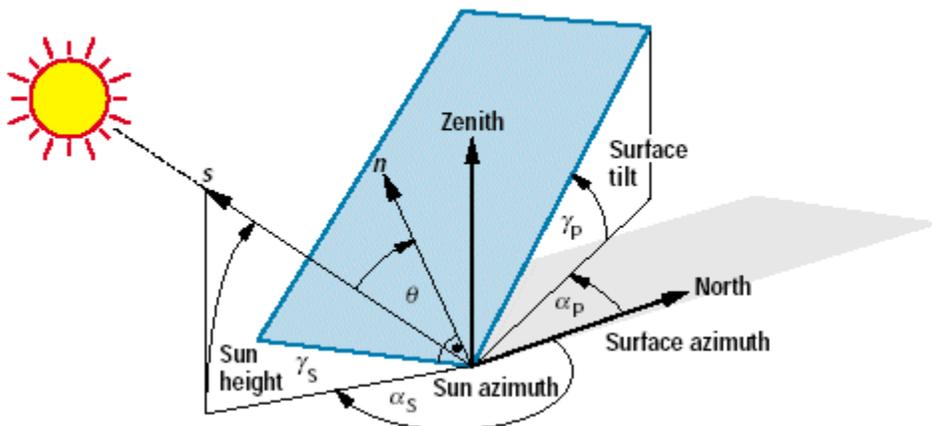


Figure 4-21: Solar azimuth angle, Source: Volker Quaschnig, “Technology Fundamentals: The Sun as an Energy Source,” 2003. [Online]. Available: <https://www.volker-quaschnig.de/articles/fundamentals1/index.php> [Accessed: 18-Jun-2020].

4.3.1.3 Array inclination angle

The inclination angle is the angle between the horizontal and the plane of the solar array. A general rule of thumb is that this angle should be equal to the latitude of the installation location. If the main loads of the building occur in winter months, it may be appropriate to increase the panel inclination to the location latitude + 15° in order to increase exposure from the winter sun which is typically lower in the sky than the summer sun. For the same reason, if main loads occur in summer, decreasing the angle by 15° may be of benefit. (Gevorkian, 2008)

4.3.1.4 Advantage of solar panels

- Free of noise pollution and durable because there are no (mechanically) moving parts in solar panels. (Ehsanul K., September 2017)
- Very little required maintenance.
- If any section of arrays were found to be faulty, the rest could continue to operate.
- Its design is flexible, additional solar modules could also be added over time to improve the energy generation capacity.

4.3.1.5 Solar panels disadvantage

- High initial installation cost (Energysage, March 2016).
- The efficiencies of most domestic solar panels are around 10–20% which is another shortcoming of solar technology (International Renewable Energy Agency, 2014).
- The performance limitations of other components such as batteries, inverters, etc.
- Short battery lifetimes and the safe disposal of spent batteries are another concern about solar energy systems.
- Batteries are often large and heavy, thereby requiring large storage space.
- Factors associated with the maintenance of systems such as a shortage of skilled manpower to meet growing demands for installation, maintenance, inspection, repair, and evaluation of solar power systems are another constraint as well. (Ehsanul K., September 2017)

- Lack of basic technical knowhow on the user's behalf (especially in rural areas of the developing world)
- The plausibility of cracks within the PV module, water intrusion, exposure to dust, and algal growth can greatly lower the performance of the system.
- Solar energy can only be harnessed during the day and works most efficiently when it is sunny. (Radivojevi AR, 2015.)
- Most buildings that generate their own energy with PV need bigger roof area. If it is assumed that a building has only its roof area available for mounting PV, then a single-story building is much more likely to achieve net-zero than a high-rise (Figure 4-22). (Malin, 2010)

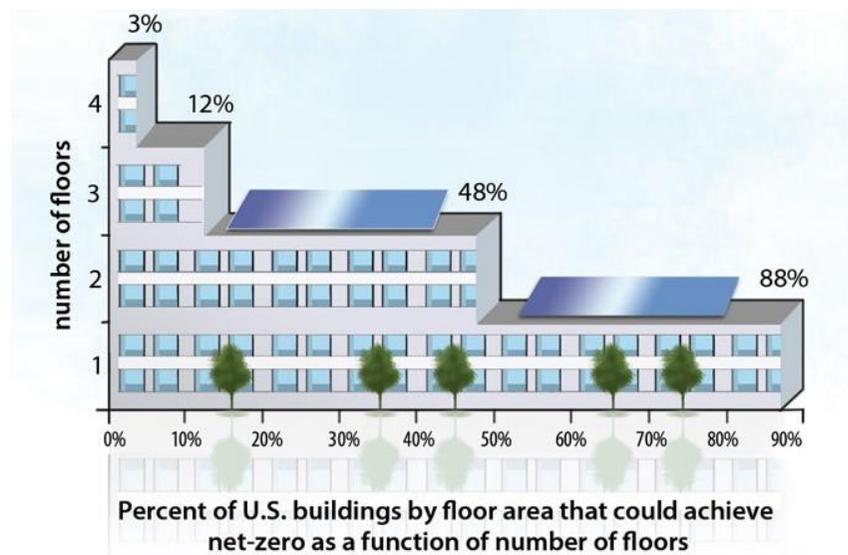


Figure 4-22: PV area according to public building floors number,
Source:<https://www.buildinggreen.com/sites/default/files/articles/Multi-Story.jpg>

4.3.2 Wind energy, building integrated turbines

Recently, wind energy has become one of the most rapidly increasing renewable energy resources. Wind turbines proved its efficiency in producing electricity due to the recent technological improvements. (Bedri Kekezoğlu, 2015) Designing appropriate building-mounted wind turbines requires the consideration of several important factors like prevailing wind conditions, neighboring geometry scenarios, building layouts and assembly forms. (D. Ayhan, 2012)

There are many wind turbines types and varied sizes, Wind turbines can be grid-connected or off-grid. Off-grid systems require battery storage to store surplus electricity for supplying more stable electricity supply.

Recent developments in building integrated wind turbine technologies focus on improving efficiency at low wind speeds and lowering capital cost. Also, wind turbine blades are now designed with lightweight materials to be sensitive to any small air movements. Furthermore, the use of permanent magnet generators, results in lightweight and compact systems that allow low cut-in wind speeds. In this way, electricity can be generated with wind speeds as low as a few metres per second.

One of the methods for converting electrical energy into wind energy is to use wind turbines (WTs). WTs are manufactured in varied sizes and powers (V., 2006). According to the IEC²⁰, WTs are divided into 2 classes: small WTs (SWTs) (Figure 4-23), and large WTs (LWTs) (Figure 4-24). According to the Small and Medium Wind UK Market Report 2013 (Renewable UK, 2016), commercially manufactured SWTs are analyzed in 3 classes: micro WTs (MWTs), SWTs, and small-medium WTs (SMWTs).



Figure 4-23: Example on building integrated turbines small scale,
https://www.climatetechwiki.org/sites/clipmatetechwiki.org/files/images/teaser/building-integrated_wind_teaser_image.jpg



Figure 4-24: The Bahrain World Trade Centre, example of building integrated wind turbines in a large scale,
https://www.climatetechwiki.org/sites/clipmatetechwiki.org/files/images/extra/building-integrated_wind_bahrain.jpg

One of the latest technologies in wind turbines is the Micro wind turbine (Simon Van Overeem, November 2017), its features as following:

²⁰ IEC: is standard of the International Electrotechnical Commission

- Micro wind turbine concept suitable for public building use and low wind speeds is proved, can generate power with wind speeds as low as 2 meters/second.
- The purpose is to manufacture light weight wind turbine components, so, the blades of the turbine are manufactured with a fiberglass reinforced composite material.
- Because of its high strength and thermal conductivity, fiberglass is minimally affected by environmental variations. (Leund, 2010)
- The micro wind turbine concept has a modular structure and can be optimized for different conditions and wind sites, this turbine blades are in the gearwheels. Thus, the swept area can be adjusted according to the requirements (Figure 4-25).
- Micro wind turbine radius is 25 cm,
- The measurement results show that turbine performance increases with increasing gearwheel numbers. The increased blade numbers also increase the turbine performance as (Figure 4-26) (Leung, December 2010).
- The power produced by 8 micro turbines or 20 turbines is shown in Table 12.

Generally, before wind turbine installation:

- It is important to collect wind data in the immediate vicinity of a building or installation site. Based on this data, a suitable type of wind turbine and suitable location can be determined to maximise the electricity generation.
- Prior to installation on an existing building rooftop, it is important to ensure the roof structure is strong enough to hold the added loads.
- These include the weight of wind turbine(s) and vibration from wind turbine operation.
- Vibration absorbent technology should be applied to prevent damage to building structure and to reduce interior noise in the building.
- Accessibility for maintenance should also be planned for.



Figure 4-25: Integrating micro wind turbines to the built roof, Source: (Leung, December 2010)

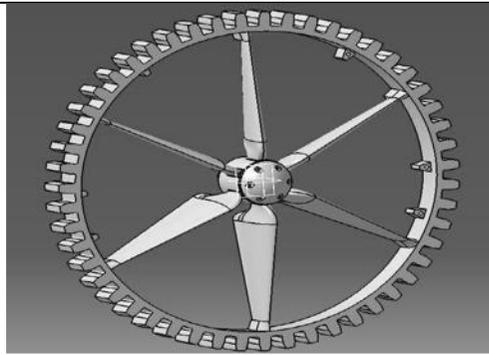


Figure 4-26: Design of micro wind turbine concept, Source: Bedri., Muğdeşem T., Ali E., A New Wind Turbine Concept: Design and Implementation, Acta Polytechnica Hungarica, Vol. 12, No. 3, 2015.

Table 12: Micro wind turbines performance (wind speed in m/s and power in watts), Source: (Leung, December 2010)

Wind speed	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
8 turbines	0.4	1.3	3	6	10	17	25	36	50	66	86	109	137	168	204	245	291	342	400
20 turbines	1	3.3	8	15	27	42	64	91	125	166	216	274	343	421	512	614	729	857	1000

4.3.2.1 Wind turbines advantage

Advantage of generating energy by using wind turbines are:

- The main advantages include an unlimited, free, clean renewable energy resource
- Wind is a natural occurrence and harvesting the kinetic energy of wind doesn't affect currents or wind cycles.
- Wind turbines available in varied sizes, can fit any design and location. (M. Faizal, 2017)
- Wind energy creates no harmful emissions, the carbon footprint from generating power can be reduced, for example, if 15 TWh/year is produced from wind energy, a staggering 7000 tons of CO2 emissions could be avoided. (Waewsak, 2015)
- The cost of wind energy can be considered less than the coal, if it was considered the cost used in trying to offset the emissions of CO2 and SO2 among other substances. (Zhao, 2017)

- Using of off-grid low-speed wind turbines in rural areas, because it is too costly and challenging to connect small rural villages to the national power grid. (Izadyar, 2016)

4.3.2.2 Wind turbines disadvantage

The disadvantages of wind turbines are:

- Wind turbines initial cost, constructing turbines and wind facilities is extremely expensive. (M. Faizal, 2017)
- the disturbance and destruction of ecosystems, cause noise pollution.
- Bird mortality has been shown to be caused by a few factors, including wind turbine arrangement, bird species, as well as climatic variables.
- wind energy creates a life cycle impact because of the material it is made from (steel). (M. Faizal, 2017)
- The amount of power needed during the manufacturing stage.

So, innovative technology is needed to lower costs, increase reliability and energy production, develop infrastructure and manufacturing facilities, and mitigate known environmental impacts

4.3.3 Geothermal Energy

Geothermal energy is thermal energy stored beneath the earth's surface. It is clean, renewable, and popular because it can be harnessed from anywhere in the world to produce heat and electricity. Geothermal energy is used for building heating and cooling, and electricity generation. Even, geothermal is not the most widely used source of energy, it is by far one of the most efficient and sustainable systems.

The most common geothermal systems are as following:

- **Borehole heat exchanges:** Individually or as an array of exchangers, right beside or below the building at a depth of between 50 to 150m.
- **Energy piles:** it is heat exchangers pipes integrated into the building's foundation piles, depth between 10 to 30m.
- **Ground absorbers:** this is a horizontal pipe loops in or below the foundation slab, it is like underfloor heating.
- **Direct use of ground water:** this is working by supplying ground water through a heat exchanger. (Gintars, 2019)

Geothermal energy is used in three main ways: direct use, power generation, and ground source heating and cooling: (Green Building Alliance, 2019)

- **Direct Use:** The hot water in geothermal reservoirs produces heat and steam, which directly used for multiple purposes. This hot water is extracted by a well and then delivered through piping, a heat exchanger, and controls for its intended purpose.
- **Power Generation:** geothermal energy can be used to produce power. Geothermal power plants capture deep deposits of geothermal energy, whether steam or hot water, and use this to drive turbines that sequentially produce electricity. There are three different types of geothermal power plants: Dry Steam Power Plants, Flash Steam Power Plants and Binary Power Plants (Figure 4-27).
- **Ground Source Heating and Cooling:** is the most common use for geothermal energy. A ground source heat pump taps into the constant temperature found within the earth's surface. Constant temperature can be captured from anywhere in the world. This system specifically transfers heat from the earth into a building during the winter season and then transfers heat back into the ground during the summer. The temperature can be controlled with the use of heat from the earth.

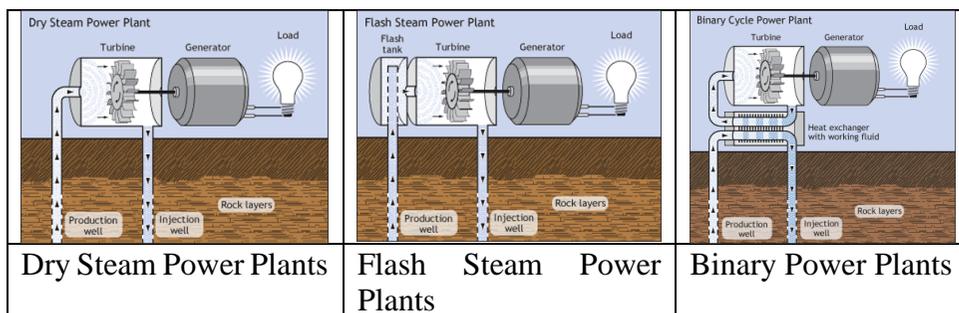


Figure 4-27: Types of geothermal power plants, Source: <http://www.wbdg.org/resources/geothermal-electric-technology>

4.3.3.1 Advantages of Geothermal Energy

Geothermal advantages are:

- It is a renewable source of energy. (Gintars, 2019)
- It is non-polluting and environment friendly.
- There is no wastage or generation of by-products.
- Geothermal energy can be used directly.

- Maintenance cost of geothermal power plants is very less.
- Geothermal power plants do not occupy too much space and thus help in protecting natural environment. (Gintars, 2019)
- Unlike solar energy, it is not dependent on the weather conditions.

4.3.3.2 Geothermal disadvantage

Disadvantages of geothermal energy are:

- Only few sites have the potential of Geothermal Energy.
- Total generation potential of this source is too small.
- Installation cost of steam power plant is extremely high.
- There is no guarantee that the amount of energy which is produced will justify. (Gintars, 2019)
- the capital expenditure and operations costs.
- It may release some harmful, poisonous gases that can escape through the holes.
- drilled during construction.

4.3.4 Hydropower integrated in building

Hydropower became a valuable resource for electricity generation at the beginning of the electricity era. Its suitable for building around river, they are generally designed to use part of the river flow.

Small hydropower energy is an excellent choice to promote productive uses because: (Practical Action, 2018)

- Hydro is usually the cheapest of all electrification options where hydro resources exist.
- Hydro energy is a mature technology, widely proven and now manufactured in several developing countries.
- Hydro energy resources are fully predictable, and generate energy 24 hours a day, so they can safely be used to supply a range of services to health and educations centres, for drinking water, for communication and other services.
- Hydro is a proper energy option for intensive energy consumption.
- It can be adapted to the local skills and capabilities for implementation, operation and maintenance.

- Hydro is a clean energy choice, which can be harnessed with minimum alteration of the environment and no green house gases emissions.
- Table 13 show hydropower classified by size.

Table 13: Classification of hydropower by size

Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 - 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW, either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid.
Pico-hydro	From a few hundred watts up to 5kW

To determine the power potential of the water flowing in a river or stream it is necessary to determine both the flow rate of the water and the head through which the water can be made to fall. The flow rate is the quantity of water flowing past a point in a given time. Typical flow rate units are litres per second or cubic metres per second. The head is the vertical height, in metres, from the turbine up to the point where the water enters the intake pipe or penstock. The potential power can be calculated as follows:

Theoretical power (P) = Flow rate (Q) x Head (H) x Gravity (g) When Q is in cubic metres per second, H in metres and $g = 9.81 \text{ m/s}^2$ then,

Equation 2: Hydro power equation

$$P = 9.81 \times Q \times H \text{ (kW)}$$

Energy is always lost when it is converted from one form to another. Small water turbines rarely have efficiencies better than 80%. Power will also be lost in the pipe carrying the water to the turbine, due to frictional losses. By careful design, this loss can be reduced to only a small percentage. A rough guide used for small systems of a few kW rating is to take the overall efficiency as 50%. Thus, the theoretical power must be multiplied by 0.50 for a more realistic figure. (Practical Action, 2018)

4.4 Building control systems

Building control systems BCSs are critical to the operation of high-performance zero energy buildings. Smart public building controls provide advanced functionality through a computerized, intelligent network of

electronic devices designed to monitor, control and optimize building services, such as, lighting, HVAC, electrical plug-loads, security, access control, audio-visual, as well as occupancy-related systems (Figure 4-28). And there is advanced technology allows the integration, automation, and optimization of any building system in support of facilities management and the building's operation and performance. (D. Kolokotsa, 2011), (Jim Sinopoli, 2016)

There are several parameters during operational conditions:

- Unpredictable user actions, that affect on building energy efficiency such as unnecessary operation of the lighting or the HVAC systems, opening and closing of windows, setting of the setback temperature too high or too low, influence of prevailing weather conditions on the thermal behavior of the building.
- The complex interaction of the NZEB active and passive climate-control and energy-generation systems installed and their effect to energy efficiency and building thermal response; and, atypical availability of energy on a “weather-basis” rather than a “need-basis” through renewable energy-generation sources.

For the calculation of the previously mentioned indicators, the energy-production calculations are usually performed uncoupled from the energy-requirement calculations, for typical winter and summer design days or weeks. Therefore, the existing performance indicators is required especially during the operational phase.

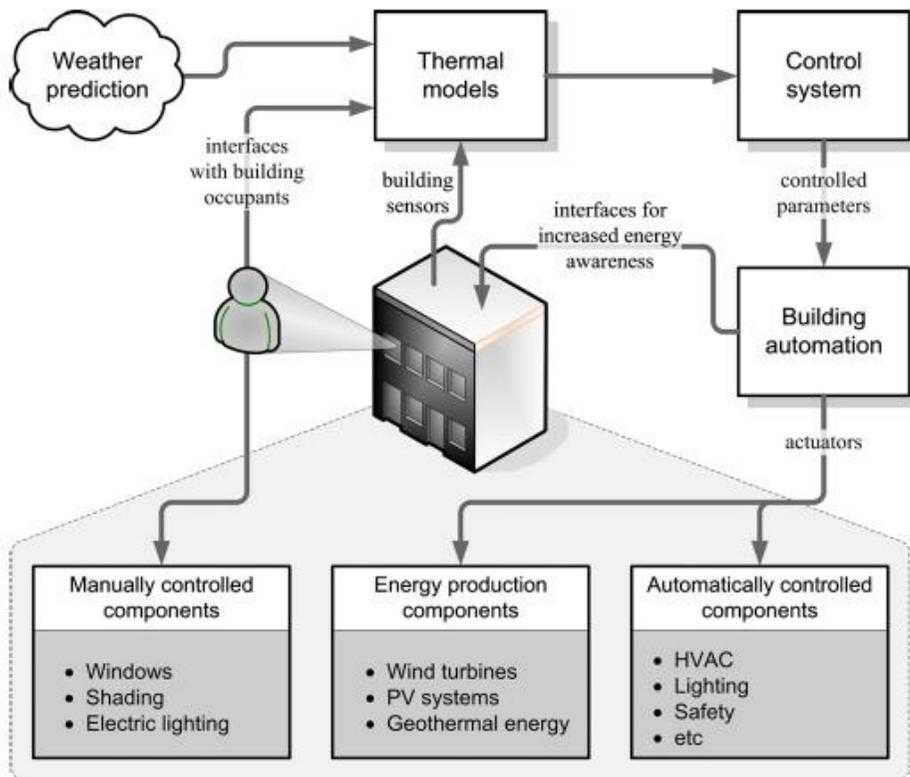


Figure 4-28: Building control system job, Source: D. Kolokotsa , D. Rovas , E. Kosmatopoulos, K. Kalaitzakis, A roadmap towards intelligent net zero- and positive-energy buildings, Elsevier, 2011

4.4.1 How's the building control system works

Many renewable energy production systems as PV panels and wind turbines are depending on weather and therefore it is difficult to control to follow the building demand during operation. On the other hand, building energy consumption need to be controlled effectively to improve the efficiency of energy conversion. Among them, CCHP (combined cooling, heating and power system), CHP or CCP are most used. (Yuehong Lu, 2015)

And simply the Control of energy systems for grid-connected and standalone nZEBs can be concluded as following (Figure 4-29)

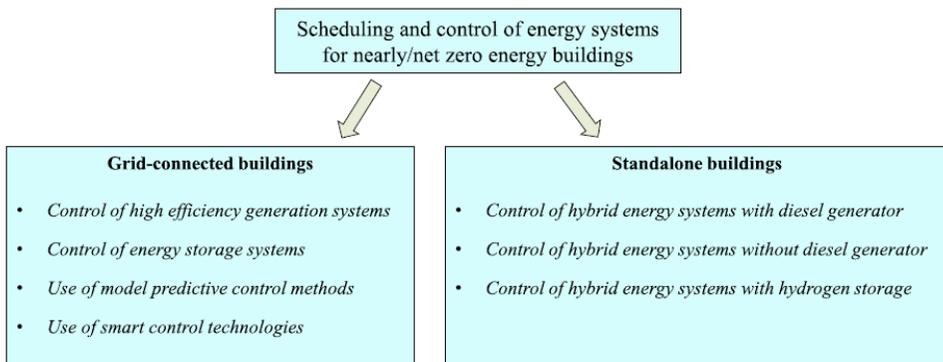


Figure 4-29: Control of energy systems for grid-connected and standalone nZEBs, Yuehong Lu, Shengwei Wang, Kui Shan, Design optimization and optimal control of grid-connected and standalone nearly/net zero energy buildings, ELSEVIER, 2015

The basic control system is working through monitors field devices and sensors that are connected to controllers or directly to a system headend, and generally are working as (Figure 4-30) show.

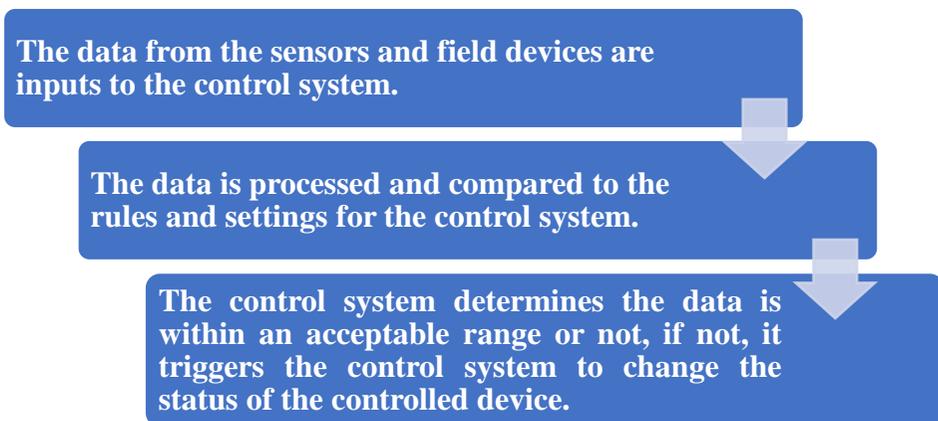


Figure 4-30 : How's the building control system work, source: Author

4.4.2 Building control components

Each of the BCSs is a network and the systems have some commonality, and the system usually consists of: (Jim Sinopoli, 2016)

- Sensors and transmitters are part of a control system may include thermostats, liquid differential pressure transmitters for pumps and chillers, differential pressure sensors for fluids and airflow, static pressure sensors, air pressure sensors, CO₂ sensors, occupancy sensors,

humidity sensors, etc. They are divided into three groups that cover both interior and exterior environment (Figure 4-31).

- Cabling and cable pathways or wireless connectivity.
- Communications protocol to exchange data within the control system.
- Databases and system administration workstations.
- IP addresses, power, and web access.
- Equipment room space.
- Direct digital control (DDC) is used in more complex HVAC systems. DDC allows for a system controller to compute the sequence of operations based on the digital input from system sensors (Figure 4-32).

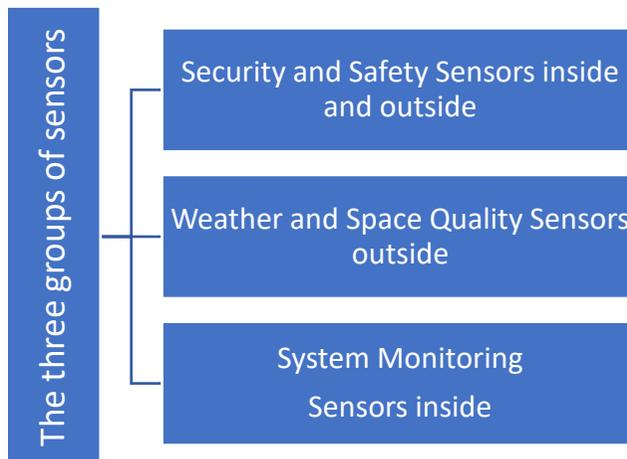


Figure 4-31: The three groups of sensors, Source: Author

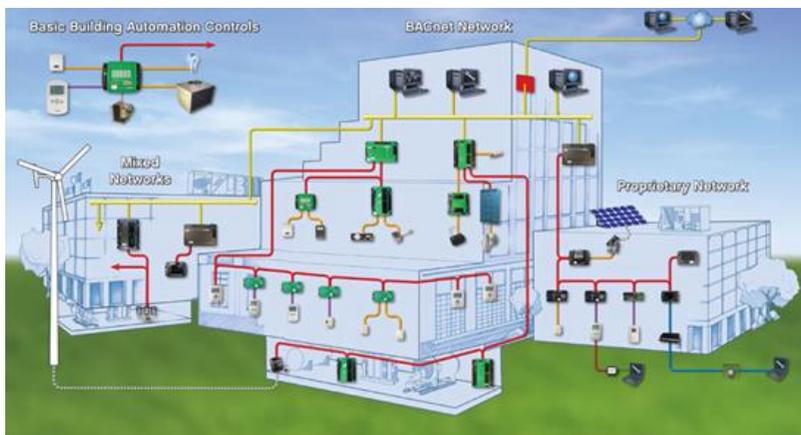


Figure 4-32: Automation control system in a public building, Source: http://www.wbdg.org/images/smartcontrols_05.png

4.4.3 Building control levels

There are three control levels at public BCSs (Jim Sinopoli, 2016),

- **The building management system** is an operator administration workstation that can communicate with, interrogate, and control any of the controllers and devices on the network.
- **Automation level controllers** handle the operations of all downstream field level controllers, collect and keep data, and can operate as stand-alone units if communication is lost to the management level.
- **Field-level controllers** serve building floors, and specific areas, applications, and devices. The field level controllers are typically limited controllers, in terms of both functionality and connectivity.

4.4.4 Public building control system based on AI

It refers to the energy conservation measures on the building energy systems and implemented by using digital control systems particularly the advanced information technologies. But the complex interplay of energy production-consumption- storage systems as well as the automatically and manually controlled building components call for the development of more intelligent control technologies considering all these interactions. (Yuehong Lu, 2015)

The building embodied energy monitoring system is based on the idea of information embedded building is represented through (T, 2008);

- The monitoring system which consists of sensors of energy use, temperature, humidity, indoor air quality, illumination intensity etc.
- The real time basis data is transferred from sensors as digital data to server.
- The input data in the sever is analysed through the process shown in (Figure 4-33).
- The visualised real time basis reporting of the analysis is accessible to all stakeholders of the building through WEB site.
- Continuous collection of real time data and analysis helps to establish accurate prediction model of energy use of building through genetic algorithm, which consider a sort of artificial intelligence.
- It is an enabler of proactive demand control by feed-forward operation based on the prediction concluded by the artificial intelligence.

- The AI control system is a continual improvement of building operation, like temperature and lighting (Tomonari.YASHIRO, n.d.) as (Figure 4-34) and (Figure 4-35).

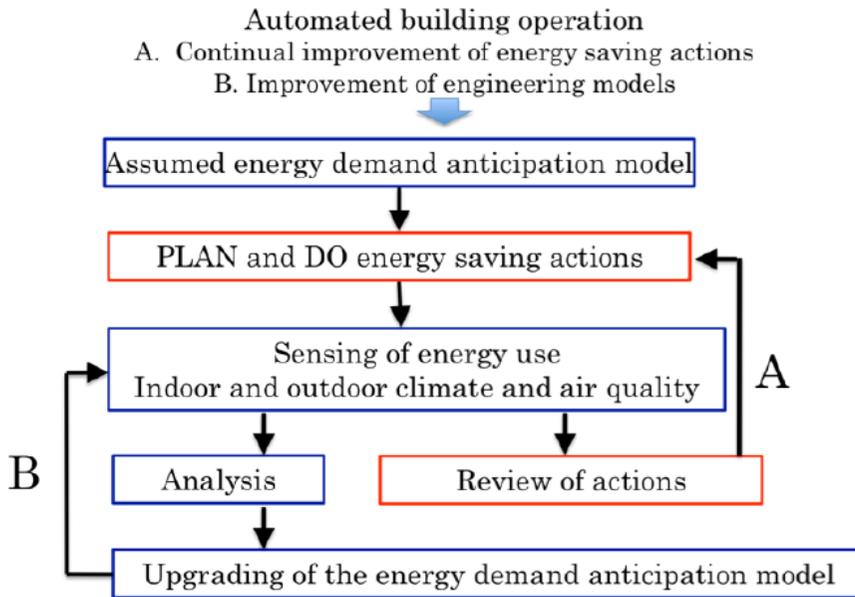


Figure 4-33: Proactive demand control system using real time energy monitoring and a sort of AI, (Tomonari.YASHIRO, n.d.)

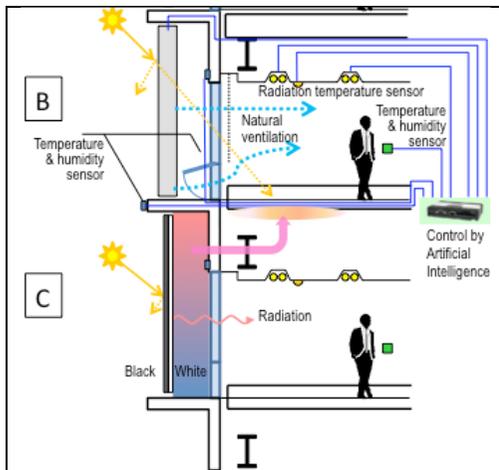


Figure 4-34: Temperature controlled by AI control system, (Tomonari.YASHIRO, n.d.)

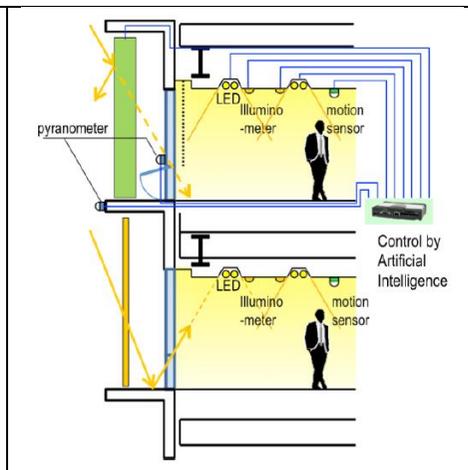


Figure 4-35: Lighting controlled by AI control system, (Tomonari.YASHIRO, n.d.)

4.4.5 Control system at ZEPB

An automated public BCS optimizes energy consumption and allowing efficient use of power and flexibility during peak use periods. In addition, savings costs are realized by more productive use of maintenance employees and more productive output by all users who are working in a comfortable environment.

For designing zero energy public building, constant monitoring with an energy management and control system can lead to optimal building performance (newbuildings.org, 2018). The important control system features at ZEPB are:

- The integrator developed a control system to monitor how all passive systems worked in cycle.
- ZEPB controls can be operated manually, automatically, and remotely turning fans on and off, opening/closing windows, and performing other control related tasks.
- Typical measurements are needed to work as input data for building control system are wind speed and direction, outside temperature, facade and cavity temperatures, outside humidity, solar insulation and inside air temperatures, daylight levels and humidity.
- The lighting controls can be a stand-alone system built into the light fixtures as part of a standard manufactured system or connected to the same control system as the other systems. **(Institute, 2017)**
- Occupancy sensors to control lighting, avoid unnecessary electricity use, and automatic controls for workstations to be into sleep mode after even just a few minutes of non-use.

Integrating building energy management systems (BEMS) can handle communication and energy coordination between ZEBs and the grid. In BEMS, scheduling controls, tariff and load controls, and smart building/environments are the three main functions for achieving energy savings ranging from 11.39% to 16.22%. (D. Lee, 2016)

For example, An Alerton building monitoring system – one of the most common use control systems in nZEB- uses carbon dioxide sensors to operate HVAC systems based on occupancy. The IDEC HVAC is centrally controlled by the operations and maintenance team where the sensors on the insides of the buildings are set to a cooler setting for meeting rooms and other higher volume spaces. In addition to, the HVAC system uses a sophisticated control

method to evaluate building and exterior climate conditions to optimize the evaporative cooling approach.

4.5 Public building energy simulation

Public buildings are complex systems and detailed simulation is needed to consider the actual climate data, building geometries, HVAC-systems, energy-generation systems, natural ventilation, occupancy, internal heat gains, shadings, etc. towards a zero energy goal. In current practice, buildings and their energy performance are estimated based on calculations using simplified physical models and taking a largely static view of the building and its operation. (D. Kolokotsa, 2011)

One of the most important zero energy design requirements is choosing a appropriate energy simulation software. Architects are in continues search for a design tool help in taking an informed decision. Decisions taken during design stage can determine the success or failure of the building. In order to design and construct public buildings it is important to assure informed decision making during the early design phases for NZEBs. This includes the integration of building performance simulation (BPS) tools early on in the design process.

Energy simulation is an extremely useful tool for assessing the energy consumption baseline and testing retrofit ideas for energy improvement. Building energy simulation is an important part of specifying the optimal measures because the building's response towards new characteristics could be very sensitive to local climate factors. (Najme Hashempour, 2020)

Simulation in theory handles dynamic and interactive design investigations, which makes it effective for enabling new knowledge, analytical processes, materials and component data, standards, design details, etc., to be incorporated and made accessible to practicing professionals. (Shady Attia, 2012) The integration of BPS in the design of NZEB is challenging, and requires making informed design decisions and strategic analysis of many design solutions and parameter ranges and simulating their performance. BPS tools' most important choice criteria are intelligence, usability, interoperability and accuracy as architects ranked, as shown in (Figure 4-36)

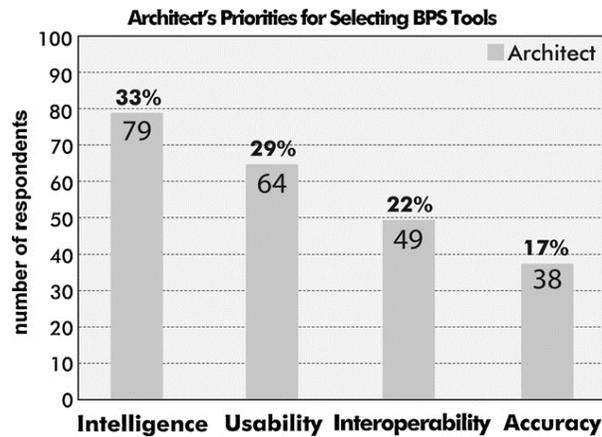


Figure 4-36: Architects ranking the most important features of a simulation tool, Shady Attia, Elisabeth Gratiaa, André De Herdea, Jan L.M. Hensen, Simulation-based decision support tool for early stages of zero-energy building design, ELSEVIER, 2012

4.5.1 Simulation tool properties

The important simulation tool properties that used in energy simulation are:

- The tool allows analysis of variations of NZEB design parameters and elements during the early design phases in hot climates.
- Its added value resides in its ability to inform the decision prior to the decision making for NZEBs design.
- The tool is contextual and is based on a model and database for Egyptian buildings, which includes local materials and construction and allows the generation of code submitting design alternatives. (Shady Attia, 2012)

4.5.2 Simulation process

Simulation process can be concluded as the many inputs that are abstracted away by using pre-sets which are determined from a few architectural considerations such as: location, main orientation, occupancy level, façade openings, surroundings, and building depth. In that way, the architect does not need to assign specific input values into the simulation tool. Instead, the designer defines few properties about geometry and location along with some desired design concepts. Based on these properties and design intentions, the tool creates building design alternatives that follow a set of built-in design

rules. An interesting feature is that the logical so generates an alternative with a degree of randomness to avoid locking the designer into one direction. In the end, the designer is presented with a list of detailed design alternatives. (Torben Østergård, 2016)

Statistical methods refer to a design process where the modeler runs many simulations in a structured manner and use statistical techniques to achieve design support from the simulated data. This approach enables the modeler to explore a large design space in a systematic way, which enlarges the solution space, and thereby improves building performance compared to typical one-at-a-time parametric analysis, as in (Figure 4-37)

To identify the input parameters 5 mandatory questions are asked on two successive screens:

- First, screen simulation program users are asked to select a city, module type and mounting position.
- Second, screen asks for input regarding panel orientation and inclination.
- There are two additional elective questions on screen two that allow users to input values regarding the panel efficiency and/or nominal peak power. (Shady Attia, 2012)

For every question, the user has to choose between different answers, corresponding to the various simulated cases. Instead of communicating those results in the form of textual/numerical data a graphical interactive interface is developed to convey the design guidelines in a visual way. The results are then compiled into performance graphs as shown in (Figure 4-38).

