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THE ECOLOGICAL APPROACHES IN SKYSCRAPERS FOR GENERATING AND REDUCING THE ENERGY LOSS BY USING RENEWABLE RESOURCES

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TEZ ONAYI

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ABSTRACT

MSc Thesis

THE ECOLOGICAL APPROACHES IN SKYSCRAPERS FOR GENERATING AND REDUCING THE ENERGY LOSS BY USING RENEWABLE RESOURCES

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Skyscrapers became the defining features of the cityscape with the advent of the 20th century. They become an inevitable and important product not only on the building scale but also on the country scale because they meet the needs of living for the present and the future. Besides the positive aspects of skyscrapers, they can be a product that may create problems in ecological and environmental terms, not only for our present but also for our future; the huge consumption of energy is the major problem of these types of tall buildings. For that reason in the design of skyscrapers, ecological designs and elements must also be developed in terms of generating and reducing the energy loss. Skyscrapers that can be adapting to the natural environment and emphasizing the ecological design criteria are the most appropriate solutions for our future and our environment. This thesis provides an overview on the notion of eco-design by highlighting some links between skyscrapers and ecological design. This research investigates also some worldwide used green building rating systems which can be utilized for evaluating the sustainability of skyscrapers. The main purpose of the thesis is to research on the ecological approaches in skyscrapers for generating and reducing the energy loss by using renewable resources. The energy generation in skyscrapers with productive mode strategies is investigated by focusing on two strategies; the first one is the solar energy and solar PVs, and the second one is the wind energy and wind turbines. The energy loss reduction in skyscrapers with passive mode strategies is investigated by focusing on two strategies; the first one is the passive solar concepts for natural solar gain and daylight, and the second one is the passive wind concepts for natural ventilation. As case studies; this thesis analyzed the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy, and reducing the energy loss in skyscrapers with passive mode strategies by using solar and wind concepts in some examples of skyscrapers that exist around the world.

Key words: Skyscrapers, ecological design, renewable energy, productive mode, passive mode, sustainability.

2018, xv + 244 pages.

ÖZET

Yüksek Lisans Tezi

GÖKDELENLERDE YENİLENEBİLİR ENERJİ KAYNAKLARI KULLANILARAK ENERJİNİN ÜRETİLMESİ VE ENERJİ KAYBININ AZALTILMASI İÇİN EKOLOJİK YAKLAŞIMLAR

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Gökdelenler, 20. yüzyılın gelişiyle kent silüetinin belirleyici özelliklerinden beri olmuştur. Bugünün ve geleceğin yaşam ihtiyaçlarını karşılayabilmesi için gökdelenler sadece yapı ölçeğinde değil, aynı zamanda ülke ölçeğinde de kaçınılmaz ve önemli ürünlerinden beri olmuştur. Gökdelenlerin olumlu yönlerinin yanında, bu binalar ekolojik ve çevresel açısından sorun yaratan bir ürün olabilmektedir, sadece günümüzde değil, aynı zamanda gelecekte sorun yaratabilmektedir. Bu tür yüksek binaların aşırı enerji tüketimi en büyük problemlerden biridir. Bu tür binalar yapay ışık, ısı ve bina soğutması için elektrik gücü ve mekanik gücü üretilmek için büyük miktarda enerji tüketmektedir. Gökdelenler ekolojik ve yeşil tasarımı açısından büyük dikkat çekmesi gerekmektedir. Bunun için gökdelenler tasarımında ekolojik tasarımlar ve unsurlar enerjinin üretilmesi ve enerji kaybının azaltılması açısından geliştirilmelidir. Doğal çevreye uyum sağlayabilen ve ekolojik tasarım kriterleri vurgulayabilen gökdelenler geleceğimiz ve çevremiz için en uygun çözümlerdir. Bu tezde, eko tasarım kavramına kısa bir bakış getirilerek gökdelenler ile ekolojik tasarım arasındaki bazı bağlantıları vurgulanmıştır. Bu araştırmada, gökdelenlerin sürdürülebilirliğini değerlendirmesi için kullanılabilecek yeşil bina derecelendirme sistemlerinin bazılarını incelenmiştir. Bu tezin temel amacı, gökdelenlerde yenilenebilir enerji kaynakları kullanılarak enerjinin üretilmesi ve enerji kaybının azaltılması için ekolojik yaklaşımlar araştırılmıştır. Bu tezde, üretken mod stratejileri ile gökdelenlerde enerjinin üretilmesi için iki strateji üzerinde odaklanılmıştır; birincisi güneş enerjisi ve güneş PV'leri, ikincisi ise rüzgar enerjisi ve rüzgar türbinleri. Bu tezde de, pasif mod stratejileri ile gökdelenlerdeki enerjinin kaybının azaltılması için iki strateji üzerinde odaklanılmıştır; birincisi doğal güneş kazancı ve günışığı kazancı için kullanılan pasif güneş tasarımları, ikincisi ise doğal havalandırma için kullanılan pasif rüzgar tasarımları. Çalışma örnekleri olarak; bu tezde, dünyada var olan bazı gökdelenlerin örneklerine ait enerjinin üretilmesi ve enerji kaybının azaltılması için kullanılan yukarıdaki ekolojik yaklaşımlar inclenmiştir.

Anahtar Kelimeler: Gökdelenler, ekolojik tasarım, yinelenebilir enerji, üretken mod, pasif mod, sürdürülebilirlik

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After an intensive period of two years, writing this acknowledgment is the end touch on my master degree thesis. It has been a period of intensive researching and learning for me, not only in the scientific area but also on the personal level. Writing this thesis has had a big impact on me to understand the methods and ecological approaches which are used for generating and reducing the energy loss in the skyscrapers in order to improve the performance of skyscrapers and make these tall buildings to have an excellent impact on their environment. I would like to reflect on the people who have supported and helped me so much throughout this period.

I would first like to express my gratitude to my God for giving me the strength, patience, and courage to complete this thesis. I would like to express my sincere gratitude to my supervisor Assoc. Prof. Tülin VURAL ARSLAN from the department of architecture at Uludağ University in Turkey for her continuous support of my Master degree study and research, for her patience, motivation, enthusiasm, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. Besides my supervisor, I would like to thank all my professors, doctors, and the teaching staff at Uludağ University in Turkey and the University of Constantine 03 in Algeria, for their encouragement, valuable guidance, and insightful comments.

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Mohammed BA ALAWI

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ABBREVIATIONS

Abbreviation	**Explanation**
AC	Alternating Current
ACEM	Association of Consulting Engineers Malaysia
ADNOC	Abu Dhabi National Oil Company
ADUPC	Abu Dhabi Urban Planning Council
AIA	American Institute of Architects
ASHRAE	American Society of Heating and Air-Conditioning Engineers
BCA	Building and Construction Authority
BD+C	Building design and Construction
BEAM Plus	Building Environmental Assessment Method Plus
BEST	Building Environmental Standards
BIE	Bureau International des Expositions (France International Office of Exhibitions)
BIPV	Building integrated photovoltaic system
BIWT	Building Integrated Wind Turbines
BOMA	Building Owners and Managers Association
BPOA	Barbados Programme of Action
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BWTC	Bahrain World Trade Center
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CIB	International Council for Research and Innovation in Building and Construction
CIBSE	Chartered Institution of Building Services Engineers
CIS	Cooperative Insurance Society
CTBUH	Council on Tall Buildings and Urban Habitat
DC	Direct Current
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (German Sustainable Building Council)
DS	Direct Sunlight
EB	Existing Buildings
Eco-design	Ecological Design
ENRB	Existing Non-Residential Buildings
ER	External Reflection
ERB	Existing Residential Buildings
ESD	Environmentally Sustainable Design (Ecological Design)
ETTV	External Thermal Transfer Value
FKI	Federation of Korean Industries
GBCA	Green Building Council of Australia
GBI	Green Building Index
GBI	Green Building Initiative

GBIG	Green Building Information Gateway
GM	Green Mark
GW	Giga Watts
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbine
HKGBC	Hong Kong Green Building Council
HVAC	Heating, Ventilation, and Air-Conditioning systems
HVAC&R	Heating, Ventilation, Air-Conditioning, and Refrigeration systems
ID+C	Interior Design and Construction
IR	Internal Reflection
KW	Kilo watts
KWhr	Kilowatt Hour
LEED	Leadership in Energy & Environment Design
Low-E glass	Low Emissivity glass
M&E systems	Mechanical and Electrical systems
MDGs	Millennium Development Goals
MSI	Mauritius Strategy of Implementation
NC	New Construction
ND	Neighborhood Development
NOAA	National Oceanic and Atmospheric Administration
NRB	New Non-Residential Buildings
NREB	Non-Residential Existing Building
NREL	National Renewable Energy Laboratory
NRNB	Non-Residential New Building
NRNC	Non-Residential New Construction
O+M	Building Operation and Maintenance
PAM	Pertubuhan Arkitek Malaysia (Malaysian Institute of Architects)
PV	Photovoltaic
RB	Residential Buildings
RNC	Residential New Construction
SAMOA	Sids Accelerated Modalities Of Action
SBSE	Society of Building Science Educators
SDGs	Sustainable Development Goals
SIDS	Small Island Developing States
SPC	Storm Prediction Center
TMD	Tuned Mass Damper
UK BRE	United Kingdom Building Research Establishment
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UN-CSD	United Nations Conferences on Sustainable Development
UN-DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
UNGASS	United Nations General Assembly - Special Session
UN-HABITAT	United Nations Habitat Program
USGBC	U.S. Green Building Council
VAWT	Vertical Axis Wind Turbine
W	Watts
WCED	World Commission on Environment and Development
WSSD	World Summit on Sustainable Development

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1. INTRODUCTION

This chapter provides an overview on the research aims and objectives, the definition of the problem, followed by the hypotheses, methodology, practical implications, and limitations of this thesis.

1.1. Definition of the Problem

Skyscrapers became the defining features of cityscape with the advent of the 20th century. They become an inevitable product for the developing countries. There are four reasons behind the increasing number of these types of tall buildings; continuous growth of the world population, the lack of spaces in urban areas, facilitating and collecting the services in one building, and showing the power and the statues of the firms and the countries which plan this kind of projects. Skyscrapers become an important product not only on the building scale but also on the country scale because they meet the needs of living for the present and the future.

Besides these positive aspects of skyscrapers, they can be a product that may create problems in ecological and environmental terms, not only for our present but also for our future; the huge consumption of energy is the major problem of these types of buildings. This kind of buildings consumes huge amounts of energy in order to generate mechanical and electrical (M&E) power to artificially light, heat and cool the building. Skyscrapers must take a huge attention in terms of ecological and green design.

For that reason in the design of skyscrapers, ecological designs and elements also must be developed in terms of generating and reducing the energy loss, skyscrapers that can be adapting with the natural environment and emphasizing the ecological design criteria are the most appropriate solutions for our future and our environment. For these reasons, this thesis aims to research on the ecological approaches in skyscrapers for generating and reducing the energy loss by using renewable resources.

1.2. Purpose and Objectives

This thesis aims to:

- Provide an overview of the notion of eco-design by highlighting some links between skyscrapers and ecological design.
- Investigate some worldwide used green building rating systems that can be utilized for evaluating the sustainability of skyscrapers.
- Research on the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy, and reducing the energy loss in skyscrapers with passive mode strategies by using solar and wind concepts.
- Investigate these ecological approaches for generating and reducing the energy loss in some examples of skyscrapers that exist around the world as case studies.

This thesis tries to reach some of the research needs which were planned by the Council on Tall Buildings and Urban Habitat (CTBUH) in their Roadmap on the Future Research Needs for Tall Buildings (Wood et al. 2014). This roadmap has been set as a joint scheme between the CTBUH, the International Council for Research and Innovation in Building and Construction (CIB) and the United Nations Educational, Scientific and Cultural Organization (UNESCO).

1.3. Research Questions and Hypotheses

The best notion that reflects the interaction between ecological design and skyscraper design is the notion of ecological skyscrapers. This thesis investigates the factors and elements affecting the links between the notions of skyscrapers and ecological design.

For improving the performance of skyscrapers and making these tall buildings to have a positive impact on their environment, it is important to understand how to evaluate skyscrapers according to green building rating systems. This thesis investigates some important green building rating systems around the world which can be used for evaluating the sustainability of skyscrapers.

In order to determinate the interaction between the skyscrapers and the environment, it is necessary to understand;

- how the energy of nature can be generated in a good way,
- and what methods are used for reducing the energy loss in skyscrapers.

This thesis focuses on the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy, and reducing the energy loss in skyscrapers with passive mode strategies by using solar and wind concepts.

Ecological skyscrapers approach would have direct benefits in terms of ecological advantage from energy; it would also have indirect benefits such as the compatibility with the natural environment and the enhancement of the indoor environmental quality. This thesis investigates the benefits of generating and reducing the energy loss on the examples of some skyscrapers that exist around the world.