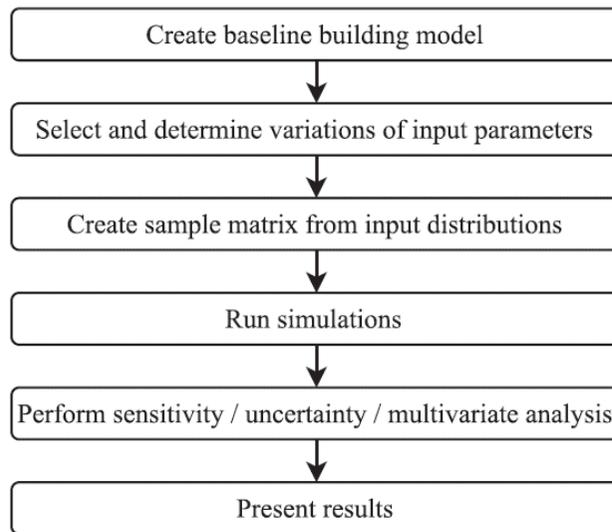


Figure 4-37: Diagram of typical implementation of statistical analyses in a building performance simulation process. Source: Torben Østergård, Rasmus L.Jensen , Steffen E. Maagaard, *Building simulations supporting decision making in early design – A review*, 2016

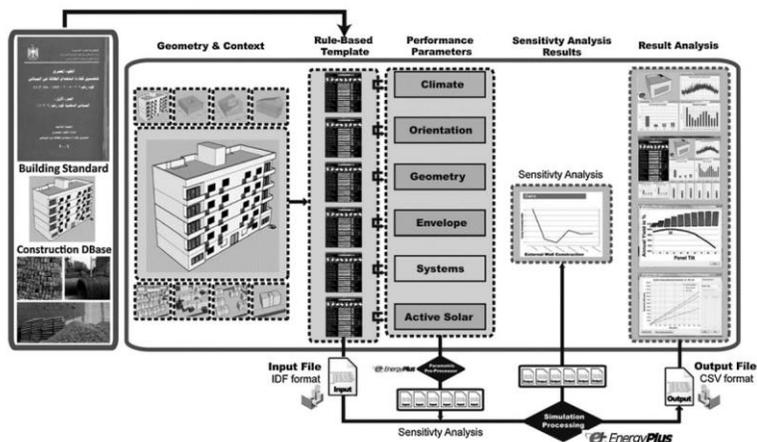


Figure 4-38: simulation process, Source: Shady Attia, Elisabeth Gratiaa, André De Herdea, Jan L.M. Hensen, *Simulation-based decision support tool for early stages of zero-energy building design*, ELSEVIER, 2012

4.5.3 Energy simulation software

The energy software programs differ greatly in scope, validation, purpose, price, level of detail, and more, but each of them can fulfill a specific purpose in the framework described in the following Table shows a comparison

between the popular software in energy simulation field, and as clear there are no existing software package satisfies all requirements. (Torben Østergård, 2016) Software programs are various between BPS (own engine) programs like DOE2, BPS (external engine) programs like Design Builder, Plug In like Honey Bee, and Glue like Grasshopper.

In the next table (Table 14) comparison of software in terms of the requirements of the proposed software framework, like the users (architects or engineers), the design stage (conceptual- preliminary- detailed – management), the software complexity (low- medium – high), also, the software objectives (energy – thermal – daylighting – air quality).

Table 14: Comparison of software in terms of the requirements of the proposed software framework, Source: Torben Østergård, Rasmus L.Jensen , Steffen E. Maagaard, Building simulations supporting decision making in early design – A review, 2016

Software	A. Users		B. Design stage			C. Interoperability	D. Core complexity	E. Objectives					F. Parametric sim.							
	Architects	Engineers	Conceptual	Preliminary	Detailed			Management	Energy	Thermal	Daylight	Air Quality	LCA	LCC	Cloud	I/O Configurable	UA	SA	OAT	Optimisation
BPS (own engine)	Be10 (ISO 13790 monthly) ³	(A)	E	✓			Standalone	Low	✓	(✓)										
	B5im		E		✓		Standalone	High	✓	✓	✓								(✓)	
	DOE2		E		✓		Standalone	Medium												
	EnergyPlus (E+)		E		✓		Standalone	High	✓	✓										
	EPC (ISO 13790 hourly)	(A)	E	✓			Standalone	Medium	✓											
	ESP-r		E		✓		Standalone	High	✓	✓										
	IDA-ICE		E		✓	✓	File exchange	High	✓	✓	✓									
	iDbuild		E	✓			Standalone	Medium	✓	✓	✓									
	IESVE	(A)	E		✓	✓	✓	File exchange	High	✓	✓	✓	✓							✓
	Radiance	(A)	E		✓	✓		Standalone	High			✓								✓
VELUX Daylight Visualizer	A	E		✓	✓		File exchange	High			✓									
BPS (external engine)	A+E3D	A		✓	✓		Integrated	Be10	✓	(✓)	(✓)									
	Daysim	(A)	E	✓	✓	✓	Run-time	Radiance												
	DesignBuilder	(A)	E	✓	✓	✓	File exchange	E+, Radiance, jE+	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	eQuest		E		✓	✓	Standalone	DOE2	✓											
	N++		E	✓	✓		Separated	E+, jE+, GenOpt	✓	✓	✓								✓	
	OpenStudio		E		✓	✓	✓	File exchange	E+, Radiance	✓	✓	✓	✓							✓
Plug-in	Riuska		E		✓	✓	File exchange	DOE 2, own engine	✓	✓	✓									
	Sefaira	A		✓	✓		Run-time	E+, Radiance	✓	✓	✓							(✓)	(✓)	
Glue ¹	DIVA for Rhino	A	(E)	✓	✓		Run-time	Radiance			✓									
	Green Building Studio	A	(E)	✓	✓		File exchange	DOE2	✓											
	HoneyBee (GH)	A	E	✓	✓	✓	File exchange	OpenStudio, E+, Radiance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Glue ¹	jEPlus (+ JESS)		E		✓		Run-time	E+, DesignBuilder, N++	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Parametric Analysis Tool		E		✓		File exchange	OpenStudio	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	Solon	(A)	E		✓		File exchange	Green Building Studio	✓										(✓)	
Glue ¹	Dynamo	A	E	✓	✓		-	-												
	Grasshopper (GH)	A	E	✓	✓		-	-												

From the previous table Design Builder software and Honey Bee plug-in are the most recommended for architects as energy simulation software.

4.6 Zero energy public building design- build team

One of the most important part in building ZEPB is the ability to get each team member oriented and saturated before starting the building process. Design and construction team commitment is essential for successful ZEPB. The more the schedule can be front loaded and the more team members can influence the

project when still on paper, the greater impact owners get in terms of change control, cost, budget, etc. (Cheng, April, 2015, p. 21)

4.6.1 ZEPB Design-build team structure

The ZEPB goal is one that **owners** can define, **design team** can reach for and **occupants** desire. So, ZEPB design team can be structured as shown in the following flowchart (Figure 4-39) to two main group, architect group which has energy engineer, mechanical engineer, electrical engineer and graphics department. And the second group under the supervision of the general contractor consists of: civil engineer, structure engineer, mechanical engineer, electrical engineer, and other departments like telecommunications, landscape, elevator, and geotechnical.

4.6.2 Selecting strategy for design team members

- Discussion about ZE and the EUI target with the design team is a critical part of the team selection and contracting process. (New Buildings Institute (NBI), 2017)
- The structure of the core project teams is responsible for providing reference for the narrative description of the contracts, team selection, and request for proposals (RFP).
- The project directory lists the primary team members and several of the subcontractors and consultants who were heavily engaged.
- Choosing a team in place from the beginning that includes the right experts. (New Buildings Institute (NBI), 2018)
- Expert in using energy modeling analysis as a design tool.

4.6.3 Design team missions after building is complete

Design team has many missions after building is constructed, like commissioning, monitoring, verification, training occupants and watch their behavior.

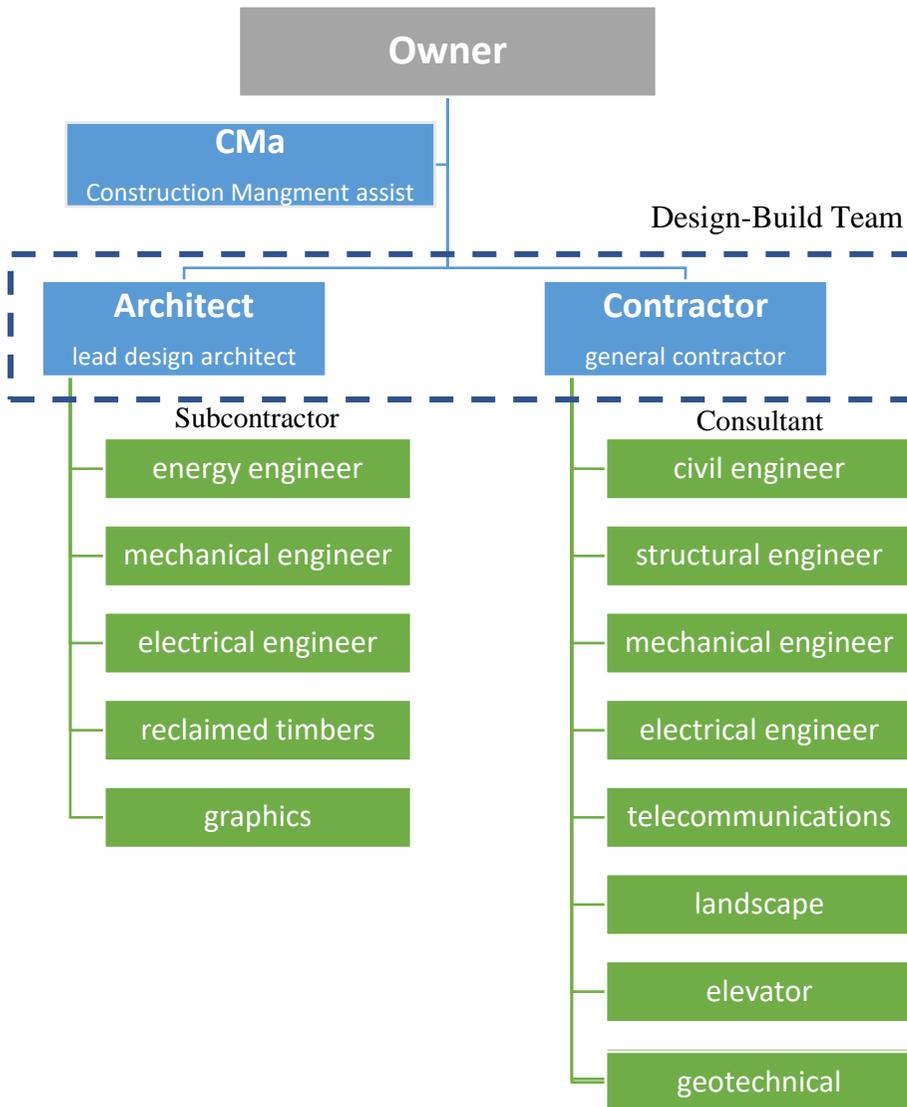


Figure 4-39: ZEPB design team structure, (Cheng, April, 2015, p. 68) adjusted by Author

4.6.3.1 Commissioning

Multiple members of the original design team carried out commissioning. The general contractor, and the rest of the design team continued to manage and adjust the building-controlled system and monitor the operations post occupancy. (Institute, 2017)

4.6.3.2 Monitoring

Once the initial commissioning and post occupancy monitoring period was complete, the owner engaged the master integrator to continue monitoring the control system and integrated building systems. Post operation, the integrator implemented a BACnet 83²¹ communications protocol with the control system to communicate with the HVAC system. Tenants also monitor their own plug loads and continually improve their own practices and equipment to reduce demand. (Institute, 2017)

4.6.3.3 Behavior, Occupant Engagement & Training

The behavior of the tenants has the largest effect on whether a building can achieve ZNE. Taking into consider the psychological interpretation of the occupants' surroundings. For example, occupants interpret grey walls as making them feel colder than they are, so by painting the walls white, tenants are less likely to feel that they need to heat a space. (Institute, 2017)

Design team has to give "driver's manual" to the occupants when first moving into the building that advises them on plug load reduction techniques.

The tenant's behavior information like turning lights on and off and what HVAC schedule and temperature set points improve the accuracy of energy conservation estimates and help fine-tune the design to determine the level of efficiency needed to achieve zero energy goal. (newbuildings.org, 2018)

To control occupant behavior, some appliances such as floor heaters and provides suggestions for Energy Star approved task with the right for approval by the building owners. (Institute, 2017)

4.6.3.4 Verification

This important phase of the process is verifying standard practice for higher-performing buildings, in which a sophisticated integration of factors contributes to meeting performance targets. (Cheng, April, 2015, p. 21)

²¹ BACnet is a communications protocol for building automation and control networks. It is an ASHRAE, ANSI, and ISO 16484-5 standard protocol that was designed to allow communication of building automation and control systems for applications such as HVAC, lighting control, access control, etc.

4.7 Zero energy public building design problems

- Main problem centers around the fact of term “environmental building” or “zero energy building” mostly describe buildings or practices that are not economic. So, zero energy buildings initial cost is higher than regular building but on the long run their running cost is lower, and the choices made during the design process make it more environmentally friend.
- Environmentally ambitious if buildings are rarely built in poorer regions or declining cities, even their long-term costs are lower. So, the researchers are working for cheaper energy savings solutions and higher in its efficiency, and by time zero energy technology will be available in poor regions.
- Public buildings that identified as environmental or zero energy buildings are currently a kind of luxury, assign of greater wealth and a means to reinforce it. (Alter, 2017) But there is no contradiction between environmental because luxury in zero energy building design is not mandatory design requirement.
- Technical maintenance is expensive and need specialists. Also, researchers are working to produce more efficient technology and reduce its need to maintenance.
- Public building occupant’s behavior playing a key role if the building will be able to achieve zero energy goal or not. And for public building occupant’s behavior it is essential to train building user how to help in minimizing building energy consumption and provide building’s visitors with manual explain the building vision and how they can be a positive part in this vision.
- The grid does not have the capacity to store all extra energy generated in summer. (Alter, 2017) Also, for the grid that does not have the capacity to store all extra energy, the government has to develop the grid to increase the storage capacity and the zero energy building can increase the batteries that store extra energy to reuse it when there is shortage or using this building as city energy cell to supply the surrounding buildings and service with electricity, like the first case study at the analytical case study. As well as, the zero energy building that depend on PV system only, the roof surface can be increased by additional cantilever surface like second case study at the analytical study or adding PV system to the building facades and openings, to increase its energy generation.

4.8 Conclusion

This chapter focused on studying the zero energy design requirements for public buildings as mechanical systems, renewable energy resources at public building, energy simulation software, control systems and zero energy design team. And this chapter can be concluded as following:

- Designing efficient lighting and mechanical systems are essential at zero energy public building.
- The mechanical systems are studied to provide the public building with efficient lighting system, HVAC system, ventilation system, and solar water heater system to reduce energy needs in zero energy public building.
- Producing energy through renewable resources that can be integrated in public buildings like photovoltaic, wind energy, geothermal energy and hydropower if there is water source close to the building site.
- Latest technology in photovoltaic energy are transparent solar glass and thin film solar panels. Also, micro wind turbines that can be easily integrated in the building is the latest technology in wind energy.
- Building energy simulation is an important part of specifying the optimal measures for zero energy design process and choosing the appropriate software for energy simulation is important step in zero energy design process. Design Builder and Honey Bee are the most recommended energy simulation software.
- Building control systems BCSs are critical to the operation of high-performance zero energy buildings.
- Smart public building controls provide advanced functionality through a computerized, intelligent network of electronic devices designed to monitor, control and optimize building services, such as, lighting, HVAC, electrical plug-loads, security, access control, audio-visual, as well as occupancy.
- The ZEPB design team consist of owner, architect, civil engineer and other experts in using energy modeling analysis as a design tool.
- Controlling systems help the design team to monitor the building behavior and the energy consumption and energy production to reach with the public building design to the zero energy goal.
- There are many problems facing zero energy public building design, but architects and researchers are working hard to solve these problems and offering more energy efficient zero energy technologies.

By the end of this chapter the literature review about public building, factors affect on design process, efficient envelop design, passive strategies, zero energy public building design requirements as mechanical systems and energy production renewable resources is ended. And can be concluded in analytical model to be able to analyses existing successful zero energy or positive zero energy public building as a step towards extracting zero energy design methodology specifically for public buildings, and this will be in the next chapter.

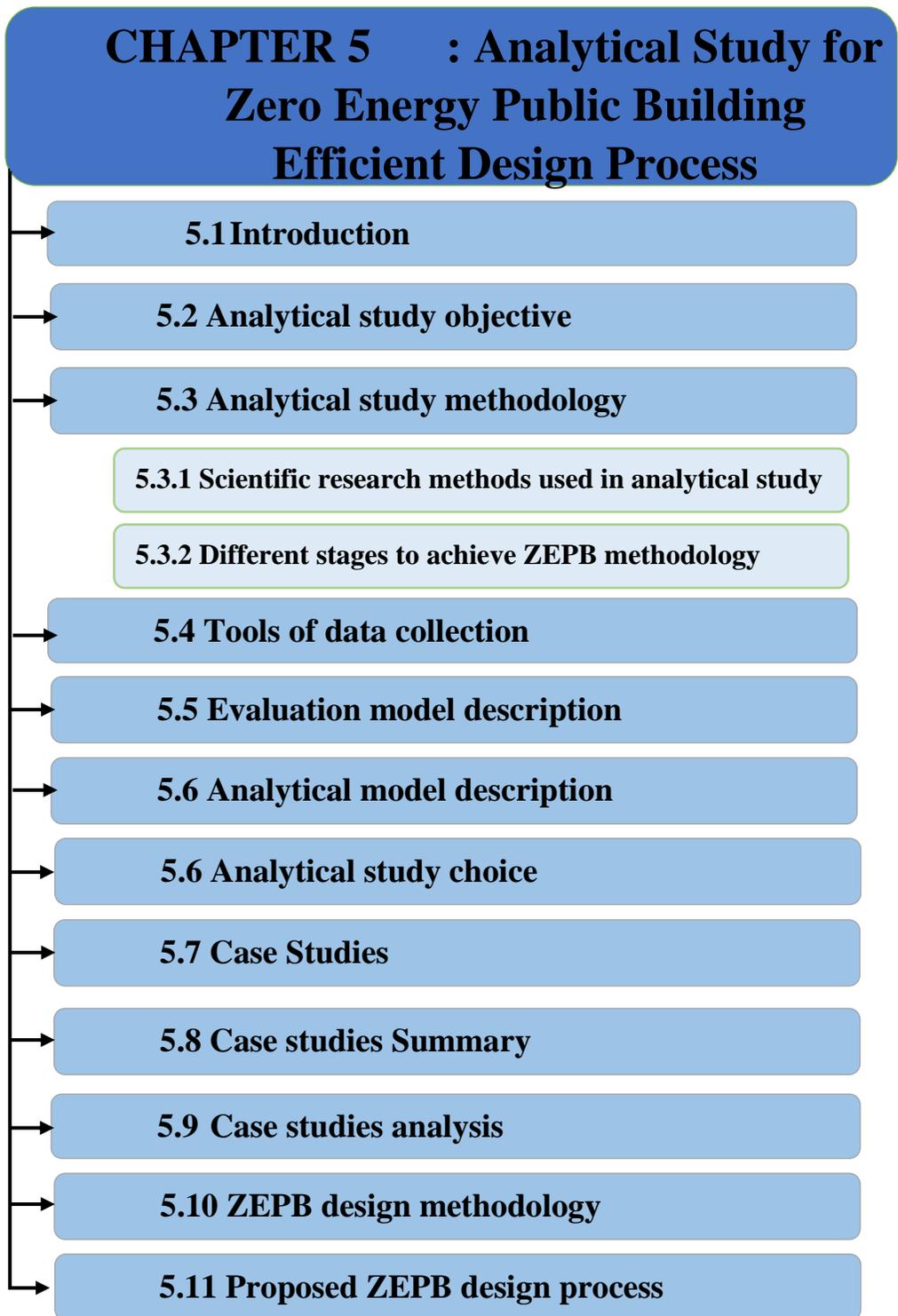


Figure 5-1 : Chapter 5 structure

5.1 Introduction

The amount of environmental improvement in public building designs is established by having energy codes which increased slowly at first. But in the last decade, standards have been pushed to 30% and even 50% (WilliamW.B., 2016) as a respond to the urgent situation of climate change and the improvements in construction, material, and operation. In addition to, changing the size, use, or location of buildings or the occupants, change the required architectural needs by the patterns of design for all public building scales. Also, LEED and the other environmental standards have successfully expanded the categories of performance evaluated (WilliamW.B., 2016) and pushed the public building design to be higher performance buildings.

Based on the previous theoretical study where it was possible to study public buildings and their characteristics, passive design strategies to reduce energy consumption and renewable energy generation techniques, **this chapter aims** to analyse successful and certificated zero energy public buildings designs in order to extract ZEPB design methodology.

5.2 Analytical study objective

The analytical study seeks to find the zero energy public building design methodology through analyzing case studies, trying to extract the design methodology which allow each architect follows in different cases towards achieving the zero energy goal.

Recently, few public buildings succeeded in reaching zero energy goal, so, these projects are studied and analysed to collect the different design strategies, techniques and steps used towards achieving zero energy goal, then combine it in one design methodology suitable to all or most of the public buildings.

5.3 Analytical study methodology

The research will analyse, evaluate and discuss the chosen case studies by:

- Reviewing each case study characteristics such as: project name, type, area, location, construction or renovation year, designing team, occupied data.
- Discussing and analyzing each case study design process by using analytical model.
- Analyzing the case studies and the environmental design strategies, techniques and technologies that integrated in these case study projects.

- Studying the case study techniques that used to reduce building energy consumption.
- Detecting which renewable energy resources are used in the case study and its position on (building roof, building facades, surrounding site).
- Explaining the effectiveness of the project design strategies in reaching general zero energy public design methodology.
- Trying to conclude ZEPB design methodology for existing and future design building.

And the study focusses on the **Correlation** between the proposed methodology elements, and all the last elements can be concluded as in (Figure 5-2).

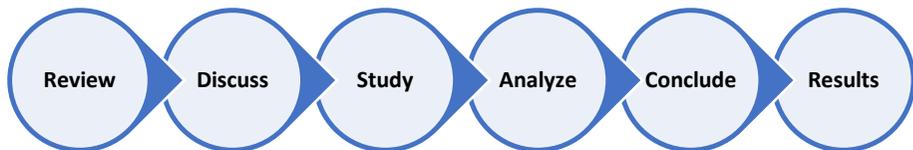


Figure 5-2: Analytical study steps, Source: Author.

5.3.1 Scientific research methods used in analytical study

The analytical study is based on “**Mixed-Methods Research**” by using more than one research method to collect and analyze the data, so, the “**Inductive & Deductive Approach**” have been used because it gathers between thinking and observation to reach to the study goal (Figure 5-3).

5.3.1.1 Inductive Approach definition

Inductive approach usually uses research questions to narrow the scope of the study. (Gabriel, 2013). The aim of using inductive approaches is usually focusing on exploring new phenomena or looking at previously researched phenomena from a different perspective. Also, the inductive approaches are associated with qualitative research and this is represented by theoretical study.

5.3.1.2 Deductive Approach definition

Deductive approach is testing theory, an inductive approach is concerning with the generation of new theory emerging from the data. (Gabriel, 2013) A deductive approach usually begins with a hypothesis and the emphasis is generally on causality. Deductive approaches are more commonly associated with quantitative research and this is represented by analytical study.

5.3.2 Different stages to achieve ZEPB methodology

Form the literature review, the analytical study methodology structure consists of the following three phases, they can be concluded in (Figure 5-3)

First: Public building design data and requirements to collect the case study design data like: Location, orientation, building shape and building surrounded environment. Also, understand the design requirements.

Second: Passive strategies and techniques, this stage focusses on identifying all the passive strategies and environmental solutions that have been applied on the design to reduce the energy consumption.

Third: Renewable Energy production resources, the third stage in the analytical study is analysing the renewable energy resources used in each project to produce energy to cover the building energy needs and achieve the zero energy goal.

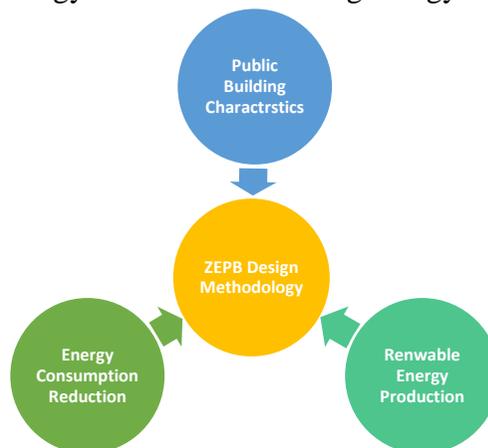


Figure 5-3 Analytical study methodology, Source: Author

5.4 Tools of data collection

Analytical study is using “case studies, analyzing tables and observation” as a tool for collecting data, the observation is defined as the process of directing the senses to observe and follow a particular behavior and to record aspects of that behavior and its characteristics, and observation can be defined as a process of watching or following the behavior of specific phenomena. (Gedely, 2011)

A case study is not a data collection tool. It is a descriptive piece of work that can provide in-depth information on a topic. It is often based on information acquired through one or more of the other tools, such as interviews or observation. Case studies are usually written, but can also be presented as photographs, films or videos. Case studies often focus on people (individuals, households, communities). But they can also focus on any other unit of analysis such as locations, organisations, policies or the environment. (Simister, 2017)

Also, qualitative research is when observations are recorded without capturing numeric data values. This type of observation is more subjective and relies on the researcher’s interpretations of why an event or behavior happens. For instance, a researcher might look at a plant and state that it looks very brown. (Lee, 2019)

5.5 Analytical model description

The analytical model is divided into three main parts as following:

Part 1: Public Building Description

- Project name, Public building location, Local climate data, Orientation, No of Floors, Floor area, Total building area, Building statement, Construction year, design team.
- Internal gain energy: The internal heat gains due to lighting, occupancy, transmitted solar heat, computer and other office equipment has to be shown on an hourly basis for a typical summer and winter day.

Part 2: Energy reduction strategies

- Building envelope: Walls section, Roof, Floor type, Windows, Shading
- Service systems: Lighting, HVAC, Ventilation, Hot water, Equipment, Plug load.

Part 3: Renewable energy production

- Which renewable resource has been used, and the covered percentage of the building energy needs?

At the end of the analytical model there is part for the building energy consumption, and the energy produced by the building to achieve the zero energy building, or nearly zero energy building. The analytical model shown in (Table 15).

5.6 Analytical case studies choice

The case studies are zero energy public buildings, chosen according to specific criteria to facilitate reaching to ZEPB design methodology.

5.6.1 Case studies criteria

The research selects zero energy international buildings as case studies by considering the choosing criteria such as:

- The selected projects must be for public building.
- Project is certificate or target a certificate to be zero energy public building.
- Selected case studies represent several types of public buildings which have different activities, scale, shape, areas, floor numbers, and occupancy number.
- Project must be used at least one renewable energy resource or more producing renewable energy.
- Integrated in the case study many passive design strategies used in building energy reduction.
- Technical report must be available about design details and energy measurements for building needs and production.
- Chosen case studies have been designed or constructed or renovated at the last decade from 2010-2010 to study the latest techniques and materials used in the construction field.
- The technical report and data must be published and available.
- Projects need to be at the nearest climate zone to Egypt climate zone, to verify the different techniques and strategies used in resisting the same climate and environment problems.

The case studies criteria fit fifteen zero energy international public buildings.

Table 15: Analytical case study model

Part 1: Public Building Description	
Project name	
Project pictures	
Publish date	
Building Location	
Project type	
Building state	
Project Size	
Floors no.	
Completion Date	
Working hours	
People capacity	
Team/Owner	
Project certificates	
Part 2: Energy reduction strategies	
Building Envelop	
Walls	
Opening	
Floor number	
Roof	
Material	
Shadings	
Service systems	
Lighting	Daylighting
	Artificial lighting
HVAC	
Hot water	
Equipment	
Plug load	
Total energy needs	
Part 3: Renewable energy production	
Renewable energy	
Control system	
Total energy generated	
results	
Notices	
Occupant Engagement and Training	
References	

5.6.2 Chosen case studies

The analytical study samples are fifteen international projects that can achieve the objectives from the study:

- a) Powerhouse Brattorkaia, office building at Trondheim, Norway.
- b) Indira Paryavaran Bhawan, office building at New Delhi, India.
- c) Mineirão stadium, stadium at Belo Horizonte, Brazil.
- d) The North Face & Vf Outdoors, office building at California, USA.
- e) 435 Indio Way, Sunnyvale, California, USA.
- f) California State Lottery Santa Fe Springs District Office at California, USA.
- g) Leon County Cooperative Extension, office building at Florida, USA.
- h) Bagatelos Architectural Glass Systems factory at California, USA.
- i) TD Bank at Florida, USA.
- j) Zero Net Energy Training Center at California, USA.
- k) Newcastle Elementary School at California, USA.
- l) Lakeline Learning Center at Texas, USA.
- m) Mosaic Centre for Conscious Community and Commerce at Canada.
- n) West Berkeley Public Library at California, USA.
- o) House of Île de France, Student Residence at Paris, France.

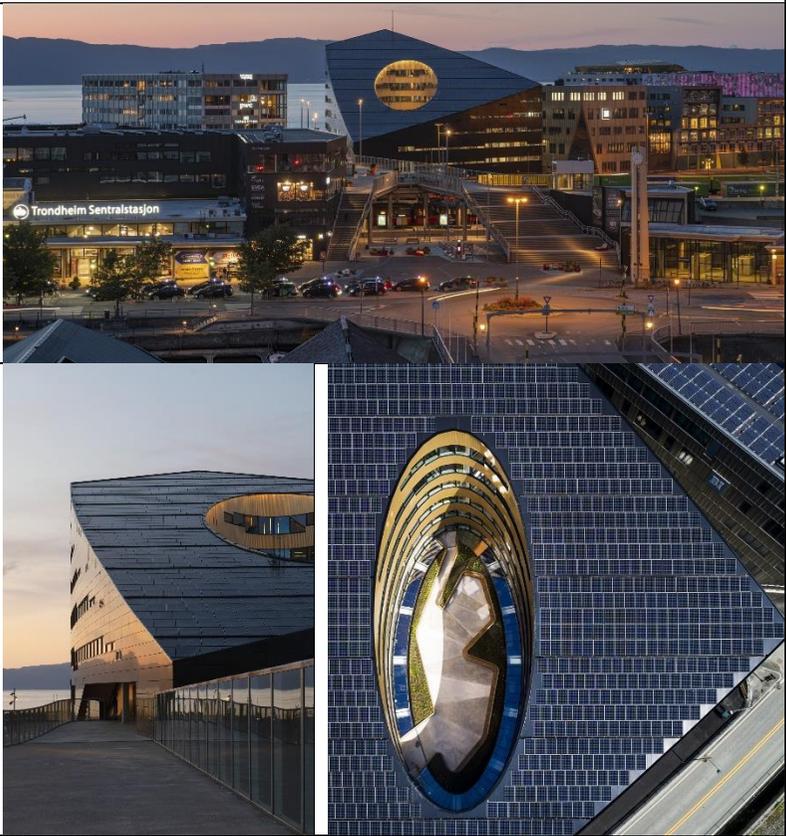
5.7 Case studies

The proposed analytical model from 5.5 is used to analysis case studies data into three main parts, first, the project description, then energy reduction strategies, third, energy production techniques used as following:

5.7.1 Project name: Powerhouse Brattørkaia office building, Norway

The world's northernmost energy-positive building which challenges the traditional construction and puts in place new standards for buildings that produce more energy than they consume. Also, the building daily function is a small power plant in the middle of the city, more details are in (Table 16).

Table 16: Case study 1: Powerhouse Brattørkaia office building, Norway

Part 1: Public Building Description	
Project name	Powerhouse Brattørkaia
Project pictures	
Publish date	2019
Building Location	Trondheim, Norway The building's site ensures maximum exposure to the sun
Project type	Office building
Building state	New

Climate Zone	Oceanic climate or humid continental climate	
Project Size	170800 m ²	
Floors no.	11	
Project description	The 18 000 m ² office building is situated by the harbor, the waterfront façade is the slimmest face of the building	
Completion Date	2019	
Working hours	-	
People capacity	Variable	
Team/Owner	Designed by Snøhetta	
Project certificates	There are no certificates yet, but the project represents the world's northernmost energy-positive building.	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - Facades clad with black aluminum and solar panels. - Facades are well insulated.
	Opening	<ul style="list-style-type: none"> - Large glass windows
	Roof	<ul style="list-style-type: none"> - The building's roof is inclined to collect more of solar energy.
	Material	<ul style="list-style-type: none"> - The building used extremely energy efficient material.
	Shadings	<ul style="list-style-type: none"> - No shadings are added.
Service systems		
Lighting	Daylighting: <ul style="list-style-type: none"> - Daylight conditions are optimized through out the building design - The sloping roof of the building allows daylight to flow into the office spaces. - There is a wide oval illuminated atrium in the middle of the project to increase the natural lighting on every floor. 	
	Artificial lighting: <ul style="list-style-type: none"> - Artificial light use is kept at a minimum. 	
HVAC	<ul style="list-style-type: none"> - Installing intelligent solutions for air flow to reduce the need for heating. - Heat recovery solutions for ventilating air. 	

Total energy needs	
Part 3: Renewable energy production	
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - 3000 square meters of solar panels are used and strategically placed on the building. - The building store the extra energy produced at summer time and reuse it in winter time when daylight is not adequate. <p>Hydropower:</p> <ul style="list-style-type: none"> - Using seawater for heating and cooling and implementing only energy efficient electrical appliance.
Control system	A series of technologies is applied to radically reduce energy use for daily operations.
Total energy generated	500000 kWh/year
Results	
	Energy-positive means that the building is producing more amount of energy than what it's consuming for its operation and resident needs.
Notices	Because the “powerhouse” produces twice the energy it needs, the surplus is passed to the neighboring buildings as well as nearby charging outlets that are used by buses, cars, and boats.
References	<ul style="list-style-type: none"> - El BENAA Journal, Volume 40, December 2019, P.39-42 - https://www.archdaily.com/924326/snohetta-completes-powerhouse-brattorkaia

This office building design is interacted to the location and climate conditions, slope in façade and roof to maximize solar energy gain, wide court in the middle to maximize daylighting at offices, also, by using solar and hydro power the building succeed in producing energy more than its needs.

5.7.2 Project name: Indira Paryavaran Bhawan, Ministry of Environment and Forests office building, India

Indira Paryavaran Bhawan in New Delhi is the first zero net energy building constructed in India with passive solar power generation. The building used geothermal and elevators kinetic energy in generating energy too. Uses 70% less energy compared to similar types of buildings as shown in (Table17).

Table 17: Case study2: Indira Paryavaran Bhawan office building, India

Part 1: Public Building Description	
Project name	Indira Paryavaran Bhawan
Project pictures	    

Publish date	2018	
Building Location	New Delhi, India	
Project type	Office building	
Building state	New	
Climate zone	Hot semi-arid climate	
Project Size	Total project size = 32000 m ² Office building area= 9565 m ²	
Floors no.	8 Floors + 3 basements	
Project description	The building has large span trusses at terrace and space frames in the central courtyard to support solar panels. The main building has been designed as RCC framed structure. Plantation and grassing in more than 50% area.	
Completion Date	2014	
Working hours	Day time	
People capacity	Variable	
Team/Owner	Chief Engineer :P. Bhagat Singh, CPWD, Thiruvananthapuram & Dr. K M Soni, Central Public Works Department (CPWD)	
Project certificates	Platinum LEED and 5-star rating under GRIHA	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - Double skin construction for noise control - Light color painting to reflect heat.
	Opening	<ul style="list-style-type: none"> - Low heat transmission glass
	Roof	<ul style="list-style-type: none"> - Reflective roofing,
	Material	<ul style="list-style-type: none"> - Local energy efficient materials and practices materials are used. - Fly ash-based products in construction.

		<ul style="list-style-type: none"> - Dholpur stone cladding has been provided over fly ash brick/AAC block walls up to two and half storeys.
	Shadings	<ul style="list-style-type: none"> - No extra shadings added on, the building facades itself are extruded and increased openings depth.
Service systems		
Lighting	Daylighting:	<ul style="list-style-type: none"> - Building envelope designed to ensure daylight in 75% of occupied areas
	Artificial lighting:	<ul style="list-style-type: none"> - Use of high efficiency Led lighting fixtures, time switches and occupancy sensors.
Natural Ventilation		<ul style="list-style-type: none"> - Natural ventilation throughout, with a central courtyard between the North and South blocks. - Landscaping with no hard paving eliminating heat island effect.
HVAC		<ul style="list-style-type: none"> - Energy-efficient chilled beam system of air conditioning with energy consumption less than 50% compared to conventional system. - Centrally air-conditioned with 400 TR capacity (HVAC).
Equipment		<ul style="list-style-type: none"> - The building has 7 lifts, typical 13-person elevator, it could save up to 25% of the energy consumed. - All essential services are provided like DG sets, UPS, IBMS, fire detection and fire-fighting systems, access control, automated parking, and other electrical, landscaping and horticulture services.
Plug load		<ul style="list-style-type: none"> - The AC plant room, electric substation, DG sets, robotic parking for 330 cars and sewage treatment plants are in the basements.
Total energy needs	14 EUI	
Part 3: Renewable energy production		
Renewable energy	Solar:	<ul style="list-style-type: none"> - Additional area was provided through 6 m cantilever structural for solar power generation. - Deploying thin film transparent PV modules on space frame over the terrace and central courtyard. - Using highest efficiency mono crystalline SPV panels.