1.4. Methodology

The first phase before starting to write this thesis was the phase of identifying and determining the main headings and sections of the thesis. The main contents are selected from the CTBUH's Roadmap on the Future Research Needs for Tall Buildings (Wood et al. 2014). The roadmap aims to determinate what researches are important in the field of skyscrapers and to identify the research gaps in this field. For these, it suggests research priorities in the field of skyscrapers in 11 areas of researches covering all aspects of skyscraper planning, design, construction and management. These areas of research sections can be cited as the followings (Wood et al. 2014):

- Urban Design, City Planning and Social Issues.
- Architecture and Interior Design.
- Economics and Cost.
- Structural Performance, Multi-Hazard Design and Geo-technics.
- Circulation: Vertical Transportation and Evacuation.
- Fire and Life Safety.

- Cladding and Skin.
- Building Materials and Products.
- Sustainable Design, Construction and Operation.
- Construction and Project Management.
- Energy: Performance, Metrics and Generation.

This thesis focuses on some of the research topics in the roadmap which are relating to the ecological approaches in skyscrapers for generating and reducing the energy loss by using renewable resources, these research topics can be found in two areas of research sections which are providing in the roadmap. From the 'Energy: Performance, Metrics and Generation' area of research section, the research topics relating to the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy are chosen. From the 'Sustainable Design, Construction and Operation' area of research section, the research topics relating to the ecological approaches for reducing the energy in skyscrapers with passive mode strategies by using solar and wind concepts are chosen.

The second phase was the phase of collecting and gathering the required sources and references for the chosen headings of the thesis. The main information and data of this research are taken from different books, theses, articles other publications related to the research. A table for the first gathering sources is made (see Appendix 1). In this table, the main problem, the important contents, and the investigated case studies of each source and reference are presented. An accurate browsing of the first collecting sources is done to take the required information from the more suitable sources. During the research phase, some of the stated and analyzed information are also taken from secondary sources and organization's websites. All sources used in this research are shown in the References section of this thesis.

This thesis examines some worldwide used green building rating systems that can be utilized for evaluating the sustainability of skyscrapers. The methodology used here is to examine the different rating categories, levels, rating method, and the scoring charts of categories in each rating system. After that, present a table of a comparison summary between rating systems, and comparison charts between the investigated scoring charts of categories.

This thesis investigates the energy generation in skyscrapers with productive mode strategies. The methodology used here is to examine the different types of solar Photovoltaic (PVs) and wind turbines. After that, investigate some examples of skyscrapers which incorporate solar PVs or wind turbines to take the advantage of the sun or wind to generate sustainable energy. The chosen case studies are considering as the most ideal tall buildings' examples of mega-scale utilization of solar PVs or wind turbines around the world.

This thesis investigates also the energy loss reduction in skyscrapers with passive mode strategies. The methodology used here is to examine some principles and design consideration for passive solar and wind concepts. After that, investigate some examples of skyscrapers which incorporate passive solar or wind concepts to take the advantage of the sun or wind. For that, a table is utilized to determinate which skyscrapers incorporate more design considerations for passive solar concepts (see Table 4.4 and Table 4.9). The investigated skyscrapers examples and their related information had been collected from different sources (see Appendix 2). The chosen case studies incorporate more design considerations for passive solar or wind concepts in comparison to the other investigated skyscrapers examples around the world.

At the end of this research, a summary table of the case studies that conclude the ecological approaches for generating and reducing the energy loss in the investigated skyscrapers is presented (see Table 5.1).

1.5. Practical Implications

According to the UN-Habitat (2018), buildings consume large amounts of energy at all the phases of their presence. Buildings need energy for the construction process, raw materials, maintenance and also for the daily operations need; (e.g. lighting, air conditioning, cleaning, etc).

According to the United Nations Environment Programme (UNEP) (2017), buildings use about 40% of global energy, 25% of global water, and 40% of other global resources. Yeang (1999) indicates that more than 45 % of the energy used in countries is consumed by buildings and more than 26 % of landfill wastes come from building constructions. According to the Schneider Electric Group (2010), buildings are the largest consumers of energy in the world and they represent 40% of the world total energy use (Figure 1.1) and according to the Urban Hub Organization (2015), this ratio will increase to 20-35% over the next 15 years.

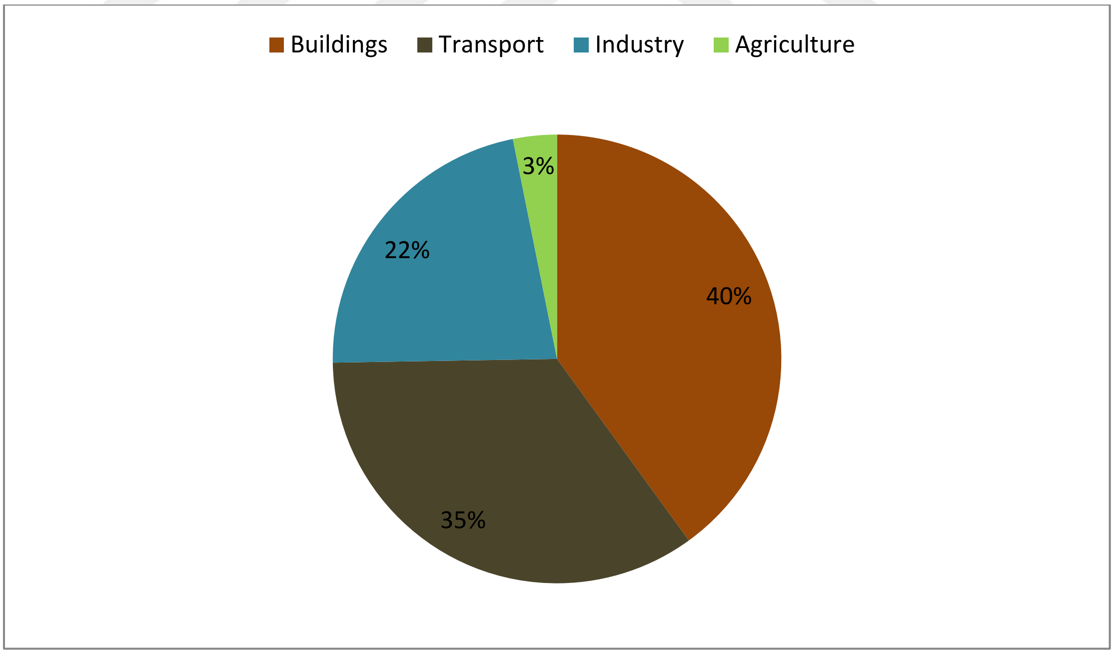


Figure 1.1. World energy consumption by sector in 2010
(Adapted from Schneider Electric Group 2010)

For example in the USA, only skyscrapers consume more than 40% of the country's total energy use (Tam 2011). As another example, Pank et al. (2002) found that buildings in London consume more than 72% of the city's total energy use, only tall office buildings consume more than 1000 KWhr/m².

The number of skyscrapers is increasing around the world. According to CTBUH's Database (2017), skyscrapers take up to 65 % of the energy used in some large cities and there are over 3,831 skyscrapers with more than 150 m in height around the world and 224 of them were built only in 2016. Figure 1.2 shows the number of the completed built skyscrapers with more than 150 m in height between the years 2011 and 2016.

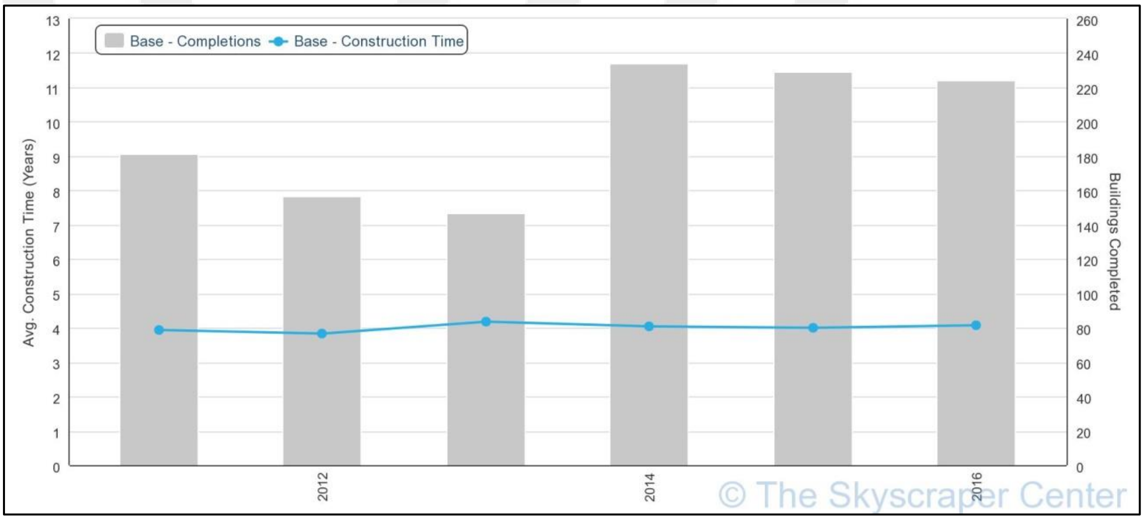


Figure 1.2. The number of the completed 150m+ skyscrapers between (2011-2016) (CTBUH's Database 2017)

The large amounts of energy consumption by skyscrapers are going to create problems in the future, so that; it is necessary to search for sustainable and ecological approaches to generate the energy from natural renewable resources and to reduce the energy consumption of skyscrapers. The only method for these is by designing buildings and skyscrapers with green design strategies.

According to Urban Hub Organization (2015), only designing with creative green technologies and strategies can reduce the world energy consumption by 10% in 2030.

Figure 1.3 shows the expected world energy consumption by sector in 2030 within and without considering green strategies.

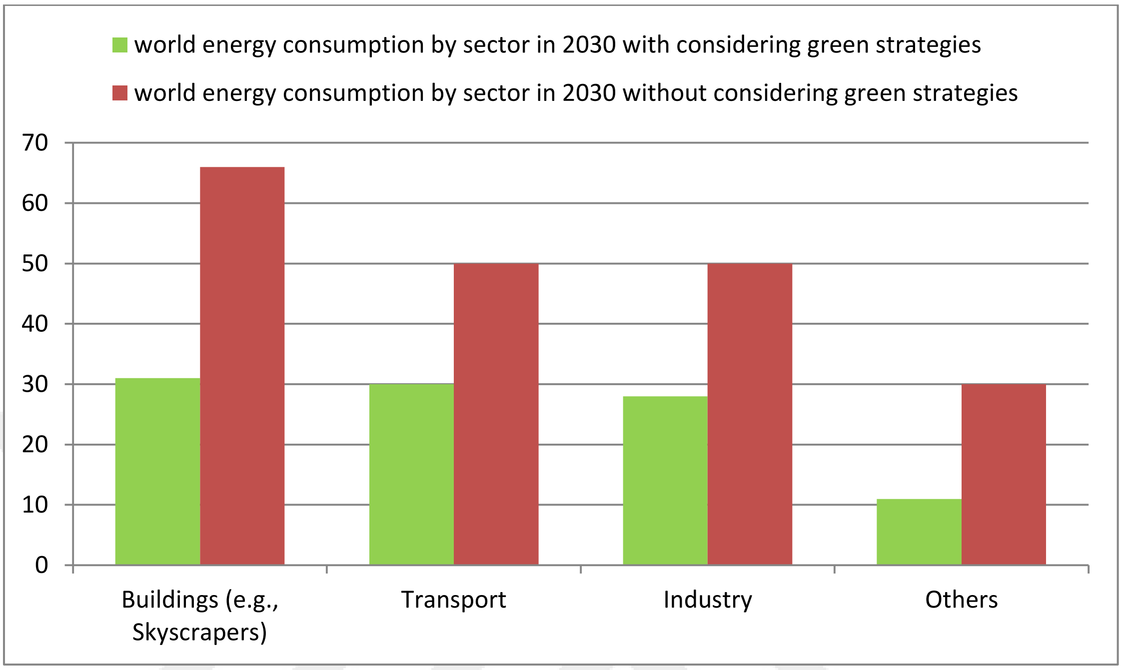


Figure 1.3. Expected world energy consumption by sector in 2030 within and without considering green strategies (Adapted from Urban Hub Organization 2015)

Research on the ecological approaches for generating and reducing the energy loss in skyscrapers by using renewable resources can be considered among the ways for designing skyscrapers with green design strategies. For these reasons, this thesis aims to reach some of these research needs and to display case studies of skyscrapers that employ these strategies.

This thesis aims to enable designers, architects and all those involved in skyscrapers design to understand what methods and ecological approaches are used for generating and reducing the energy in the skyscrapers in order to improve the performance of skyscrapers and make these tall buildings to have a positive impact on their environment.

1.6. Limitations of Thesis

Renewable energy indicates a clean, nontoxic energy resource that can't be exhausted. Oil, coal, and natural gas are examples of non-renewable energy resources. The main renewable energy resources are the solar, wind, biomass, geothermal, and hydropower energy. This thesis focuses on the solar and wind energy because they are two leading choices for renewable energy. Solar and wind energy are more affordable and more available than the other types of renewable resources. These types of energy can be found almost everywhere and have more cost-effectiveness in power generation in comparison to the other renewable energy resources. The following points provide some information about the main renewable resources.

- Solar energy: it considers as a renewable energy because it is available as long as the sun continues to shine. Solar energy can be converted into electricity by using the PVs technology (Foster et al. 2010).

- Wind energy: some cities are characterized by high wind speeds and patterns that can be qualified them to harness wind for energy generation. Wind energy can be converted into electricity by using the wind turbines (Al-Kodmany 2015).

- Biomass energy: biomass is a renewable energy resource, where biological materials derived from living, or recently living organisms (e.g. plant materials, wood, and animal waste) are used as fuel. It can be used to power tri-generation systems (combined heating, cooling, and power production). Remarkable amounts of biomass are ubiquitous in office skyscrapers in the form of paper, most of which is used only briefly and trashed. The waste paper output would produce a significant amount of the system's fuel required (Al-Kodmany 2015). The production and distribution of bio-oils and biodiesel fuels derived from bio-based materials are growing in momentum. Heating systems are available to burn used vegetable oils. Most diesel-fueled machines can run on biodiesel without any modifications (Lawrence et al. 2013).

- Geothermal energy: geothermal is one of the most considerable renewable energy resources. This energy consists of heat from the earth caused by the decay of radioactive particles and residual heat from gravitation during formation of the earth. Volcanoes are fiery examples of the movement of geothermal energy from the extremely hot interior of the earth to the cooler surface (Nelson 2014). This form of energy can be extracted to support the functioning of the building that built deep into the ground by using the geothermal wells. The geothermal wells can cool the buildings in summer and heat them in winter, and can also eliminate the need for boilers or electrical air conditioners (Al-Kodmany 2015).

- Water and hydropower energy: water is a valuable renewable resource. Hydropower energy has different forms, from conventional power generation to emerging technologies like the ocean and wave energy, hydrokinetic, and tidal power. For examples; wave energy conversion devices can capture mechanical power from the waves and use it directly or indirectly to power a turbine and a generator, the flow from the tides of an ocean or stream can also be harvested to produce power, pumped storage can be combined with other renewable energy resources systems to meet power demand variations (Lawrence et al. 2013).

The renewable and non-renewable energy resources can be used in skyscrapers by incorporating the building operational systems. The building operational systems can be categorized according to their functions and their relation and impact on the energy resources into passive mode, mixed mode, full mode, productive mode, and composite mode systems. To create environmentally sustainable skyscrapers, it is necessary to maximize reliance on passive mode systems, minimize reliance on full mode (or active systems), and seek to generate the energy from renewable resources by using productive mode systems. (Yeang 1999, 2006). This thesis focuses on the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy, and reducing the energy loss in skyscrapers with passive mode strategies by using solar and wind concepts. The following points provide some information about the main building operational systems.

- Passive mode systems: these systems are commonly referred to as bioclimatic design that needs to understand the climatic conditions of the locality over the year, and then design to improve the internal comfort conditions without the use of any non-renewable resources of energy or M&E systems. Passive mode considerations include built-form configuration and orientation, façade design, use of greenery and vegetation, etc. (Yeang 2006, Al-Kodmany 2015).

- Mixed mode systems: these partially active systems involve the use of renewable resources of energy in combination with some M&E systems. Mixed systems aim to design in relation to the climate of the locality for improving internal comfort conditions with partial use of the non-renewable resources of energy. Mixed mode considerations include propeller fans, active and interactive walls, evaporative coolers, dehumidifiers, radiant heat barriers, etc. (Yeang 2006, Al-Kodmany 2015).

- Full mode systems: these conventional fully active systems depend on the M&E systems that are always properly operated and maintained to avoid wasting energy consumption. Full mode provisions for heating, cooling, lighting, and ventilation are all controlled artificially through energy-intensive mechanical plant and the internal environment may thus be protected from the fluctuations of the exterior environment. These systems are also usually automated. Full mode systems aim to design to improve internal comfort conditions with full use of the non-renewable resources of energy. Full mode systems include the artificial Heating, Ventilation, Air-Conditioning, and Refrigeration (HVAC&R) systems (Yeang 2006).

- Productive mode systems: these are productive M&E systems that generate on-site energy. These systems aim to design in relation to the climate of the locality by the independent production of energy, and to reach the objective of zero and/or partial use of the non-renewable resources of energy. Productive mode systems include solar PVs, wind turbines, water generators, etc. (Yeang 2006, Al-Kodmany 2015).

- Composite mode systems: composite mode is essentially a composite of passive mode, mixed mode, full mode, and productive mode, all designed to act in tandem as a low energy design. These systems aim to design in relation to the climate of the locality for improving internal comfort conditions with composite means. An example of the composite mode systems is the fuel cells (Yeang 2006).

2. THEORETICAL FUNDAMENTALS AND LITERATURE REVIEW

This chapter covers three sections; the first section of the literature review covers research relating to the notions of sustainability and ecological design, the second section examines an overview research relating to skyscrapers, and the third one investigates some worldwide used green building rating systems that can be utilized for evaluating the sustainability of skyscrapers.

2.1. The Notions of Sustainability and Ecological Design

This section investigates the definitions of sustainability, eco-design, ecological approaches, and green buildings.

2.1.1. Definitions of sustainability

Cities face unmatched demographic, environmental, social, economic and spatial challenges. The transformation to urbanization is rising more and more these days. Due to lack of functional and efficient urban planning, the consequence of the rapid urbanization will be dramatic and undesirable (UN-Habitat 2018). The notion of sustainability can be considered as the only way for solving these problems.

Sustainability and sustainable development came to the center of the discourse in 1972 with the United Nations Conference on the Human Environment in Stockholm, Sweden (UNEP 2015). The most widely accepted definition of sustainability came from the Brundtland Commission by the World Commission on Environment and Development (WCED) in 1987, which defines sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs (UN 2017). Friedman (2008) defined sustainability as the best chance for addressing the issues such as combatting climate change, reducing waste, safeguarding natural resources, supplying energy, trading ethically and building a healthier nation and environment. Emas (2015) mentioned that sustainable development is the long-term stability of the economy and environment; which is only achievable by the integration of economic, environmental, and social concerns during the decision making process.

Sustainability and sustainable development aim to balance the needs of the present with the future viability of natural resources and global ecosystem (Yeang 2006). Sustainable development arises as the leading driver for the long-term global development (UN 2017).

In spite of the fact that sustainability appears to be a recent concern, it has been discussed and developed for many years. There have been many summits, meetings, and conferences that concerned about sustainability and sustainable development. Figure 2.1 concludes some of the important summits and events that concerned about sustainability and sustainable development.

One of the important events was the United Nations Conference on Environment and Development (UNCED), Rio Earth Summit, in 1992 in Rio de Janeiro, Brazil. This event recognized the three pillars of sustainable development which are; economic development, social development, and environmental protection. During Rio Earth Summit, world leaders adopted Agenda 21, with specific action plans to realize sustainable development. This was followed by the World Summit on Sustainable Development (WSSD) in 2002, Johannesburg Summit, in Johannesburg, South Africa, which adopted the Johannesburg Plan of Implementation (UN 2017).

Before that in September 2000, world leaders came together at United Nations Headquarters in New York to adopt the United Nations Millennium Declaration, in which they committed to achieving a set of Millennium Development Goals (MDGs) that range from halving extreme poverty and hunger to promoting gender equality and reducing child mortality, by the target date of 2015. Another important event was the United Nations Conference on Sustainable Development (Rio+20) in 2012 in Rio de Janeiro, Brazil. In this conference, Member States decided to launch a process to develop a set of Sustainable Development Goals (SDGs). The purpose was to make a group of universal goals that meet the urgent ecological, political, social and economic challenges facing the world (UNDP 2017). The SDGs was completed and announced in the United Nations Sustainable Development Summit 2015 in New York, which adopted the SDGs of the 2030 Agenda for Sustainable Development (UN 2017). The

SDGs came into effect in 2016, and they will continue guiding the United Nations Development Programme (UNDP) policy and funding for the next 15 years (UNDP 2017).

- 1972 • United Nations Conference on the Human Environment (Stockholm Conference), Stockholm, Sweden
- 1987 • World Commission on Environment and Development (Brundtland Commission) - Our Common Future (definition of sustainability)
- 1992 • United Nations Conference on Environment and Development (UNCED), Earth Summit, Rio de Janeiro, Brazil (the three pillars of sustainable development, Agenda 21)
- 1994 • Barbados Programme of Action (BPOA), Barbados (Barbados Declaration)
- 1997 • UN General Assembly - Special Session (UNGASS), Review and Appraise the Implementation of Agenda 21, New York
- 1999 • BPoA+5 , Five year review of the Barbados Programme of Action, Barbados
- 2000 • Millennium Summit, New York, USA (UN Millennium Declaration, launch MDGs)
- 2002 • World Summit on Sustainable Development (WSSD), Johannesburg Summit, Johannesburg, South Africa (Agena 21 Johannesburg Plan of Implementation)
- 2005 • Mauritius Strategy of Implementation (MSI), BPoA +10 (Ten Year Review of BPoA), Port-Louis, Mauritius
- 2005 • World Summit, High-Level Plenary Meeting of the UN General Assembly, New York (develope MDGs)
- 2010 • UN Summit, High-Level Plenary Meeting of the UN General Assembly, New York (global action plan of MDGs)
- 2010 • MSI+5 : Five-year review of the Mauritius Strategy of Implementation, New York, USA
- 2012 • United Nations Conference on Sustainable Development, Rio+20, Rio de Janeiro, Brazil (launch SDGs)
- 2014 • International Conference on Small Island Developing States (SIDS), Apia, Samoa (Sids Accelerated Modalities Of Action (SAMOA) Pathway)
- 2015 • United Nations Sustainable Development Summit, New York (announce SDGs)

Figure 2.1. Sustainable development timeline (Adapted from UN 2017)

2.1.2. Eco-design and ecological approaches

This section investigates the definition of ecological design (Eco-design), and the principles and the strategies for ecological design.

2.1.2.1. Definition of ecological design

Eco-design or ecological design is the use of ecological design principles and strategies to design our built environment and our ways of life (Yeang 2006). Some architects and designers named ecological design (eco-design) as Environmentally Sustainable Design (ESD) and define it as minimal energy use, minimal water use, minimal waste within the building footprint that aims to maximize human health and promote biodiversity in environmental design (Yeang 1999). Ecological design means, in this case, to build with minimal ecological and environmental impact, and to create a positive reaction with building's surrounding natural environment.

Freedman et al. (2004) mentioned that ecological design provides a framework for an environmentally suitable system of design and management by incorporating the consideration of ecological concerns at spatial and temporal scales. Freedman et al. (2004) defined ecological design as any form of design that reduces ecologically wasteful impacts by simulating and integrating them with natural ecosystems.

Yeang (1995) defined ecological design as a design process in which the designer completely reduces the expected unfavorable impacts that affect the earth's ecosystems and resources. Yeang defined the ecosystem as the interaction of the living and the non-living parts with their global environment.

For these in order to design with ecological design criteria, it is important to understand the principles and the strategies for ecological design. The next part summarizes these principles and strategies.

2.1.2.2. Principles and strategies for ecological design

Yeang (1995, 1999, 2006) and Freedman et al. (2004) provide the principles and the strategies for ecological design. These can be summarized as the followings:

1. The ecological design considers the flexibility of the natural environment and its limit; this aims to profit from natural environment benefits and reduce the negative impacts of the built environment (Yeang 1999, 2006).

2. The ecological design considers the relationship between ecological systems; this aims to make the three environmental zones of air, water and land interact with the biotic factors as shown in Figure 2.2 (Yeang 1999, 2006).

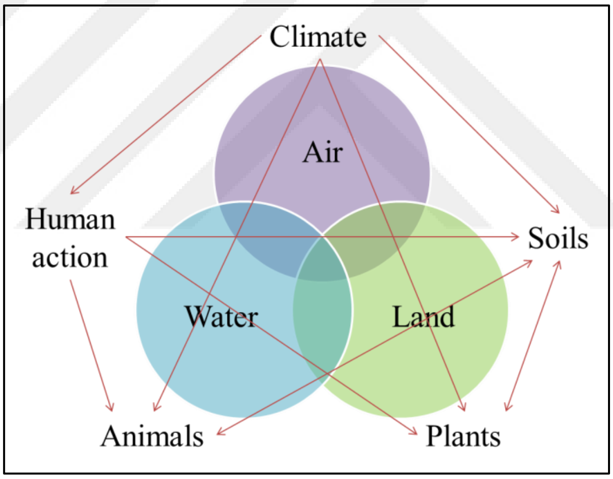


Figure 2.2. The interaction between the environmental zones and the biotic factors (Yeang 1999)

3. The ecological design considers the ideal spatial planning of built form; this aims to design on a site of lower ecological impacts, respond to the characteristics of the local ecosystem and respond to the climatic characteristics of the location (Yeang 1995, 2006).

4. The ecological design tries to repair and restore ecosystems; this aims to fix and recover the negative impacts of the natural environment (Yeang 1999, 2006).

5. The ecological design considers the importance of biodiversity; this aims to maintain the relationship between the man-made environment and the ecosystem, and to integrate natural ecological systems into the built systems (Yeang 1999, 2006, Freedman et al. 2004).