	<ul style="list-style-type: none"> - 6000 sqm for supporting solar panels. <p>Geothermal heat exchange system:</p> <ul style="list-style-type: none"> - Vertical closed loop system of geothermal heat exchange system to reduce the load on the HVAC. - This system was adopted for the first time in a government building in India on such a large scale. - The system has vertical closed loop system done with 32 mm diameter U – loops, 180 in number and 80m deep each. <p>Kinetic power: The power regenerated from the elevator was to be used for power requirement of the elevators.</p>
Control system	All services were controllable and could be monitored using IBMS for greater reliability and to effect optimum level of operating engineering services system.
Total energy generated	14 EUI
Results	
	The building is zero energy
References	<p>Bhagat Singh, P. (2017), First Net Zero Energy Government Building. http://cpwdpims.nic.in/display_cpwd/technical_ltr/tech.aspx</p> <p>https://www.nbmcw.com/tech-articles/case-studies/38475-indira-paryavaran-bhawan-first-on-site-zero-net-energy-building-of-india.html?fbclid=IwAR0mctESTqKgZNcSG14nYjrjPgfcXbG2itugTyJAbzRIcdF-lib5mSOoc_g</p>

Conclusion:

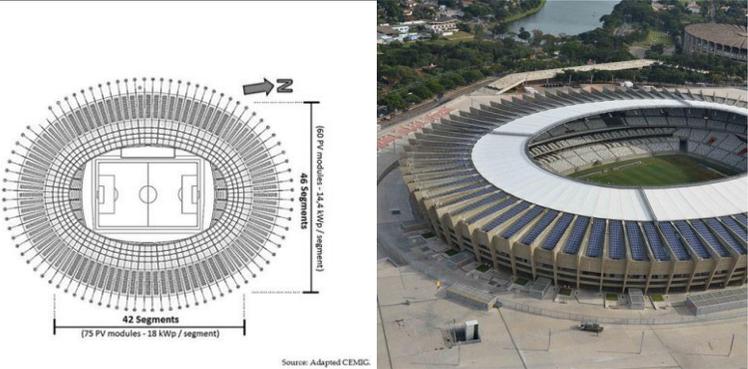
This building is designed to be energy efficient building, envelope designed to ensure daylight in 75% occupied areas by using low heat transmission glass, landscaping with no hard paving eliminating heat island effect, natural ventilation throughout, with a central courtyard, and energy efficient chilled beam system of air conditioning. The building design overcome the huge energy needs by generating energy from more than one renewable energy resource, solar, geothermal and kinetic energy from elevators movement.

Solar power is maximized by increasing the roof surface, which is increased by 6m at each direction.

5.7.3 Project name: Mineirão stadium, Brazil

In 5 September 1965 Mineirão officially opened, the stadium was in need to be renovated before the world cup at 2014. The solar panels were distributed on the rooftop to generate electricity, the installed PV system is the biggest rooftop PV in football stadium in Brazil. (Table18)

Table 18: Case study 3, Mineirão stadium, Brazil

Part 1: Public Building Description	
Project name	Mineirão stadium
Project pictures	
Publish date	2017
Building Location	Belo Horizonte, Brazil
Project type	Stadium
Building state	Renovated
Climate zone	Tropical savanna climate
Project Size	348,900 m ²
Floors no.	1 floor
Project description	Capacity: 64,000 seats, with its rhythmic structure of reinforced concrete and its monumental proportions.
Completion Date	2014
Working hours	Working during matches or trainings.
People capacity	Variable
Team/Owner	Eduardo Mendes Guimarães Junior and Gaspar Garreto

Project certificates	LEED Platinum Sustainability Certification, granted by the U.S. Green Building Council (USGBC)	
Part 2: Energy reduction strategies		
Building Envelop	Walls	-
	Opening	-
	Roof	The 360° rooftop is divided into 88 physical segments with 42 segments (east and west sectors) containing 75 PV modules each (18 kWp/segment) and 46 segments (north and south sectors) with 60 PV modules each (14.4 kWp/segment).
	Material	The building is painted with light color to reflect the heat. Roof covered with PV panels.
	Shadings	Vertical shadings are distributed radically.
Service systems		
Lighting	Daylighting: The building structure	
	Artificial lighting: Led lighting units installed to reduce the energy consumption.	
Part 3: Renewable energy production		
Renewable energy	Solar: <ul style="list-style-type: none"> - PV system installed on the rooftop of the stadium. - 5910 polycrystalline silicon PV modules Mprime. - The system has a total installed power capacity of 1.42 MWp and occupies an area of 11,530 m² (70% of total roofing area 16,424 m²). 	
Total energy generated	Only 10% of energy generated required to power stadium remaining 90% distributed to surrounding community: the solar photovoltaic power plant generated more than 300 MWh in two months of operation, supplying energy to about 1,200 houses.	
Results		
	The stadium is energy positive building.	
References	<ul style="list-style-type: none"> - Luís G. Monteiro, Wilson N. Macedo, Pedro F. Torres, Márcio M. Silva, Guilherme Amaral, Alexandre S. Piterman, Bruno M. Lopes, Juliano M. Fraga, and Wallace C. Boaventura, One-Year Monitoring PV Power Plant Installed on Rooftop of Mineirão Fifa World Cup/Olympics Football Stadium, Energies, 2017. - https://www.stadiumguide.com/mineirao/ - Jonathan Laski, Victoria Burrows, From Thousands to Billions, World Green Building Council, 2017, P.45. - https://www.archdaily.com/383430/mineirao-stadium-bcmf-arquitetos 	

5.7.4 Project name: The North Face & Vf Outdoors office building, USA

This project located in compass consist of four building, the North Face comprises two of the four campus buildings. The entire campus was designed with zero net energy (ZNE) goals, and the company is close to offsetting nearly all of the site’s electricity use.

The design team essential goal was to design an efficient building and then see if it can meet the demand with onsite solar generation or not. The building awarded LEED Gold Certification, all materials used in construction are LEED standard or above, this building is energy plus, more details in (Table19)

Table 19: Case study 4: The North Face & Vf Outdoors analyses office building, USA

Part 1: Public Building Description	
Project name	The North Face & Vf Outdoors
Project pictures	 
	
	
Publish date	2017

Building Location	Alameda, California, USA	
Project type	Office building	
Building state	New	
Climate zone	Mediterranean climate zone	
Project Size	14,864 m ²	
Floors no.	2 floors	
Project description	The campus consists of four building: The North Face comprises two of the four campus buildings, with Jan Sport and Lucy in a third building each being 4,200 meter square. The fourth building is a 2,400 meter square which includes a complete fitness center, a café, and an outdoor training area.	
Completion Date	2012	
Working hours	Working hours are: <ul style="list-style-type: none"> - Monday to Friday 12 h, from 7:00 a.m. to 7:00 p.m. - Saturday from 8:30 a.m. to 5:00 p.m. - Sunday closed 	
People capacity	Variable	
Team/Owner	Architect: FME Architecture + Design Structural Engineer: SEI MEP Engineering: Syserco Civil Engineering: Kier & Wright Developer: SRM Associates Landscape Architect: April Philips Design Works Inc. Interior Design: Rapt Studio General Contractor: J.M. O'Neill Commissioning Agent: Rick Unvarsky Consulting Services LEED Consultant: Sage Green Development	
Project certificates	LEED Gold Certification (Buildings B, C, & D)	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - Thick, 40cm walls - Wall insulation: has an R-value of 13.

		<ul style="list-style-type: none"> - 5,500 pairs of recycled blue jeans for traditional insulation. - fiberglass insulation material used
	Opening	<ul style="list-style-type: none"> - Double glazed windows. - These windows also feature energy efficient glass which limits overheating of the facility.
	Roof	<ul style="list-style-type: none"> - Rigid insulation. - Roof insulation has an R-value of 30
	Material	All materials are LEED standard or above with CRI Green Label Plus Certified carpeting, reclaimed wood, FSC Certified wood, or are Greengard Certified.
	Shadings	Exterior sun shades work to block hot, high-angle sun in the summer.
Service systems		
Lighting	Daylighting: <ul style="list-style-type: none"> - 90% Of the offices have daylight spaces, views, and access to operable window. - Reflectors were installed to help increase interior penetration of daylighting. 	
	Artificial lighting: <ul style="list-style-type: none"> - Light sensors were installed 4.5m from the windows to adjust and lessen the need for electric lighting. - Occupancy sensors were also installed to mitigate any issues of occupant lighting control during unoccupied times. <p>The lighting that is installed in the building is highly efficient T5 fluorescent lights or LEDs.</p>	
HVAC	An indirect-direct evaporative cooling (IDEC) system which conditions air without the use of compressors or refrigerants.	
Equipment	Inactive workstations were put into sleep mode after even just a few minutes of non-use.	
Plug load	Occupancy sensors control much of the lighting and automatic controls were put in place.	
Total energy needs	16.8 EUI	
Part 3: Renewable energy production		

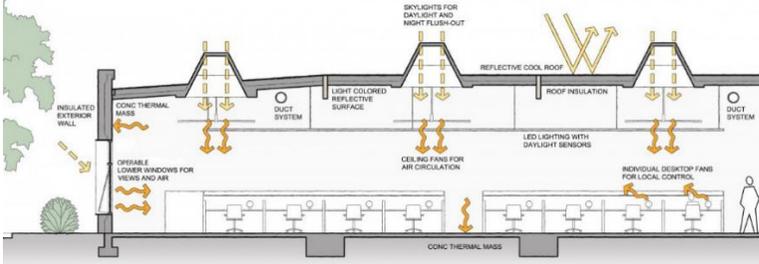
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - An 856 kW photovoltaic system offsets the remainder of the electricity use onsite. - A 256 kW building array distributed across the four buildings includes, solar panels attached to exterior window shades that account for 7% of total site generation and a rooftop array that accounts for 23% of total site generation. - Twelve carport arrays account for the remaining 70% of the total site generation <p>Wind: Five cylindrical wind turbines located near the entrance of the main building generate minimal electricity The campus also has gas usage in the café and gym facility</p>
Control system	The building systems and controls are run by an Energy Management System, called Energy 2.0, by Alerton Building Automation
Total energy generated	29.5 EUI
Results	
	<p>16.8 – 29.5 = - 12.7 EUI Project successes to be energy plus project.</p>
Occupant Engagement and Training	<ul style="list-style-type: none"> - VF has an on-site sustainability manager who provides occupants with instructions on how to operate the building systems. - When new employees start, they are given an orientation of the green features of the building and site and how they may best operate them.
References	<ul style="list-style-type: none"> - VF Dashboard: http://live.deckmonitoring.com/?id=vf_outdoor_inc - FME Project Overview: http://www.fme-arch.com/vf-outdoor - Energy Information Administration 2015-2016 rates for California commercial buildings: https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a - (New Buildings Institute, 2018)

The design succeeded in minimizing the building energy consumption by allowing 90% of the offices have daylight spaces, also, reflectors were installed to help increase interior penetration of daylighting, inactive workstations were put into sleep mode after even just a few minutes of non-use, as well as, occupancy sensors control much of the lighting and automatic controls were put in place. Also, more than one renewable energy recourse is installed to generate energy, the building succeeded in covering the building energy needs and more.

5.7.5 Project name: 435 Indio Way office building, USA

As one of the first of its kind, the building puts forward a test of the feasibility and success of cost-effective ZNE office buildings. Both owner and developer wanted this design to be created as a prototype for a common building type in the real estate market. (Table 20).

Table 20: Case study 5, 435 Indio way analyses office building, USA

Part 1: Public Building Description	
Project name	435 Indio way
Project pictures	  
Publish date	2017
Building Location	California, USA
Project type	Office building

Building state	Retrofit	
Climate zone	Mediterranean climate zone	
Project Size	2,950 m ²	
Floors no.	1 floor	
Completion Date	2013	
Working hours	Working hours are: <ul style="list-style-type: none"> - Monday to Friday 12 h, from 7:00 a.m. to 7:00 p.m. - Saturday from 8:30 a.m. to 5:00 p.m. - Sunday closed 	
People capacity	Unknown	
Team/Owner	Owner: Huettig & Schromm, Inc. Architect: RMW Architecture & Interiors Structural Engineer: SEI (Structural Engineers Inc.) MEP Engineering: Integral Group Landscape: Taniguchi Landscape Architects Developer: SHARP Development General Contractor: Hillhouse Construction Master System Integrator: Intertie Automation	
Project certificates	-	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - The building's interior concrete walls and slab serve as an outstanding heat sink. - The insulation was added on the exterior walls by using a ceramic-based coating, 14-20 mm thick polystyrene and 30 meter square of leasable space 15cm was added all the way around the building. - After completion, the walls now have a R-20 insulator value.
	Floor	<ul style="list-style-type: none"> - The concrete floor also acts as thermal storage, so carpet was excluded from the design and is discouraged in tenant renovations
	Opening	<ul style="list-style-type: none"> - Windows were electrochromic (self-tinting) windows.

		- Dynamic Glass are installed in both fixed and operable windows, and doors.
	Roof	<ul style="list-style-type: none"> - Improved with insulated foam roofing to provide better insulation. - A cool roof coating was applied over the foam roofing and 25cm batt insulation was added to keep the building cool during summer months. - The roof has a R-factor of 40.
	Material	Acoustic fabric combats noise and contributes to driving down lighting loads.
	Shadings	<ul style="list-style-type: none"> - Exterior sun shades work to block hot, high-angle sun in the summer. - The existing trees surrounding the building provide additional shade to other windows and add value to the natural outdoor gathering spaces.
Service systems		
Lighting	Daylighting:	<ul style="list-style-type: none"> - Access to natural light through skylights, windows, and doors during the renovation. - Forty-three daylight cupolas are carved out of the roof to minimize heat loss and heat gain, while allowing more direct daylight as south facing cupolas than a traditional north-facing skylight. - As a result, natural light illuminates the building from an hour after sunrise until an hour before sunset.
	Artificial lighting:	<ul style="list-style-type: none"> - Suspended LED fixtures placed further apart than normal supplement typical daylight levels when necessary. - The fixtures are wired to both occupancy motion sensors and infrared sensors, allowing tenants full control of the lighting while still responding to daylight availability. - At 25%, lighting is still the second biggest energy consumer in the building despite the daylight responsive techniques used.
Ventilation		- Operable windows are motorized and automated to permit natural ventilation.

	<ul style="list-style-type: none"> - Outside, an awning covering the front doors provides shade and passive cooling. - Night ventilation of thermal mass is a primary strategy at 435 Indio. - Actuators open the skylights and ground-level windows and rising hot air is moved by steel fans as part of a night flushing program for pre-cooling of the thermal mass in the warmer months. - Other perimeter windows are also operable for tenant adjustment. - As part of the passive flow for the space, conference rooms and other larger spaces are located at the perimeter, so they can be passively heated and cooled.
HVAC	<ul style="list-style-type: none"> - The HVAC system consists of two air-source heat pumps that serve as the backup heating and cooling for the passive systems of the building. - The HVAC system is 22% of a traditionally sized system
Hot water	There are two solar thermal panels installed on the roof for hot water.
Plug load	<ul style="list-style-type: none"> - The plug loads are the biggest energy end use of the project 58%. - Information are given to tenants at the time of leasing includes recommendations for plug load management and energy reduction. - Installed circuit metering in these tenant-occupied spaces also provides real-time information to tenants about their plug use.
Total energy needs	13.5 EUI
Part 3: Renewable energy production	
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - The building has a 113.2-kW flat-panel solar photovoltaic system across the entire roof site along. - The roof-top photovoltaic system generates 266,000 kWh per year and the solar thermal system generates 500 kWh per year. - This system is generating 113% of what the building uses on an annual basis.
Control system	The lighting sensor technology did not perform as expected and it took tuning time to work as part of the omni-control system.

Total energy generated	28.7 EUI
Results	
	13.5 – 28.7 = - 15.2 EUI Project successes to be energy plus project.
Occupant Engagement and Training	<ul style="list-style-type: none"> - Occupants are given a “driver’s manual” when first moving into the space that advises them on plug load reduction techniques. - Some tenants commented about how the opening and closing of windows was initially disconcerting. - Tenants benefit from a real-time dashboard in the lobby or on their smart devices that show their energy use and power generation. - Other lessons learned include considering the effect occupant education has on energy consumption and the adjustment period for tenants.
References	<ul style="list-style-type: none"> - https://newbuildings.org/wp-content/uploads/2017/03/CPUC_435Indio.pdf , access in November 14, 2018 - A Real Estate Developers Case for Net Zero: http://www.integralgroup.com/blog/a-real-estate-developers-business-case-for-net-zero/ - 435 Indio Way: http://hillhouseconstruction.com/project/435-indio-way-sunnyvale/ - 435 Indio Way Net Zero Energy Offices: http://rmw.com/projects/435-indio-way/ - PG&E Case Study: http://bit.ly/29VOVwx - (New Buildings Institute, 2018)

This one floor office building used many techniques to reduce the energy consumption in walls, openings and roof cross sections, maximize the daylighting through studies which determined the size, spacing, direction, and degree of tilt to achieve the highest intensity of daylight while minimizing heat gain.

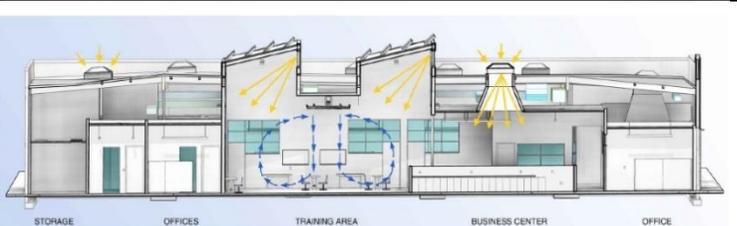
Retrofitting the design succeeded in transforming the regular building to be energy plus building. This project was a stunning example of profitability for ZNE design.

5.7.6 Project name: California State Lottery Santa Fe Springs District Office, USA

The office design focus on a highly efficient envelope to reduce heating and cooling loads in the building. That estimated consumption along with climate data and baseline design energy assumptions, were used to calculate how much power would need to be generated by PV panels to achieve ZNE. But the existing roof and landscape placed restrictions on the available surface area for solar generation which forced the team to focus on reducing energy consumption. Details about design in (Table 21).

Table 21: Case study 6, California State Lottery Santa Fe Springs District Office analyses, USA

Part 1: Public Building Description	
Project name	California State Lottery Santa Fe Springs District Office
Project pictures	
	
	
	

	  <p>North-South Section Diagram: toplighting by skylight, solar tube, and light monitors; air circulation by high-efficiency fan</p>
Publish date	2018
Building Location	California, USA
Project type	Office
Building state	Retrofit
Climate zone	Mediterranean climate
Project Size	1193 m ²
Floors no.	2
Completion Date	2015
Team/Owner	Architect: LPAS Architecture + Design Contractor: DPR Structural Engineer: KPFF MEP Engineer: Interface Engineering Building Performance Engineer: Integral Group

	Builder: DPR Construction	
Project certificates	Anticipates LEED Gold certification	
Part 2: Energy reduction strategies		
Building Envelop	Walls	Interior batt insulation and 7.5cm rigid insulation yield an R-value of 38
	Floor	-
	Opening	All windows use glazing units that exceed code for solar heat gain coefficient (SHGC), with the curtain wall offering a U-value of 0.35 and an SHGC of 0.5.
	Roof	Roof insulation, with 2.5cm wool. In addition to the batt and rigid insulation of the walls, offers a 30% improvement above code with an R-value of 40.
	Material	-
	Shadings	-
Service systems		
Lighting	Daylighting:	
	<ul style="list-style-type: none"> - A daylight model was designed to help in reducing the necessary lighting power density. - Daylighting is now the primary source of illumination. - The roof was optimized to enhance daylighting opportunities by including 22 prismatic lens skylights, four solar tubes, and two north-facing light monitors to strategically illuminate workspaces and circulation paths. - Interior glass walls (known as relights) distribute the light throughout the office and work to provide even light levels. - Exterior glass curtain walls bring diffuse daylight into the lobby from the north and east. 	
	Artificial lighting:	
	High-efficiency LED lights supplement these daylighting strategies when the natural light levels decrease below an acceptable value.	
Ventilation	Three large, high-volume, low-speed fans circulate air more evenly keeping occupants comfortable in both summer and winter.	

HVAC	<ul style="list-style-type: none"> - An intelligent HVAC system uses an efficient, single zone, variable air volume (VAV) system. - Controls sense room temperature and automatically adjust the frequency and volume of air released as needed. - The system prevents overheating and overcooling which typically account for a high percentage of energy use in buildings built to code.
Plug load	<ul style="list-style-type: none"> - An early plug load study identified areas for potential improvements and established a baseline for occupant power usage. - The data revealed that the building's off-hours plug load accounted for 36% (6,020 kWh) of its total plug load. The analysis revealed that turning off lottery machines and printers during nights and weekends could save 65% of this unnecessary energy consumption. - Shutting down computers and monitors could further reduce the off-hours plug load to nearly zero. - The design approach integrated smart plugs at each workstation which allows workers to customize the shutoff times to their office hours, so systems are turned off when not in use.
Total energy needs	22.1 EUI
Part 3: Renewable energy production	
Renewable energy	<p>Solar: Sizing the PV system to the energy use estimated, helped reduce the anticipated plug load EUI from 8.1 kBtu/sf/year to 4.6 kBtu/sf/year.</p>
Control system	<ul style="list-style-type: none"> - Lights operate with motion sensors to reduce unnecessary lighting energy use. - Photocells automatically adjust the lighting to the amount of daylight in the space. - The HVAC system requires minimal user attention to function efficiently. - A thermal sensor detects the room temperature, which allows diffusers to run only when necessary and release an appropriate amount of air.

	<ul style="list-style-type: none"> - A building management system incorporates the HVAC, lighting, plugs, and PV energy system. - The building management system allows operators to closely track the building's performance and identify issues such as unexpectedly high plug loads.
Total energy generated	22,2 EUI
Results	
	22.1 – 22.2 = -0.1 EUI, the building is zero energy public building.
Occupant Engagement and Training	<ul style="list-style-type: none"> - An energy dashboard in the lobby displays real-time performance data to encourage occupants to balance their energy use with PV generation. - The public can also access a live online dashboard which shares electricity consumed and produced. - The building has a staff sustainability analyst available to help occupants reduce energy and water consumption, as well as suggest efficiency improvements to building operators.
References	https://newbuildings.org/wp-content/uploads/2017/03/CPUC_CALottery.pdf , access November,14,2018

The design focus on designing energy efficient building and reduce the energy consumption to the minimum by maximizing the daylighting through many techniques, reduce the plug loads consumption, using efficient HVAC and lighting systems. At the end the building reached the zero energy goal by generating equal energy to the building needs.

5.7.7 Project name: Leon County Cooperative Extension office building, USA

This office was the perfect opportunity to inform the community about cost-effective energy savings opportunities and net zero energy.

Table 22: Case study 7, Leon County Cooperative Extension analyses, office building , USA

Part 1: Public Building Description	
Project name	Leon County Cooperative Extension
Project pictures	
Publish date	2017
Building Location	Florida, USA
Project type	Office building
Building state	Retrofit
Climate zone	Tropical climate zone
Project Size	1200 m ²
Floors no.	1
Completion Date	2012
Team/Owner	Owner: Leon County Architect: Barnett Fronczak Barlowe Architects Engineer: H2 Engineering
Part 2: Energy reduction strategies	
Service systems	
Lighting	Artificial lighting:

	Lighting fixtures were upgraded from 40-Watt T 12 lamps with magnetic ballasts to 32-Watt T8 lamps. Additionally, private offices were retrofitted to include occupancy sensors.
HVAC	<ul style="list-style-type: none"> - High Efficiency HVAC – A closed-loop geothermal well field. - HVAC control setpoints were adjusted to set back to 26 degrees Celsius on nights and weekends.
Hot water	Instead of a conventional hot water heater, waste heat from the geothermal system is used to heat hot water.
Total energy needs	19 EUI
Part 3: Renewable energy production	
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - The 60 kW array consists of 253 panels that can each produce up to 240 Watts of electricity. - The building’s flat, circa 1960’s roof was not capable of supporting the 580 m² solar array, so the solar array was ground mounted in the parking lot. - Micro-inverters on each of the 253 solar panels help to prevent a situation where a malfunction on a single panel takes the entire system offline <p>Geothermal:</p> <ul style="list-style-type: none"> - A closed-loop geothermal well field of 60 vertical wells 90 feet deep is divided into three loops that manifold into a single loop that runs to the building’s mechanical rooms. This allows for a downsized compressor and provides for a 40% energy savings.
Control system	Private offices were retrofitted to include lighting occupancy sensors.
Total energy generated	19 EUI
Results	
	$19 - 19 = 0$ The building is zero energy building
References	New Building Institute, https://newbuildings.org/wp-content/uploads/2015/12/NBI_ZNE_CaseStudy_LeonCountyExtCenter_2.pdf

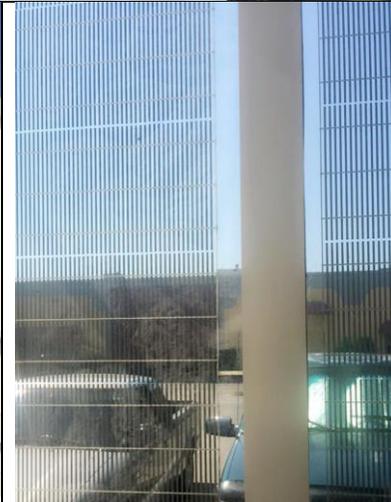
Retrofitting the building design to be energy efficient building helps in reducing the energy demand, solar power and geothermal systems used to produce energy, roof was not capable of supporting the 580 m² solar array, so the solar array was ground mounted in the parking lot.

5.7.8 Project name: Bagatelos Architectural Glass Systems

Manufacturing Facility, USA

The manufacturing facility succeeds to be zero energy building by increasing the daylighting access and using efficient artificial lighting and mechanical systems, also, natural ventilation was designed. Energy production depend on solar power by using PV Cells on the rooftop, PV curtain walls in facades and PC semi transparent glass on all the openings. More details at (Table23).

Table 23: Case study 8, Bagatelos |Glass systems Manufacturing Facility analyses, USA

Part 1: Public Building Description	
Project name	Bagatelos Architectural Glass Systems Manufacturing Facility
Project pictures	 
	  <p>View through PV curtain wall</p>
Publish date	2016

Building Location	Sacramento, California	
Project type	Industrial	
Building state	Retrofit	
Climate zone	Dry summer subtropical	
Project Size	5850 meter square	
Floors no.	1	
Completion Date	2012, evaluated ²² July 2015 to June 2016	
Team/Owner	Owner: Nick and Chris Bagatelos Utility: Sacramento Municipal Utility District	
Project certificates	2012 Sacramento Business Journal Green Leadership Award for Energy Efficiency	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - Wall section was designed to contain three layers of insulation to reduce the load on the heating and cooling system. - These added layers of standard fiberglass batt insulation are a cost-effective strategy. - Exterior walls achieved an R-value of 30 and it is more than twice that required by code.
	Opening	<ul style="list-style-type: none"> - Operable windows. - Casement windows in the office space and large. - Roll-up doors in the manufacturing area.
	Roof	Most of the roof was covered by PV system
	Material	-
	Shadings	-
Service systems		
Lighting	Daylighting: <ul style="list-style-type: none"> - Daylight from a total of 60 skylights illuminates the factory, facility to operate primarily with daylight. 	

²² New Buildings Institute has evaluated the building's energy performance data from utility bills dated July 2015 to June 2016 and verified Bagatelos' facility is a ZNE building.

	<ul style="list-style-type: none"> - Additional skylights, coupled with 16 operable windows, illuminate the office space and reduce the need for electric lighting.
	<p>Artificial lighting:</p> <ul style="list-style-type: none"> - High-efficiency fluorescent lamps was chosen. - A daylight sensor allows these lights to automatically adjust to daylighting received through the windows and skylights, reducing the need for user control. - Occupancy sensors conserve energy by shutting off lights in rooms that are not in use.
Ventilation	Operable windows allow workers to passively condition their space, reducing the running time of the heat pump system and improving outdoor air ventilation.
HVAC	An electric heat pump provides an efficient solution to both heat and cool the facility.
Equipment	Efficient lighting and mechanical systems reduced the energy consumption of the facility by 40% of the average for comparable building types
Plug load	The company converted its manufacturing equipment to efficient computer numerical control (CNC) machines imported from Germany to reduce energy consumption.
Total energy needs	17.1 EUI
Part 3: Renewable energy production	
Renewable energy	Solar: The entire PV system, which sits exclusively on the building and covers the majority of the roof, in addition to using PV curtain walls, the solar system generates 108,500 kWh per year.
Total energy generated	17.5 EUI
Results	
	$17.1 - 17.5 = -0.4$ EUI
	The manufacturing facility successes to be zero energy building
References	<ul style="list-style-type: none"> - newbuildings.org, CPUC Bagatelos.pdf , access November 14,1018 - NBI Buildings Database: http://newbuildings.org/resource/getting-to-zero-database/#70377 - Bagatelos Architectural Glass Systems: http://bagatelos.com/index.html

Bagatelos used building energy modeling and daylighting modeling to estimate the building's energy performance and provided valuable studies to identify opportunities for additional efficiency improvements.

5.7.9 Project name: TD BANK, USA

This project is a good example for new construction public buildings, increased insulation help reducing overall building energy consumption to approximately 40% below code levels. The project certificates LEED Platinum.

Solar energy integrated into the building design and covered 100% of the building energy needs. More details in (Table24).

Table 24: Case study 9, TD Bank analyses, USA

Part 1: Public Building Description	
Project name	TD Bank
Project pictures	
Publish date	2017
Building Location	Ft Lauderdale, Florida, USA.
Project type	Retail Bank
Building state	New
Climate zone	Tropical climate zone
Project Size	370 m ²
Floors no.	2
Completion Date	2011

Working hours	8h	
Team/Owner	Owner: TD Bank Architect: Bergmann Associates Contractor: Turner Construction Energy Consultant: Spiezle Architects Solar Consultant: Solular Energy Civil: Bohler Engineering	
Project certificates	LEED Platinum	
Part 2: Energy reduction strategies		
Building Envelop	Walls	Increased insulation help reduce overall building energy consumption to approximately 40% below code levels.
	Opening	Low-E glazing, shaded windows and increased insulation help reduce overall building energy consumption to approximately 40% below code levels.
	Roof	Increased insulation help reduce overall building energy consumption to approximately 40% below code levels.
	Material	-
	Shadings	Vertical shadings are used.
Service systems		
Lighting	Daylighting: A design with roof monitors and carefully controlled daylight harvesting along with advanced lighting controls to reduce the electrical lighting load to an operational.	
	Artificial lighting: 400-Watt metal halide site lights were replaced with 210-Watt LED exterior lights with step dimming control for an energy savings of 18,550 kWh/Year (64%).	
Ventilation	- An air-to-air heat exchanger tempers incoming ventilation air. Dehumidification is set to turn off at 72% relative humidity.	
HVAC	- The HVAC design features a variable refrigerant flow (VRF) system with 10 separate zones.	

	<ul style="list-style-type: none"> - A split system with modulating digital scroll compressors and hot gas reheat is used for dehumidification.
Plug load	<ul style="list-style-type: none"> - Plug loads represented 40% of total energy consumption. - Understanding and optimizing equipment (such as office equipment, ATMs, computers and monitors) is key to reduce energy consumption. - The standard three-hot-plate coffee maker was replaced with an insta-hot 'eco' version. This saved 660 kWh/year (91% over standard practice).
Total energy needs	92 EUI
Part 3: Renewable energy production	
Renewable energy	Solar: 86 kW of roof and site-mounted PVs (400 panels) generate 100% of the electricity used onsite.
Control system	The lighting controls were reprogramed to maximize savings.
Total energy generated	96 EUI
Results	
	$92 - 96 = -4$ The building is zero energy building
Notices	Photovoltaic systems had to be carefully sized and located. Based on predicted energy use from the design model, additional PV arrays had to be mounted over open ground. Shading studies were a critical part of the design because any single inverter subject to shade can disrupt power generation for the whole array.
References	Resources: New buildings Institute, TD Bank, https://newbuildings.org/resource/td-bank/

5.7.10 Project name: Zero Net Energy Training Center, USA

Zero net energy training center Targeting: LEED Gold Certification, the training center design is energy efficient building, and energy reduction strategies are integrated into the design to minimize the energy consumption. Solar and wind systems are used to generate adequate electricity. For more details at (Table 25).

Table 25: Case study 10, Zero Net Energy Training Center analyses, USA

Part 1: Public Building Description	
Project name	Zero Net Energy Training Center
Project pictures	
Publish date	2017
Building Location	San Leandro, California, USA
Project type	Educational
Building state	Retrofit
Climate zone	Mediterranean climate zone
Project Size	4270 m ²
Floors no.	2
Completion Date	2013
Team/Owner	Owner: International Brotherhood of Electrical Workers Local 595 (IBEW) and the Northern California Chapter of the National Electrical Contractors Association (NECA) Architect: FCGA Architects

	Green Building Consultant: Environmental Building Strategies General Contractor: NOVO Construction Renewable Energy Consultant: Cubed Energy Solutions	
Project certificates	Targeting: LEED Gold Certification	
Part 2: Energy reduction strategies		
Building Envelop	Walls	- All south-facing rooms include 3m of exposed concrete adjacent to the windows. - During the cooler fall and winter months, these can absorb and store heat from the sun
	Floor	-
	Opening	- Operable windows at the front of the building to force warmer air out. - Operable windows located in roof monitors.
	Roof	- A roof monitor located toward the center of the building faces south, allowing the sun to fall on and heat a concrete wall during the cooler months.
	Material	-
	Shadings	Roof was extended to represent horizontal shades on the building.
Service systems		
Lighting	Daylighting: - The numerous north-facing roof monitors. - Besides being used as an outlet for exhausting warm air, these monitors allow natural daylight to meet a majority of the lighting requirements. - Hallways and circulation areas are daylit by solar tubes.	
	Artificial lighting: Controls turn on electrical lights when additional lighting is needed.	
Ventilation	- All south-facing rooms were included exposed concrete walls adjacent to the windows. - During the cooler fall and winter months, these can absorb and store heat from the sun. - A roof monitor located toward the center of the building faces south, allowing the sun to fall on and heat a concrete wall during the cooler months.	

	- The front of the building features a storefront of operable windows that can provide an intake for air which then forces warmer air out through operable windows located in roof monitors.
HVAC	Variable Refrigerant Flow (VRF) System: Mechanical heating and cooling is provided by four VRF units which circulate refrigerant to remove and redistribute warm air within the building.
Total energy needs	18 EUI
Part 3: Renewable energy production	
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - The building features both flat and tilted roof-mounted photovoltaic panels - A dual-axis solar tree which tracks the sun for maximum generation. <p>Wind:</p> <p>Three 12 kW wind turbines</p>
Total energy generated	18 EUI
Results	
	<p>18 – 18 = 0</p> <p>The building is zero energy building.</p>
References	Resources: https://newbuildings.org/resource/zero-net-energy-training-center/ , access in December 5, 2018

5.7.11 Project name: Newcastle Elementary School

The school is retrofitted to be zero energy building, daylighting is the primary lighting source, and the artificial lighting is replaced to be Led units. The building produce energy by using solar PV system, more details in (Table 26).

Table 26: Case study 11, Newcastle Elementary School analyses, USA

Part 1: Public Building Description	
Project name	Newcastle Elementary School
Project pictures	  
Publish date	2018
Building Location	Newcastle, California, USA
Project type	Educational
Building state	Retrofitted
Climate zone	Mediterranean climate zone
Project Size	2920 m ²
Floors no.	2
Project description	The campus site contains two schools in addition, two separate buildings on the same site.
Completion Date	2017
Working hours	Daytime

People capacity	148	
Team/Owner	Owner: Newcastle School District Architect: DLR Group ZNE Pilot Design Consultant: Point Energy Innovations ZNE Pilot Monitoring Consultant: Frontier Energy, Inc. Civil Engineer: Warren Consulting Engineers, Inc. Energy Service Company: ABM Building Solutions	
Project certificates	-	
Part 2: Energy reduction strategies		
Building Envelop	Walls	-
	Floor	-
	Opening	Wide windows to increase daylighting
	Roof	-
	Material	-
	Shadings	Vertical shadings are used.
Service systems		
Lighting	Daylighting: - Classrooms needed to manage glare, so teachers would not be tempted to disable the daylighting. - The team used lighting simulation to investigate daylighting and perimeter glazing options. - Daylighting design involved the integration of tubular skylights.	
	Artificial lighting: Replace fluorescent lamps with high quality LED lamps.	
HVAC	- Two types of HVAC units were installed to replace the aging systems. - Five new high-efficiency Bard wall hung units were installed at five of the portable classrooms. - A high-efficiency Trane rooftop unit was installed on the multi-purpose room.	
Total energy needs	14 EUI	
Part 3: Renewable energy production		
Renewable energy	Solar:	

	<ul style="list-style-type: none"> - A108 kW photovoltaic (PV) array would generate 150,400 kWh/year, - Due to the challenge of adding weight to the roof. - The PV system was ground mounted and fenced- in on the recently acquired lower campus.
Control system	<ul style="list-style-type: none"> - Occupants were informed that they would be Responsible for turning off electric light when daylighting was sufficient. In lieu of automatic dimming controls. - A building management system upgrade tracks and controls all HVAC units. - The software tracking features enable the district facilities manager to easily identify malfunctions in the system, saving time in daily operations and enabling quick correction of problems that arise.
Total energy generated	15.4 EUI
Results	
	<p>14 – 15.4 = -1.4 EUI The school succeed to be zero energy building</p>
Notices	<ul style="list-style-type: none"> - Using energy modeling analysis as a design tool. - The team found a package of deep retrofit options that are expected to deliver an EUI of 14 kBtu/sf/yr. - The other energy goal stewarded by the team was affordability of future utility bills. - The school district preferred producing all electricity on site through renewable photovoltaic systems.
Occupant Engagement and Training	<ul style="list-style-type: none"> - Training teachers and students on how to use the lighting and daylighting system was critical to ensure optimal performance. - The team also developed a controls and equipment manual and trained facilities managers on efficient building operation and the proper use of controls.
References	<p>https://newbuildings.org/wp-content/uploads/2018/01/NBI_Case-StudyProp39_Newcastle.pdf access December 5, 2018</p>

5.7.12 Project name: Lakeline Learning Center, USA

This learning center is designed to be zero energy building. the building awarded ILFI Zero Energy Certified, more details about design energy reduction strategies and energy generated in (Table 27).