6. The ecological design considers the built environment is dependent upon the natural environment as the provider of energy and material resources; this aims to utilize renewable resources perfectly and optimize the efficiency of the non-renewable resources (Yeang 1995, 1999, 2006, Freedman et al. 2004).

7. The ecological design considers the ideal choice of building materials and construction systems; this aims to use local sources of materials, to design for facility re-using within the built environment, and to design for long-term use (Yeang 1995, 2006, Freedman et al. 2004).

8. The ecological design considers that manmade systems can never suitably match the complexity of natural ecological systems; this aims to no make artificial systems take the place of self-regulating natural systems (Yeang 1999).

9. The ecological design considers the management of outputs from the built environment into the ecosystem; this aims to solve the problems of recycling and disposal of the waste (Yeang 1995, 1999, Freedman et al. 2004).

10. The ecological design considers the ideal choice of inputs in service systems; this aims to reduce consumption and optimize the use of energy and material inputs (Yeang 1995, 2006).

11. The ecological design must be an expected design approach; this aims to control the expected changes of the built environment in the future (Yeang 1995, 1999).

12. The ecological design must be environmentally holistic; this aims to understand that the context of the ecosystem must practice as a whole and not in relation to only one of its components (Yeang 1995, 1999, 2006).

13. The ecological design must consider the life cycle design concept; this aims to understand the use of energy and materials by the designed system both before and after its construction (Yeang 1995, 1999, 2006).

14. The ecological design meets the inherent needs of humans; this aims to solve economic challenges and design for long-term use (Freedman et al. 2004).

15. The ecological design is multi-disciplinary; this aims to understand that ecological design doesn't only include in ecology and architecture disciplines, but also in other disciplines, such as engineering, chemistry and material sciences (Yeang 1999).

2.1.3. Green buildings

Green buildings are the buildings designed according to green design criteria and have positive impacts on their environments. According to Yeang (1999), for building with green or ecological design criteria, it is important to start by asking what is going to be built and how it can be built. After that, it is necessary to assess the set of design requirements and whether these requirements are ecologically and environmentally viable. It is important also to understand that the green design approach is not a set of built forms, variations are possible and important, and the invention in green and ecological design comes from the combination of different forms and the compensation for deviations from the norms.

Since the oil crisis in 1973, green buildings have become the selection of many new buildings projects. Architects, designers, builders, and even building owners started to interest more and more in building with the green design approach. The main purpose of the green building is to obtain both ecological and aesthetic accordance between the building and its surrounding environment (Kubba 2012).

Kim (1998) proposed three principles of green buildings design (Figure 2.3); the first principle is the economy of resources which is focusing on the actions of natural resources, the second one is the life cycle design which is focusing on methodologies for analyzing the building process and its impact on the environment, the third principle is the human design which is focusing on the interactions between humans and the natural world.

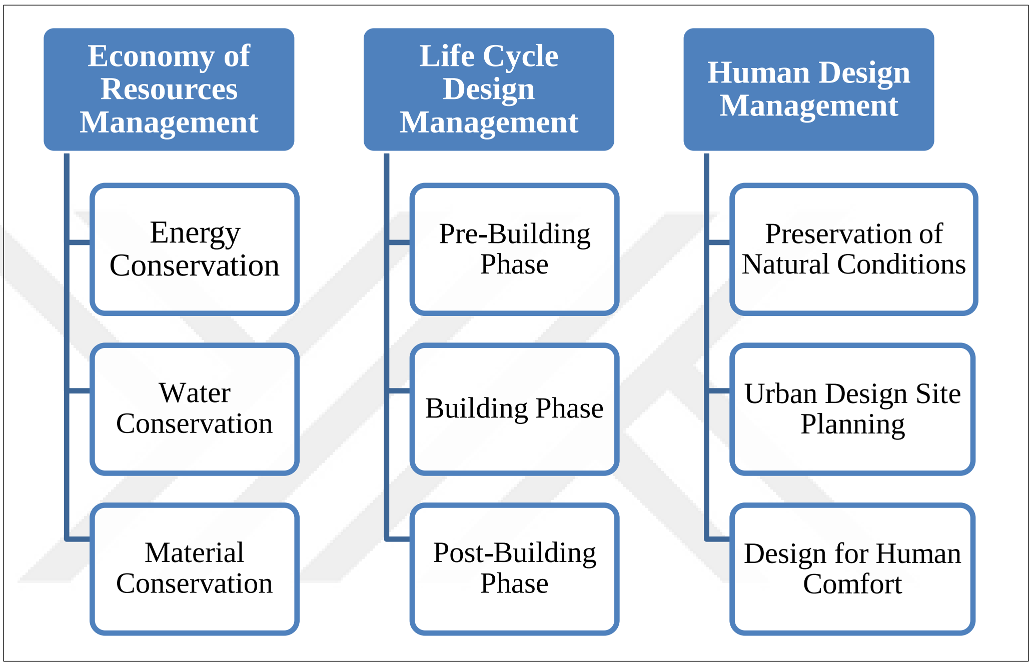


Figure 2.3. The three principles of sustainable and ecological design (Adapted from Kim 1998)

Gonçalves (2010) summarized the approach to low-energy and green building design in four steps. The first step is to reduce the demand for energy through architectural design and review the comfort criteria, the second step is for the use of more efficient technical systems, the third step is for the use of renewable energy generation systems and the fourth step is for the use of other alternatives for supply involving passive and technical solutions. Figure 2.4 shows these four strategies of green or environmental design for buildings.

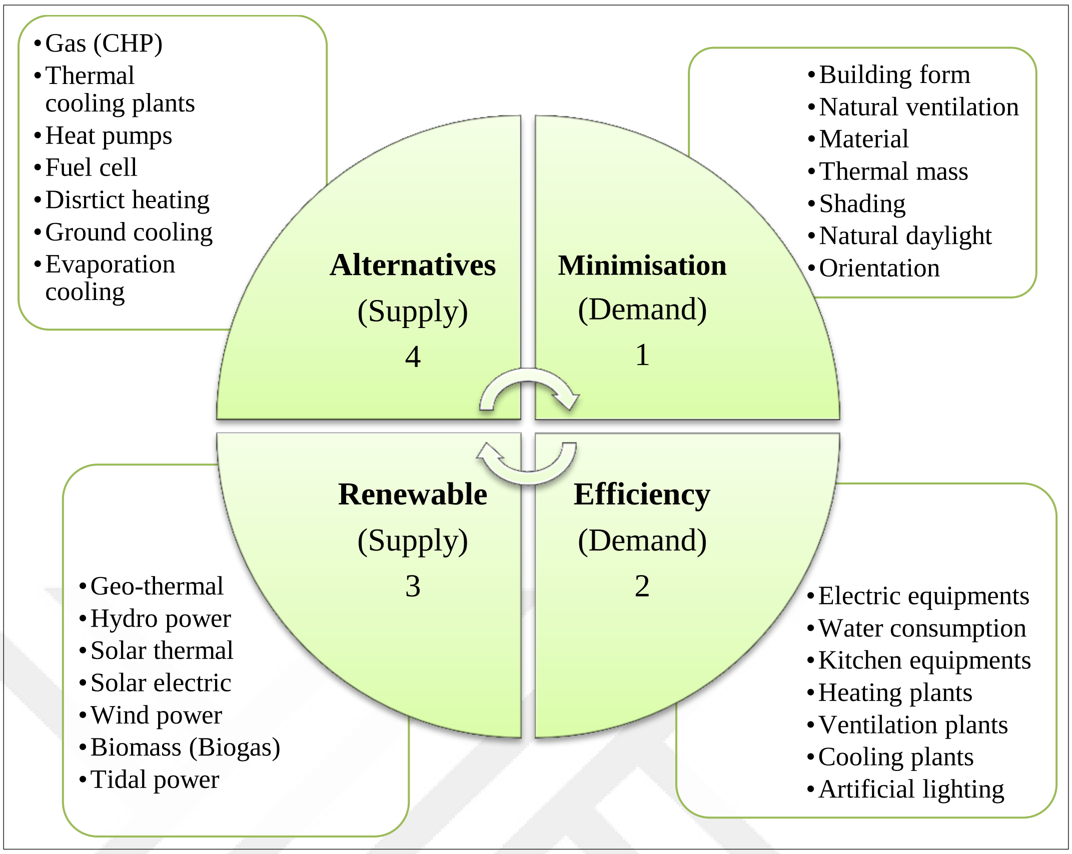


Figure 2.4. The four strategies of green or environmental design for buildings (Adapted from Gonçalves 2010)

Green buildings have many benefits; from reducing energy consumption, waste and pollution, to the enhancement of user's comfort and the conservation of ecosystems. Thereby these kinds of buildings are significant to improve our built environment and our ways of life.

2.2. Skyscrapers

This section focuses on the skyscraper's definition, history, and the ecological features and approaches for skyscrapers which highlight some links between skyscrapers and sustainability.

2.2.1. Definition

According to Günel and Ilgin (2014), the terms of skyscraper, tall building, and high-rise building have the same meanings and refer to the notion of very tall buildings. The term of skyscraper is the most effective, energetic, and taking social wondering. The term of high-rise building has been known as a tall building type since the 19th century. The history of the term tall-building is older than the term high-rise building.

Uffelen (2012) mentioned that the term of skyscraper was taken from seafaring at the end of the 19th century where skyscraper referred to the highest mast of a sailing ship. Günel and Ilgin (2014) indicated that the first use of the term skyscraper in the sense of tall building was in an article published by James R. Osgood & Co. in 'The American Architect and Building News' journal in 1883, appearing as 'America needs tall buildings; it needs skyscrapers'.

Al-Kodmany and Ali (2013) defined the term skyscraper as is a relative term for a building that seems to reach the sky and characterizes by tall and extensive facades and small roofs. Yeang (1999) mentioned that the term skyscraper is a suitable abbreviation for the tall building that generally over 10 stories and defined as a building that characterizes by a small site layout, tall facades, small roof area and special engineering systems.

American Society of Heating and Air-Conditioning Engineers (ASHRAE) Technical Committee defined the tall building as a building with more than 91 meters in height (Simmond 2015).

However, according to CTBUH (2017), building height is a poor indicator for defining tall buildings. Tall buildings are buildings that show some aspects of tallness in one or more of the following three categories, if a building has one or more of these categories, it can be considered as a tall building:

- Height Relative to Context (see Figure 2.5); A 14-story building, for example, can’t be considered as a tall building in high-rise cities like Chicago and Hong Kong, but it can be considered as a tall building in rural European cities or suburbs.

- Proportion (see Figure 2.6); there are many buildings that are not high enough, but there are slender enough to give the appearance of a tall building. On the contrary, there are many large-scale buildings that are quite high, but their floor area gives them the appearance of a tall building.

- Containing technologies which made buildings tall (see Figure 2.7); (e.g., specific vertical transport technologies, structural wind bracing as a product of height).

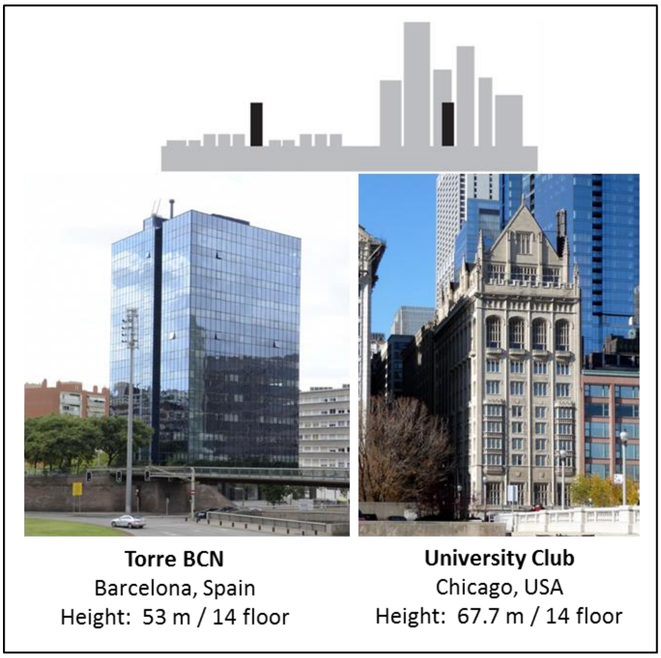


Figure 2.5. The tallness of 14-story building in relative to two different contexts (Adapted from CTBUH’s Database 2017)