Table 27: Case study 12, Lakeline Learning Center analyses, USA

Part 1: Public Building Description	
Project name	Lakeline Learning Center
Project pictures	
	
	
	

Publish date	2017	
Building Location	Austin, TX, USA	
Project type	Educational	
Building state	New	
Climate zone	Semi-arid climate	
Project Size	2180 m ²	
People capacity	40	
Team/Owner	<p>Owner: Foundation Communities Project Manager: Sunshine Mathon / Aubrie Christensen General Contractor: BEC Austin Architect: hatch + ulland owen architects Mechanical Engineer: APTUS Engineering Electrical Engineer: APTUS Engineering Lighting Design: APTUS Engineering Interior Design: hatch + ulland owen architects Plumbing: APTUS Engineering Structural: Integrity Structural Key Subcontractors: Integral Group (energy modeling, daylighting), Harvested Rain Solutions (rainwater collection design and install), Lighthouse Solar (solar design and install and battery system design)</p>	
Project certificates	ILFI ²³ Zero Energy Certified	
Part 2: Energy reduction strategies		
Building Envelop	Walls	<ul style="list-style-type: none"> - Wall R value and section specification R31/R25. - The original intent was for thermal mass infill walls between classrooms to help improve passive cooling and heating. - Energy modeling results showed this method was unnecessary to achieve net zero, and the cost became prohibitive.
	Floor	-

²³ ILFI international Living Future Institute

	Opening	Windows Double-paned with Sun Coat Max low-e coating.
	Roof	Roof R value 29
	Material	-
	Shadings	-
Service systems		
Lighting	Daylighting: <ul style="list-style-type: none"> - Analysis revealed inadequate daylighting in the main gathering room in the original design. - The addition of skylights and slight shifting of clerestories made significant improvements. 	
	Artificial lighting: Lighting is 100% LED throughout the Learning Center.	
Ventilation	<ul style="list-style-type: none"> - Ceiling fans in each classroom, the main gathering room, and the screened porch, increase airflow and extend the days in the fall and spring when HVAC can be turned off. - An energy recovery wheel allows the unit to capture waste heat from the building, which is used to retreat the ventilation air. 	
HVAC	<ul style="list-style-type: none"> - The building utilizes a single, roof-mounted, 25 Ton High Efficiency Direct Expansion Variable Air Volume (VAV) system. - A VAV box and thermostat in each classroom allow precise occupant comfort and control. - Utilizing zone demand control ventilation along with supply air temperature setback control, the unit can continuously monitor the building's HVAC needs and cut back on capacity and usage when possible to save energy. 	
Hot water	<ul style="list-style-type: none"> - A heat pump provides hot water for restroom fixtures, handwashing troughs, and the STEAM (Science, Technology, Arts, Engineering, and Math) classroom sink. - The team chose to use a point-of-use hot water for the kitchen, located on the opposite side of the building from the rest of the plumbing, to reduce plumbing lines throughout the building. 	
Plug load	<ul style="list-style-type: none"> - Plug loads are independently monitored per room. 	

	<ul style="list-style-type: none"> - Typical Foundation Communities learning centers include a dedicated computer lab with desktop computers. - To reduce load and provide more flexible classroom space, this learning center shifted to a mobile laptop cart.
Total energy needs	43 EUI
Part 3: Renewable energy production	
Renewable energy	Solar: 220 Solar Electric (PV) Panel, each PV Array produce 70.4 kW, and 9 PV Inverter location on the rooftop.
Total energy generated	-
Results	
	Zero energy building
Occupant Engagement and Training	Students are engaged in monitoring the plug loads through energy-use competitions among classrooms.
References	https://living-future.org/lbc/case-studies/lakeline-learning-center/

The design energy efficient plan based on increasing the envelop R value, increase ventilation effect by using ceil fans to extend the days in the fall and spring when HVAC can be turned off. HVAC, plug loads and hot water are carefully calculated and optimized.

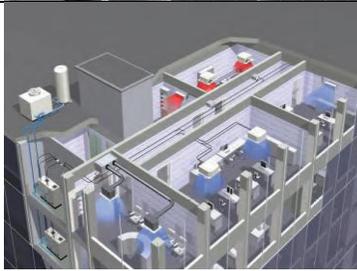
Energy needs covered totally by solar PV cells system located on the rooftop.

5.7.13 Project name: Mosaic Centre for Conscious Community and Commerce, Canada

This commercial building is the first of its type in Canada, the building is going for LEED platinum certification and a Living Building Challenge petal certification as well.

This zero energy commercial building focus on energy optimization through applying energy reduction strategies, and generating energy by solar and geothermal systems, more details in (Table28).

Table 28: Case study 13, Mosaic Centre analyses, commercial building, Canada

Part 1: Public Building Description	
Project name	Mosaic Centre for Conscious Community and Commerce
Project pictures	
	 
	  VRF – HR system
Publish date	2016
Building Location	Canada
Project type	Commercial

Building state	New	
Climate zone	Temperate	
Project Size	2780 m ²	
Floors no.	3	
Completion Date	2015	
Team/Owner	building owners: Mosaic Family of Companies Co-owners Dennis and Christie Cuku Architects :Vedran Skopac of Manasc Isaac. Planning Department: City of Edmonton Sustainable Development General Contractor and major sub-trades	
Project certificates	The building is going for LEED platinum certification and a Living Building Challenge petal certification as well.	
Part 2: Energy reduction strategies		
Building Envelop	Walls	Well insulated
	Floor	Thermally massive concrete floors.
	Opening	- Large glass areas were increased to 57% on all facades to enhance day lighting. - Higher performance glazing to compensate the heat gain or lose.
	Roof	- The majority of the roof will be covered by photovoltaic panels. - A secondary steel support frame will be required below the panels.
	Material	
	Shadings	Optimized solar shades were added on all sides.
Service systems		
Lighting	Daylighting: - Large south-facing windows to enhance day lighting. - Through case study review, we set the aggressive target of reducing the building's lighting energy demand by 75%.	
	Artificial lighting: - LED fixture usage and task-specific lighting level design. - An overall lighting energy reduction of 62%	

Ventilation	<ul style="list-style-type: none"> - Use of manually operable perimeter window and powered louvres or awnings in the upper atrium area. - Dual-core reversing air-to-air heat exchangers will be provided to extract contaminated air from washrooms, and service area, along with providing general common area exhaust as needed. - Tempered supply air from these units will be directed into the occupied spaces as needed to meet the ventilation air quality requirements for each space. - The heat recovery ventilation system will include a heat exchanger by-pass mode of operation that will permit ambient air free cooling of the ventilation air when conditions are suitable. - System could also allow for a small amount of manual or automated nighttime purge cycle.
HVAC	<ul style="list-style-type: none"> - The design became heating dominant, with 52% reduced annual energy demand. - The heating and cooling system is fully electric, Variable Refrigerant Volume (VRV) heating & cooling system.
Plug load	Virtualizing workstations and centralizing their loads to a central datacenter which rejects heat into the Parkade.
Total energy needs	Was reduced from 319806 kWh – 108 kWh/m² to 216065 kWh – 66 kWh/m².
Part 3: Renewable energy production	
Renewable energy	<p>Solar:</p> <ul style="list-style-type: none"> - 213 kilowatts of solar panels that are on the roof and façade of the building. <p>Geothermal:</p> <ul style="list-style-type: none"> - The heating and cooling system is a geo-exchange or ground source heat pump system. - The parking lot was turned on the north side of the building into a geothermal field with 32 boreholes going down 70 meters in depth.
Control system	<ul style="list-style-type: none"> - The buildings electrical loads is monitored throughout the building down to the individual plug loads through a power bar at each work station. - Most of the automated interior climate control for the building will be via local zone-based thermostats with integrated occupancy sensors.

	<ul style="list-style-type: none"> - Centralized equipment, such as heat pumps, pumps, and boilers, are equipped with their factory mounted controls and can operate semi-autonomously. - A limited building management control system would be provided using locally supported systems. - The system would include a graphical interface that would be accessible via the Internet using a standard web browser. - The control system would provide scheduling and for any of the common equipment along with monitoring and alarm functions. - Pre-cooling and nighttime purge functions could be provided through this Building Management System as either a manual or automated function.
Total energy generated	-
Results	
	The building succeeded to be zero energy building
Notices	<p>The Mosaic Centre for Conscious Community and Commerce will reference and be informed by the following standards and guidelines:</p> <ul style="list-style-type: none"> - Owner’s Project Requirements - National Building Code of Canada (NBCC) 2005 - Alberta Building Code (ABC) 2007 - National Plumbing Code - Canadian Electrical Code - National Fire Code of Canada (NFCC) - Alberta Fire Code - LEED Canada Reference Guide for New Construction - Passive Haus Design Standards - Living Building Challenge
References	Schematic Design report, Mosaic centre for Conscious community and commerce – 213180, MANASC ISAAC ARCHITECTS, Canada.

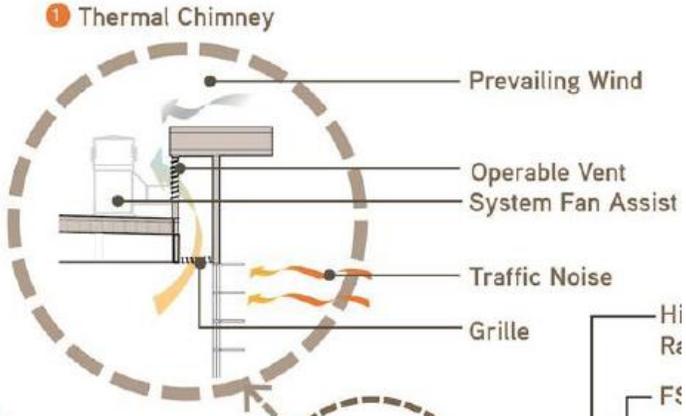
5.7.14 Project name: West Berkeley Public Library USA

This zero energy library design received many certificates like LEED Platinum at 2016 and Living Building Challenge Net Zero Energy Certified; International Living Futures Institute at 2015.

The energy reduction plan based on using daylighting as a primary lighting source, also, solar system is the main source of electricity. More design details in (Table 29).

Table 29: Case study 11, West Berkeley Public Library analyses, USA

Part 1: Public Building Description	
Project name	West Berkeley Public Library
Project pictures	  

	
	<p>1 Natural Ventilation / Mix Mode 2 On Site Energy Generation 3 Daylighting- 90% of Spaces is Daylit 4 On Site Storm Water Technology 5 FSC Certified Wood 6 Dense Urban Site / Site Selection 7 Rental Radiators</p> <p>Thermal Chimney</p>  <p>Zero Net Energy Features</p>
	<p>1 Thermal Chimney</p> 
<p>Publish date</p>	<p>2017</p>
<p>Building Location</p>	<p>Berkeley, California, USA.</p>
<p>Project type</p>	<p>Public assembly, cultural building.</p>
<p>Building state</p>	<p>New</p>
<p>Climate zone</p>	<p>Mediterranean climate zone</p>
<p>Project Size</p>	<p>870 m²</p>
<p>Floors no.</p>	<p>2</p>

Completion Date	2013	
Working hours	Daytime	
Team/Owner	Architect: Harley Ellis Devereaux Civil Engineering: Moran Engineering Structural Engineer: Tipping Mar Mechanical, Electrical, Plumbing Design Engineer: Timmons Design/Harley Ellis Devereaux Landscape Architect: John North Roberts Sustainability Consultant: Harley Ellis Devereaux Audio Visual: Smith, Fause & McDonald Inc Photography: Mark Luthringer Photography	
Project certificates	AIA COTE Top Ten Award, 2016 LEED Platinum, 2016 Living Building Challenge Net Zero Energy Certified; International Living Futures Institute, 2015 East Bay Annual Design Awards, American Institute of Architects, 2015 Gold Nugget Award, Pacific Coast Builders Collaborative (PCBC), 2015 IES Illumination Award, Illuminating Engineering Society (IES), 2015	
Part 2: Energy reduction strategies		
Building Envelop	Walls	- R31 walls when considering the thermal bridging at the microlam studs.
	Floor	- The building was built on a 30cm structural slab, with a single layer of rigid insulation between the 10cm radiant slap and the 45cm mat slap. - All conduit was run beneath the mat slab.
	Opening	A triple-paned, store-front glazing system
	Roof	- Roof with an R40 insulation value - Solar photovoltaics and solar thermal collection systems cover the roof of the building, along with a series of interspersed skylights.
	Material	-
	Shadings	-

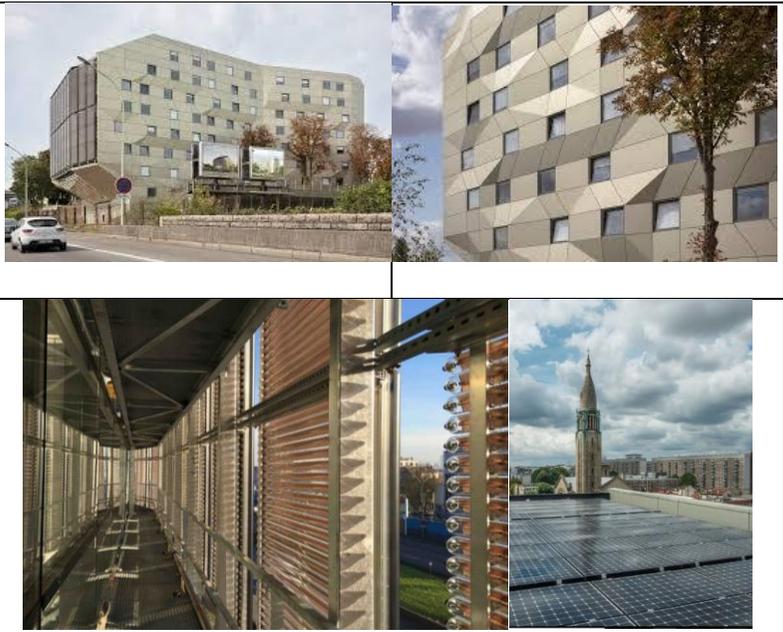
Service systems	
Lighting	Daylighting: There are series of skylights and a large glass façade designed to eliminate the need for artificial lighting during the day.
	Artificial lighting: Electrical lighting is tied to daylight sensors, which is used to supplement the daylight on cloudy or darker days.
Ventilation	<ul style="list-style-type: none"> - The vestibule at the entrance maintains pressurization in the building and prevents warm or cool air from escaping. - Manually operable windows. - Automatically controlled windows are located high in the space and have preheating hydronic convectors at the openings to prevent cold drafts caused by cold air entering the space in winter.
HVAC	<ul style="list-style-type: none"> - The library's primary mechanical system is a hydronic radiant slab used for both heating and cooling. - To supply the radiant system, the solar thermal collector and heat pump operate in a primary-secondary function, with the heat pump supplementing the solar collector as needed to meet water temperature set points.
Plug load	<ul style="list-style-type: none"> - Laptops are charged by staff and checked out to users to help limit plug loads and allow the staff to keep track of the energy consumed by the computers. - Public electric outlets are provided at reading tables in the stack area and in wall outlets in the meeting room for patrons to use.
Total energy needs	23 EUI
Part 3: Renewable energy production	
Renewable energy	Solar: <ul style="list-style-type: none"> - Solar photovoltaics and solar thermal collection systems cover the roof of the building, along with a series of interspersed skylights. - Four photovoltaic (PV) arrays arranged between three rows of skylights, for a total of 120 panels. - The library also has 16 solar thermal panels, which are arranged into two arrays in the northeast corner of the roof.

Control system	<ul style="list-style-type: none"> - An integrated building automation system (BAS) controls the photovoltaic system, lighting, radiant heating and cooling. - The HVAC system is controlled using several modes of heating and cooling, with various levels of natural ventilation, fan-assisted ventilation, and radiant heating and cooling. - The systems are optimized for energy consumption and the lowest energy operating mode is used to satisfy the heating, cooling, and ventilation loads. - If loads can't be met, the system incrementally incorporates fans and eventually the heat pump as needed to meet the loads with minimal energy use.
Total energy generated	28 EUI
Results	
	<p>23 – 28 = -5 EUI The building is zero energy building.</p>
Notices	<p>By focusing on passive strategies first, the design team was able to drive down the anticipated energy consumption of the building, which then made the task of generating adequate energy to cover the consumption much more cost-effective and achievable.</p>
References	<p>International Living Future Institute West Berkeley Library Case Study: http://living-future.org/case-study/174erkeley</p> <ul style="list-style-type: none"> • Green Architecture and Building Report Case Study: http://www.gabreport.com/2014/05/californias-first-net-zero-energy-library

5.7.15 Project name: House of Île de France, Student Residence, France

The Île-de-France is the first 100% solar-powered positive energy collective housing building with an inter-seasonal thermal storage system of this size realized in France. More design details are in (Table 30).

Table 30: Case study 15: House of Ile de France, student residence, France

Part 1: Public Building Description	
Project name	House of Ile de France
Project pictures	 <p>Double skin solar façade</p>
Publish date	2018
Building Location	Paris, France
Project type	Students residence
Building state	New
Climate zone	Oceanic
Project Size	5000 m ²
Floors no.	9 floors

Project description	House of Ile de France is a student residence with 142 rooms, this residence of 5,200 m ² stands out for its exceptional ecological qualities.	
Completion Date	2017	
Working hours	24 h	
People capacity	Variable	
Team/Owner	ANMA, DEERNS	
Part 2: Energy reduction strategies		
Building Envelop	Walls	Well insulated
	Opening	large windows opening
	Roof	Covered with PV cells
Service systems		
Lighting	Daylighting: The building openings designed to maximize the daylighting	
HVAC	Fully natural ventilation strategy, no cooling installations	
Part 3: Renewable energy production		
Renewable energy	Solar: <ul style="list-style-type: none"> - The southern façade covered with PV cells the building widens so that it can capture as much solar energy as possible. - Roof is covered with PV cells 	
Total energy generated	100% solar-energy strategy, covering all the energy needs	
Results		
	The building is zero energy public building	
Occupant Engagement and Training	Technology informs occupiers in real-time about their actual consumption	
References	<ul style="list-style-type: none"> - Jonathan Laski, Victoria Burrows, From Thousands To Billions, World Green Building Council, 2017, P.45. - https://www.archdaily.com/887498/house-of-ile-de-france-anma 	

5.8 Case studies Summary

All the fifteen case studies are summarized in (Table 31) as following:

Table 31: Case studies Summary

Project no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Part 1 : General information															
Project pictures															
Publish date	2019	2018	2017	2017	2017	2018	2017	2017	2017	2017	2018	2017	2016	2016	2018
Building Location	Norway	India	Brazil	USA	USA	USA	USA	USA	USA	USA	USA	USA	Canada	USA	France
Project type	Office	Office	Stadium	Office	Office	Office	Office	Industrial	Bank	Training center	School	Learning center	Commercial	Library	Students residence
Building state	New	New	Renovated	New	Retrofit	Retrofit	Retrofit	Retrofit	New	Retrofit	Retrofit	New	New	New	New
Climate Zone	Oceanic climate	Hot semi-arid climate	Tropical savanna climate	Mediterranean climate	Mediterranean climate	Mediterranean climate	Tropical climate	Dry summer subtropical	Tropical climate zone	Mediterranean climate	Mediterranean climate	Semi-arid climate	Temperate climate	Mediterranean climate	Oceanic climate
Project Size/m ²	170,800	32,000	348,900	14,864	2,950	1,193	1,200	5,850	340	4,270	2,920	2.180	2,780	870	5000
Floors no.	11	8	1	2	1	2	1	1	1	2	2	1	3	2	9
Project description	1B	1B	1B	Campuses	1 B	1 B	1 B	1 B	1 B	1 B	Campus	1 B	1 B	1 B	1 B
Completion Date	2019	2014	2014	2012	2013	2015	2012	2012	2014	2013	2017	2014	2016	2013	2017
Working hours	12	8h	12	12h	12h	12h	12h	12h	8h	8h	8h	8h	12h	8h	24h
People capacity	Variable	Variable	Variable	Variable	Variable	Variable	Unknown	Unknown	unknown	Variable	148	40	Variable	Variable	Variable
Project certificates	-	LEED Platinum, others	-	LEED Gold	-	LEED Gold	-	GLA	LEED Platinum	LEED Gold	-	ILFI	LEED Platinum ILFI	LEED Platinum, others	-
Part 2: Energy reduction strategies															
Building Envelop															
Walls	X	X	-	X	X	X	-	X	X	X	-	X	X	X	X
Wall resistance	-	-	-	R13	R20	R38	-	R30	-	-	-	R31/ 25	-	R31	-
Floor	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-
Opening	X	X	-	X	X	X	-	X	X	X	-	X	X	X	X
Roof	X	X	X	X	X	X	-	X	X	X	-	X	X	X	X

Project no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Roof resistance	Cover PV	Cover PV	Cover PV	R30	R40	R40	-	Cover PV	-	Cover PV	Cover PV	R29	Cover PV	R40	Cover PV	
Material	X	X	X	X	X	X	-	-	-	-	-	-	-	-	X	
Shading	X	-	-	X	X	-	-	-	-	X	-	-	X	-	-	
Part2: Energy reduction strategies																
Service systems																
Lighting	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Daylighting	X	X	X	X	X	X	-	X	X	X	X	X	X	X	X	X
Artificial lighting	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ventilation	X	X	-	-	X	-	-	X	X	X	-	X	-	X	X	
HVAC	X	X	-	X	X	X	X	X	X	X	X	X	X	X	X	
Hot water	-	X	-	-	X	-	X	-	-	-	-	X	X	-	-	
Equipment	X	X	-	X	-	-	-	X	-	-	-	-	-	-	-	
Plug load	-	X	-	X	X	X	-	X	X	-	-	X	X	X	-	
Total energy needs	-	14 EUI	-	16.8 EUI	13.5 EUI	22.1 EUI	19 EUI	17.1 EUI	92 EUI	18 EUI	14 EUI	43 EUI	66 EUI	23 EUI	16 EUI	
Part 3: Renewable energy production																
Renewable energy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Solar	X	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wind	-	-	-	X	-	-	-	-	-	X	-	-	-	-	-	-
Geothermal	-	X	-	-	-	-	X	-	-	-	-	-	X	-	-	
Hydropower	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Other	-	X Kinetic	-	-	-	-	-	-	-	-	-	-	-	-	-	
Control system	X	X	X	X	X	X	X	-	X	-	X	-	X	X	-	
Total energy generated	-	14EUI	-	29.5 EUI	28.7 EUI	22.2 EUI	19 EUI	17.5 EUI	96 EUI	18 EUI	15.4 EUI	-	-	28 EUI	-	
Results																
Final results	Energy plus	ZEPB	Energy plus	Energy plus	Energy plus	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB	ZEPB
Occupant Engagement and Training	-	-	-	X	X	X	-	-	-	-	X	X	-	-	-	

5.9 Case studies analysis

Case studies analysis consist of three parts as the analytical model, first part is about projects general information, second part is about energy reduction strategies used at the buildings, third part is about renewable energy recourses used at the design, and at the end the final conclusion.

5.9.1 Case studies information analysis

Project information is the first part at the analytical model, it contains report publish year, building type, building floor number, building size, building working hours and people capacity in the building,

After analyzing the data collected from fifteen case studies, the image will be clearer to understand which type of building easier to be zero energy building? What is the common height for zero building? What is the average building size suitable for ZE goal? Which type of public building closer to be zero energy? new or renovated or retrofitted? These questions are answered at next analysis.

5.9.1.1 Report publish year

The chosen case studies technical reports were published within the last 3 years (2016 - 2017- 2018- 2019) as shown in (Figure 5-4), the year 2017 when the most technical reports are published, more technical reports need to be published to share the successful experiences in this field.

5.9.1.2 Building types of case studies

The chosen case studies are divided by building activity into:

- Office buildings represent 40% of the ZEPB.
- Learning centers represent 20% of ZEPB.
- Industrial, bank, school, commercial, library, student resident and stadium each represent 6% as shown in (Figure 5-5).

Also, the chosen case studies represent many types of public buildings, this is proving that the most of public building types can reach to the zero energy goal like the sports facilities and hotels.

The case studies were divided by building type into:

- Administration projects are represented in four office projects and bank represent 46% of the case study.
- Educational buildings are represented in learning center, training center, and school represent 20% of the case study.
- Cultural project is represented in the library, industrial and commercial projects, each represent 8% of the case studies as shown in (Figure 5-6)

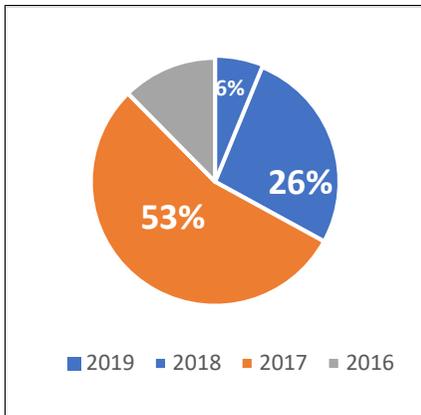


Figure 5-5: Case studies publish date, reference: Author.

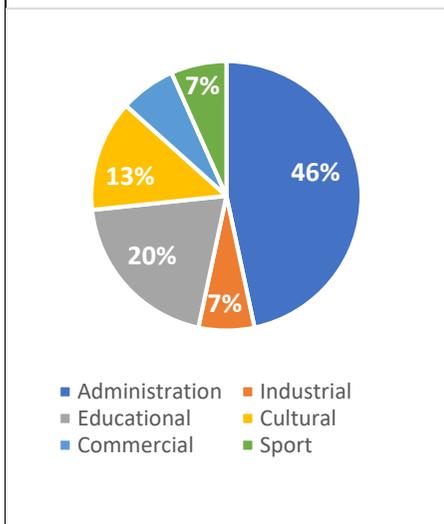


Figure 5-4, Case study according to public Building type, Reference: Author

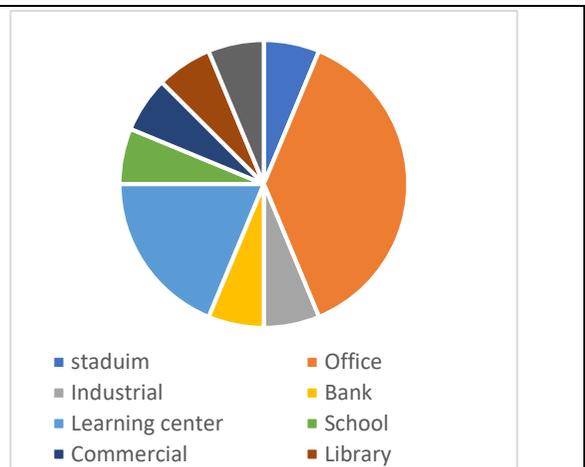


Figure 5-6, Public building according to the building activity, Reference: Author.

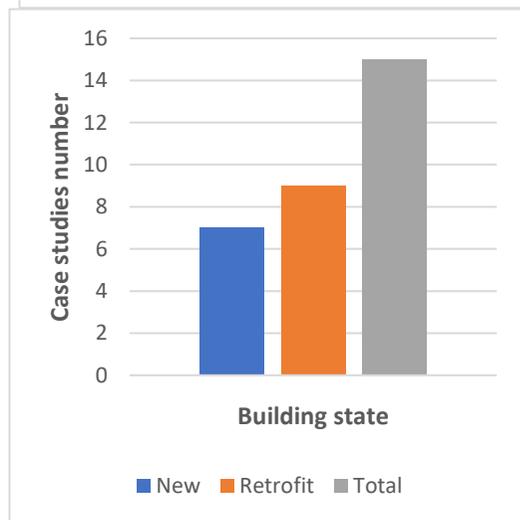


Figure 5-7: Building state of case studies, Reference: Author

5.9.1.3 Building state of case studies

47% of the case studies (7 projects) are new buildings, these new buildings were meant to be ZEPB starting from the early design stages, and 53% (8 projects) are retrofitted buildings which have been retrofitted to reach to be nearly zero or zero energy building, these results almost equal, which means new or existing buildings have equal chance in reaching to ZE goal.

5.9.1.4 Case studies climate zones

Case studies had various climate zones, Mediterranean climate represents 40% of the case studies, and this is the highest climate zone ratio, others climate zones like Tropical represents 20%, Hot semi-arid and Oceanic represent 13% each, Dry and Temperate 6% each.

5.9.1.5 Buildings floor numbers

40% of the case study buildings consist of one floor, 33% of them consist of tow floors, 6% consist of three floors,6% represents 8 floors, 6% represents 9 floors, and 6% represents 11 floors as represented in (Figure5-8).

As shown in the figure 80% of the zero energy building floor number is less than 5 floors because by increasing building floors more than three, the energy demand is increasing and more renewable energy resources are needed to be integrated into the design to cover the building extra need, solar PV cells only will not be adequate.

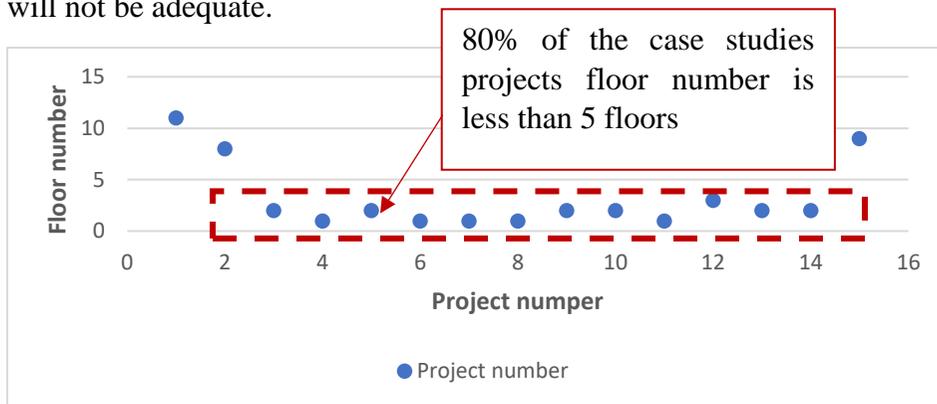


Figure 5-8: Buildings floor numbers, Reference: Author.

5.9.1.6 Project size of case studies

Projects sizes are variable starting from 340 m² to more than 300,000 m², 66% of the case study's projects size less than 5,000m², 6% of the projects between 5,000 and 10,000 m², 6% of the projects between 10,000 and 15,000 m² and 13% between 30,000 and 40,000m² as (Figure 5-9). These percentages prove that it is easier to achieve ZEPB goal for small size projects less than 5,000m², bigger projects will need more efficient design techniques and strategies to be ZEPB.

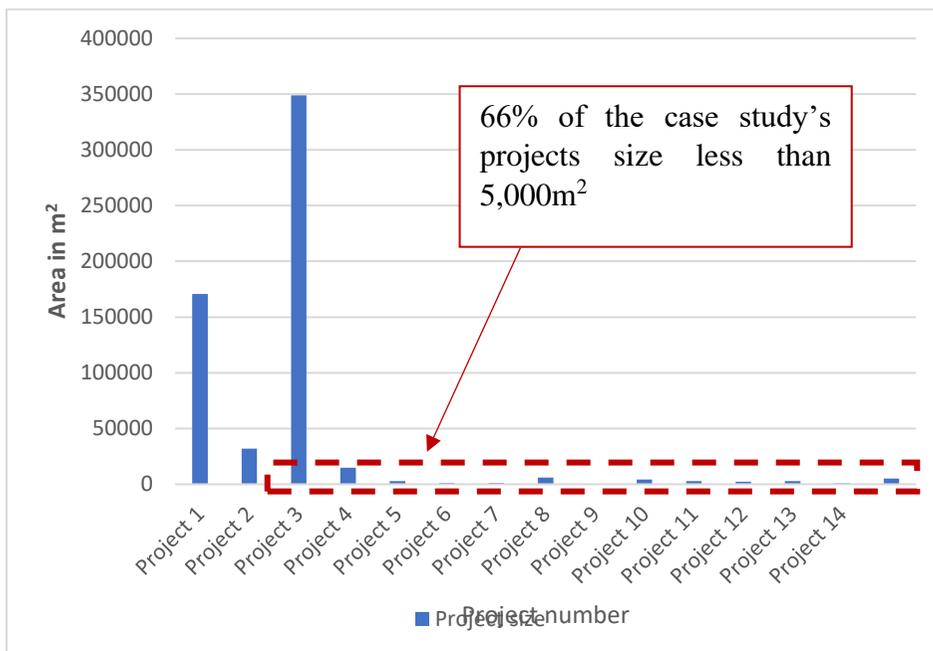


Figure 5-9: Case studies buildings size, Reference: Author.

5.9.1.7 Working hours at case studies

The working hours for more than 50% of the case studies is 12h and 40% of the projects working is 8h, there is only one ZEPB working for 24h which represent 6%.

94% of the case studies working at daytime to take benefit from the daylighting and reduce the building energy consumption. (Figure 5-10).

5.9.1.8 People capacity at case studies

At public buildings people capacity is various most of the time, it can start with few tens as in small office buildings to more than 60 thousand as in stadium. Only two projects that the people capacity was defined, the other case studies were variable numbers according to the building activity or unknown number. (Figure 5-11). People capacity at public building is variable according to the building activity and offered services.

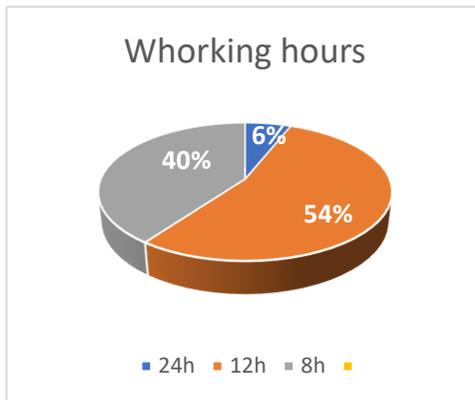


Figure 5-10: case studies working hours, Reference: Author.

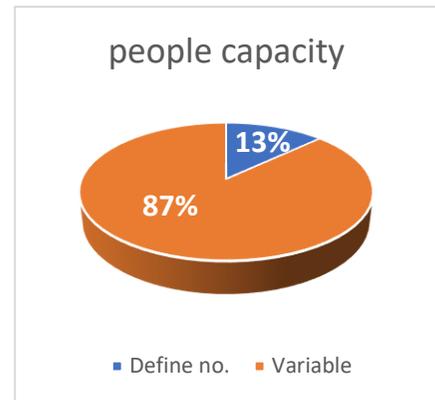


Figure 5-11: People capacity at case studies, Reference: Author.

5.9.2 Energy reduction strategies analytical study

All the case study projects worked on tow main axis to reduce the building energy consumption to the minimum, first is designing efficient building envelop and the second is using efficient building systems.

5.9.2.1 Building envelop strategies

Each case study applied different energy reduction strategies and techniques on building envelop (walls, floors, openings, roof and shadings) to design energy efficient building envelop, also, some projects used special environmental material to help in the design process. As shown in (Figure 5-12):

- Walls and roof treatments applied in 87% (13 case studies) which represents the first priority in designing efficient envelop.
- Openings also represents the second priority because it is effectively designed in 73% (11 case studies).
- Choosing the efficient environmentally friend material came in the third place which represented in 47% (7case studies).
- Adding shadings to building design represented in 27% (4 case studies).
- Floor treatments at the last place in efficient envelop design, represents 13% (2 case studies).

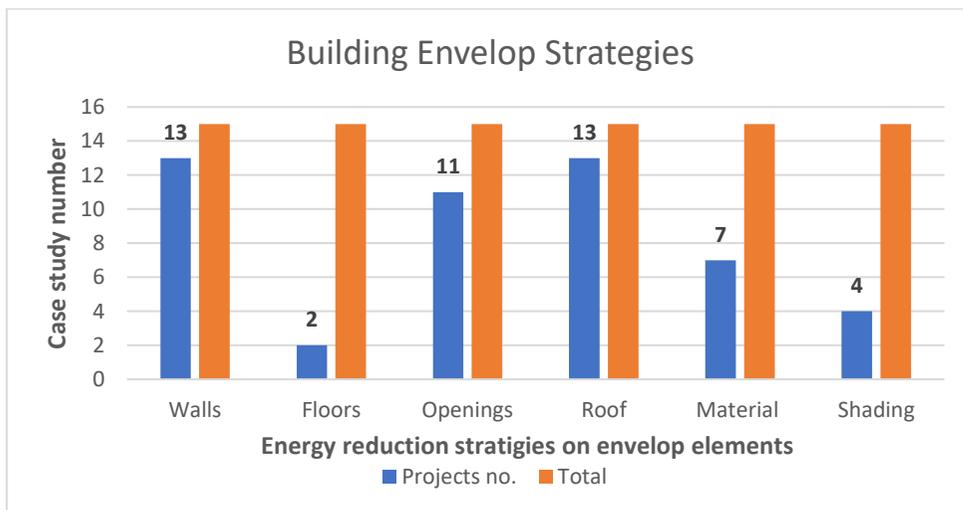


Figure 5-12: Building Envelop Strategies, Reference: Author

5.9.2.1.1 Wall section

80% of case studies design wall section to be well insulated by using many techniques and efficient materials, and the other 20% did not change in the existing wall section or it is missing data from there technical report.

The fourth project used recycled blue jeans for traditional insulation and fiberglass insulation, the fifth used on the exterior walls by a ceramic-based coating, thick polystyrene and leasable space was added all the way around the building, while the seventh used Interior batt insulation and 7.5cm rigid insulation, the eighth project wall section was designed to contain three layers of insulation of standard fiberglass batt, and the last one used double skin front façade.

5.9.2.1.2 Wall resistance

Case studies projects worked on a wide range starting from R13 to R38. Designing well insulated wall section is mandatory in designing ZEPB, because insulation helps in reducing overall building energy consumption to approximately 40% below code levels and wall resistance between R20 and R30 is highly recommended for ZEPBs. (Figure 5-13)

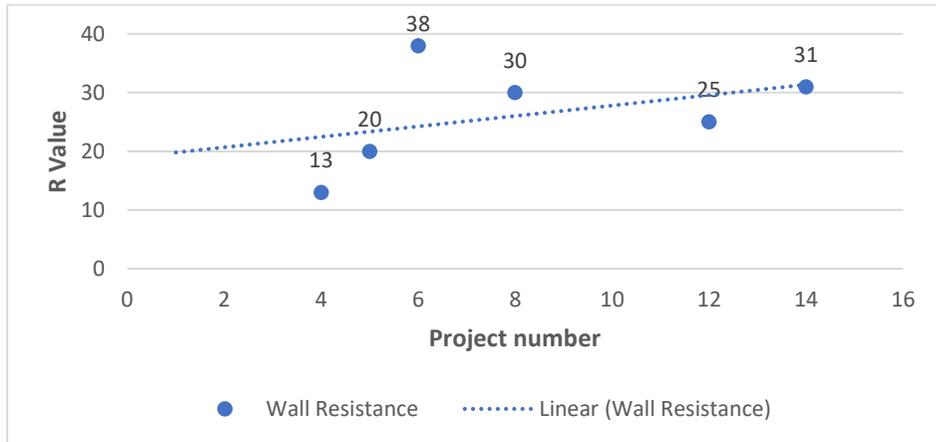


Figure 5-13: Case Studies Wall Resistance, Reference: Author.

5.9.2.1.3 Openings

80% of case studies (12 projects) designed openings to be well insulated by using many techniques and sections, and the other 20% even they did not change in the existing openings section or it is missing data from there technical report.

The first, fourth, ninth and twelfth projects used Double glazed, Low-E coated and shaded windows, the fifth used electrochromic (self-tinting) windows and this Dynamic Glass were installed in both fixed and operable windows, and doors, the sixth and the thirteenth projects focused on using higher performance glazing, while the fourteenth project used A triple-paned, store-front glazing system.