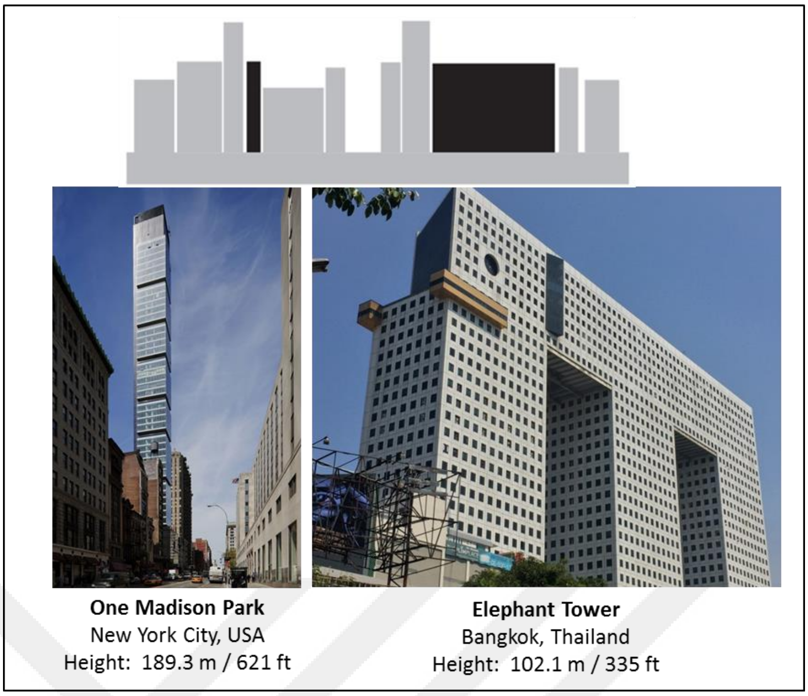


Figure 2.6. Tallness in relative to building proportion
(Adapted from CTBUH's Database 2017)

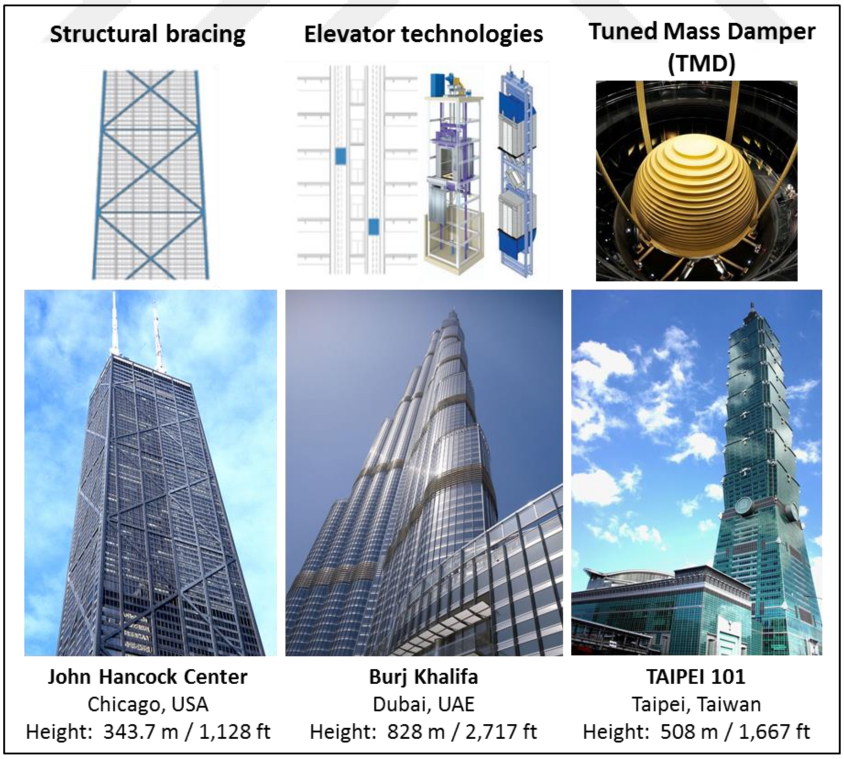


Figure 2.7. Some technologies in tall buildings
(Adapted from CTBUH's Database 2017)

According to CTBUH (2017), in height criteria terms, there are the Super-tall buildings and Mega-tall buildings (Figure 2.8). The Super-tall building is a tall building with more than 300 meters in height, and the Mega-tall building is a tall building with more than 600 meters in height. Until 2017, there are 115 super-tall buildings and three mega-tall buildings completed around the world.

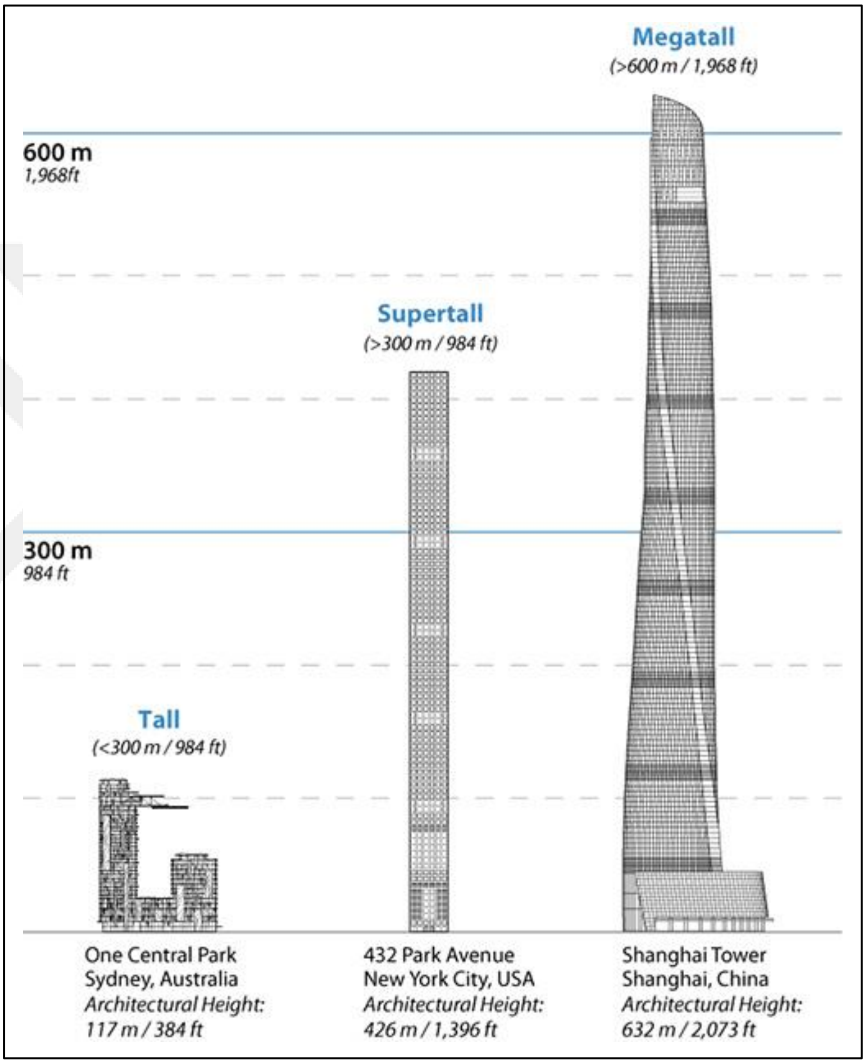


Figure 2.8. The illustration of Tall, Mega-tall and Super-tall buildings (CTBUH 2017)

2.2.2. History

The history of tall structures and buildings began approximately 4 700 years ago. The Great Pyramids of Giza in Egypt (Figure 2.9) with their height from 62 m to 146 m was the tallest man-made structure over 3 millennia (Aiello 2010).

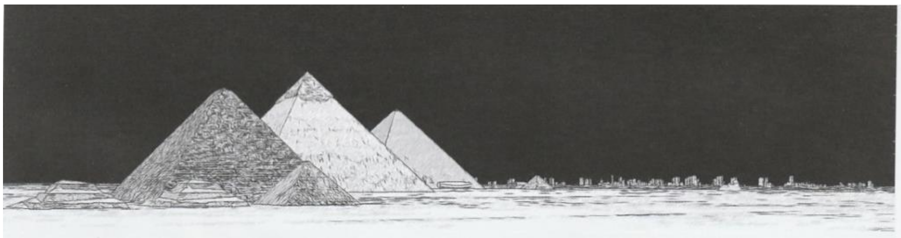


Figure 2.9. The Great Pyramids of Giza, Egypt (Al-Kodmany 2015)

Approximately before 500 years ago, a city with tall buildings was built in the desert of Yemen, this city is called Shibam (Figure 2.10). This city is often named by "the oldest skyscraper city in the world", "the Manhattan of the Desert" and "the Chicago of the desert". El-Shorbagy (2009) mentioned that these tall buildings that reach up to fourteen stories in height were built with mud brick. Shibam skyscraper’s structures were built of load-bearing walls, as opposed to modern frame-and-cladding techniques of the modern skyscrapers. Most of the city's tall buildings originate in the 16th century.

Figure 2.10. Shibam, Hadramout, Yemen (El-Shorbagy 2009)

After the Great Fire of 1871 in Chicago, among the technological factors that led to the reconstruction of the city of Chicago and searching for new design type of tall buildings were the invention of electric elevators and the new foundation systems that carried heavy building loads (Al-Kodmany and Ali 2013). Solving the increased population and commercial growth that time was also one of the main reasons for starting to search for new building type. The Home Insurance Building (Figure 2.11) which built in 1885 with 12 stories (55 m) in Chicago and designed by William Le Baron Jenney is known as the first skyscraper by using a frame structural system, this skyscraper became a model for the next skyscrapers (Günel and Ilgin 2014).

Figure 2.11. Home Insurance Building, Chicago, USA, 1885 (Günel and Ilgin 2014)

After Home Insurance Building, a series of skyscrapers were built in Chicago; e.g., the Wainwright Building in 1890, and the Reliance Building in 1895. Constructing skyscrapers continued in New York; e.g., the Chrysler Building in 1930, and the Empire State Building in 1931 (Al-Kodmany and Ali 2013). Skyscrapers design had been developed after World War II, first in the USA, followed by Pacific Rim countries, parts of Europe, and the Middle East. With the technological and structural innovation, the architectural styles of tall buildings are changing and a series of new forms of skyscrapers is appearing.

2.2.3. Ecological features and approaches for skyscrapers

According to Gonçalves (2010), the basis for ecological design for skyscrapers rests on the principles of environmental architecture, which brings together ecology and architecture. For these, the aim of reducing energy demand in buildings in general and skyscrapers specifically begins with considering the local climate and the specific ecological conditions of the site, passing to considerations of form and orientation, facades and materials, and finally the building's technical systems and the controls of building components and systems. Figure 2.12 shows the methodological approach for ecological design of skyscrapers.

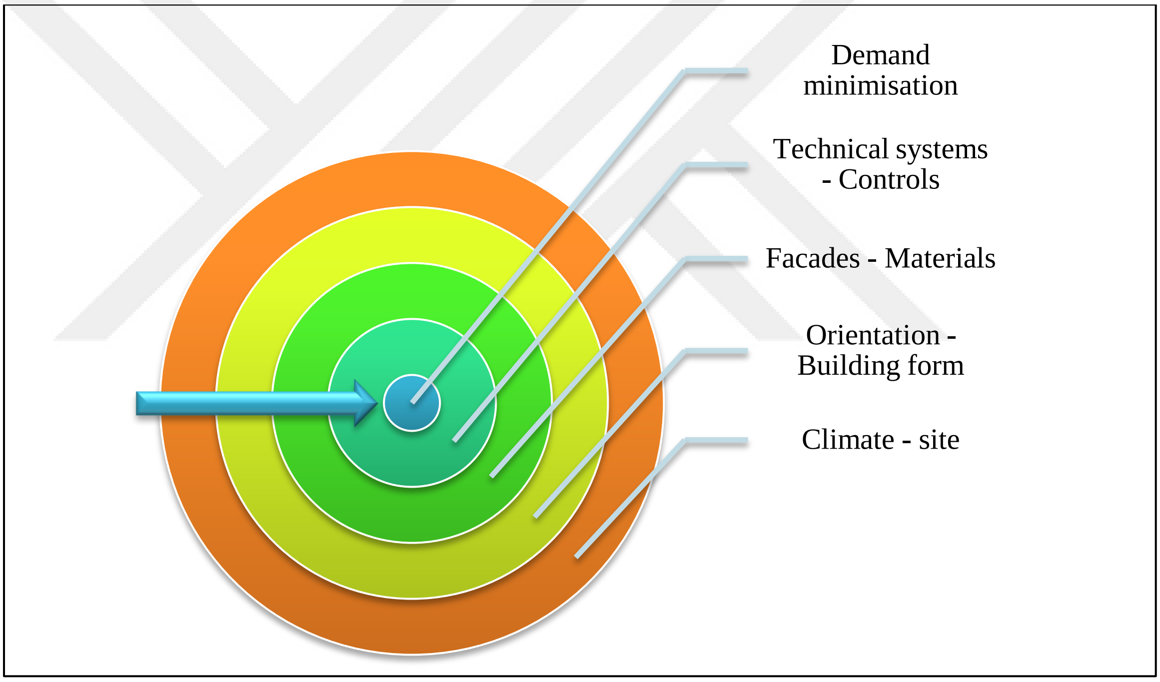


Figure 2.12. The methodological approach for ecological design of skyscrapers (Adapted from Gonçalves 2010)

This methodological approach for ecological design of skyscrapers guides to use the ecological design features and approaches for enhancing the ecological and environmental performance of skyscrapers. The following points mention some of these adaptable ecological features and approaches, and give some skyscrapers' examples of them.

- One of the important ecological features for skyscrapers is considering the use of renewable energy like solar and wind energy to generate the sufficient energy (Smith and Killa 2007), an example for this is the Bahrain World Trade Center (Figure 2.13) with its three wind turbines. This feature will be taken in details in the next chapter.