So, for designing ZEPB the Double glazed, Low-E coated openings is highly recommended and to get more energy efficiency results it is better to use self shaded or dynamic glass windows.

5.9.2.1.4 Roof insulation

94% of case studies (14 projects) design roof to be well insulated by using many techniques, and the other 6% even they did not change in the existing roof section or it is missing data from there technical report.

The first, second, third projects used PV panels to cover the roof, the fourth project used rigid insulation for the roof, the fifth project designed the roof insulation to consist of 3 layers, first foam roofing, second a cool roof coating and third 25mm batt insulation, the sixth project used roof insulation with 2.5cm wool, while the eighth, the fourteenth and the fifth projects also covered the roof with PV system.

So, for designing ZEPB its mandatory to insulate the roof to help reduce overall building energy consumption to approximately 40% below code levels. Also, its highly recommended to cover the roof with the PV system that will be used in generating energy to the project.

5.9.2.1.5 Roof resistance

Case studies projects roof insulation varies from R29 to R40. Designing roof insulation is obligatory in designing ZEPB where roofs are the most element exposed to the sun radiation for a long time, so Roof resistance between R30 to R40 is highly recommended. (Figure 5-14)

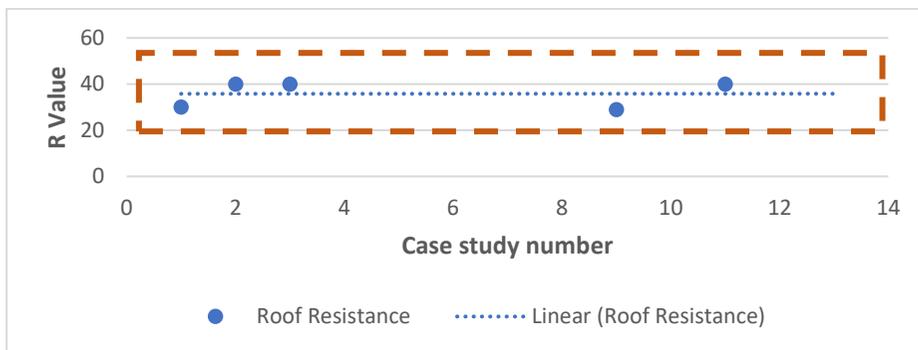


Figure 5-14: Case Studies Roof Resistance, Reference: Author

5.9.2.1.6 Material choice

All materials have to be LEED standard or CRI Green Label Plus Certified carpeting, reclaimed wood, FSC Certified wood, or Greengard Certified.

5.9.2.2 Efficient buildings systems

Building systems are important part in designing energy efficient building, the results of analysing case studies systems and plug loads as shown in (Figure 5-15) are:

- 100% of the case studies adopted different strategies for lighting, cause minimizing lighting energy consumption has a significant effect on reducing the total building needs.
- 94% (14 projects) chose energy efficient HVAC system to reduce the building energy consumption as much as possible.
- 100% of the new buildings adopted energy efficiency envelop strategies for walls, roof, openings, and material, while 84% of the existing buildings adopted the energy efficiency envelop strategies, over all 87% of the case studies (13 projects) used different techniques on their building envelop to reduce the energy consumption.
- Building ventilation systems came at the fourth place in the importance, 60% of the case studies (9 projects) used different ventilation systems to reduce the HVAC loads and save energy.
- Reducing the energy consumption for building plug loads was the main concern in the energy reduction plan for 60% of the case studies project (9 projects).
- Only 33% of the case studies (5 projects) care about providing the building with hot water by using renewable energy resources because hot water is not an essential need at all public buildings.
- Reducing the building equipment's energy consumption represents 33% of the case studies (5 projects) concern about reducing their energy, it also depend on the building activity to determine if the equipment energy consumption has a great or minor effect on the total energy needs.

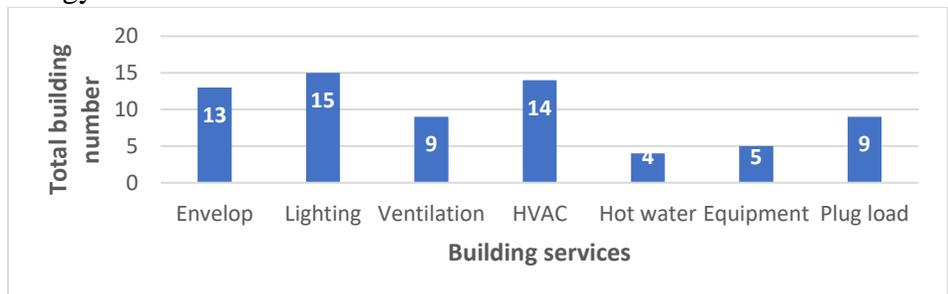


Figure 5-15: Case studies systems and plug loads, Reference: Author.

5.9.2.2.1 *Daylighting design*

There were many techniques have been used to enhance the daylighting at the case studies buildings like:

- The first project integrated wide core in the middle to maximize the day lighting at all the floors.
- The second project building envelope designed to ensure distributing daylight in 75% occupied areas.
- The third project is open air stadium, most of the time no additional artificial lighting needed to illuminate the match at daytime.
- The fourth project installed reflectors to increase interior penetration of daylight.
- The sixth project used interior glass walls (known as relights) to distribute the light throughout the interior space.
- Skylights and solar capsules were used at daylighting design of 46% of the case studies (7 projects) at the fifth, sixth, eighth, tenth, eleventh, twelfth, and the fourteenth project
- In addition to using large glass façade 20% of case studies at first, fourteenth and fifteenth projects to maximize the daylight design effect.

So, after analysing the daylighting design at case studies, there are some recommendation for getting the best results from the daylight:

- Design a daylight model help in reducing the necessary lighting power density.
- Studies determine the size, spacing, direction, and degree of tilt to achieve the highest intensity of daylight while minimizing heat gain.
- Orienting the building to the direction that is going to increase the daylighting effect.
- Techniques like solar capsules and large glass curtain wall are recommended for public building lighting design.

5.9.2.2.2 *Artificial lighting system*

54% of the case studies used LED units, 6% used High-efficiency fluorescent lamps, and other 20% the lighting unit is unknown. Also, 27% used Occupancy sensors, and 20% used daylight sensors.

Recommendation, the LED lighting units is highly recommended in the artificial lighting design, and for better results, its better to install daylight and occupancy sensors.

5.9.2.2.3 Ventilation system

As mentioned, 80% of the case studies (12 projects) used many natural ventilation techniques to reduce the energy consumption loads and it can be concluded as following:

- 33% of the projects used manual or automated windows.
- 13% of the case studies used an air-to-air heat exchanger tempers incoming ventilation air, automated skylights windows help ventilation process.
- Some projects used ceiling to increase airflow, other used large, high-volume, low-speed fans to circulate air more in the space.
- Also, night ventilation is recommended for the passive heat exchange.
- The best ventilation results when windows face the north.

5.9.2.2.4 HVAC system

There are many efficient HVAC systems, the systems that used at the case studies are:

- Variable refrigerant flow (VRF) system used by 20% of the case studies (sixth, seventh, tenth projects).
- Variable air volume (VAV) system used by 13% of the case studies (third and ninth projects).
- The other case studies, each project used different type of HVAC taking into consideration the energy consumption.

And, its recommended to adjust the setpoints to 26 degrees Celsius on nights and weekends to save more energy.

5.9.2.2.5 Equipment and Plug loads

After analysing the case studies, the building equipment and plug loads consume 40% to 58% from the total energy consumption of the building, so, by using efficient lighting and mechanical systems the energy consumption will be reduced by 40%. And the saving energy strategies used were:

- Occupancy sensors for lighting control.
- Turning off machines and printers during nights and weekends.
- Shutting down computers and monitors could further reduce the off-hours plug load to nearly zero.
- And integrating smart plugs at each workstation which allows workers to customize the shutoff times to their office hours, so systems are turned off when not in use.

And it strongly recommended to give workers, users, occupants and visitors at the first time they enter the building recommendations for plug load management and energy reduction.

5.9.3 Renewable energy production analytical study

All the case studies used renewable energy resources to generate electricity enough of more than its needs as they are represented in (Figure 5-16).

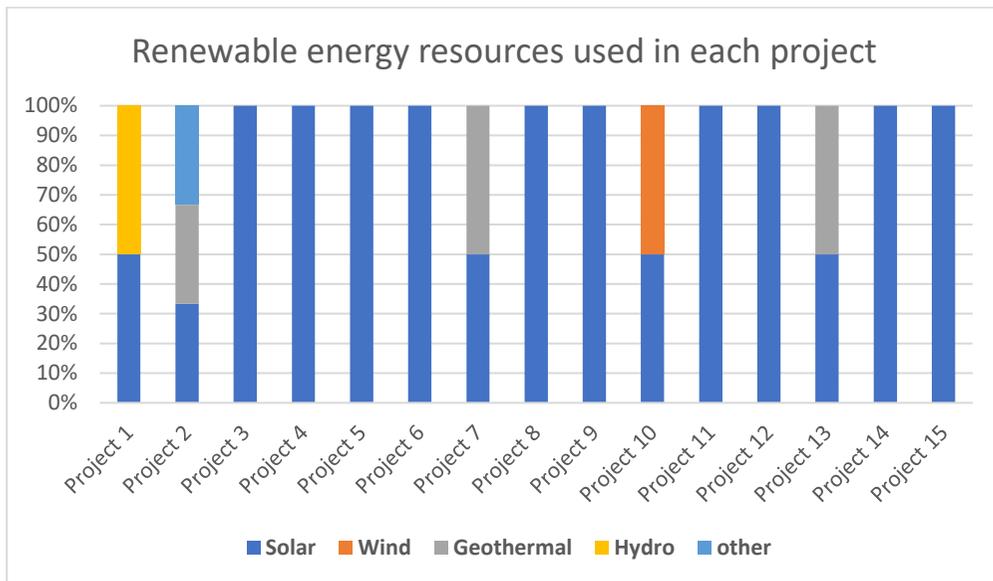


Figure 5-16: case studies renewable energy production resources, Source: Author.

From the last chart, renewable resources used in case studies can be conclude as: 100% of the case studies used solar PV to produce energy , 74% of the case studies used only solar energy for energy production, 6% used solar and wind energy, 6% of case studies used solar and hydropower and 20% used solar and geothermal energy. The second project used solar, geothermal, and kinetic energy generated from elevators movement.

So, solar power is the first choice to cover the building needs, if it is not adequate, it is essentially to integrate another source of energy or even more than one, to achieve the zero energy goal.

5.9.3.1 Solar energy analysis

Zero energy public building which use solar power as source of energy can integrate more than one technique in the design. The solar techniques that used in the case studies are:

- Photovoltaic system.
- Solar panels attached to exterior window shades.
- Flat-panel solar photovoltaic system.
- The roof-top photovoltaic system.
- If the roof is not capable of supporting the solar array, so the solar array can be ground mounted in the parking lot.
- The fifth project also used PV curtain walls.

5.9.3.2 Wind energy analysis

Fourth and eleventh projects used, cylindrical wind turbines in addition to the solar energy to achieve zero energy goal.

5.9.3.3 Geothermal

The case studies that used geothermal energy are:

- Second project used **geothermal** heat exchange system vertical closed loop system of geothermal heat exchange system to reduce the load on the HVAC. The system has vertical closed loop system done with 32 mm diameter U – loops, 180 in number and 80m deep each.
- Also, seventh project used a closed-loop geothermal well field of 60 vertical wells 90 feet deep is divided into three loops that manifold into a single loop that runs to the building's mechanical rooms. The stable ground temperature serves to moderate water temperature, allowing the system to either dump or recover heat, depending on the season. This allows for a downsized compressor and provides for a 40% energy savings.
- And the thirteenth project used a geo-exchange or ground source heat pump system for the heating and cooling system. The parking lot was turned on into a geothermal field with 32 boreholes going down 70 meters in depth.

5.9.3.4 Hydropower as renewable energy source

Using hydropower as renewable energy source in public buildings is conditioned with located close to natural water source like river or sea.

First case study project integrated hydropower as secondary energy source because it located close to city harbor. Seawater is used for heating, cooling and implementing only energy efficient electrical appliance.

5.9.3.5 Other renewable resources

Second case study uses the power regenerated from the elevator for power requirement of the elevators.

5.9.4 Building energy needs compare to energy produced

All the case studies projects worked on minimizing the energy consumption and producing equal or more energy as shown in (Figure 5-17).

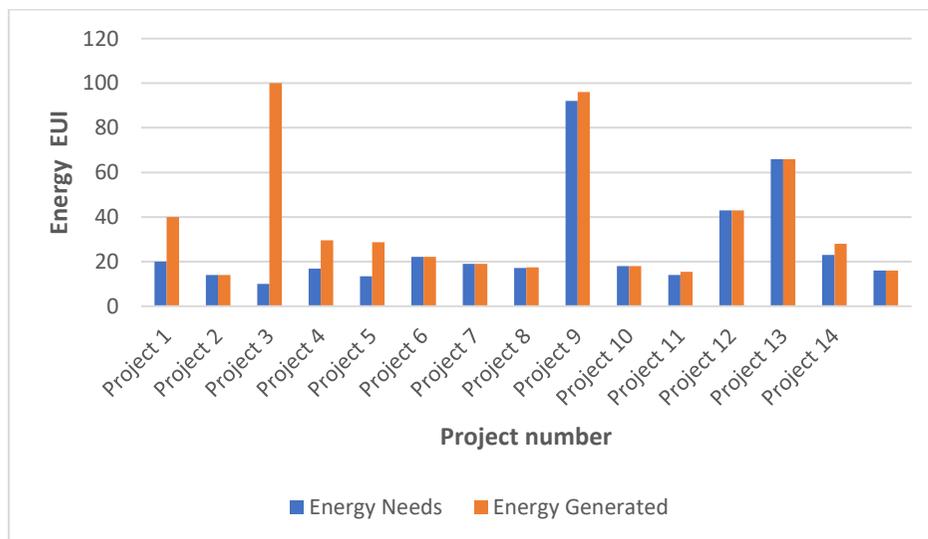


Figure 5-17: case studies energy needed and generated, Reference: Author.

Some zero energy public buildings are functioned as city energy cell and supply neighbours with electricity like first project supply the neighboring

buildings as well as nearby charging outlets that are used by buses, cars, and boats and the third case study which support 1200 homes.

5.9.5 Factors help in designing ZEPB at the analytical study

There are several factors helping in designing ZEPB as:

5.9.5.1 Control system

Control systems help in designing energy efficient public building, 74% of the case studies used control systems like:

- motion sensors for operating lights to reduce unnecessary lighting energy use.
- Photocells automatically adjust the lighting to the amount of daylight in the space.
- A thermal sensor detects the room temperature, which allows diffusers to run only when necessary and release an appropriate amount of air.
- A building management system incorporates the HVAC, lighting, plugs, and PV energy system.
- The building management system allows operators to closely track the building's performance and identify issues such as unexpectedly high plug loads.

5.9.5.2 Occupant training

42% of the case studies are providing training programs to their building users and different strategies to encourage them to watch and control energy consumption, like:

- Users can interact with the data to modify the timescale and view kilowatt hours, dollars or equivalent carbon emissions.
- Training building users on how to use the lighting and daylighting system was critical to ensure optimal performance.

5.10 ZEPB design methodology

Few public buildings achieved the zero energy goal worldwide, each public building design team worked hard to reach zero energy design because of the high energy consumption and the various users' number. Some design teams depend on their experience in this field and others work by using "try and

error” in energy simulation software, and other used algorithm energy simulation software to reach to the optimum design solutions. From the literature review and analytical study Zero energy Public Building Design Methodology is extracted to facilitate the zero energy design and share the knowledge, as the methodology is “shaping form to guide flow” (Lyle, 1994).

It means that designers have to understand basic public building design needs. This approach to design would create form as an index of all the energy, materials, and information flows interacting with buildings: light, water, electricity, heat, gravity, functional human activity, social patterns, site forces, and human perception and meaning. (DeKay, 1996) And the proposed methodology which extracted from cases studies technical report and design analyses is shown in (Figure 6-19) which clarify that the ZEPB design processes is divided into three main parts as following:

- **Part 1: Public Building Data and Design requirements:** this part focuses on forming conceptual design by understanding the public building requirements like the activity type, users number, building state, ... etc., and the available data like location, local climate data, suitable orientation, number of floors allowed, max. floor area, total building area, building construction methods, building form that interacted to all the previous and result an initial conceptual design.
- **Part 2: Applying Energy Reduction Strategies:** this part of design methodology working on two main axis, the first focuses on building envelope efficient design by designing: walls section, roof, floor type, windows, shading, and the second axe work on integrating energy efficient service systems: lighting, HVAC, ventilation, hot water, equipment, plug load. In each stage, public building form can be developed to meet the energy efficiency requirements and reduce the building energy consumption to the minimum. Each choice is measured by energy simulation program. This part ended by determining the value of building energy needs.
- **Part 3: Renewable energy production:** the third part in zero energy design methodology specified in integrating renewable energy resource and control system into the building design.

At the end, if the energy produced equal to the building energy needs or more, then this public building is zero energy, but if the produced energy less than the building energy needs, the design restart the third part from the design methodology to produce more energy and reach to zero energy goal.

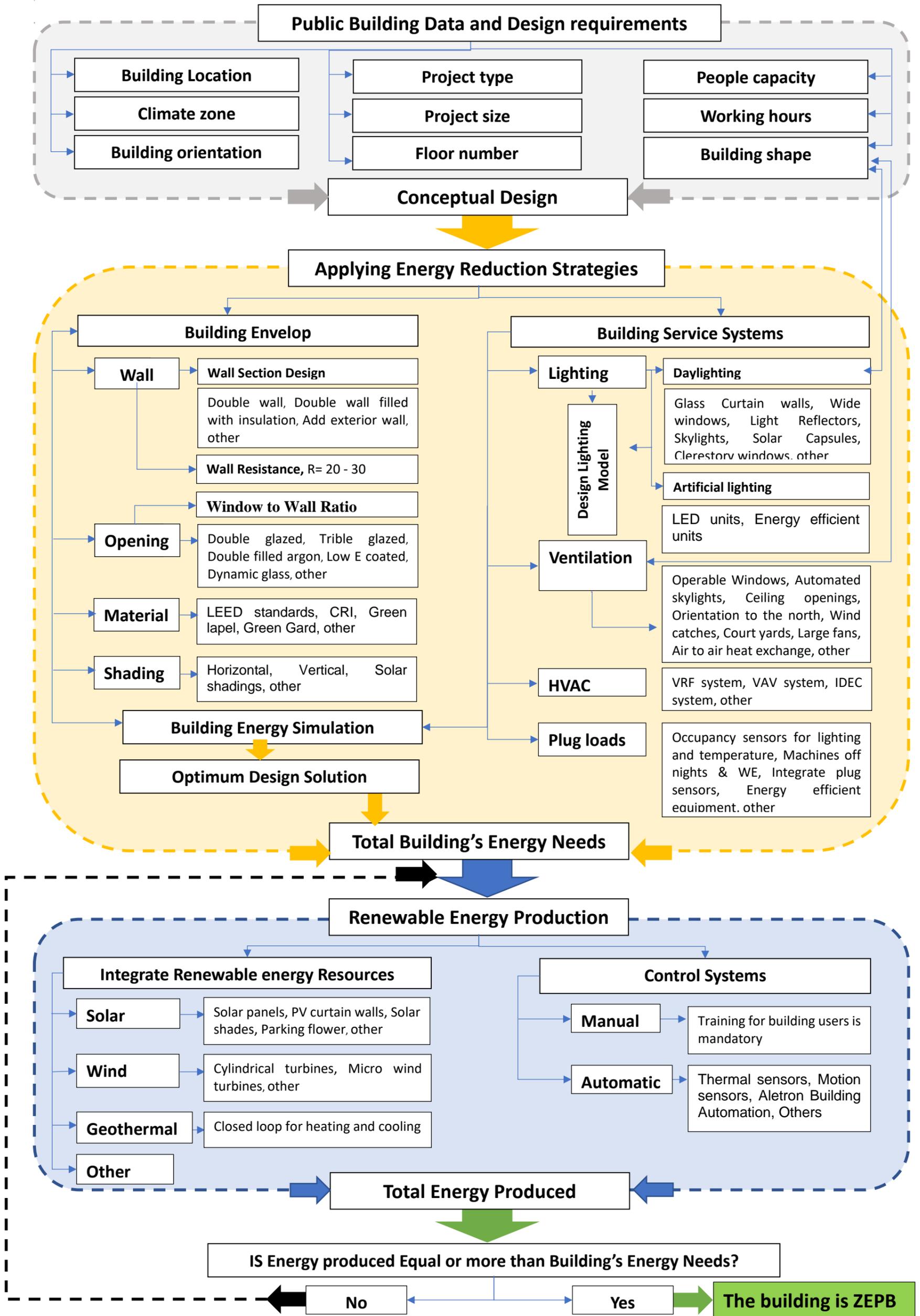


Figure 5-18: The Extracted Zero Energy Public Building Design Methodology, Reference: Author.

5.11 Proposed ZEPB design process

The ZE design process is defined as shown in (Figure5-19) start with define program, then sketch design which include analyse energy demand, then full concept design, and finally coordinated design. (Katrien Biesbroeck, 2019)

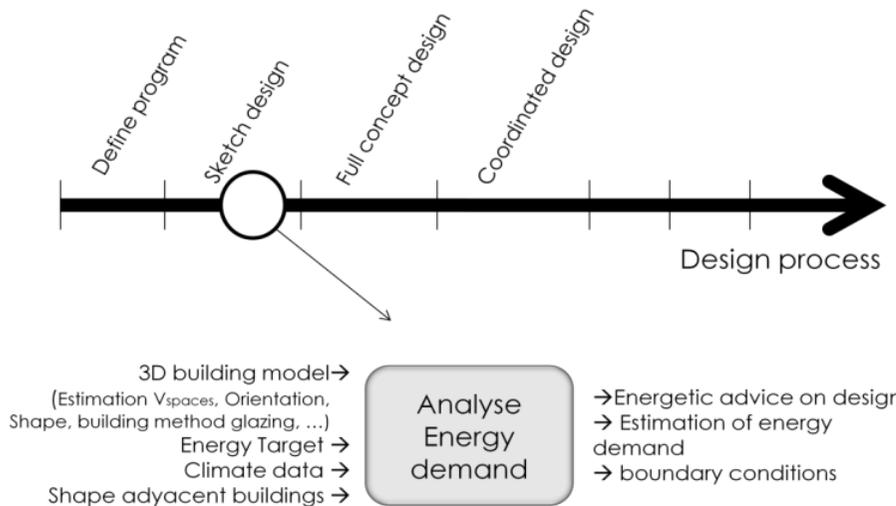


Figure 5-19: Tool selection according to the needs of the design process, Source: Katrien Biesbroeck, Ralf Klein, Alexis Versele, Hilde Breesch, Design processes for Net-Zero Energy Buildings Reinventing the design process: How to improve information exchange and software tools, www.irbnet.de, 20th, March, 2019.

But according to the proposed design methodology, the ZEPB design process is modified to be as following: (Figure 5-20):

- First, set the zero energy design as a goal, then define the program through the building design standards, building information, location, getting the climate data.
- Then, the building form selection, 3D building model will be built.
- Energy reduction strategies by using proposed ZEPB design methodology, estimating the spaces, building shape, openings glazing methods, natural daylighting and ventilation techniques, walls and roof insulation and specify the best orientation.
- The fourth stage is running an energy simulation to estimate the building energy needs and set the design conditions for the design.
- The fifth stage is getting full concept design by integrating renewable energy resources to the building design to cover the building energy needs, if the building design is not zero energy yet, restart the design process from the third stage.
- Finally, reaching to coordinate ZEPB design.

The ZEPB design methodology and design process are used in the application study.

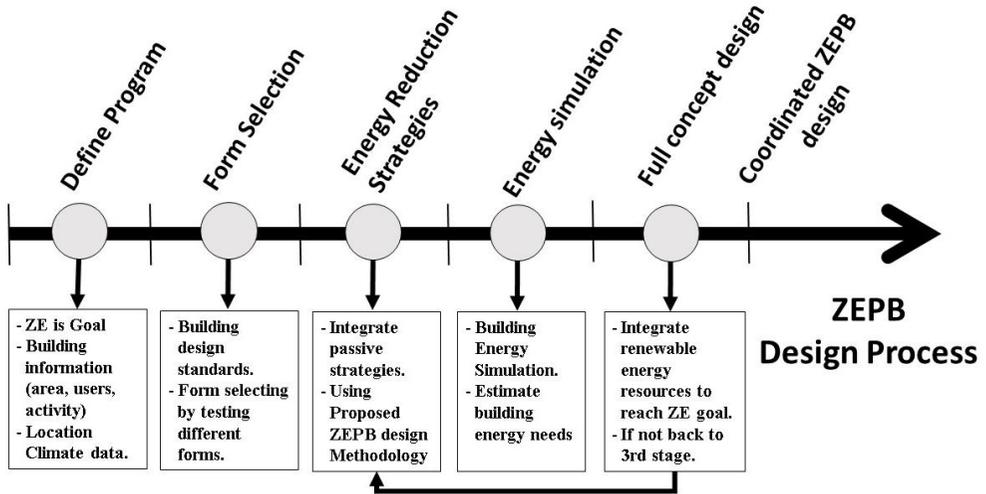
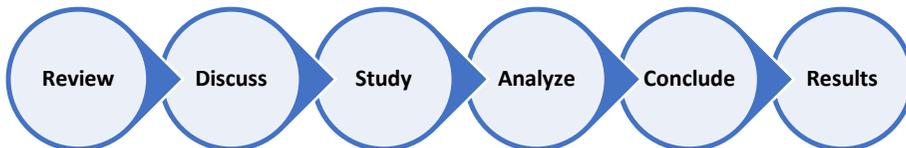


Figure 5-20: ZEPB Design process, source: Author

5.12 Summary

This chapter aims to analyse successful and certificated zero energy or nearly zero public buildings designs in order to reach the ZEPB design methodology.

- Analytical study methodology is as following shape:



- The analytical study based on “**Mixed-Methods Research**” by using more than one research method to collect and analyze the data, so, the “**Inductive & Deductive Approach**”.
- The analytical study methodology structure is consisting of three phases;
 - First: Public building design analysis where the information about the case study project design is collected like: Location-Orientation- Building shape- Building surrounded environment.
 - Second: Passive strategies and techniques, where all the passive strategies and environmental solutions that applied on the design to reduce the energy consumption is analyzed.
 - Third: Renewable Energy production resources, where the renewable energy resources of each project that used to produce energy to cover the building energy needs and achieve the zero energy goal is analyzed.
- The analytical study samples are twelve international projects that chosen according to specific criteria.

Chosen case studies are analysed by using the analytical model at the last chapter, in this chapter the data is collected in each field and had more analyses to extract general design methodology can be applied on public buildings.

The analytical model is divided in three parts, and the results in each part as following:

Part 1: Building information analysis:

- Case studies building types are different and office buildings represent 33% of the ZEPB.
- 33% of the case studies are new buildings, 67% are retrofit buildings have been retrofitted to reach to be nearly zero or zero energy building.
- 42% of the case studies buildings consist of one floor, 50% of them consist of tow floors, and 8% consist of three floors. By increasing building floors more than three, more renewable energy resources need to be integrated to cover the building extra need, solar PV cells only will not be adequate.
- The working hours for 50% of the case studies is 8h and the other half is 8h, there is not yet ZEPB and working for 24h.
- Projects sizes are variable starting from 340 m² to more than 30,000 m², 75% of the case study's projects size less than 5,000m².

Part 2: Energy reduction strategies analysis:

For building envelop strategies:

- Each case study applied different strategies and techniques on walls, floors, openings, roof and shadings to design energy efficient building envelop, also, some projects used special environmental material to help in the design process.
- Wall resistance between R20 and R30 is highly recommended for ZEPBs.
- For designing ZEPB the Double glazed, Low-E coated openings is highly recommended.
- Roof resistance between R30 to R40 is highly recommended.
- All materials have to be LEED standard or CRI Green Label Plus Certified carpeting, reclaimed wood, FSC Certified wood, or Greengard Certified.

For efficient buildings systems:

- Design a daylight model help in reducing the necessary lighting power density.
- Studies determine the size, spacing, direction, and degree of tilt to achieve the highest intensity of daylight while minimizing heat gain.
- Orienting the building long axis to have a primary East/West orientation.
- The LED lighting units is highly recommended in the artificial lighting design

- 75% of the case studies used many natural ventilation techniques to reduce the energy consumption loads
- Night ventilation is recommended for the passive heat exchange.
- The best ventilation results when windows face the north façade.
- For HVAC its recommended to adjust the setpoints to 26 degrees Celsius on nights and weekends to save more energy.
- After analysing the case studies, the building equipment and plug loads consume 40% to 58% from the total energy consumption of the building, so, by using efficient lighting and mechanical systems the energy consumption will be reduced by 40%.

Part 3: Renewable energy production:

- 100% of the case studies used solar PV to produce energy, 16% of the case studies used wind turbines in addition the solar panels, and 16% of the case studies used geothermal with the solar panels.
- 95% of case studies projects worked on minimizing the energy consumption and producing equal or more energy except one project the energy produced was less than the building needs.
- 66% of the case studies used control systems.
- 42% of the case studies are providing training programs to their building users.

After analyzing the case studies, the design methodology for zero energy public building is extracted. Next step is testing this design methodology on public building to check if it is guiding the design to be ZEPB or not? And if it is applicable in Egypt or not? The answer of these questions will be clarifying at the next chapter.

CHAPTER 6 : Application study

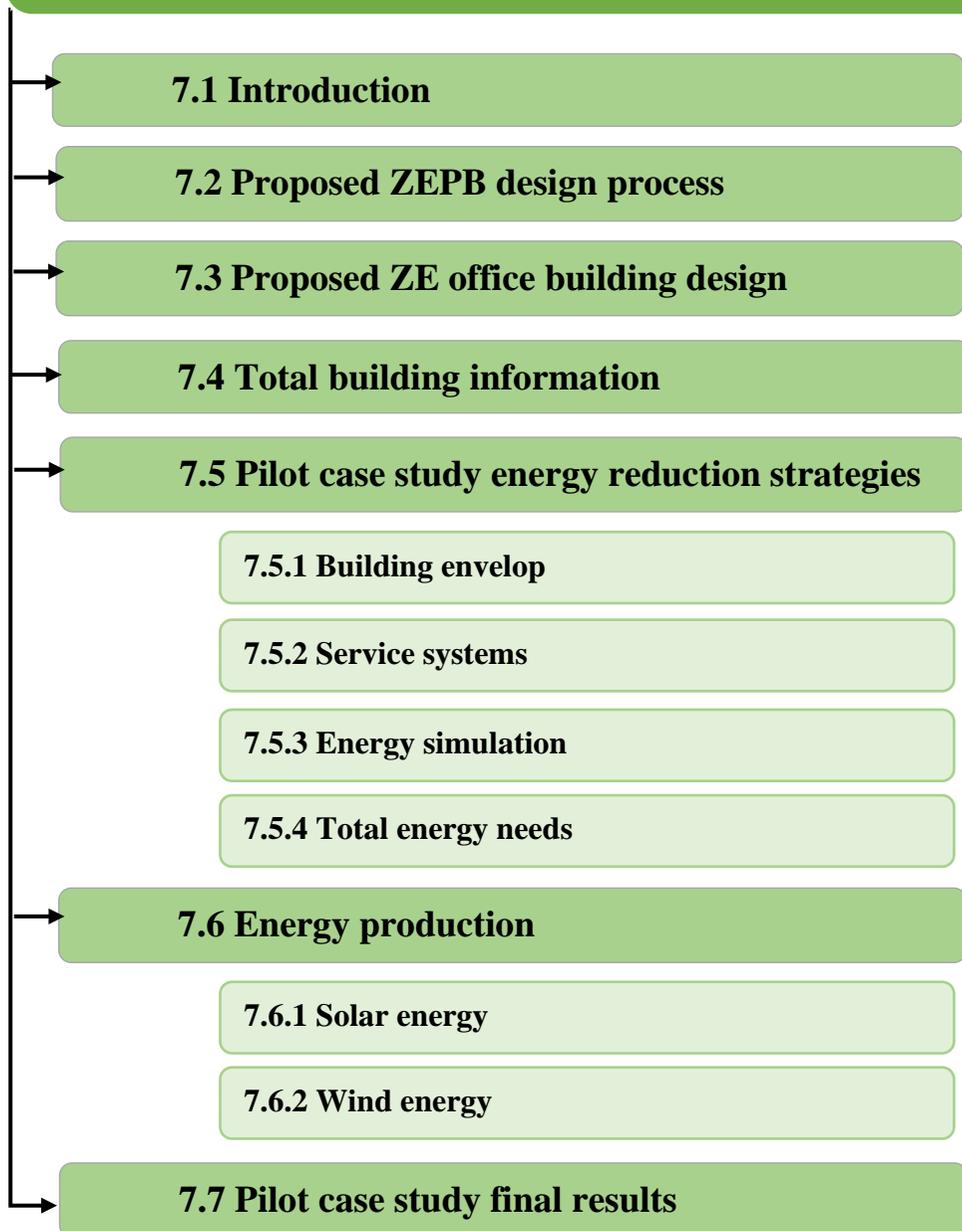


Figure 6-1 : Chapter 7 structure

6.1 Introduction

Public building design for zero energy performance has been framed as an improvement over current practice. In this chapter the ZEPB design methodology which extracted from the analytical study is tested through using it in designing public building as a step towards designing zero energy public building. Also, the proposed public building is designed in Egypt, Cairo, to test theoretically the ability of achieving ZEPB in Egypt.

As mentioned at the second chapter, there are many public buildings types but the chosen public building type for proposed ZEPB design is an office building because office buildings make up the largest sector of building type within the public building, for example it comprises 17% of all public buildings in US, also, consumes 17% of the energy (aceee.org, 2019), as well as, it represents 30% is a study for 34 case studies of net zero energy buildings in hot and humid climate zones (Wei Fengb, 2019), also, it is the largest part 33% of the case studies.

By using the ZEPB design methodology, the proposed office building design is adopting energy reduction strategies to minimize the building energy needs and renewable energy resources are integrated to reach the zero energy goal. Energy simulation software is used to estimate the building energy need and measuring the effect of applying the reduction strategies on the design.

The first part at ZEPB design methodology is the building design stage according to the environmental considerations mentioned in the literature review. So, there is a comparison between popular regular rectangular office building design and proposed design from the recommended environmental strategies in measuring the building energy need while the two buildings have the same area, design program, location and orientation to the north.

The better design environmentally through energy simulation is passing to the second part of ZEPB design methodology. Starts by working in improving the building envelop efficiency and building service systems, through testing different design options by energy simulation program to reach to the optimized solution and the minimum energy building demand.

Then the third part starts, which responsible for producing energy by integrating renewable energy resources to cover the building energy needs.

After the last three main design stages, coming the important question, is the energy produced equal or more than building's energy need? If the answer is

“yes”, then this design succeeds to achieve zero energy goal, if the answer is “no”, then this design needs more optimization choices or adding another source of energy and retry the energy simulation.

6.2 Energy simulation software for the application study

Building energy simulations help in predicting the building performance before it is built and is essential to view the reducing of energy consumption and the generated amount of renewable energy. (Banerjee, May 2015, p. 145) As mentioned in the literature review that computer based 3D modelling and energy simulation is a proven technique for evaluating building energy consumption. So, choosing the suitable energy simulation software is playing an essential rule in evaluating the building energy usage and comparing between the different design proposals to get the best results.

6.2.1 Choosing the simulation tool

There are many available software for calculating whole building energy performance simulation for example BLAST, eQUEST, TRNSYS, Energy Plus, Energy Express, EFEN, Design Builder, etc. or plug in like Honey Bee and Lady Bug.

As, the energy simulation process includes a range of design variables such as: building location, local climate, building orientation, window and door type, insulation and size, walls and roof insulation types and values, air tightness, the efficiency of heating, cooling, lighting and other equipment. So, the chosen program needs to calculate more than one operation in each energy simulation, and that is why Design Builder simulation program is chosen,

And the reasons of choosing **DesignBuilder** for testing the proposed design methodology is:

- The program ability of the prediction of the building energy consumption.
- Creates a virtual environment where the operation of the Heating, Ventilation and Air Conditioning (HVAC) system and the lighting energy consumption of the whole building can be studied in detailed.
- The factors that affect building energy performance and thermal comforts of the occupants during summer and winter can be identified.
- At the end, this simulation will be led to evaluate whole building annual thermal performance and retrofit decision making.

6.3 Proposed ZE office building design

The design process is conducted on a five story office building located in Egypt hypothetically. And two different office buildings are designed, the first represents the regular office building form and the second represents office building designed by using the proposed ZEPB design methodology. Building information such as building size, location and occupation schedule were used within the Design Builder energy simulation software for the both designs to calculate the energy consumption. And the better design is chosen to continue in applying ZEPB design methodology stages like applying energy reduction strategies, in addition to, calculating the produced energy by using solar and wind renewable energy resources. The effectiveness of the approach for finding optimal building configuration is demonstrated in the presented test case. (Sadik Yigit, November 2018)

6.3.1 Office building design program

The office layout must be flexible, and it easier through modular walls and furniture. And the design program for proposed office building includes several space types to meet the needs of staff and visitors, these include: offices (open space, semi closed, closed space) (Figure6-2), conference rooms, meeting rooms, reception, support spaces like (filing space, storage space, print and copy area), cafeteria , toilets , general storage, computer/information technology (IT) closets, maintenance closets.

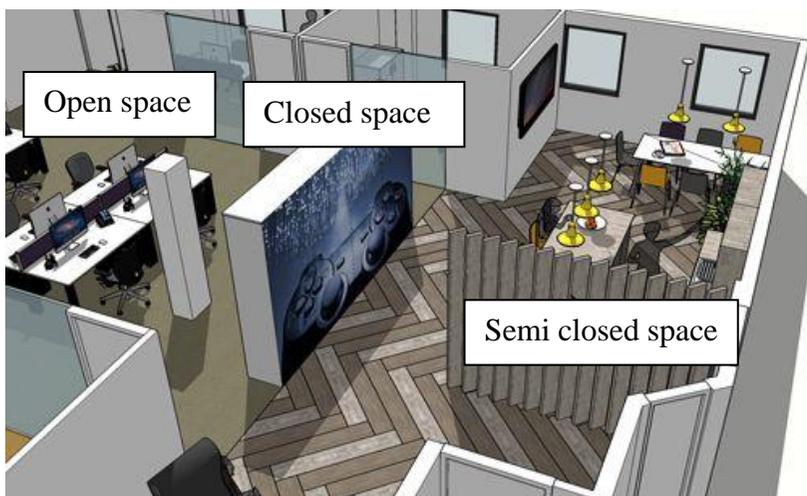


Figure 6-2: several office space types, Source:

<https://www.oaktreeoffice.com/images/CorsairEntrance.jpg> , edited by Author

6.3.2 Total office building information

The following table represents a brief description of the proposed office building design.

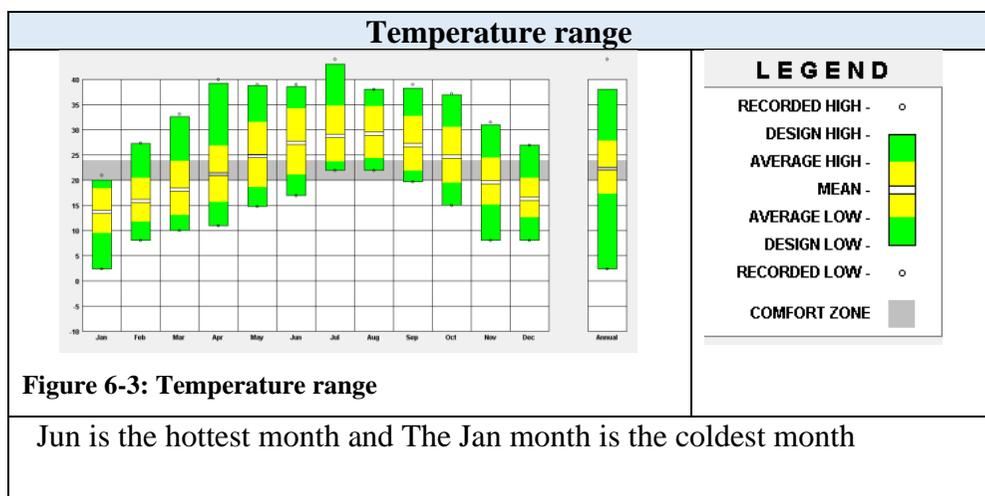
Table 32: Brief description of the proposed office building, Source: Authors

Location	Egypt
Climatic zone	Hot arid
Building type	Office building
Floor no.	5
Floor area	500-700 m ²
Building area	2250-2500 m ²
Design grid	4*4 m or 5*5
Structure system	Simple beam-concrete structure
Working hours	8:00 a.m. – 4:00 p.m.
People capacity	200
Building state	Conceptual design

6.3.3 Site analysis

Before starting in the design, it is important to study the location climate because it is a critical variable in the design an office building project. Egypt located in the hot arid climatic region, by using Climatic Consultant program and importing Cairo weather files into it, the program shows the results as following in Table 33.

Table 33: Climate Consultant Results



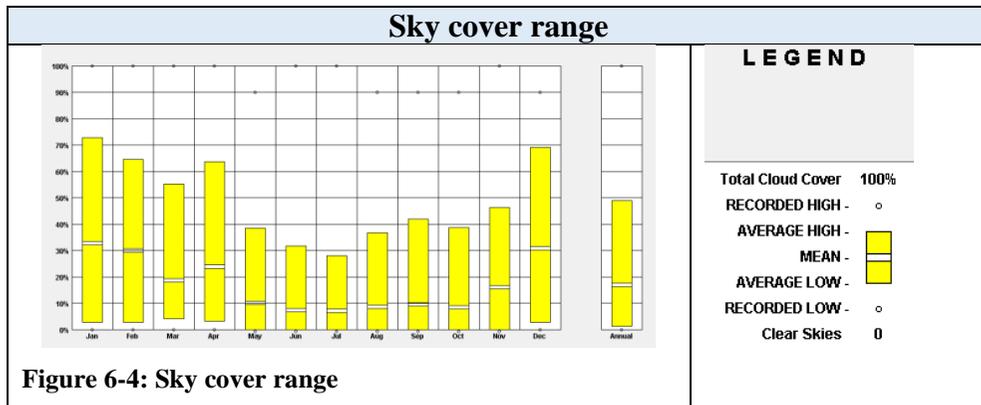


Figure 6-4: Sky cover range

Sep is the lowest month in the amount of the sky that is covered by clouds and The Jan month has the maximum sky cover range.

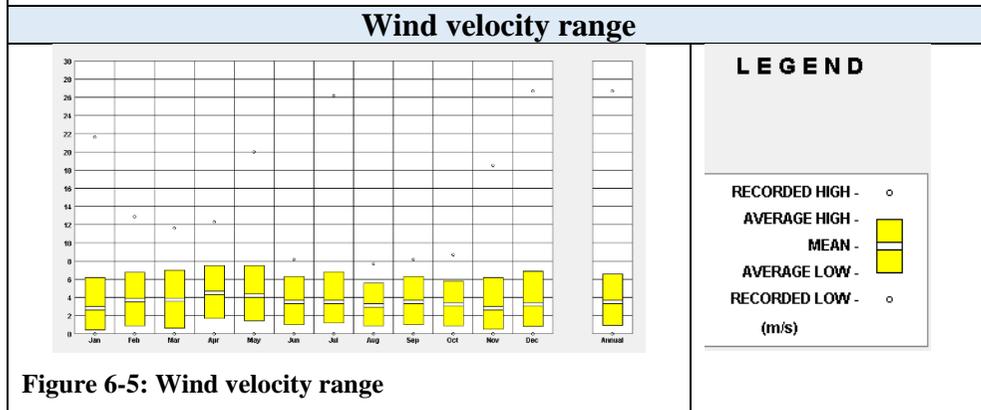


Figure 6-5: Wind velocity range

Apr month has the maximum wind velocity and the Dec month has the lowest wind velocity in the year.

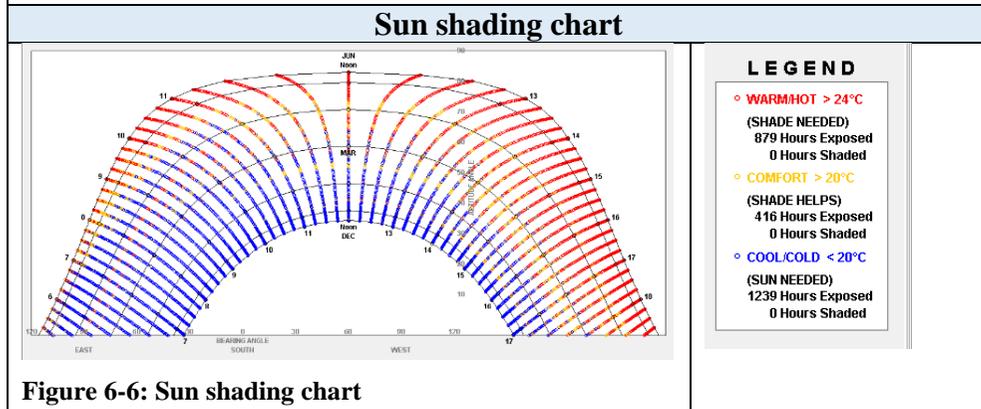


Figure 6-6: Sun shading chart

The building in the Jun month needs shading and in the winter months sun is needed.

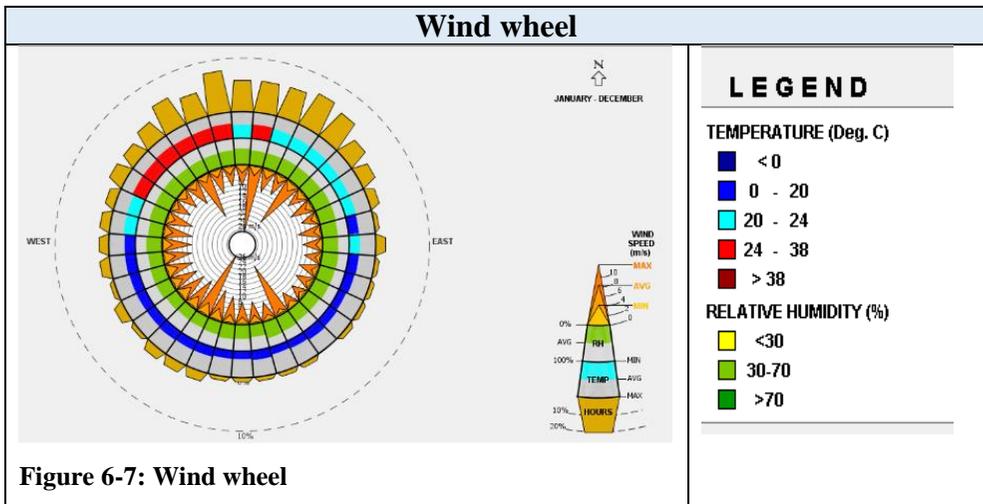


Figure 6-7: Wind wheel

Wind wheel which identifies the best orientation for the building is the North and North-West direction.

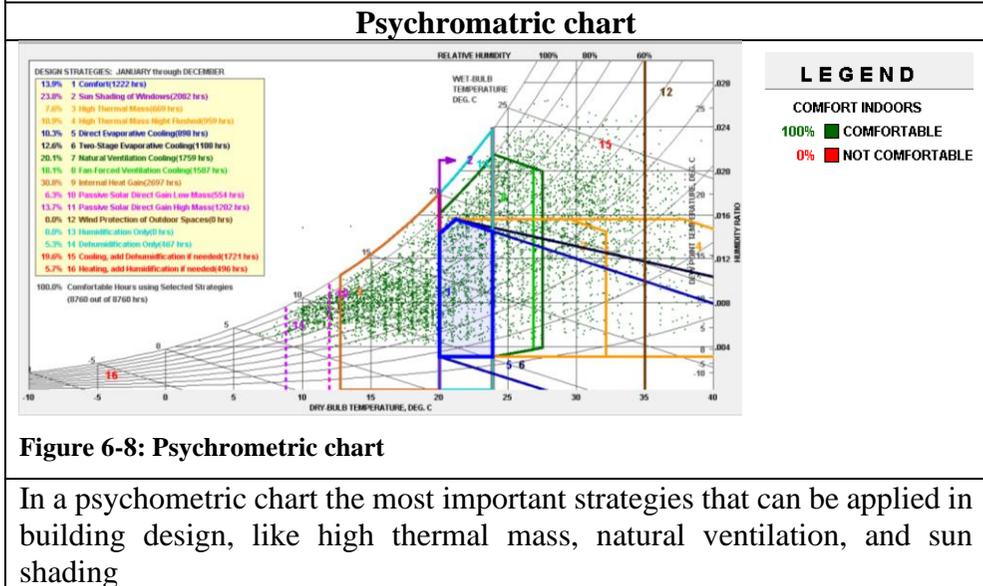


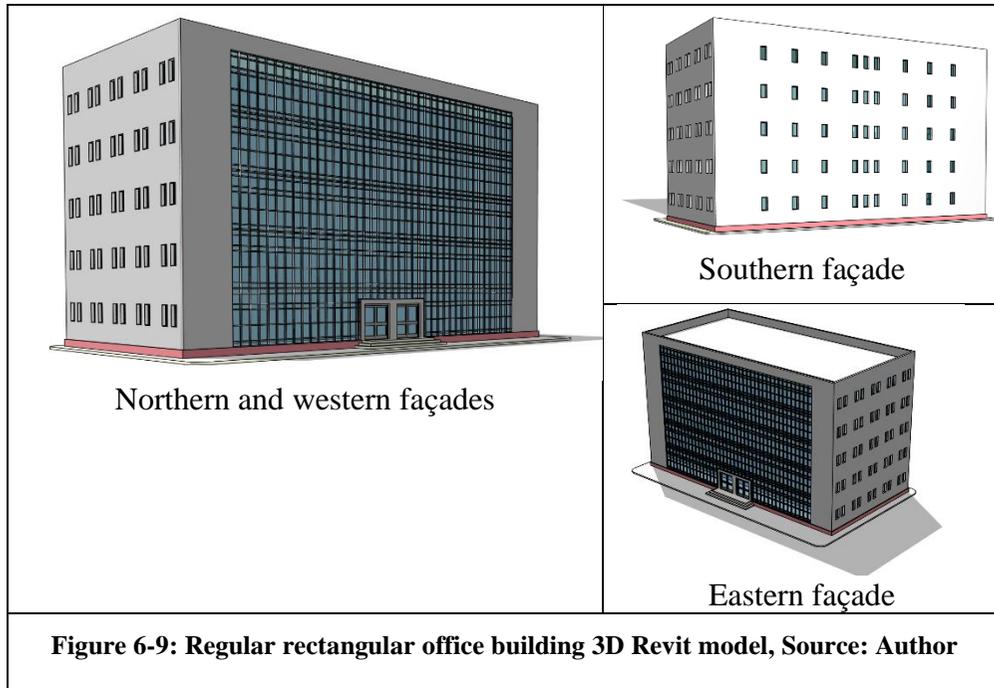
Figure 6-8: Psychrometric chart

In a psychrometric chart the most important strategies that can be applied in building design, like high thermal mass, natural ventilation, and sun shading

6.3.4 Regular office building design

The regular office building design is rectangular form, and its dimension is 15m*30m, its the northern façade is curtain wall to enhance the day lighting and ventilation. Eastern, western and southern openings are narrow to reduce the thermal load on the building (Figure 6-9).

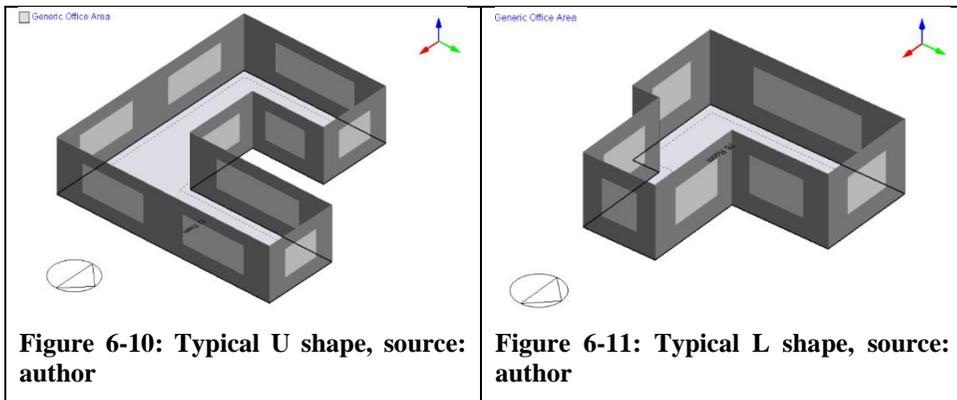
The building design grid is module 5*5m to construct the building with simple beam concrete structure system as shown.



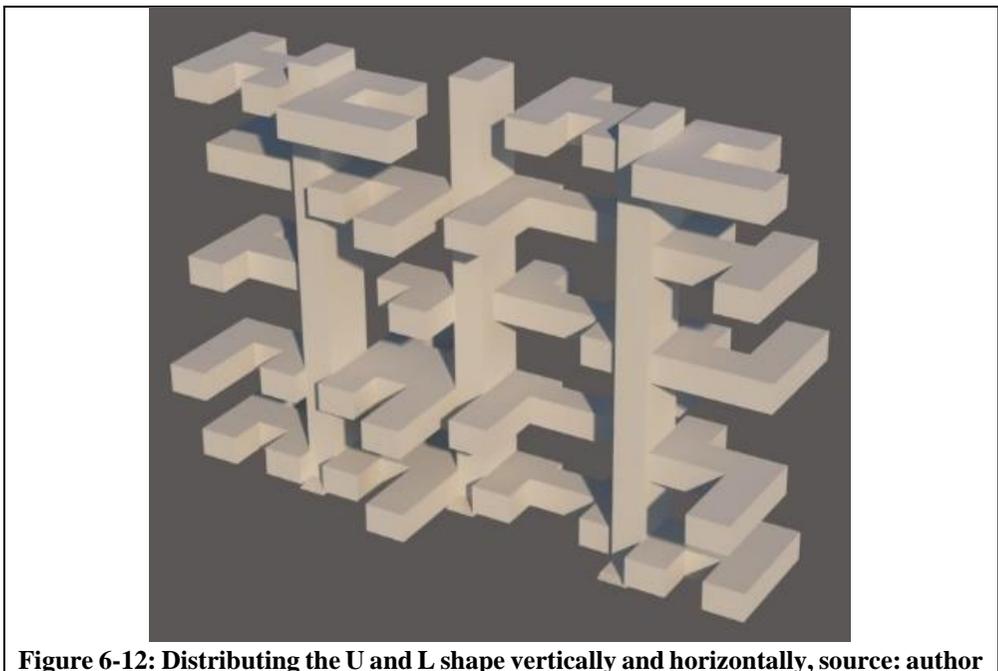
6.3.5 The proposed office building form concept

The proposed design interacts with the hot, arid climate of Egypt, by enhancing self-shading building. And the main concept is to design an office building with low energy needs by using some traditional environmental features to enhance natural ventilation through using vertical courtyards, wind catchers, also designing the building envelope with local highly insulating materials.

Office space unit is designed as typical U shape or L shape prototype to achieve the best results for daylighting and natural ventilation, it fit in the structure grid, as shown in (Figure 6-10,11)



The design is flexible into distributing the U and L shapes vertically and horizontally, they are connected horizontally to form courtyards and interactive outdoor spaces, and vertically units create dynamic vertical courtyards and self-shaded masses as shown in (Figure 7-13, 14), this distribution enhances shading and natural ventilation, in addition, to increase the exposure of the daylighting as shown in (Figure 6-12, 16).



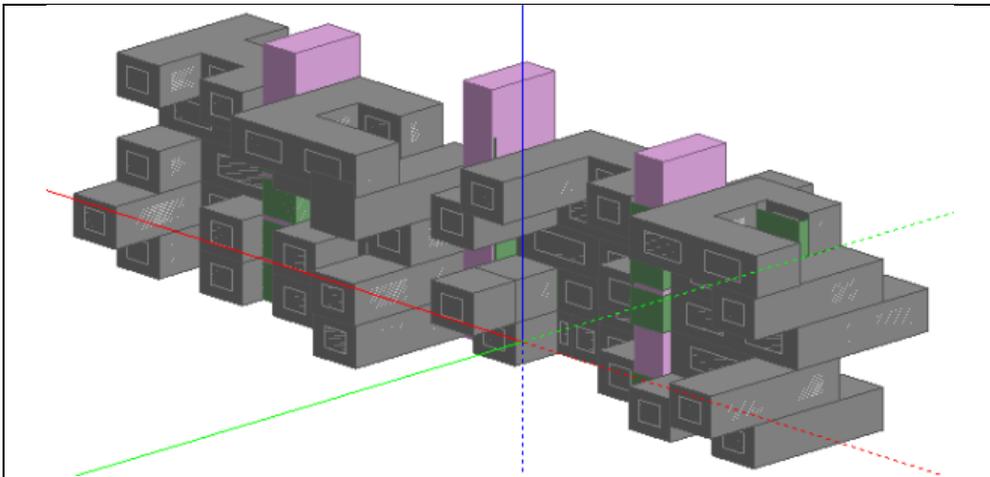


Figure 6-13: 3D mass model for the proposed office building, Source: Author

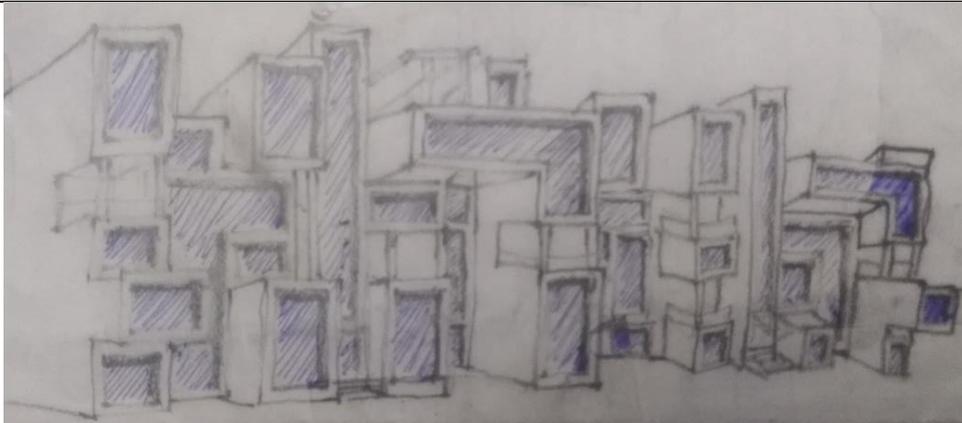


Figure 6-14: Office building north facade proposal sketch, Source: Author



Figure 6-15: 3D building proposal sketch, Source: Author.

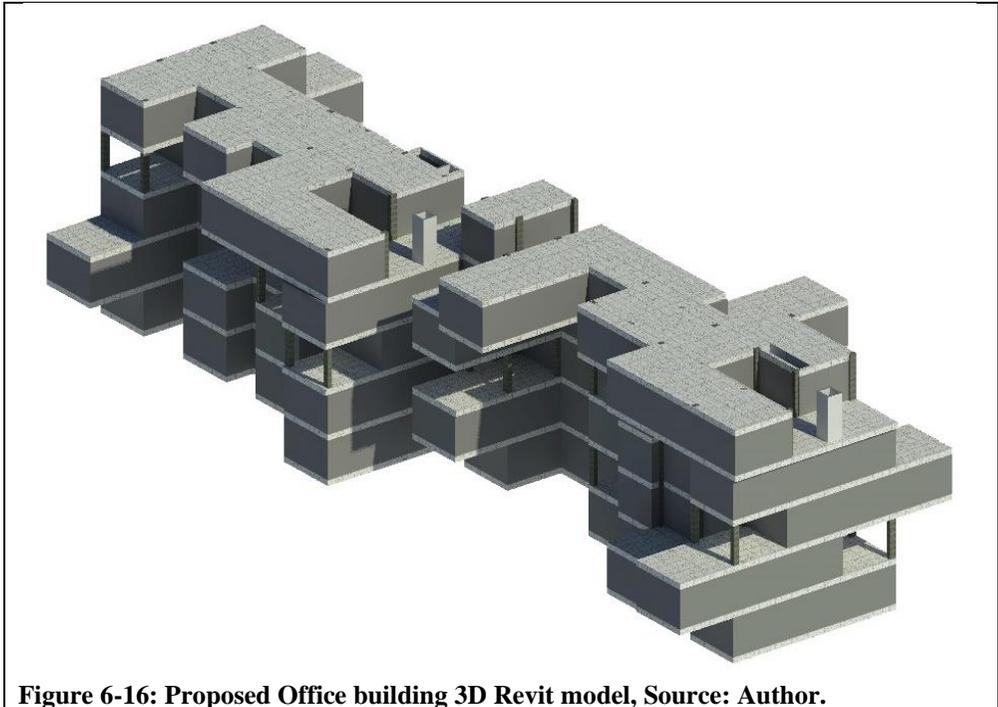


Figure 6-16: Proposed Office building 3D Revit model, Source: Author.

The building design grid is module 4*4m to construct the building with simple beam concrete structure system as shown. This structured system was chosen as an economical choice and locally available technic in Egypt as shown in (Figure 6-17).

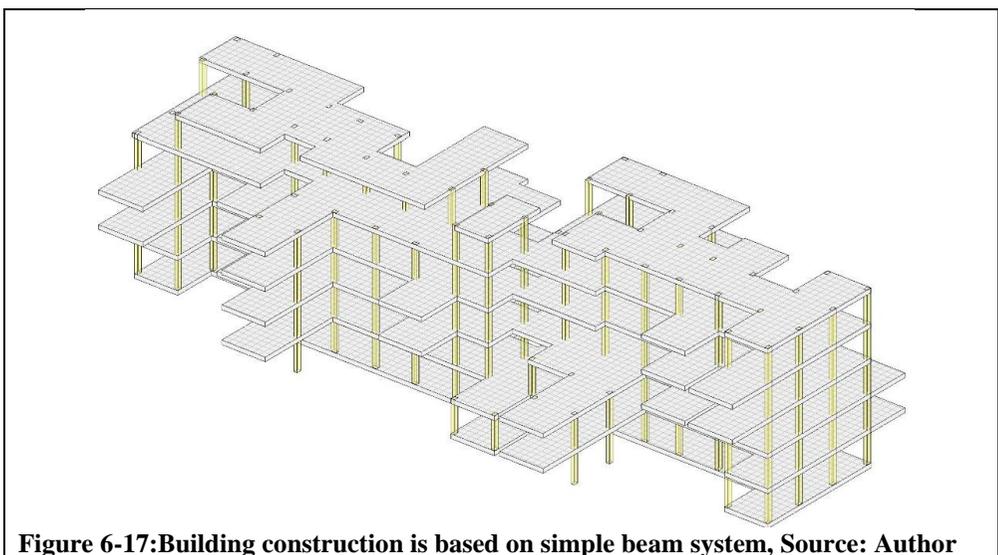


Figure 6-17: Building construction is based on simple beam system, Source: Author

6.3.5.1 Proposed office building plans

The proposed office building plans are shown in (Figure 6-18, 19, 20, 21, 22)

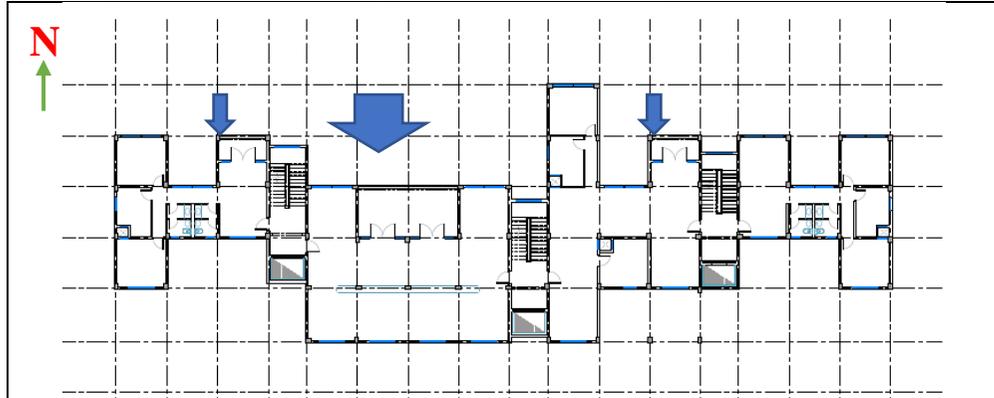


Figure 6-18: Office building proposed ground floor plan, Source: Author

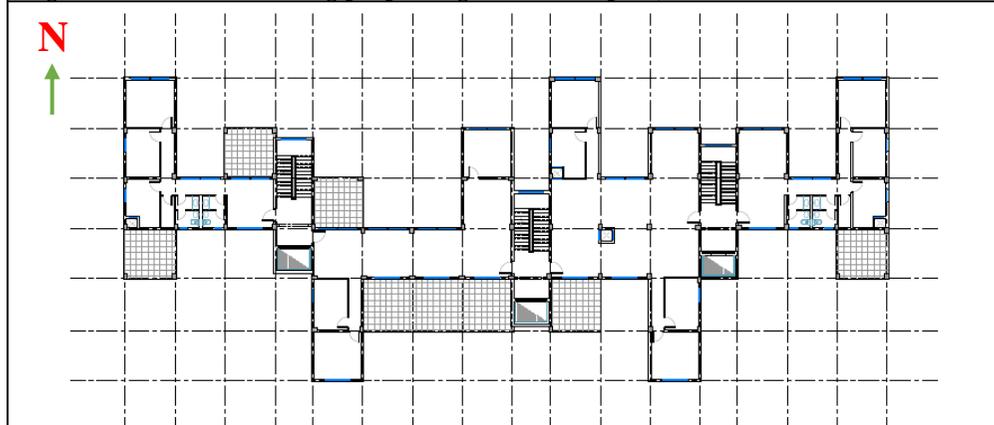


Figure 6-19: Office building proposed first floor plan, Source: Author

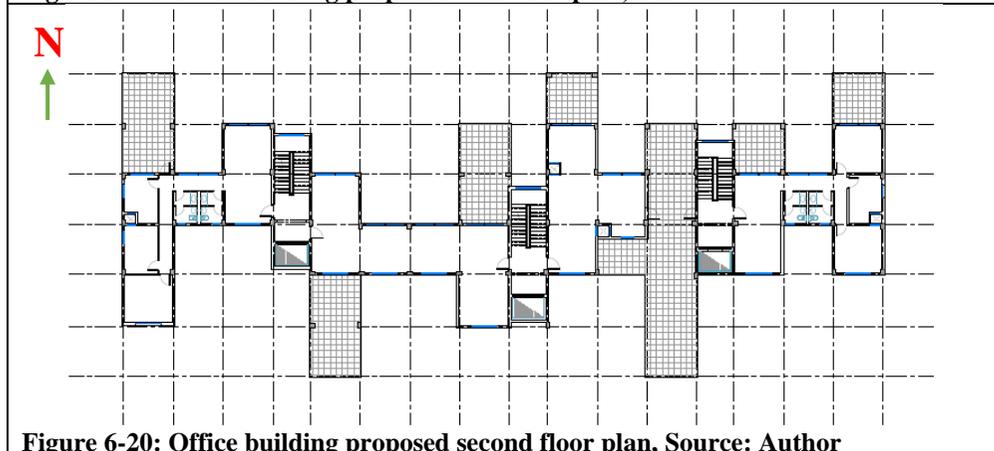


Figure 6-20: Office building proposed second floor plan, Source: Author

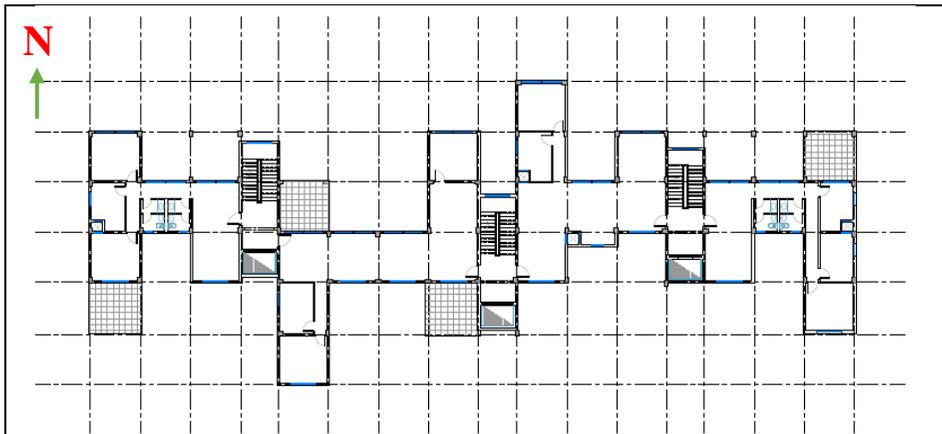


Figure 6-21: Office building proposed third floor plan, Source: Author

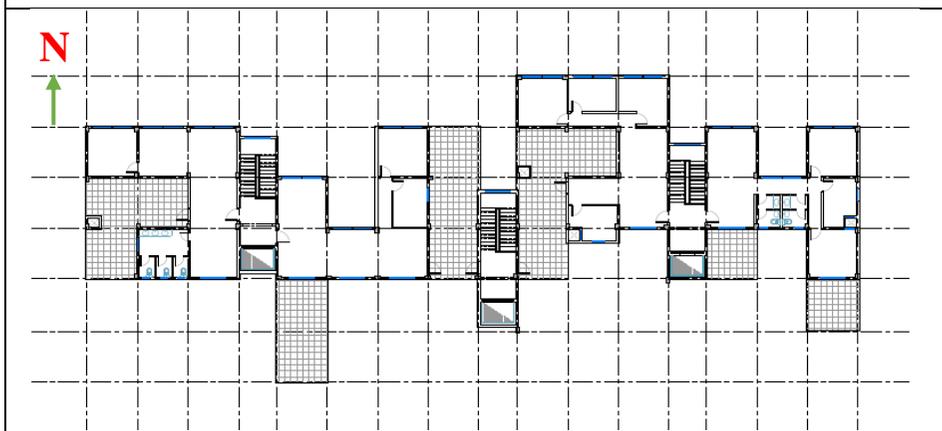


Figure 6-22: Office building proposed fourth floor plan, Source: Author

6.4 Comparison between the regular and proposed office building designs

After designing two proposals for office building, each design is integrated into Design Builder simulation program to compare the energy consumption needs for each one. The comparison results will define which design is lower in energy demand to continue towards achieving the zero energy goal. Software calibration is needed first to get accurate results.

6.4.1 Office building equipment energy consumption

Plug loads are the major contributor to the building's overall energy consumption; therefore, their power consumption is an important input for the load calculations. As the office building equipment is common energy load at the two designs, the equipment energy consumption is used in program calibration, by calculating the energy loads manually and by the Design Builder.

Weekdays and weekend power consumption profiles are developed for the most commonly used office equipment. ((ASHRAE, 2017). as shown in the following table:

Table 34: Equipment energy consumption

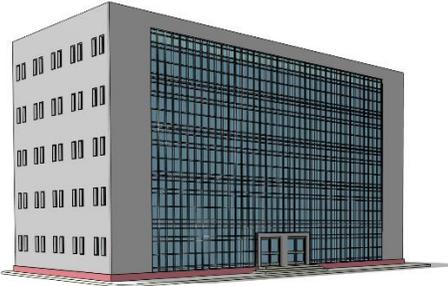
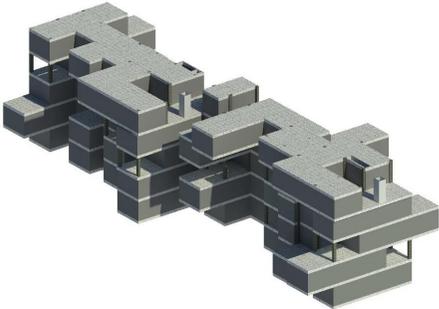
Space	Equipment	No.	Power	Total power
Reception	Computer	2	300	1,050
	Printer	1	200	
	Fax machine	1	250	
Offices	Computer	10	300	3,600
	Printer	3	200	
Meeting room	Computer	3	300	1,500
	Projector	3	200	
Work space	Computer	30	300	10,000
	Fax machine	4	250	
Copy and printer space	Printer	5	1400	7,000
Conference room	Computer	1	300	615
	Projector	1	315	
Support space	Computer	4	300	2,000
	Printer	4	200	
IT office	Computer	4	300	1,200
Control room	Computer	2	300	2,200
	Screen	8	200	
Cafeteria	Microwave	6	1200	28,400
	Boiler	6	3000	
	Coffee maker	4	800	
Total equipment energy consumption (kWh/year)				57,565

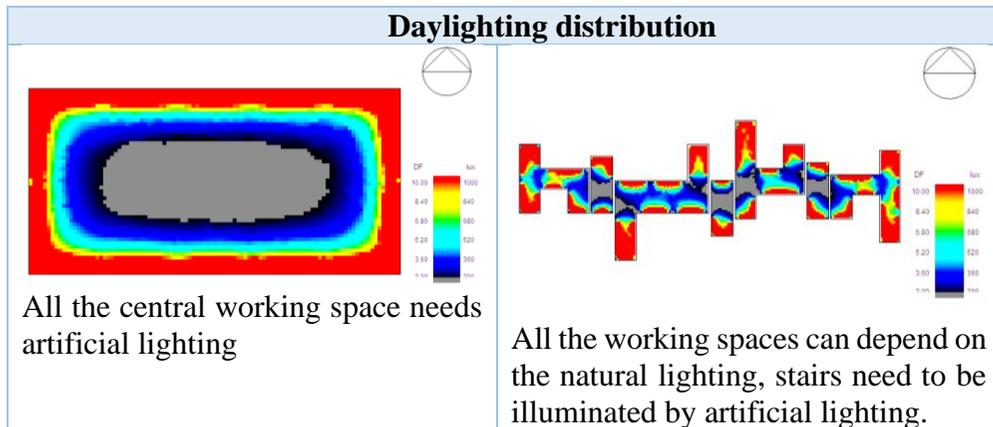
The total equipment energy consumption is 57,565 kWh/year from the manual calculation, and the simulation program equipment energy consumption = 46,193.97 kWh/year, the difference in the calculation due to specifying the working hours and extract the weekends and holidays from the total at the program.

6.4.2 Regular and proposed designs comparison

Each design is integrated at Design Builder program after its calibration, and the results as shown in the following table:

Table 35: Proposed design comparison, Source: Author.

Regular office building design	Proposed office building design
Building 3d form	
	
Total Building Area	
2250 m ²	2286 m ²
Energy simulation inputs	
Energy simulation is done for the both office building designs where: <ul style="list-style-type: none"> - The external walls thickness is 25cm brick. - Openings have regular single layer glass. - Roof has regular insulation layers. - No shadings are added - Fluorescent lighting is chosen for internal lighting. - Same HVAC system. 	
Energy simulation results	
<ul style="list-style-type: none"> - Total building energy consumption is 385127 kWh/yr. - The energy per total building area is 171.17kWh/m² 	<ul style="list-style-type: none"> - Total building energy consumption is 350103.99 kWh/yr. - The energy per total building area is 153.15kWh/m²



The comparison results show that the proposed design almost save 10% of the total building energy consumption, so the proposed design is chosen to evaluate the effect of applying the ZEPB design methodology on the rest of design steps.

6.5 Pilot case study energy reduction strategies

Integrating energy reduction strategies on the proposed office building design represents the second part at ZEPB design methodology, and it focuses on improving thermal comfort in the design by enhancing the building envelop, also, minimizing the building energy consumption as much as possible by designing and using efficient building service systems.

6.5.1 Enhancing the building envelop

Enhancing building envelop efficiency through increasing the envelop shell R value (walls, openings, and roof) to increase the building thermal resistance, and adding shadings to help in reducing building energy consumption.

In this part only each envelop design element is tested individually, by changing only one element and test its different options to choose the best choice for the final model.

6.5.1.1 External walls test

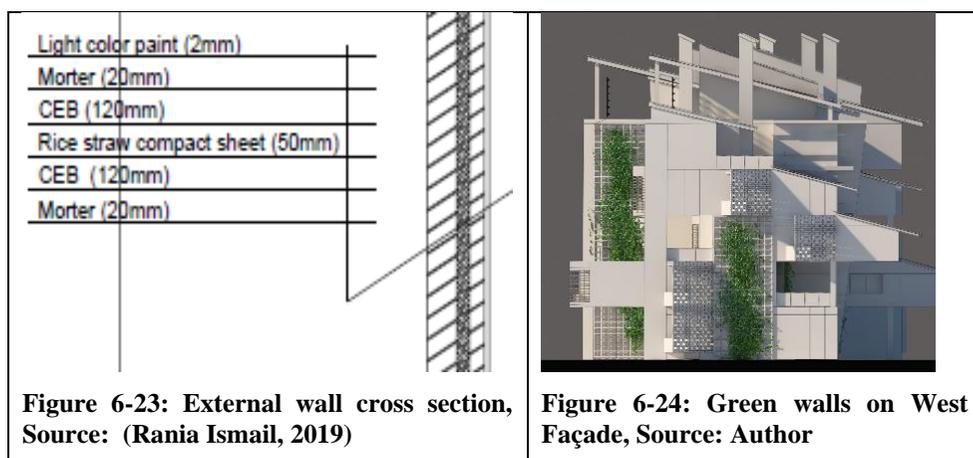
Increasing wall cross section by increasing thickness and adding insulation will increase time lag and save the building from the external influences subsequently will improve building and human thermal comfort.