Figure 2.13. Bahrain World Trade Center, Bahrain (CTBUH's Database 2017)

- Another ecological feature for skyscrapers is considering the use of façade technologies to enhance the environmental performance of skyscrapers (Al-Kodmany 2015), an example for this is Al Bahar Towers (Figure 2.14) with its Mashrabiya, a lot of units of Mashrabiya shape the second outer skin of the buildings, these units are to control sun rays and heat inside the building. Mashrabiya is a functional and decorative architectural element that combined the function and form of the traditional Arabic-Islamic architecture style to add ecological features to buildings (Aksamija 2013)

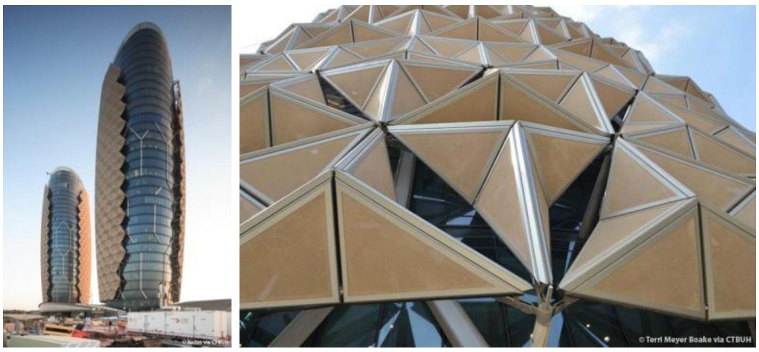


Figure 2.14. Al Bahar Towers, Abu Dhabi (CTBUH's Database 2017)

- Another ecological feature for skyscrapers is considering the natural ventilation to reduce energy consumption in skyscrapers and enhance the indoor air quality (Pank et al. 2002), an example for this is Commerzbank Tower (Figure 2.15) with its sky gardens, internal gardens, central atrium, and double skin glazed façade. This feature will be taken in details in the fourth chapter of this thesis.

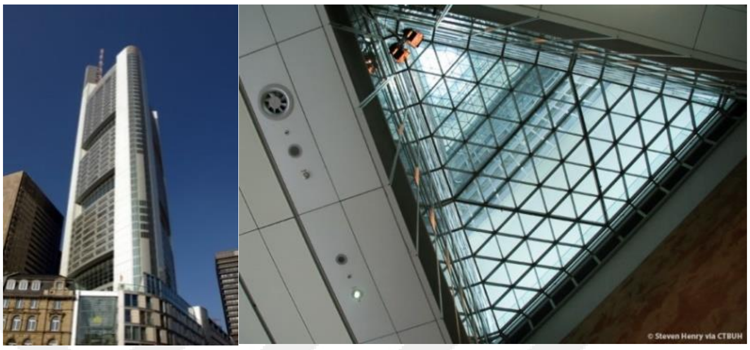


Figure 2.15. Commerzbank Tower, Germany (CTBUH's Database 2017)

- Considering the biosmic eco-design approach is one of the important ecological approaches for skyscrapers. Biomimicry is a field of study that studies nature's best practice and then imitates them in the process of solving practical built environment problems (Al-Kodmany 2015), an example for this is Doha Tower (Figure 2.16) which inspired the desert plant Cactus, the skyscraper skin contains smart shades that open and close to control heat gains, this process imitates the activity of Cactus.

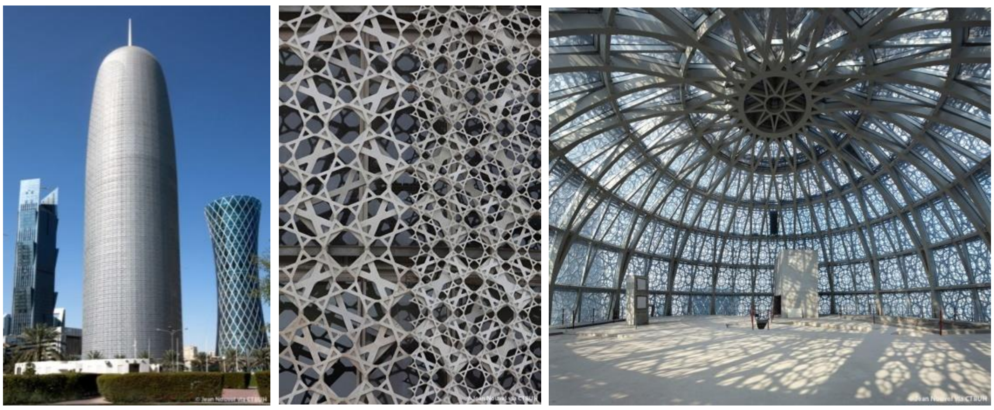


Figure 2.16. Doha Tower, Qatar (CTBUH's Database 2017)

- Considering the bioclimatic design approach which applied and proposed by Ken Yeang is also one of the important ecological approaches for skyscrapers. According to Yeang (2010), bioclimatic design is an eco-design strategy that gives low energy consumption systems by taking the advantage of the surrounding climate of the locality, bioclimatic design approach aims to maximize natural and surrounding energy resources and minimize the use of non-renewable energy resources, an example for this is Menara Boustead Tower (Figure 2.17) with its bioclimatic features which are compatible with tropical climate zone. This approach will be taken in details in the fourth chapter of this thesis.

Figure 2.17. Menara Boustead Tower, Malaysia (CTBUH's Database 2017)

- Considering structural efficiencies like aerodynamic forms for skyscrapers is a technological feature that can be ecological at the same time, this feature can maximize the rigidity of the skyscraper and minimize large wind loads (Gonçalves 2010), an example for this is Swiss Re Building (Figure 2.18) which has adopted an efficient aerodynamic form and utilized efficient diagrid steel structural system.

Figure 2.18. 30 St Mary Axe (Swiss Re Tower), London (CTBUH's Database 2017)

2.3. Green Building Rating Systems

Green building rating systems generally are point-based systems in which buildings and skyscrapers earn points for satisfying green buildings criteria. These systems contain a collection of strategies that can reduce the negative environmental impacts. Hundreds of certified green buildings and skyscrapers across the world provide real evidence of what sustainable building design can achieve in terms of aesthetics, comfort, energy, and resource efficiency (Kubba 2012). Since 1990, when the United Kingdom established the first ecological building assessment system, many other countries have started to adopt and create their rating systems according to specific ecological and environmental values (Reeder 2010). Green buildings rating systems are very important to play a major role in raising awareness and in popularizing green design to improve the performance of buildings and skyscrapers, and to make them have a positive impact on their environment. This section investigates some worldwide used green building rating systems that can be utilized for evaluating the sustainability of skyscrapers.

2.3.1. LEED rating system

Leadership in Energy & Environment Design (LEED) program is a green building rating system developed by the United States Green Building Council (USGBC) and began in 1994, it was officially launched in 2000 with the first rating system for new construction and since then has enlarged its influence around the world (Letízia Lau 2015). The most recent version of this rating system is LEED v4 which started in 2014.

According to USGBC (2016), LEED projects earn points across nine basic areas that address key aspects of green buildings; integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority. LEED is a point based system in which buildings earn points for achieving specific green building criteria. There are 110 possible base points distributed across nine credit categories. The scoring is determined by the total 110 point score collected over all categories. Based on the number of points achieved, buildings and skyscrapers earn one of the four LEED rating levels (Table 2.1); Basic, Silver, Gold or Platinum.

Table 2.1. LEED rating levels (Adapted from USGBC 2016)

LEED rating level	Points score
Certified	40 – 49 points
Silver	50 – 59 points
Gold	60 – 79 points
Platinum	80 – 110 points

LEED has five rating systems; Building Design and Construction (BD+C), Interior Design and Construction (ID+C), Building Operation and Maintenance (O+M), Neighborhood Development (ND), and Homes. Two of these five rating systems can be used for evaluating the sustainability of skyscrapers; LEED v4 BD+C, and LEED v4 O+M; the first one is LEED v4 BD+C which is applied to skyscrapers that are being newly constructed or going through a major renovation, and the second one is LEED v4 O+M which is applied to existing skyscrapers (USGBC 2016). Figure 2.19 shows the credit scoring of categories of the two LEED v4 rating systems that can be used for evaluating the sustainability of skyscrapers.

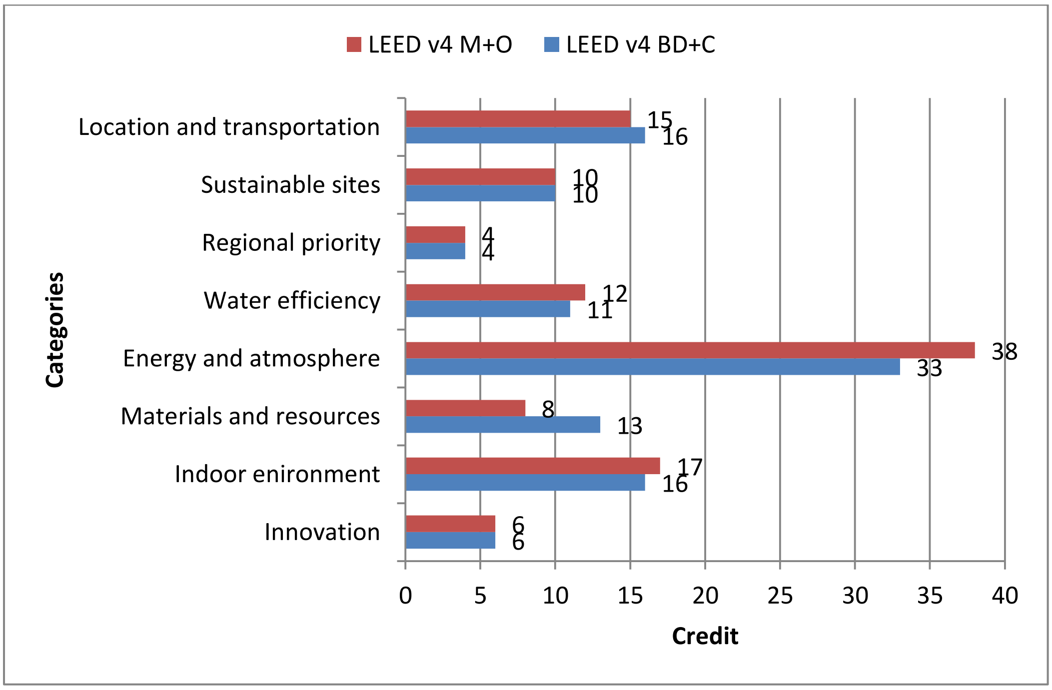


Figure 2.19. LEED v4 credit scoring of categories (Adapted from USGBC 2016)

According to the result shown in Figure 2.19, it is remarkable that LEED v4 BD+C and M+O give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment quality take the second position for evaluating the sustainability of skyscrapers.

2.3.2. BREEAM rating system

Building Research Establishment Environmental Assessment Method (BREEAM) is a green building rating system launched in the UK in 1990; this rating system is developed by the United Kingdom Building Research Establishment (UK BRE) (Reeder 2010). According to BRE (2016), BREEAM projects earn points across ten categories that measures sustainable value and ecological factors; energy, health and well-being, innovation, land use, materials, management, pollution, transport, waste and water.

According to BRE (2016), each category in BREEAM rating system is made to score the relative performance of the building. Individual credit scores and percentages are calculated for each category. Once all of the individual credit scores and percentages are applied, a final percentage score for the building is given summed over all categories. Based on the percentage achieved, buildings and skyscrapers earn one of the BREEAM rating levels (Table 2.2); Pass, Good, Very Good, Excellent or Outstanding.

Table 2.2. BREEAM rating levels (Adapted from BRE 2016)

BREEAM rating level	Score %
Unclassified	< 30
Pass	≥ 30
Good	≥ 45
Very good	≥ 55
Excellent	≥ 70
Outstanding	≥ 85

BREEAM has five rating systems; BREEAM Communities, BREEAM Infrastructure, BREEAM International New Construction, BREEAM In-Use International, BREEAM International Refurbishment and Fit-Out. Two of these five rating systems can be used for evaluating the sustainability of skyscrapers; BREEAM International New Construction and BREEAM In-Use International; the first one is BREEAM International New Construction which is applied to skyscrapers that are being newly constructed or going through a major renovation, and the second one is BREEAM In-Use International which is applied to existing skyscrapers (BRE 2016). Figure 2.20 shows the credit scoring of categories of the two BREEAM rating systems that can be used for evaluating the sustainability of skyscrapers.