After trying at the energy simulation program the effect of regular 25cm thickness brick external wall (R-Value = 2.4) or double 12cm thickness brick walls filled with air (R-Value= 3.3) on the building performance, the building energy consumption is not reduced.

Then trying external wall cross section consists of doubled brick wall 12cm thickness each and filled with thermal insulation sheet 5cm thickness (R-Value= 19.5) as shown in (Figure 7-23|), and the external walls are painted with light colors to reflect the heat. When the insulation sheet is Polystyrene, the total building consumption reduced to be 342315.07 kWh/year, and by trying Fiber glass or strawboard, it reduced the total building energy consumption to 339813.35 kWh/year, achieved the best results which is 3% reduction in energy consumption.

For the thermal insulation sheet, rice straw compact sheet is recommended to be used as insulation layer because rice straw one of the most important environmental problems in Egypt due to burning it instead of using or investing it as it can be used as an insulation material. (Ismail, 2019)

Also, Green walls are used in southern, eastern and western facades to reduce the thermal load on the external walls (Figure 6-24)

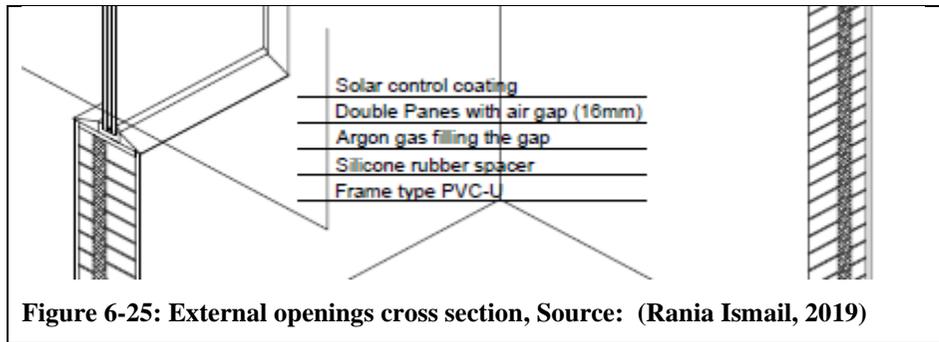


6.5.1.2 External Opening type

Improving external openings cross section gives a significant improvement of energy consumption and energy efficiency to the whole building. So, after trying single layer glass window (R-Value= 1.2) or double glazed fill with air (R-Value= 3.27), the double glazing glass fill with argon gas (R-Value= 4.08)

succeed to reduce the amount of heat transmitted into the building and achieve best energy reduction results which is reducing the total energy consumption to 329945.39 kWh/year and caused extra 3% reduction in energy needs.

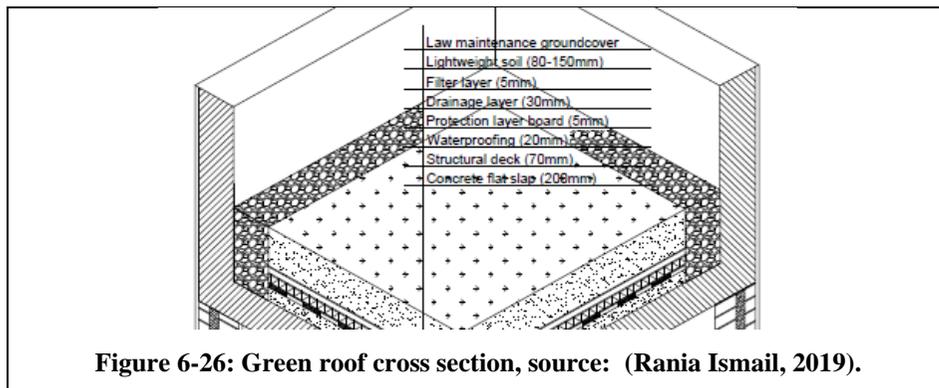
Also utilizing high-performance glazing with a low-E coating on the inner side of the inner pane (R-Value= 4.56) (faculty.ivytech.edu, 2019) helps in reflecting heat back out the building as shown in (Figure 6-25).



6.5.1.3 Roof design

Building roof design has a significant effect on transmitting heat and radiation into the building due to its large exposed area to sun rays and solar radiation.

The roof is designed to be covered by incline surface 35° carry on PV cells or Green roof which used to reduce heat transfer through the roof cross section as shown in (Figure 7-26). The components of the used green roof (R-Value= 26.4) are of 70mm structural deck, 20mm waterproofing, 5mm protection layer board, 30mm drainage layer, 5mm filter layer, and 80-150 mm lightweight soil. The roof design reduces the total energy design to 32795.02 kWh/year.



Enhancing the building envelop properties caused totally 7% energy reduction in building energy needs.

6.5.1.4 Shadings

Adding shadings is reducing energy consumption and save energy, many types of shading devices are used at different façade orientation according to literature review recommendations, the design include the following shadings:

- Horizontal and 35⁰ inclined shades with photovoltaic cells in the south façade.
- Vertical shading device semi open in the eastern and western facades to allow light but not heat.
- Building masses are designed to make shading in the facades as shown in (Figure 6-27).

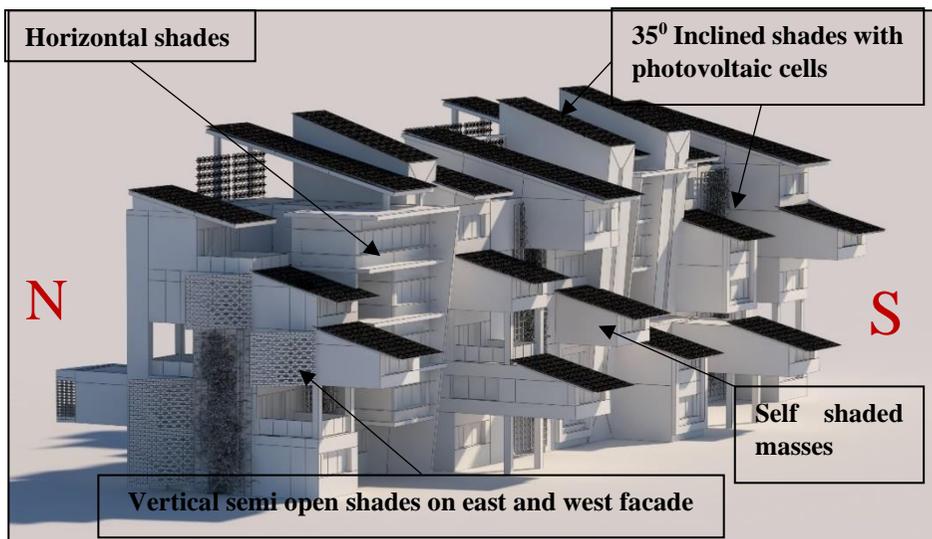


Figure 6-27: Building shades types at southern and western facades, source: author.

Adding shadings to the building caused in reducing building energy demand to 298702.35, which means 9% reduction in building energy needs.

6.5.2 Efficient Service systems

Designing and using efficient service systems are including ventilation system, lighting system, HVAC, and building equipment is required to reduce the building energy needs.

6.5.2.1 Proposed design ventilation study

Natural ventilation concept is integrated in the design from the early design stages, and it is one of the most important reason in reducing the building energy consumption. Natural ventilation strategies that used in the proposed office building design according literature review are:

- Building orientation is to the north, the preferable wind direction.
- Wide openings placed in the north façade in the windward to get a large amount of preferable air.
- Wind catchers to ventilate the spaces that not orientated to the north direction by catch the preferable air from the windward.
- Both wide opening and wind catchers make cross ventilation to facilitate the flow of air inside the building as shown in (Figure 6-28).
- Vertical courts with green elements and wind catchers are used to move the air across the building and gives a good ventilation and view to the surrounding spaces as shown in Figure (/ -0) and (Figure 6-29) to improve human thermal comfort and decrease cooling energy consumption.

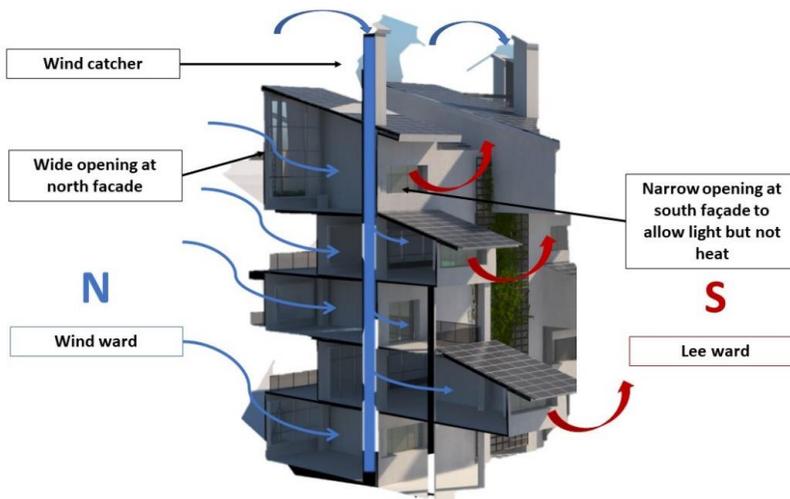


Figure 6-28: Section shows the ventilation flow in the proposed office building design,
Source: Author

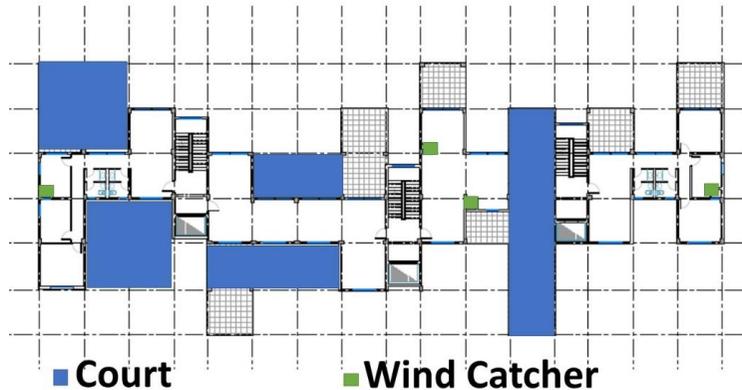


Figure 6-29: Plan shows the location of the wind catcher and courts, Source: Authors

6.5.2.2 Lighting study

The majority of the building offices can depend on natural lighting in the day and the daylighting distribution analyses is coming at the simulation results, in addition to an efficient artificial lighting system by using LED to enhance energy saving and reduce building energy consumption to 247315.25 kWh/year, which means 18% reduction in energy consumption.

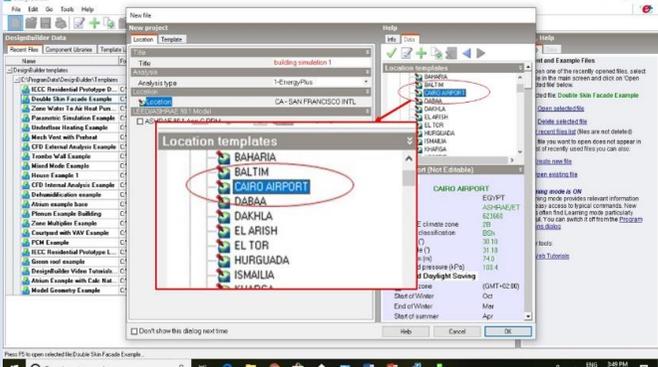
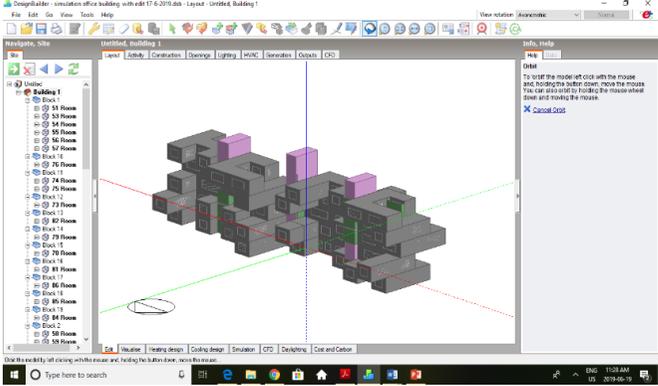
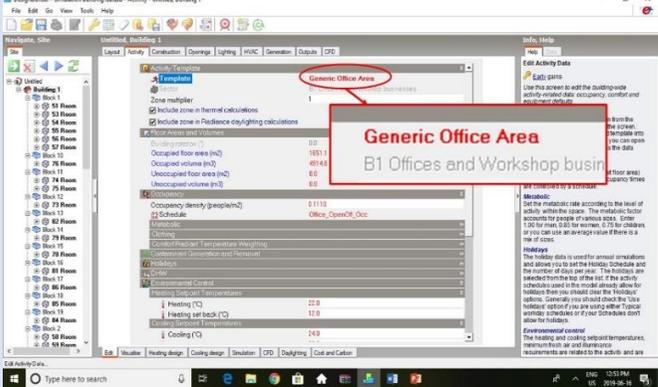
6.5.2.3 HVAC

A four-pipe fan coil unit is used in the building HVAC system, and it consists of a fan, chilled water cooling coil, hot water heating coil, and air filter. Fan coil units provide conditioned air to the area served by recirculating space air through the coils. (facilitiesnet.com, 2019)

6.5.3 The energy simulation steps on Design Builder for the proposed office building design

After finishing the 3D Revit model, the file is imported to DesignBuilder program and the building inputs is entered as shown in the following table (Table 36):

Table 36:Input model data into the DesignBuilder simulation program

Steps	DesignBuilder screen
<p>1-Choose the building location. And Cairo airport file is chosen.</p>	 <p>Figure 6-30: Choose building location in DesignBuilder, Source: Author.</p>
<p>2-Build the office building mass in Design Builder or import 3D Revit model file into Design Builder program.</p>	 <p>Figure 6-31: Building Revite model is imported to DesignBuilder program, Source: Author</p>
<p>3-Choose building activity as Generic Office Area,</p> <ul style="list-style-type: none"> - Set the working hour schedule from 8:00 – 16:00 weekdays. - Annual holiday schedule 18 days off. - Choose heating and 	 <p>Figure 6-32: Choose building activity in DesignBuilder, Source: Author.</p> <p>8h daytime working hours is recommended from the analytical study.</p>

cooling set points from environmental control, and office equipment power factor (W/m^2).
 - Office equipment power density as ASHRAE is $11.77 w/m^2$

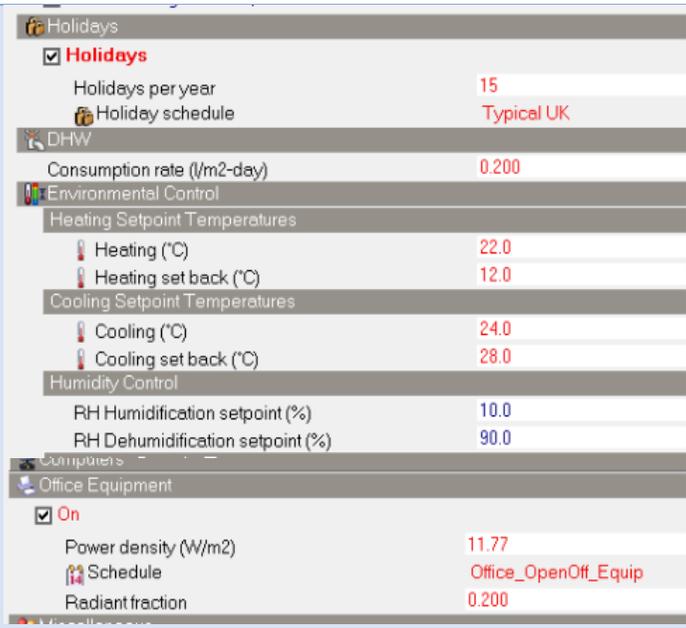


Figure 6-33: Set Holidays per year, heating and cooling set points, office equipment power density factor. Source: Author

Hearing and cooling set points determined by ASHRAE

4- From the construction tab choose the external, internal wall and roof layers.

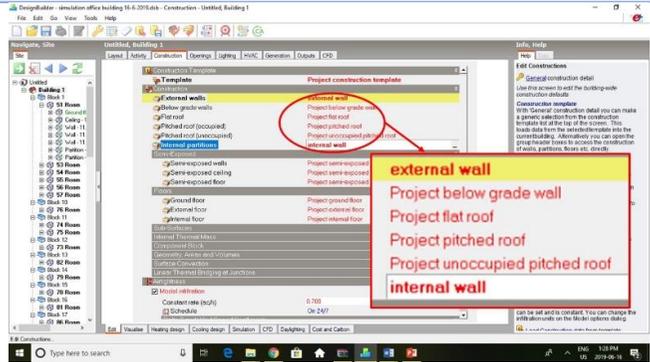


Figure 6-34: Choose building construction details in DesignBuilder, Source: Author.

After trying many external walls cross section, double wall 12cm thickness filled with insulation sheet achieved the best results.

Edit construction - external wall

Constructions

Layers Surface properties Image C

General

Name external wall

Source

Category Walls

Region EGYPT

Colour

Definition

Definition method 1-Layers

Calculation Settings

Layers

Number of layers 5

Outermost layer

Material Copy of Cement/plaster/mortar - cement plaster

Thickness (m) 0.0200

Bridged?

Layer 2

Material Brick

Thickness (m) 0.1200

Bridged?

Layer 3

Material Glass fibre/wool - fibre, strawboard-like

Thickness (m) 0.0500

Bridged?

Layer 4

Material Brick

Thickness (m) 0.1200

Bridged?

Innermost layer

Material Cement/plaster/mortar - cement plaster

Thickness (m) 0.0200

Bridged?

Model data

Insert layer

Figure 6-35: Choose external wall layers. Source: Author

- 4- Chooses from opening tab:
 The opening type double glazed filled with argon gas.
 The openings measurement.
 Choose the shadings type applied on the building facades.

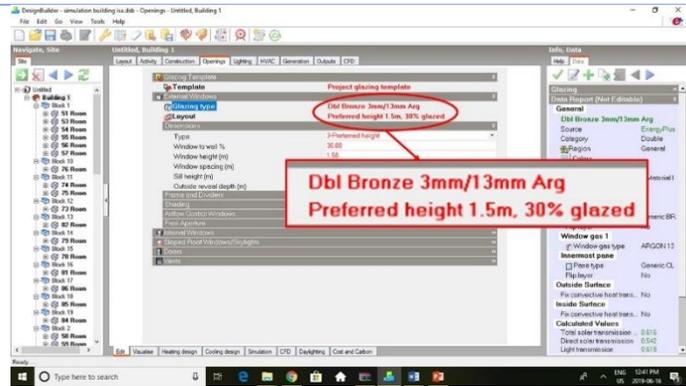


Figure 6-36: Choose building opening type in DesignBuilder, Source: Author.



Figure 6-37: choosing building shadings type in DesignBuilder, Source: Author.

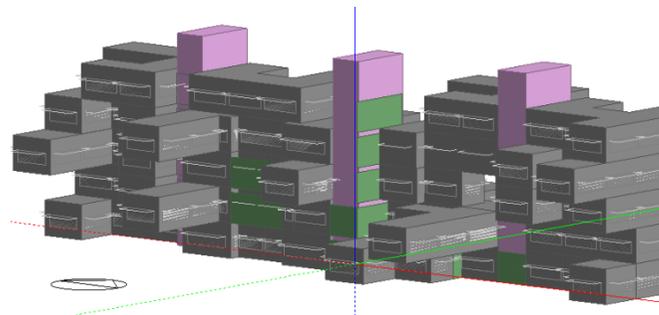


Figure 6-38: Horizontal shadings applied on southern façade, Source: Author.

5- Choose from the HVAC tab the system used in the proposed design which is Fan Coil 4 pipes unit for building cooling and heating.

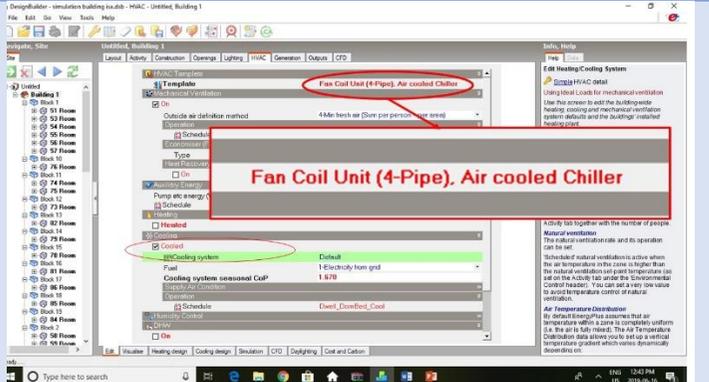


Figure 6-39: Choose building HVAC system in DesignBuilder, Source: Author.

- 6- Insert all the deferent variables and modifications on the design that can affect on the building consumption into the DesignBuilder simulation file.**
- 7- Run the energy simulation to get the results.**

6.5.4 Simulation results

Several energy simulations have been performed to calculate and choose the best choices for the envelop materials and the effect of shadings added on, but in this part the search is discussing main four energy simulation scenarios the proposed office building design to minimize the building energy needs to the minimum. The first simulation is for the office building design base case without any energy reduction strategies to calculate the building energy needs after modifying the regular rectangular office building form to interactive environmentally design, the second simulation is for the design when the building shell (walls – openings – roof) is insulated to study building envelop insulation effect and this simulation scenario name is “Treatment 1”, the third simulation is for the base case with shadings added on to study the shadings effect in reducing the building energy consumption and this scenario name is “Treatment 2”, and the fourth simulation is for the proposed design while treatment 1 and 2 are combined to calculate the effect of insulating the building envelop and adding shading and this scenario name is “Treatment3”.

6.5.4.1 Office building base case

Energy simulation is done for office building base case where the external walls thickness is 25cm brick, openings have regular single layer glass, roof has regular insulation layers and no shadings are added. Also, fluorescent lighting is chosen for internal lighting. And using the same HVAC system.

The building energy consumption without applying the energy reduction strategies on the envelop is **350103.99 kWh/year** and the energy per total building area is **153.15kWh/m²**, by comparing the results with the rectangular regular form, shows that the proposed design almost saves **10%** of the total building energy consumption.

Base case energy consumption details are:

- Heating (heating 8723.55, water system 2498.63)11222.18 kWh
- Cooling 210742.08 kWh
- Lighting 78968.94 kWh
- Equipment 49170.79 kWh.

6.5.4.2 Treatment 1: Changing walls, openings and roof insulation

This energy simulation is done after changing the external walls cross section to the proposed one, changing openings to double glazed fill argon gas, changing roof insulation layers to green roof, the total building energy consumption is **32795.02 kWh/year** which means **5.75%** reduction in energy consumption, and energy per total building area is **143.17kWh/m²**.

“Treatment 1” energy consumption details are:

- Heating (heating 3255.07, water system 2359.5) 5614.57 kWh the change caused 50% reduction.
- Cooling 202929.98 kWh the change caused 3.2% reduction.
- Lighting 74192.50 kWh the change caused 6.0% reduction.
- Equipment 46193.97 kWh the change also caused 6.0% reduction.

And the following chart (Figure 6-40) shows the deference between base case and Treatment1 in building energy consumption.

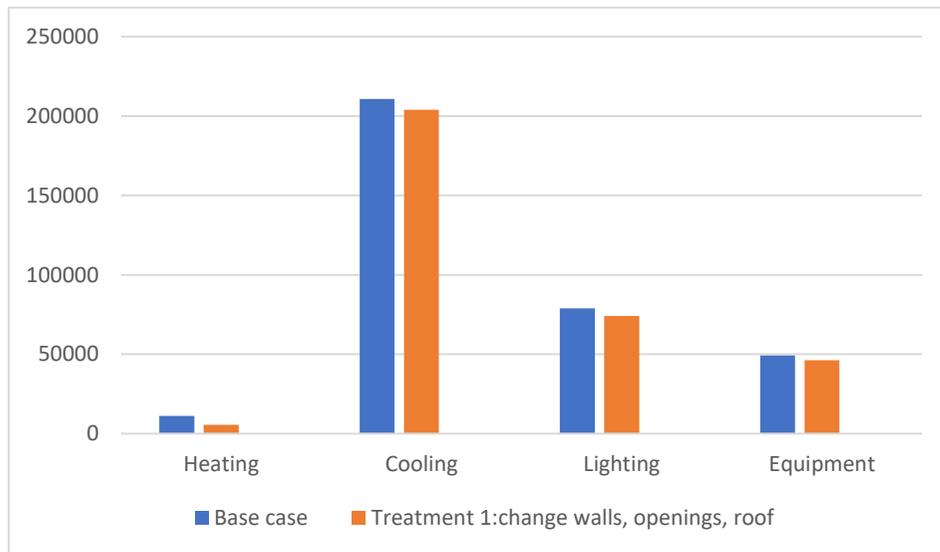


Figure 6-40: Difference in energy consumption between Base case and Treatment 1, Source: Author

6.5.4.3 Treatment 2: Adding shadings to the building design

Energy simulation is done after adding horizontal shadings on the base case, the total building energy consumption is **319049.37 kWh/year** and energy per total building area is **139.57kWh/m²**, the change addition to the design caused **9%** reduction in energy consumption.

“Treatment 2” energy consumption details are:

- Heating (heating 10907.32, water system 2498.63) 13,405.95 kWh the change caused 16.28% increase in heating energy consumption.
- Cooling 177,500.69 kWh the change caused 15.77% reduction.
- Lighting 78,968.94 kWh the change caused no energy reduction.
- Equipment 49,170.79 kWh the change caused also no reduction.

And the following chart (Figure 6-41) shows the deference between base case and Treatment2 in building energy consumption.

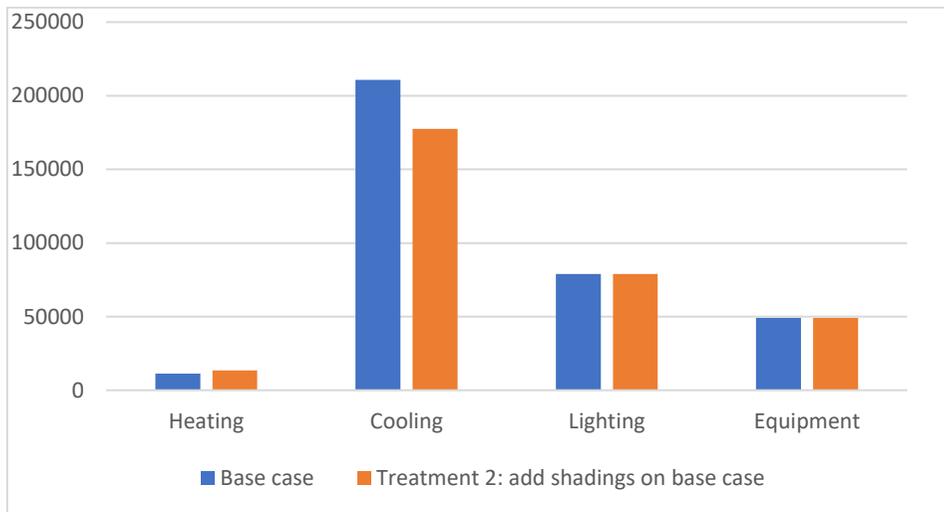


Figure 6-41: Difference in energy consumption between Base case and Treatment2,
Source: Author

6.5.4.4 Treatment 3: Energy simulation of proposes office building design

After applying the proposed energy reduction strategies from the proposed ZEPB design methodology on the office building design by combining treatment1 with treatment 2 and change the artificial lighting to Led, the building energy consumption is **245232.39 kWh/year** and energy consumption per total building area is **107.28kWh/m²**, this changes helped in building energy optimization by **30%** reduction in energy consumption.

“Treatment 3” energy consumption details are:

- Heating (heating 7420.10, water system 601.23) 8021.34 kWh the change caused 28.52% reduction.
- Cooling 153920.83 kWh the change caused 26.96% reduction.
- Lighting 37096.25 kWh the change caused 53.02% reduction.
- Equipment 46193.97 kWh the change caused also 6.0% reduction.

And the following chart (Figure 6-42) shows the deference between base case and Treatment3 in building energy consumption.

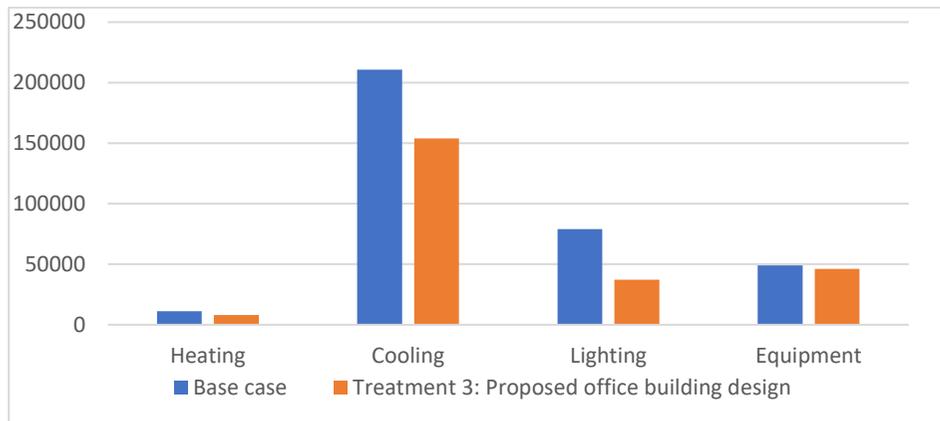


Figure 6-42: Difference in energy consumption between Base case and Treatment3, Source: Author

6.5.4.5 Comparison between total energy consumption results

This comparison shows the effect of applying each element in the ZEPB design methodology on the public building design, the energy consumption for each scenario is:

- Regular rectangular office building energy consumption is 385127 kWh/year.
- Base case total energy consumption is 350103.99 kWh/year.
- Treatment 1 total energy consumption is 329945.39 kWh/year when the building envelop is insulated.
- Treatment 2 total energy consumption is 319049.37 kWh/year when shadings added on the building.
- Treatment 3 total energy consumption is 245232.39 kWh/year when all the energy reduction strategies are applied in the energy simulation as shown in (Figure 6-43).

This comparison between energy consumption results shows that:

- Interacting the building form to the local climate conditions saves up to 10% of the total building energy consumption.
- Insulating the building envelop can save up to 5.75% from the total energy consumption.
- Adding shadings on the building openings can save up to 8.87% from the total energy consumption.

- After enhancing the building form environmentally, applying all the energy reduction strategies together can reduce the energy consumption by 28.52%.
- Changing the artificial lighting type from florescent to LED reduce lighting energy consumption by 53% as shown in Treatment 3.
- Developing the design from the regular form to Treatment 3 saves 36.33% from the building energy needs.

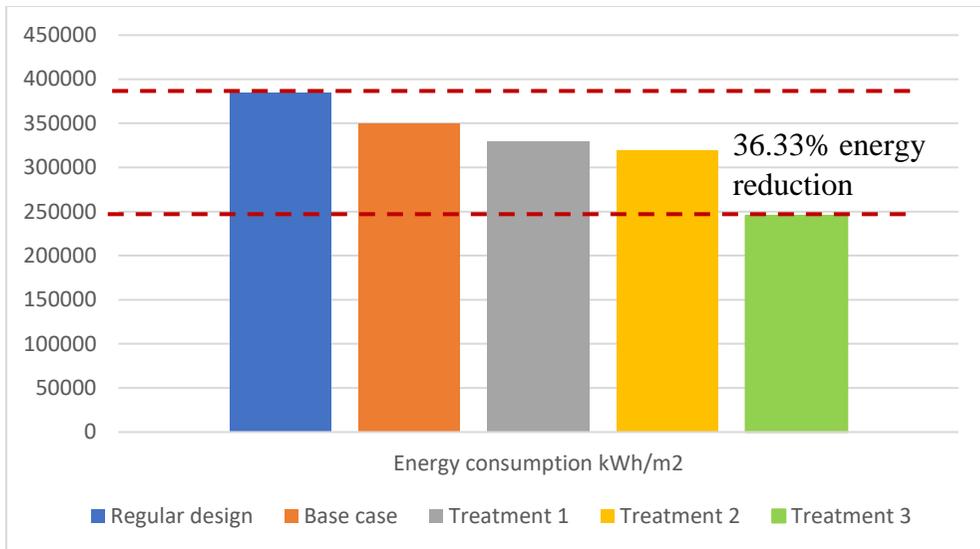


Figure 6-43: comparison between all cases in total energy consumption, Source: Author.

After simulating the proposed office building design scenarios and making, the optimum solution at “Treatment 3” achieved the best results which is reducing the total energy needed to **245232.39 kWh/year**.

6.5.4.6 Comparison between energy consumption per meter square

In Europe energy consumption for public building was estimated at 280 kWh per square meter (dexma.com, 2019), in USA and Canada the analysis found that the energy consumption of non-certified buildings could be minimized to 159 kWh/m² and in certified buildings (LEED, BREEAM), the average electricity consumption per square meter is 150 kWh/m² (SKANSKA, 2017). In the practical study at regular form the energy consumption per meter square is 171.17 kWh/m², base case is 153.15kWh/m², at (Treatment 1) it is 144.33kWh/m², at (Treatment 2) it is 139.57kWh/m², until (Treatment3) design is succeeded in reducing it to 107.28kWh/m². (Figure 7-44)

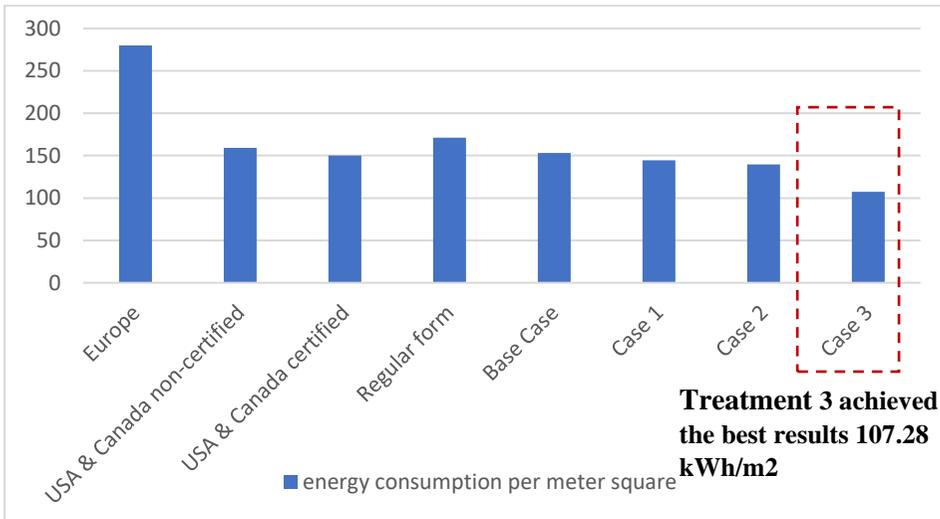
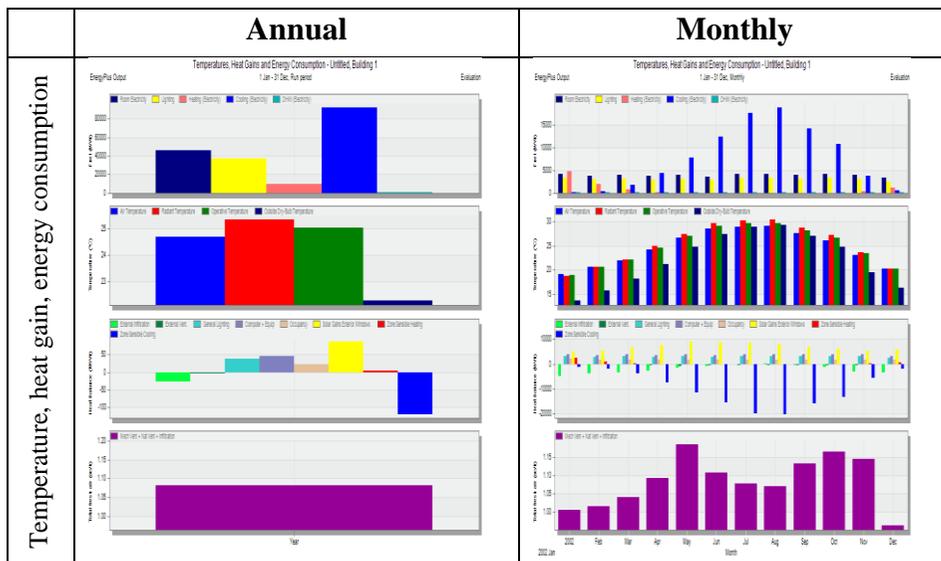


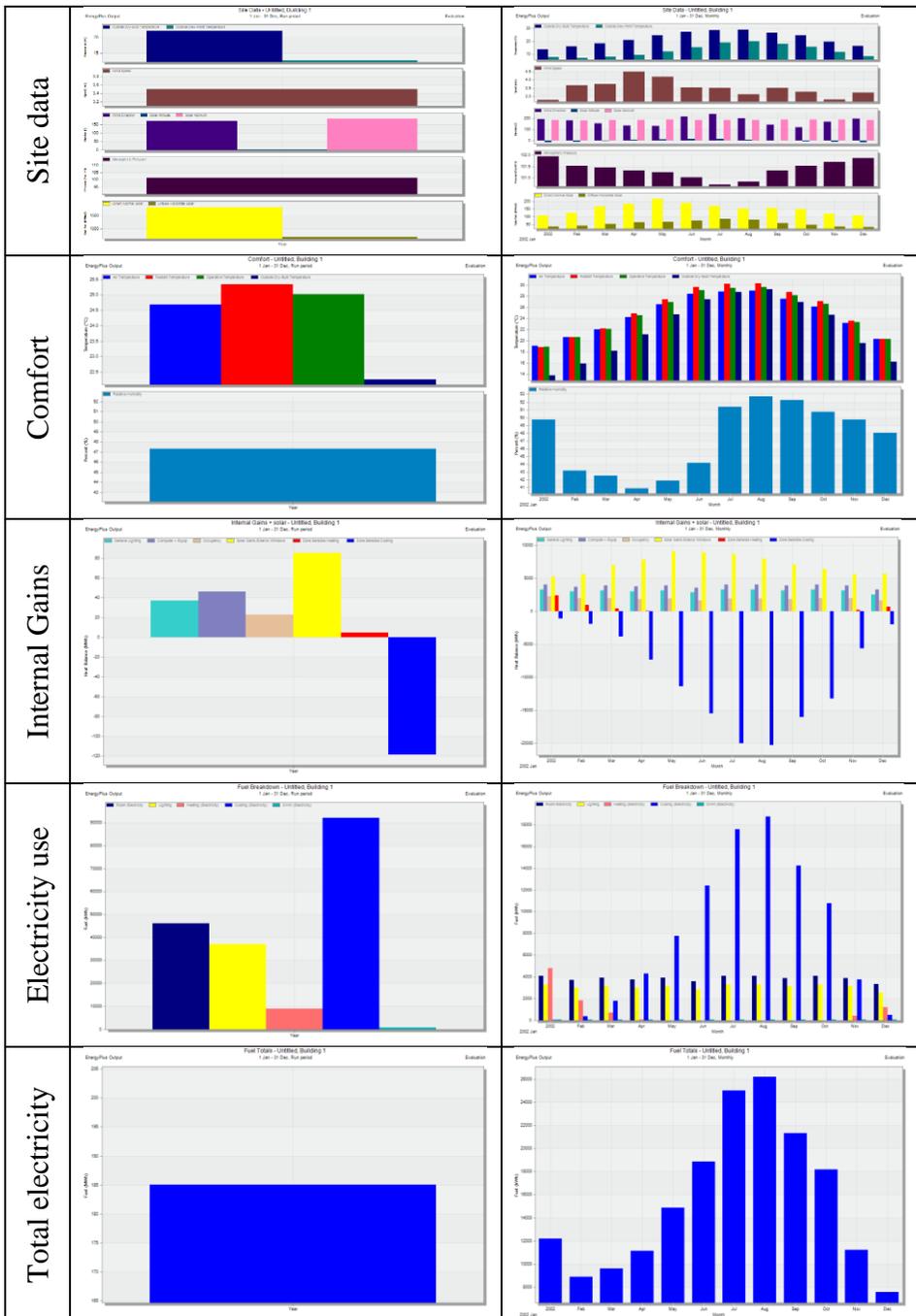
Figure 6-44: Energy consumption per meter square between international studies and practical study, Source: Author.