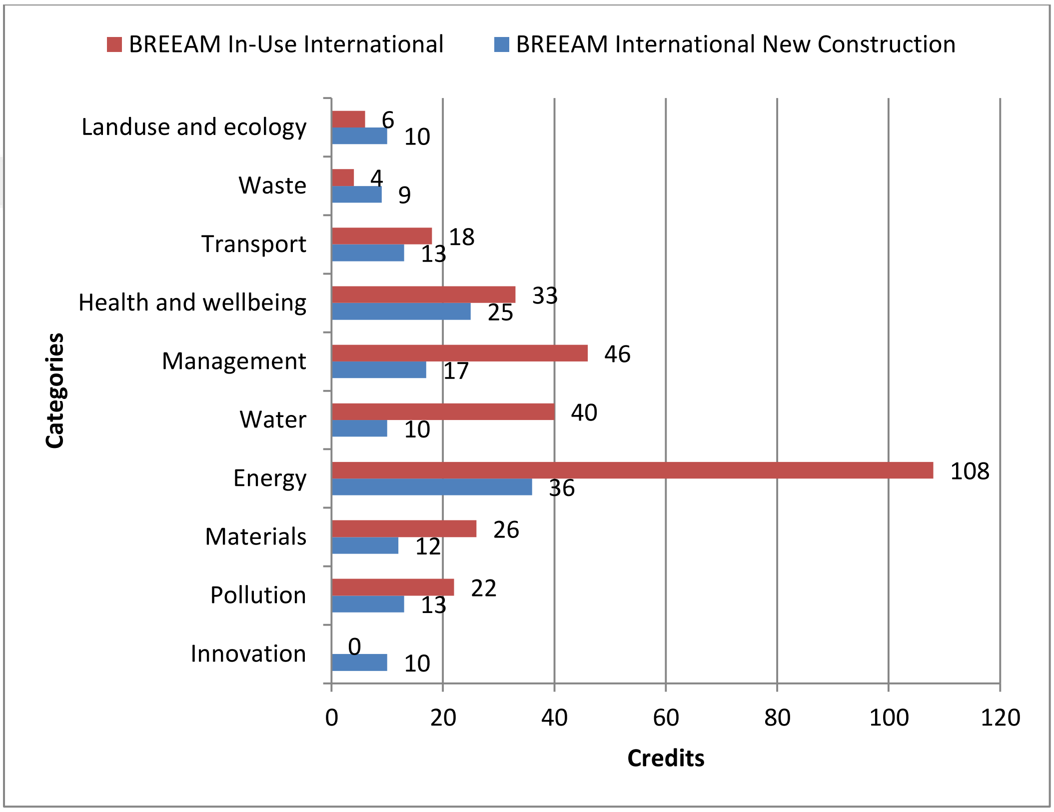


Figure 2.20. BREEAM credit scoring of categories (Adapted from BRE 2016)

According to the result shown in Figure 2.20, it is remarkable that BREEAM International New Construction and BREEAM In-Use International give important credits for evaluating the energy performance of skyscrapers. The credits of health and wellbeing take the second position for evaluating the sustainability of skyscrapers with BREEAM International New Construction.

2.3.3. Green Star rating system

Green Star program is a green building rating system launched in 2003 and developed by the Green Building Council of Australia (GBCA). Green Star rating system was developed with the assistance of the basics of BREEAM and LEED rating systems (GBCA 2015).

According to GBCA (2015), Green Star projects earn points across nine basic categories; management, indoor environment quality, energy, transport, water, materials, land use and ecology, emissions, innovation. Green Star is a point based system in which buildings earn points for achieving specific green building criteria. There are 110 possible base points distributed across nine credit categories. The scoring is determined by the total 110 point score collected over all categories. Based on the number of points achieved, buildings and skyscrapers earn one of the Green Star rating stars (Table 2.3).

Table 2.3. Green Star rating levels (Adapted from GBCA 2015)

N° of stars rating	Green star rating	Points score
1 star rating	Minimum Practice	10 points score
2 star rating	Average Practice	20 points score
3 star rating	Good Practice	30 points score
4 star rating	Best Practice	45 points score
5 star rating	Australian Excellence	60 points score
6 star rating	World Leadership	75+ points score

Green Star has four rating systems; Green Star – Communities, Green Star – Design and As Built, Green Star – Interiors and Green Star – Performance. Two of these four rating systems can be used for evaluating the sustainability of skyscrapers; Green Star – Design and As Built and Green Star – Performance; the first one is Green Star – Design and As Built which is applied to skyscrapers that are being newly constructed or going through a major renovation, and the second one is Green Star – Performance which is applied to existing skyscrapers (GBCA 2015). Figure 2.21 shows the credit scoring of categories of the two Green Star rating systems that can be used for evaluating the sustainability of skyscrapers.

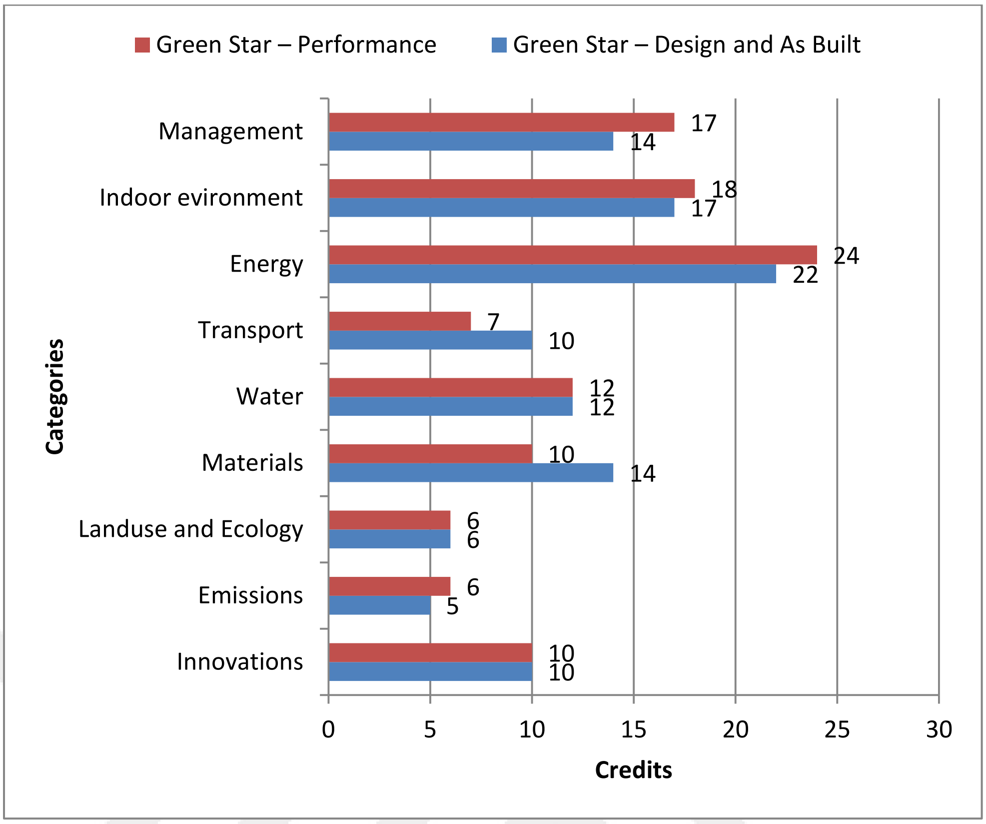


Figure 2.21. Green Star credit scoring of categories (Adapted from GBCA 2015)

According to the result shown in Figure 2.21, it is remarkable that Green Star – Design and As Built and Green Star – Performance give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment take the second position for evaluating the sustainability of skyscrapers.

2.3.4. Green Globes rating system

Green Globes is a green building rating system that is used primarily in Canada and the USA. Green Globes was developed by the Energy and Environment Canadian Department (ECD) in 2000. Green Globes is licensed for use by the Building Owners and Managers Association (BOMA) in Canada and the Green Building Initiative (GBI) in the USA (GBI 2016). The method and the ideas of Green Globes rating system are similar to LEED and many other systems around the world like BREEAM.

According to GBI (2016) and BOMA (2016), Green Globes projects earn points across seven categories; management, site, energy, water, materials and resources, emissions and indoor environment. Green Globes is based on the final percentage score summed over seven categories. There are 1000 possible base points distributed across the seven credit categories. Based on the final percentage score, buildings and skyscrapers earn one of the Green Globes rating globes for USA rating for new and existing buildings, and Canadian rating for new buildings, or earn one of the five Green Globes BOMA Building Environmental Standards (BOMA BEST) rating levels for Canadian rating for existing buildings; Certified, Bronze, Silver, Gold or Platinum (Table 2.4).

Table 2.4. Green Globes rating levels (Adapted from GBI 2016, BOMA 2016)

Green Globes systems	Green Globes rating	Score %
USA Green Globes rating levels for new and existing buildings	One green globes	35 – 54 %
	Two green globes	55 – 69 %
	Three green globes	70 – 84 %
	Four green globes	85 – 100 %
Canadian Green Globes rating levels for new buildings	One green globes	25 – 39 %
	Two green globes	40 – 54 %
	Three green globes	55 – 69 %
	Four green globes	70 – 84 %
	Five green globes	85 – 100 %
Canadian Green Globes BOMA BEST rating levels for existing buildings	BOMA BEST Certified	Under 19 %
	BOMA BEST Bronze	20 – 49 %
	BOMA BEST Silver	50 – 79 %
	BOMA BEST Gold	80 – 89 %
	BOMA BEST Platinum	90 – 100 %

Green Globes has two version modules, one is for rating the buildings in Canada and the other is for rating the buildings in the USA. Each version has its own systems. USA Green Globes has three rating systems; USA Green Globes for New Construction (NC), USA Green Globes for Existing Buildings (EB), and USA Green Globes for Sustainable Interiors. Canada Green Globes has three rating systems; Canada Green Globes for NC, Canada Green Globes BOMA BEST 3.0 for EB, and Canada Green Globes for Sustainable Interiors. Four of these six rating systems can be used for evaluating the sustainability of skyscrapers; USA Green Globes for NC, USA Green Globes for EB, Canada Green Globes for NC, Canada Green Globes BOMA BEST 3.0 for EB; the first one is USA Green Globes for NC which is applied to skyscrapers that are being newly constructed or going through a major renovation, the second one is USA Green Globes for EB which is applied to existing skyscrapers, the third one is Canada Green Globes for NC which is applied to skyscrapers that are being newly constructed or going through a major renovation, the fourth one is Canada Green Globes BOMA BEST 3.0 for EB which is applied to existing skyscrapers (Green Globes 2016, BOMA 2016). Figure 2.22 shows the credit scoring of categories of the four Green Globes rating systems that can be used for evaluating the sustainability of skyscrapers.

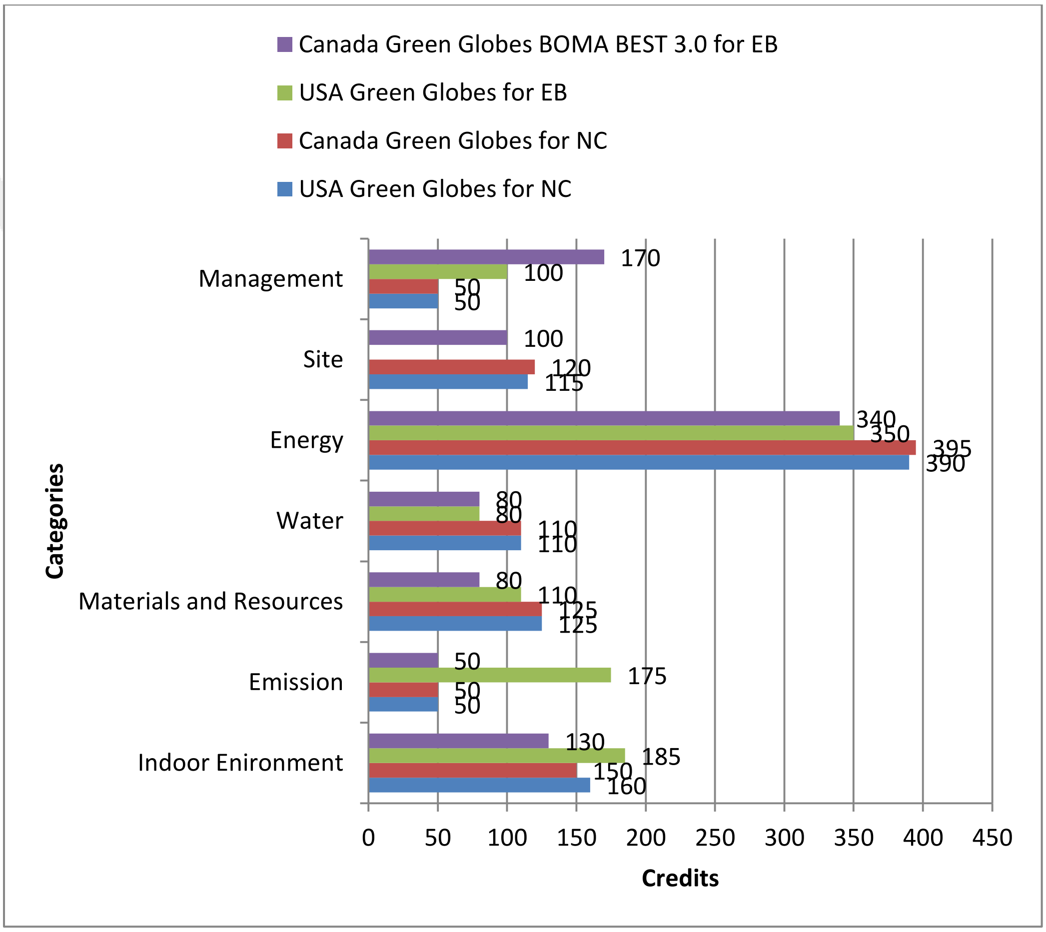


Figure 2.22. Green Globes credit scoring of categories
(Adapted from GBI 2016, BOMA 2016)

According to the result shown in Figure 2.22, it is remarkable that Green Globes rating systems give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment take the second position for evaluating the sustainability of skyscrapers.