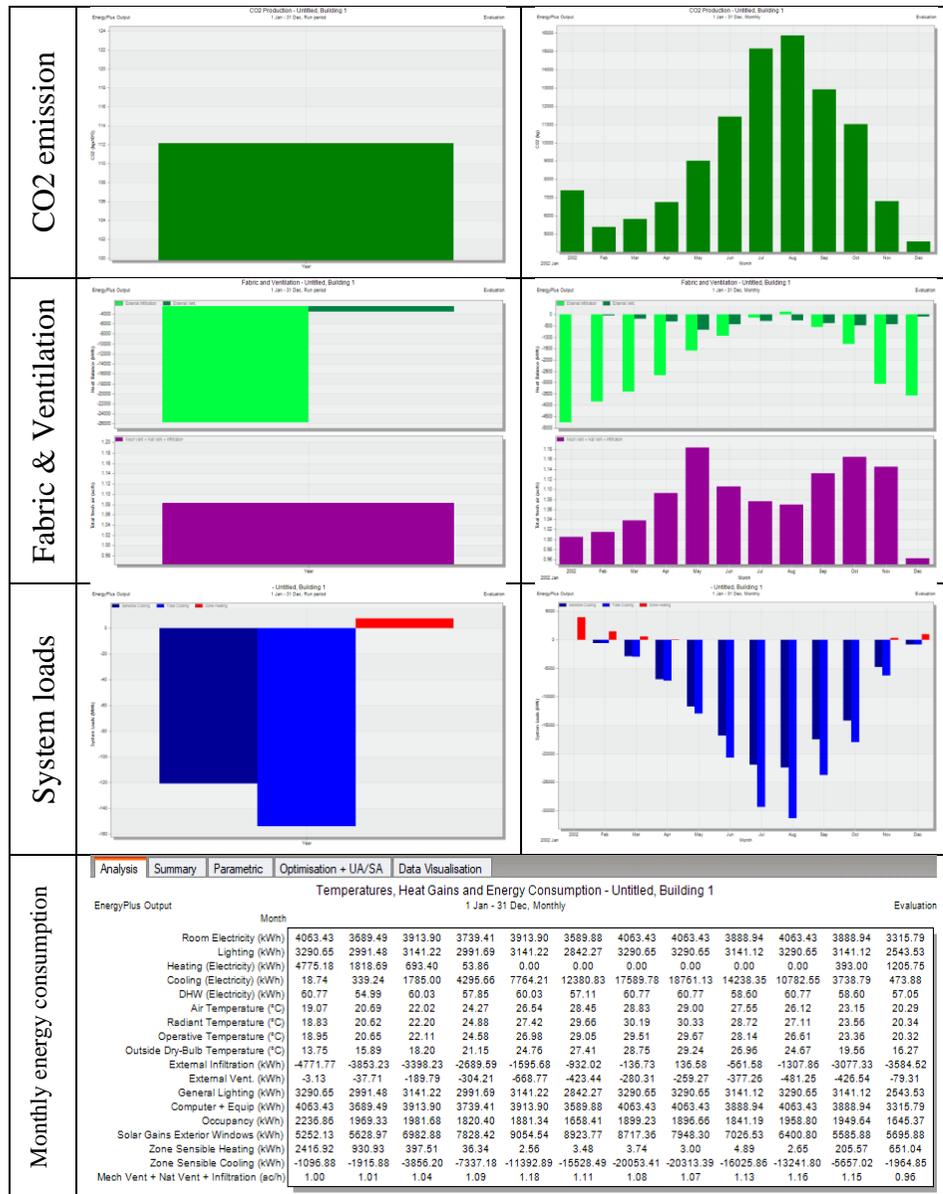
6.5.4.7 Annual and monthly simulation results for Treatment 3

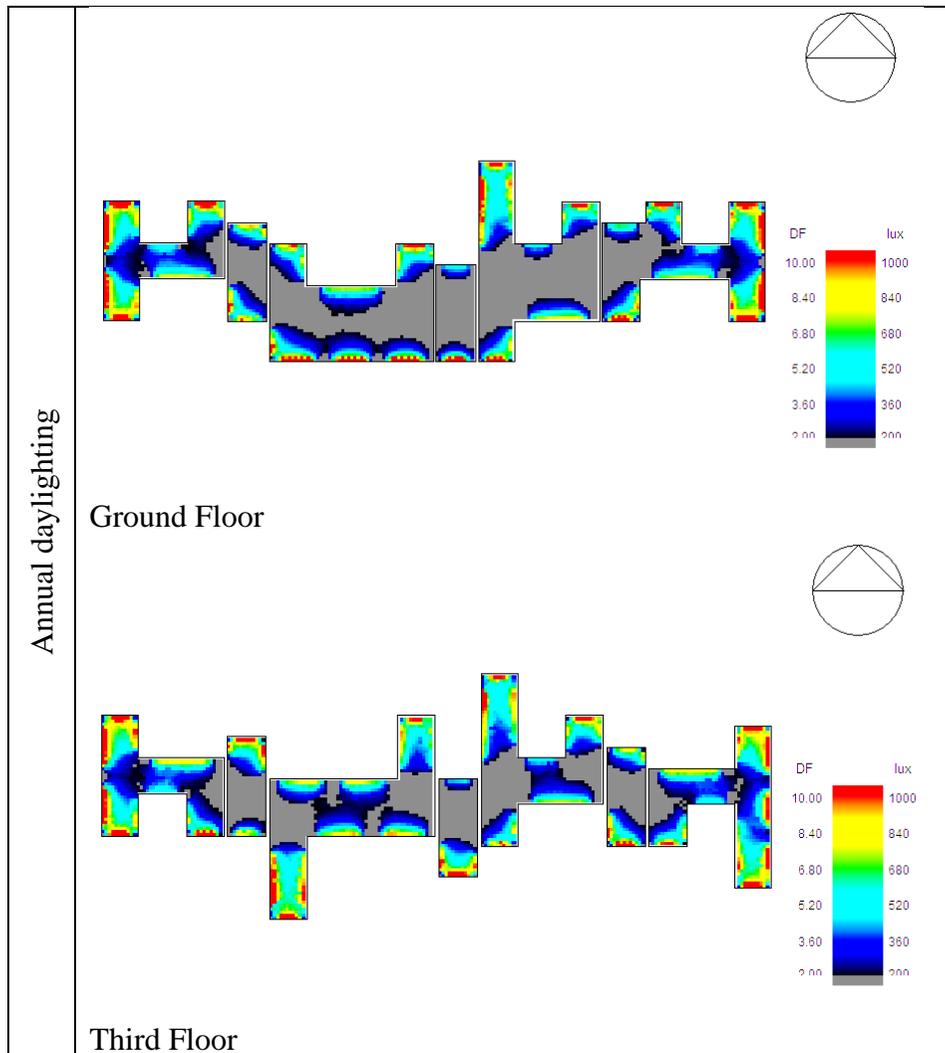
“Treatment 3” reached to the best results in energy consumption rate and the energy demand reduced to the minimum, the design builder energy simulation results for annual and monthly consumption are in the following table:

Table 37: Case 3 DesignBuilder energy simulation results









General notes on DesignBuilder energy simulation are:

- Temperature, heat gain, and energy consumption annual and monthly chart show that cooling is the highest factor in energy consumption.
- Comfort monthly chart shows that August is the highest month in temperature of air, radiant, operative, outside dry bulb, and humidity.
- The internal gains chart shows that solar gains from exterior treatment are the highest.
- Electricity use annual chart shows that cooling is the highest energy consumer, specially at July and August.

- Co2 emissions annual and monthly chart equal to total fuel annual and monthly chart, which refer to reducing building energy consumption equal directly reducing in CO2 emission.
- Lighting simulation refers to the daylighting distribution and the places where artificial lighting is necessary.

6.6 Energy production at the office building design

Integrating renewable resources to the building design is mandatory decision to design ZEPB. The proposed office building is designed to produce electricity by solar energy to cover building energy needs, if it does not cover the total energy needs, another renewable energy resource will be integrated into the design as a try to achieve zero energy goal in Egypt.

6.6.1 Solar energy integration into office building design

Solar energy is integrated into the building design by several ways, first, solar water heater is used to supply the building with hot water, second, solar photovoltaic cells which is integrated into the building roof and southern façade to take the advantages of the sun and third, semi transparent PV sheets which is integrated on all the building external openings to take advantages of daylighting in generating electricity.

6.6.1.1 Solar water heaters

Solar water heaters are used to supply hot water to the building, the heaters sunlight strikes are placed on the roof face the south direction and the water storage tanks are placed on the basement. AP*30 solar collector is chosen (Apricus Solar, 2014) and it can be used to produce 300L of hot water, As the office building consist of 5 story and serve 200 person so 3 solar water heater can be installed to serve the whole building as shown in the (Figure 6-45,46).

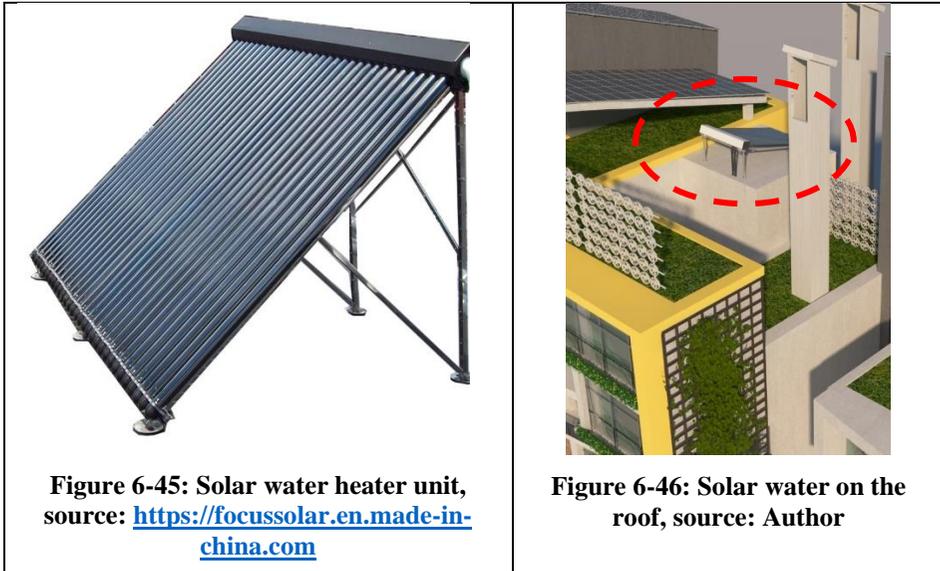


Figure 6-45: Solar water heater unit,
source: <https://focussolar.en.made-in-china.com>

Figure 6-46: Solar water on the roof,
source: Author

6.6.1.2 Solar photovoltaic cells

Solar photovoltaic cells are integrated into the building roof and south façade. All the solar cells are inclined to maximize its efficiency. And to calculate the number of PV panels that covered the inclined roof surface and south façade incline shadings by 35 degrees as shown in (Figure 6-47), first, choose the type of photovoltaic cells which is Mono-crystalline blue PV panel (ENF Solar, 2018) that can generate 300watt in average, second, calculate the area of the chosen type of photovoltaic cells which is $= 0.99 \times 1.95 = 1.94 \text{m}^2$, Then divide the total inclined roof area available on the design of the building $= 568 \text{m}^2$ by the PV panel area 1.94m^2 , so the total number of PV panels can be integrated into the building design is 292 panel.

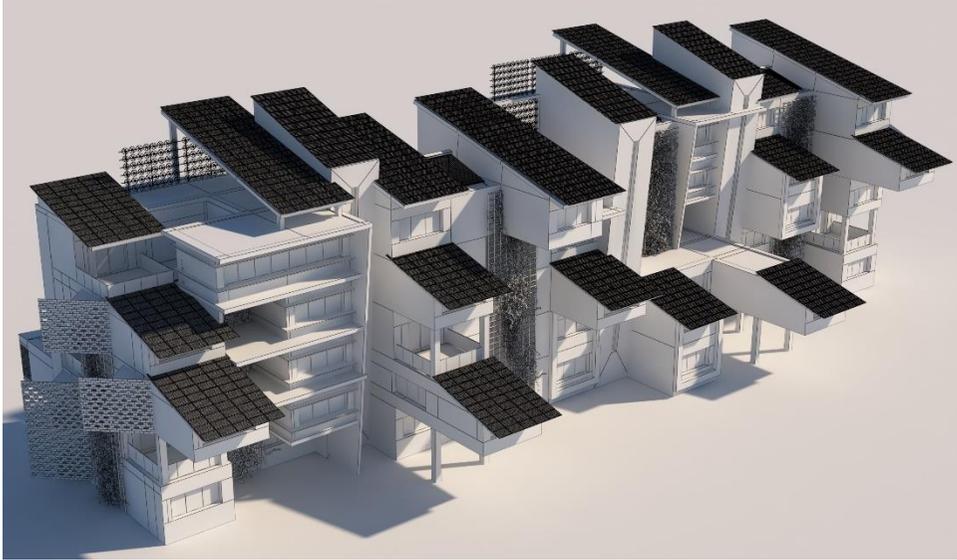


Figure 6-47: PV panels that covered roof incline surface and south façade incline shadings, Source: Author.

And to estimate the electricity generated in output of a photovoltaic system, the global formula is used (photovoltaic-software.com, 2019) which is:

Equation 3: Energy generated in output of a photovoltaic system

$$E = A * r * H * PR$$

E = Energy (kWh), A = Total solar panel Area (m^2), r = solar panel yield or efficiency (%), H = Annual average solar radiation on tilted panels (shadings not included), PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75).

Where:

- A in the proposed design for the inclined roof top and south façade inclined surfaces by 35 degrees to get the maximum efficiency = **568m²**.
- r efficiency rate which is the yield of the solar panel given by the ratio: electrical power (in kWp) of one solar panel divided by the area of one panel, in the solar panel used is Monocrystalline solar panels (Mono-Si) $r = 20\%$ as shown in (Figure 6-48) but in reality it varies from 18% to 20% (T. Ibn-Mohammed, 2017), so the calculation is calculated by using the value **18%**.

Solar Cell Type	Efficiency-Rate	Advantages
Monocrystalline Solar Panels (Mono-SI)	~20%	High efficiency rate; optimised for commercial use; high life-time value

Figure 6-48: solar type used in the energy simulation, source:
<https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels>

- H in Egypt has an average monthly Global Horizontal Irradiance (GHI) of 4.4 kilowatt hours per square meter per day (kWh/m²/day) = **1606 kWh/m²/year**. (solarenergylocal.com, 2019)
- PR : (Performance Ratio) is an important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses; the default ratio is **0.75**.

So, the total energy that produced on 568m² from the roof and south inclined surface area is:

$$E = A * r * H * PR = 568 * 18\% * 1606 * 0.75 = \mathbf{123148.08 \text{ kWh/year.}}$$

Or by using this equation:

Equation 4: Power of the PV panel

$$P = G \eta_o [1 - \beta_c (T_c - 25^\circ\text{C})]$$

Where P is the instant power of the PV panel, G is the solar radiation on the PV plane (W/m²), η_o is the PV efficiency under standard conditions (18% – 20% for mono-crystalline PV given by manufacture), β_c is the temperature coefficient-0.72%, and T_c is the solar cell temperature (unknown and must be provided by using heat balance models. (Xu, 2014)

$$P = 150 * 18\% * [1 - (-0.72) (35 - 25)] = 221.4 \text{ kWh/m}^2$$

The total power produced = $P * \text{total area} = 221.4 * 568 = \mathbf{125755.2 \text{ kWh/year.}}$

6.6.1.3 Semi-transparent photovoltaic integrated in envelop openings

As the roof and southern façade photovoltaic panels covered almost **50%** of the building energy needs, there is a need for another energy source. So, mono-crystalline semi-transparent PV cells are integrated to Northern and Southern façades openings to generate electricity from daylighting.

Same equations are used to calculate the energy produced from semi-transparent PV, but the deference is its efficiency rate , which is various from 17% maximum to 13% minimum, in the calculation the average value is used which is 15%, semi transparent power is 300W, North façade opening area is 343.2 m², South façade openings area is 108 m², so the total openings area is 451.2 m².

So, by using Equation 7-1

$$E = A * r * H * PR = 451.2 * 15\% * 1606 * 0.75 = \mathbf{81520.56 \text{ kWh/year.}}$$

Or by using the second equation:

$$P = G \eta_o [1 - \beta_c (T_c - 25^\circ\text{C})] = 150 * 15\% [1 - (-0.72) (35 - 25)] = 184.5 \text{ kWh/m}^2/\text{year.}$$

The total power produced = $P * \text{total area} = 184.5 * 343.2 = \mathbf{83246.4 \text{ kWh/year.}}$

6.6.1.4 Total power generated by solar energy

The total electricity generated by solar energy = total solar roof and shadings panels energy production + total semi transparent PV openings energy production

According to the first equation total electricity = $\mathbf{123148.08 + 81520.56 = 204668.64 \text{ kWh/year}}$, which cover **83.5%** of the building energy needs.

And the total electricity generated from the solar energy according to the second equation = $\mathbf{125755.2 + 83246.4 = 209001.6 \text{ kWh/year}}$, which represents **85.2 %** of the building energy needs.

The solar power covered **83.5% to 85.2%** of the total office building energy need. If the design process stopped in this stage, the proposed office building design is nearly zero energy public building, and there is 14.77% to 16.5% of

building energy need is not covered yet, so, another renewable energy source is integrated into the design to achieve the zero energy goal.

6.6.2 Wind energy integration into office building design

Because of the need for another renewable energy resource to be integrated into the proposed office building design, there are many choices, for example, integrates wind energy source or geothermal system. Wind energy is chosen to be integrated into the design and supply the building with the remaining energy needs because of the suitable wind speed in Egypt and there are different options in shape and size.

Motorwave micro wind turbines (MMWT), this technique is chosen cause of its light weight, less vibration and its cost is approximately equal to one-third of conventional turbines for equivalent power output. It can generate power with wind speed as low as 2 m/s. The chosen type is 25 cm diameter wind turbine gather in rows, each row consist of 8 MWT and each 6 rows are connected together, installed on the roof by metal web (Figure 6-49) (Leund, 2010).



Figure 6-49: Micro wind turbines rows installed on the roof, Source: Author.

Average wind speed is 4 m/s in Cairo according to Cairo weather files, and according to micro wind turbines performance table at chapter 4, when the wind speed is 4m/s, 8 micro wind turbines generate 3 W (Leund, 2010), (Leung, December 2010) = 1555.2 kWh/year, So, the total energy produced

from an array of 408 microwind turbines integrated into the building (51 rows) $1555.2 * 51 = 79317.52 \text{ kWh/yr}$.

Or

Adding on the building roof 5 of Wind turbines which generate 10kWh each (Manwell, 2010) (getsmartenergy.com, 2019), and the formula for calculating the power from a wind turbine is shown in Sphere (Figure 7-54). (Manwell, 2010)

<p style="text-align: center;">$Power = C_p \frac{1}{2} \rho A V^3$</p> <p>Where:</p> <ul style="list-style-type: none"> - P = Power output, watts - C_p = Maximum power coefficient, ranging from 0.25 to 0.45, (theoretical maximum = 0.59) = 0.35. - ρ = Air density, $\text{kg/m}^3 = 1.225$. - A = Rotor swept area, m^2 or $\pi D^2 / 4$ (D is the rotor diameter in m, $\pi = 3.1416$) = 21.089 m^2. - V = Wind speed, $\text{mps} = 4 \text{ m/s}$. 	
<p style="text-align: center;">Figure 6-50: wind sphere, source: https://www.getsmartenergy.com/windsphere/index.aspx</p>	

The integrated micro wind turbines covered 100% of the total office building energy needs, as the energy produced from micro wind turbines is more than the remaining of required energy ($40563.75 - 56156.79 \text{ kWh/yr}$), therefore, the proposed office building design in Egypt is **Zero Energy Public Building** by using the proposed ZEPB design methodology.

6.7 Pilot case study final results

At the design process, the comparison results show that the proposed design almost save 10% of the total building energy consumption than the regular rectangular form.

Applying energy reduction strategies to minimize the building energy needs:

- The external wall cross section consists of doubled brick wall 12cm thickness each and filled with thermal insulation sheet 5cm thickness (R-Value= 19.5) reduced the total building energy consumption by 3% reduction in energy needs.
- Improving external openings cross section and using the double glazing glass fill with argon gas (R-Value= 4.08) succeed to reduce the amount of heat transmitted into the building and achieve best energy reduction results and caused extra 3% reduction in energy needs.
- Using green roof in specific parts of the roof and the other parts covered with PV panels, Enhance the building envelop properties and caused totally 7% energy reduction in building energy needs.
- Horizontal 35⁰ inclined shades with photovoltaic cells in the south façade and vertical shading device semi open in the eastern and western facades to allow light but not heat, these shadings caused 9% reduction in building energy needs.
- Efficient daylighting and artificial lighting design by using LED, enhance energy saving and reduce building energy consumption by 18% in energy needs.

Energy simulation is generated by using Design Builder software program for 5 cases, the energy consumption for each scenario is:

- Regular rectangular office building energy consumption is 385127 kWh/year.
- Base case total energy consumption is 350103.99 kWh/year.
- Treatment 1 total energy consumption is 329945.39 kWh/year when the building envelop is insulated.
- Treatment 2 total energy consumption is 319049.37 kWh/year when shadings added on the building.
- Treatment 3 total energy consumption is 245232.39 kWh/year when all the energy reduction strategies are applied in the energy simulation

After simulating the proposed office building design scenarios, the optimum solution at “Treatment 3” achieved the best results which is reducing the total energy needed to **245232.39 kWh/year, which means 36.33% less energy needs than the regular rectangle design.**

Energy production at the office building:

- Solar energy is integrated into the building design by several ways, first, solar water heater is used to supply the building with hot water

- Solar photovoltaic cells which is integrated into the building roof and southern façade to take the advantages of the sun produced **123148.08 - 125755.2 kWh/year.**
- Semi transparent PV sheets which is integrated on all the building external openings to take advantages of daylighting in generating electricity and produced **81520.56 - 63320.4kWh/year.**
- The solar power covered **77.1% to 83.5%** of the total office building energy need.
- Wind energy is integrated into the design by using micro wind turbines which generate 793175.2 kWh/year or adding on the building roof 5 of Wind turbines which generate 10kWh each.
- The renewable generated energy can be stored in batteries and transferred to drive electrical appliances from the two sources. (Bedri Kekezoğlu, 2015)

Finally, the proposed office building design in Egypt achieved the zero energy goal and it is **Zero Energy Public Building**, guided by the proposed ZEPB design methodology.

6.8 Conclusion

In this chapter the ZEPB design methodology is tested through using it in designing a public building in Egypt as a step towards achieving zero energy goal. The chosen public building type for proposed ZEPB design is an office building because office buildings make up the largest sector of building type within the public building.

According to the proposed design methodology, the ZEPB design process is First, defining the program, then, sketch the building design, also, compare the proposed design to regular one, and integrate passive strategies, the second stage, generate an energy simulation to estimate the building energy needs and calculate the effect of each choice in the envelop material or the building service systems, the third stage, get full concept design by integrating renewable energy resources to the building design to cover the building energy needs, finally, reaching to ZEPB design.

Part 1: Public Building Description:

- The proposed public building design is located in Egypt, Cairo, to test if the proposed ZEPB design methodology is applicable in Egypt.
- ZEPB design methodology is applied on office building design.
- The design is interacting to location and climate properties to enhance self-shadings, daylighting and natural ventilation, to minimize the building energy needs.
- Comparison between the regular rectangular design and the proposed one, and the interactive design saved 10% of the building energy needs.

Part 2: Energy reduction strategies:

The proposed design is developed by using energy reduction strategies as following:

a) Building envelop

- Due to the hot, arid climate of Egypt, the design is based on enhancing self-shading building.
- Designing the building envelope with local highly insulating materials.
- Increasing the R value for building's walls, openings, and roof, increases the building thermal resistance, and help in reducing building energy consumption.
- External wall cross section consists of doubled brick wall 12cm thickness each and filled with thermal insulation sheet 5cm thickness

(R-Value= 19.5) and walls are painted with white and light colors to reflect the heat.

- External openings, the double glazing glass fill with argon gas (R-Value= 4.08) is used.
- The roof is covered by incline surface 35⁰ carry PV cells or Green roof.
- To reduce energy consumption and save energy, many types of shading devices are used at different façade orientation.

b) Service systems

- Service systems are including Ventilation system, lighting system, HVAC, and building Equipment.
- Vertical courts with green elements and wind catchers are used to move the air across the building and gives a good ventilation.
- Most of the building offices can depend on natural lighting in the day and an efficient artificial lighting system by using LED.
- A four-pipe fan coil unit is used in the building HVAC system.

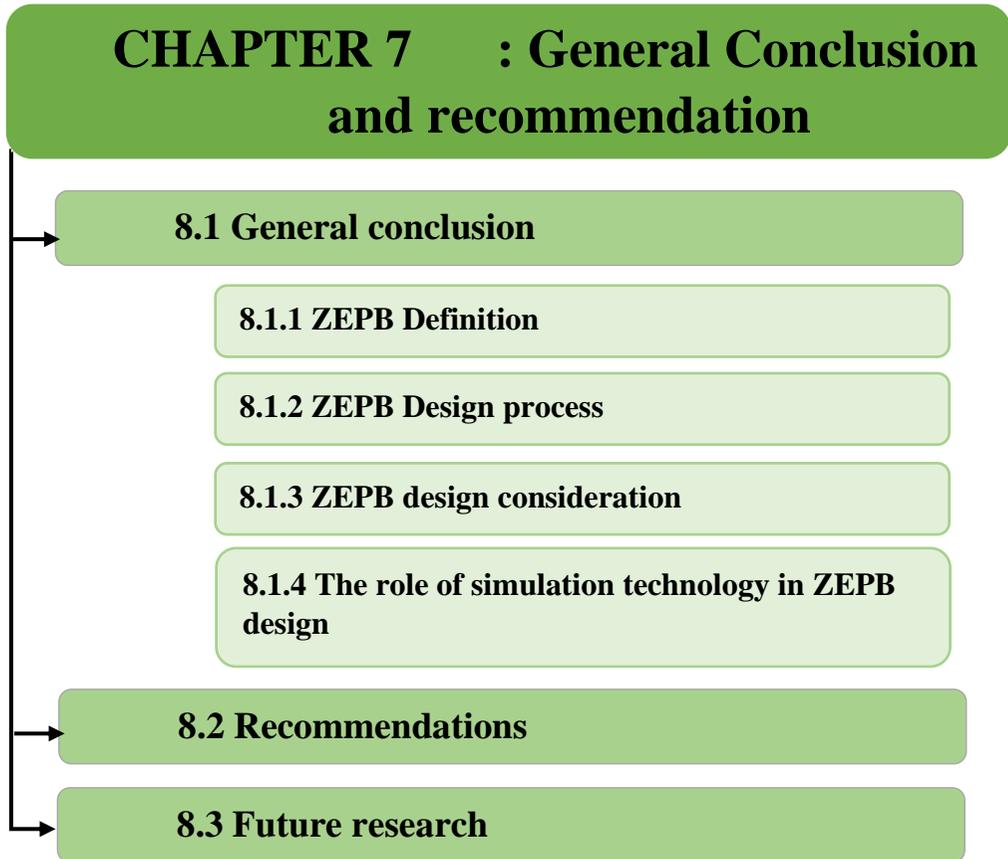
c) Energy simulation

- **DesignBuilder** as an energy simulation program for calculating the building energy needs and the effect of each treatment on the building consumption.
- There are four scenarios for the proposed office building design and energy simulation had been done for each one.
- The fourth scenario “Treatment 3” achieved the best results which is reducing the total energy needed to 245232.39 kWh/yr.

Part 3: Renewable energy production:

- Solar water heaters are used to supply hot water,
- Solar photovoltaic cells produced **123148.08 - 125755.2 kWh/year.**
- Semi transparnt PV sheets which is integrated on Northern and southern facades external openings produced **81520.56 - 63320.4kWh/year.**
- The solar power covered **77.1% to 83.5%** of the total office building energy need.
- Wind energy is integrated into the design by using micro wind turbines which generate 793175.2 kWh/yr or adding on the building roof 5 of Wind turbines which generate 10kWh each.

The proposed office building design in Egypt is **Zero Energy Public Building**, guided by the proposed ZEPB design methodology.



7.1 Conclusions

- Climate effect on ZEPB design strategies (Building orientation, shape, urbanization, comfort zone).
- Consider in the ZEPB design the factors that increase building energy efficiency envelop like wall section design, glazing and opening control, roof insulation, and more, they need to be carefully studied.
- There are many factors affecting public building energy consumption like; the building activity, number of occupied, the operating hours, building equipment, the form of cooling source.
- At any public building the great energy consuming is the technical systems and the building equipment
- Zero energy public building need to be designed as off Grid Connection building, by using renewable energy system (Solar, wind, geothermal, ...)
- Building control systems BCSs are critical to the operation of high-performance zero energy buildings.
- Design and construction team commitment is essential for successful ZEPB.

7.1.1 ZEPB Design Process

- ZEPB design methodology points are a matter of balance, scale, and proportion in complex self-organizing systems.
- Designing zero energy building to reduce national energy consumption and reduce global warming effect.
- The proposed design is based on enhancing self-shading building, low energy needs by using some traditional environmental features to enhance natural ventilation, and daylighting.
- Using ZEPB design methodology in the proposed design.
- Reducing energy strategies that used in the proposed design for enhancing natural ventilation by using traditional architecture feature like orient the building to face the North, courtyards, wind catcher, creating void spaces on the building façade to create cross ventilation, also, increasing the exposure of the daylighting by using wide openings in north façade, enhance building self-shading, horizontal and vertical shadings shown high feasibility to reduce the thermal performance specially on south, east and west facades, improving building envelope U value, utilization of

natural resources more efficiently reduces a building's negative impact on the environment.

- Energy simulation analyses is essential to investigate the effect of various passive systems and design strategies on designing zero energy public buildings in Egypt.
- Energy conservation measures that selected for analysis are aimed to improve the thermal performance, ventilation and lighting systems.
- Renewable energy production is mandatory in designing zero energy public building, more than one energy source can be installed on the building.
- Installing solar panels on inclined surface by 35 degrees and face the south to reach the maximum efficiency.
- After applying the saving energy strategies and adding the renewable energy production sources to the proposed design, the result is achieving zero energy public building with local materials, local techniques and local technologies available within the building sector in Egypt.

7.1.2 ZEPB design consideration

- Wall resistance between R20 and R30 is highly recommended for ZEPBs.
- The Double glazed, Low-E coated openings is highly recommended and to get more energy efficiency results it is better to use self shaded or dynamic glass windows.
- **ZEPB its mandatory to** insulate the roof to help reduce overall building energy consumption to approximately 40% below code levels. Also, its highly recommended to cover the roof with the PV system that will be used in generating energy to the project.
- Roof resistance between R30 to R40 is highly recommended.
- LED lighting units is highly recommended in the artificial lighting design, and for better results, its better to install daylight and occupancy sensors.
- The best ventilation results when windows face the north façade.
- Its recommended to adjust the setpoints to 26 degrees Celsius on nights and weekends to save more energy.

7.1.3 The role of simulation technology in ZEPB design.

Building energy simulation is essential in zero energy design process. And there are several energy simulation software help architects to reach the

optimum energy solution. The importance of Simulation process can be concluded as following:

- Public Building energy simulations help in predicting the building performance before it is built.
- Building energy simulation is the third step from the second part at ZEPB design methodology, after applying the reduction strategies on the building envelop and the service systems.
- Decisions taken during design stage can determine the success or failure of the building
- Simulation the building energy design options to evaluate and compare to get the best results.
- Energy simulation is essential to view the reducing of energy consumption and the generated amount of renewable energy.
- Computer based 3D modelling and energy simulation is a proven technique for evaluating building energy consumption.
- There are many available simulation programs for evaluate building performance for example BLAST, eQUEST, TRNSYS, Energy Plus, Energy Express, EFEN, Design Builder, etc.
- The energy simulation process includes a range of design variables.
- The reason of choosing **DesignBuilder** as an energy simulation program for testing the proposed design methodology is:
 - The ability of the prediction of the building energy consumption.
 - Creates a virtual environment where the operation of the Heating, Ventilation and Air Conditioning (HVAC) system and the lighting energy consumption of the whole building can be studied in detailed.
 - The factors that affect building energy performance and thermal comforts of the occupants during summer and winter can be identified.

7.2 Recommendations

- **On the level of Nation:**

- Egypt must make a clear map toward achieving ZEPB goal for the new and existing buildings.
- Egypt must set policies and programs to move with the building sector to be ZEB.
- Egypt must lead the region in ZEPB field and holding international conferences to spread the awareness.
- Collaborating with countries achieved progress in this field to get benefits from their experience.

- **On the level of Government:**

- Government should encourage public institutions to adopt new building materials, energy-saving equipment during energy efficient retrofitting and install renewable energy resources.
- Considering that zero energy buildings are frequently connected to the electricity grid to export electricity to the grid when there is an extra and drawing electricity when not adequate electricity is being produced. Other buildings may be fully autonomous.
- Government must encourage financially the public projects that targeting ZE goal.
- Government must start with retrofitting the existing governmental building to be ZEPB, and build any new buildings considering ZE principals.
- Government responsible for encouraging manufacturing and providing sustainable products, new technologies, materials in the market to be available and reachable for clients, architects and contractors.
- Supporting renewable energy production projects such as solar and wind technologies.

- **On the level of Architects and engineers:**

- Building envelop heat preservation and insulation should be improved; by improving roofs and walls insulation, using energy-saving windows and doors, or install external shading devices.
- Zero energy public building should be designed with full use of renewable energy and new energy sources.
- The use of computer modeling to set the parameters of the design and the testing of assumptions to confirm design choices are critical to achieve the project's ZE performance goals.

- Architects should be well trained to choose the appropriate techniques and strategies for the different building's sites, climate conditions, buildings type, buildings usage and requirements.
- Architects should be well educated to provide clients with knowledge, encourage them to use new materials and new technologies.
- **On the level of Universities and Research Institutes:**
 - Setting rules and regulation is important to insure the implementation of the required goals for energy efficiency.
 - The research institutes should adopt holding conferences which encourages and supports ZE trend experiences.
 - Universities should provide measuring tools to their students and researchers in the laboratories of the environmental studies to help them in achieving precise research results.
 - Universities and research institutes should send Master and Ph.D. Egyptian students to learn more about new ZE techniques and technologies.
- **On the level of Building design:**
 - The public building heat transfer coefficient in various parts of the building envelope, shading coefficient, air tightness, should meet the related requirements stipulated by "public building energy efficiency (green building) design standard".
 - Most of small public buildings should adopt split air conditioners the most energy-efficient way or use air-conditioning system in the form of multi-line.
 - Zero energy public building design should make full use of natural light, promote the use of intelligent control devices, optimize the use of energy efficient lighting, and design the building exterior decorative lighting with LED units.
 - Follow the ZEPB two years from occupancy to ensure longer tuning times needed in ZNE buildings.
 - Building envelop insulation is essential.
 - Using LED in lighting to reduce lighting energy consumption.
 - it strongly recommended to give workers, users, occupants and visitors at the first time they enter the building recommendations for plug load management and energy reduction.

- **On the level of Individuals:**

- Using energy-efficient equipment can effectively reduce energy consumption of public building.
- Awareness is important to highlight the impact of the buildings user's energy use and the logical ways that can help to regulate and decrease the building consumption.
- Different stakeholders should become motivated to consider energy efficiency and its applications.

7.3 Future research

- A net zero waste design methodology.
- Finding specific and more detailed ZEB methodology for each type of public building
- More study about following up the ZEPB design after the building is constructed.
- Testing the proposed design methodology on several types of public buildings.
- Testing the proposed design methodology on different public building project's sizes.
- The effect of cost on achieving ZEB goal.
- Targeting zero energy construction methods.
- The urbanism effect on public building energy consumption behavior.
- The difficulties that face reaching ZEPB goal in Egypt.
- Comparison between energy simulation software results and efficiency.

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قسم العمارة

منهجية تصميم المباني العامة صفرية الطاقة

أطروحة للحصول علي درجة الدكتوراه الفلسفية في العمارة

مقدمه من

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