2.3.5. DGNB rating system

DGNB rating system was founded by the German Sustainable Building Council (DGNB–Deutsche Gesellschaft für Nachhaltiges Bauen e.V.) in 2007 (DGNB 2016). According to DGNB (2016), DGNB rating system evaluates the performance of the buildings across six categories that covers important key aspects of sustainable buildings; environmental quality, economic quality, sociocultural and functional quality, technical quality, processes quality and site quality. The DGNB focuses on buildings' overall performance rather than individual measures. The total score for the overall project is calculated from the five quality sections based on their weighting. Site quality is considered separately and this aspect of the building is included in the commercial viability criterion. Based on the total score achieved, buildings and skyscrapers earn one of the four DGNB rating levels (Table 2.5); Bronze, Silver, Gold or Platinum. Bronze level is valid only for existing buildings.

Table 2.5. DGNB rating levels (Adapted from DGNB 2016)

DGNB rating level	Total performance Index %	Minimum performance Index %
Bronze	0 %	From 35 %
Silver	35 %	From 50 %
Gold	50 %	From 65 %
Platinum	65 %	From 80 %

The DGNB has developed the CORE 14 system for international use. The CORE 14 scheme for offices is available in English language. Further schemes are in the process of translation. The following schemes are currently available for buildings in German (DGNB 2016): Offices, Residential buildings, Dwellings, Healthcare, Education facilities, Hotels, Retail, Assembly buildings, Industrial, Tenant fit-out, Districts: Urban districts, Office and Business districts, Industrial locations and Event-areas. DGNB CORE 14 offices version can be used for evaluating the sustainability of skyscrapers; this system is applied to office skyscrapers that are being newly constructed or existing office skyscrapers (DGNB 2016). Figure 2.23 shows the credit scoring of categories of DGNB CORE 14 offices rating system.

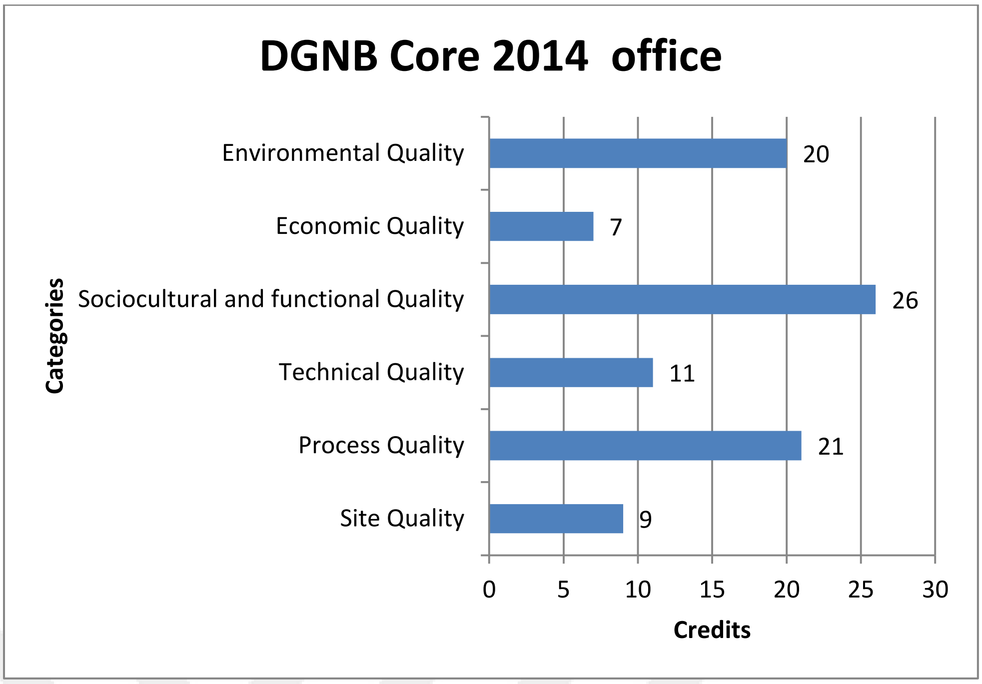


Figure 2.23. DGNB CORE 14 credit scoring of categories (Adapted from DGNB 2016)

According to the result shown in Figure 2.23, it is remarkable that DGNB Core 2014 office give important credits for evaluating the sociocultural and functional performance of skyscrapers. The credits of environmental and process quality take the second position for rating and evaluating the sustainability of skyscrapers.

2.3.6. BCA GM rating system

The Green Mark (GM) rating system was developed by the Building and Construction Authority (BCA) of Singapore in January 2005 to promote sustainability in the construction industry and raise environmental awareness among stakeholders of the projects (BCA 2016).

According to BCA (2016), BCA GM projects earn points across categories that cover different sustainable aspects of green buildings. GM rating systems cover the following key areas: energy efficiency, water efficiency, environmental protection, indoor environmental quality, other green features and innovation. There are new versions were made for rating the new buildings, the categories' key areas had been re-named but the continents of sustainable criteria still similar to those in the previous versions. The previous versions are still used with the existing buildings. The categories' key areas of GM rating systems for rating the new buildings are; climate responsive design, resource stewardship, smart & healthy building, building energy performance, advanced green efforts. BCA GM is a point based system in which buildings earn points for achieving specific green building criteria. There are possible points distributed across the different credit categories of BCA GM rating systems. Based on the overall assessment and the number of points achieved, buildings and skyscrapers earn one of the four BCA GM rating levels (Table 2.6); Platinum, Gold Plus, Gold or Certified.

Table 2.6. BCA GM rating levels (Adapted from BCA 2016)

BCA GM for new buildings		BCA GM for existing buildings	
Green Mark Rating	**Green Mark Score**	**Green Mark Rating**	**Green Mark Score**
GM Platinum	70 and above	**GM Platinum**	90 and above
GM Gold Plus	60 to 70	**GM Gold Plus**	85 to 90
GM Gold	50 to 60	**GM Gold**	75 to 85
		GM Certified	50 to 75

There are so many BCA GM schemes and systems. The following systems can be used for evaluating the sustainability of skyscrapers (BCA 2016):

- BCA GM for New Residential Buildings GM RB: 2016
- BCA GM for New Non-Residential Buildings GM NRB: 2015
- BCA GM for Existing Non-Residential Buildings GM ENRB 3.0
- BCA GM for Existing Residential Buildings GM ERB 1.1

The first one is GM RB: 2016 which is applied to new residential skyscrapers, the second one is GM NRB: 2015 which is applied to new non-residential skyscrapers, the third one is GM ENRB 3.0 which is applied to existing non-residential skyscrapers, the fourth one is GM ERB 1.1 which is applied to existing residential skyscrapers. Figure 2.24 shows the credit scoring of categories of the four BCA GM rating systems that can be used for evaluating the sustainability of skyscrapers.

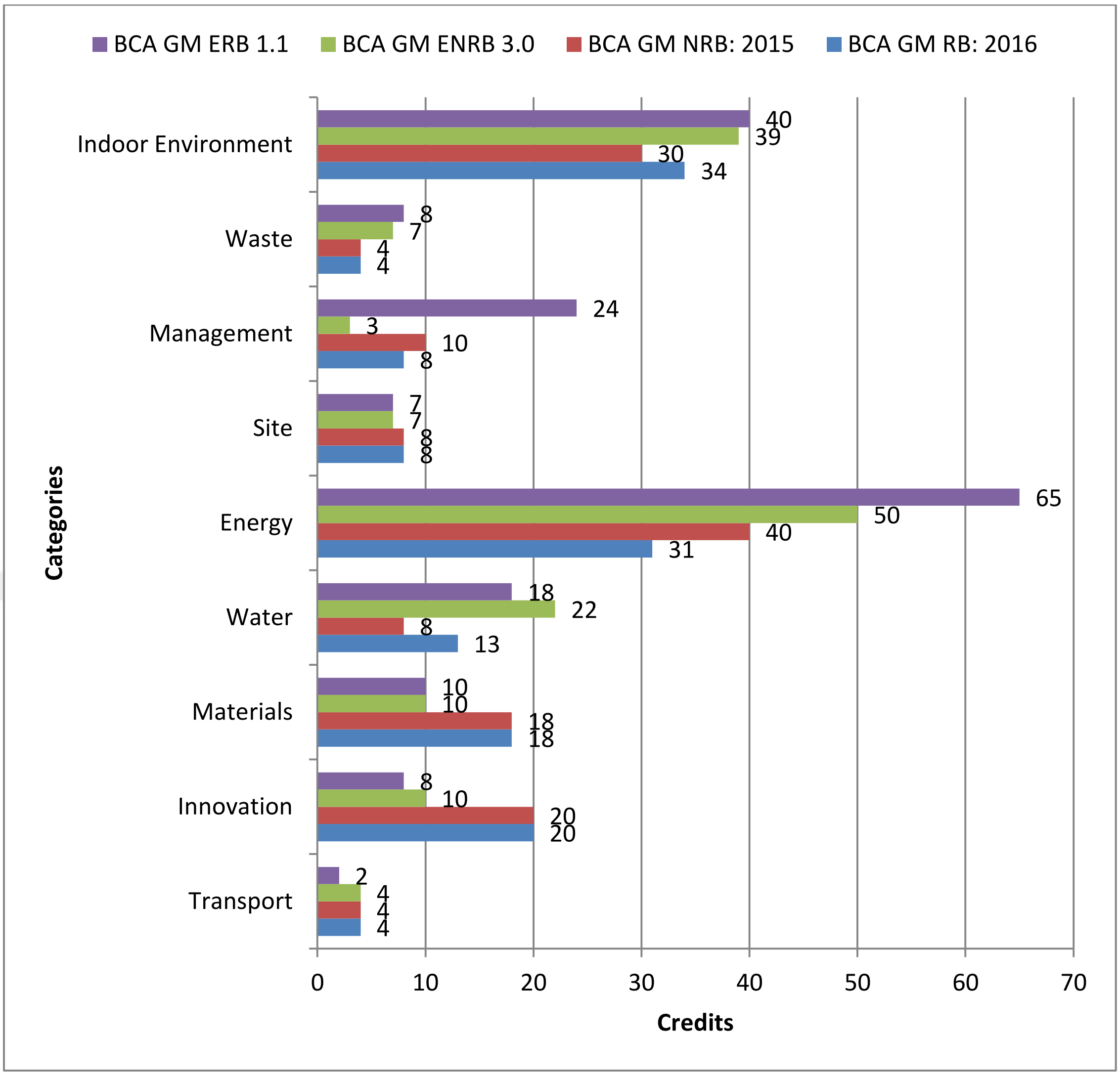


Figure 2.24. BCA GM credit scoring of categories (Adapted from BCA 2016)

According to the result shown in Figure 2.24, it is remarkable that BCA GM rating systems give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment take the second position for evaluating the sustainability of skyscrapers.

2.3.7. GBI rating system

Green Building Index (GBI) program is a Malaysian green building rating system developed in 2009 by PAM (Pertubuhan Arkitek Malaysia / Malaysian Institute of Architects) and ACEM (Association of Consulting Engineers Malaysia). GBI rating system is based upon some of the existing rating systems such as the Singaporean Green Mark and the Australian Green Star system (PAM and ACEM 2016).

According to PAM and ACEM (2016), GBI projects earn points across six categories that cover key aspects of green buildings; energy efficiency, indoor environment quality, sustainable site planning & management, materials & resources, water efficiency and innovation. GBI is a point-based rating system in which buildings earn points for achieving specific green building criteria. There are 100 possible base points distributed across six credit categories. The scoring is determined by the total 100 point score collected over all categories. Based on the number of points achieved, buildings and skyscrapers earn one of the four GBI rating levels (Table 2.7); Certified, Silver, Gold or Platinum.

Table 2.7. GBI rating levels (Adapted from PAM and ACEM 2016)

GBI rating level	Points score
Certified	50 – 65 points
Silver	66 – 75 points
Gold	76 – 85 points
Platinum	86 – 100 points

There are so many GBI schemes and systems. The following rating systems can be used for evaluating the sustainability of skyscrapers (PAM and ACEM 2016):

- GBI for Non-Residential New Construction (NRNC).
- GBI for Residential New Construction (RNC).
- GBI for Non-Residential Existing Building (NREB).

The first one is GBI for NRNC which is applied to non-residential skyscrapers that are newly constructed or going through a major renovation, the second one is GBI for RNC which is applied to residential skyscrapers that are newly constructed or going through a major renovation, and the third one is GBI for NREB which is applied to non-residential existing skyscrapers. Figure 2.25 shows the credit scoring of categories of the three GBI rating systems that can be used for evaluating the sustainability of skyscrapers.

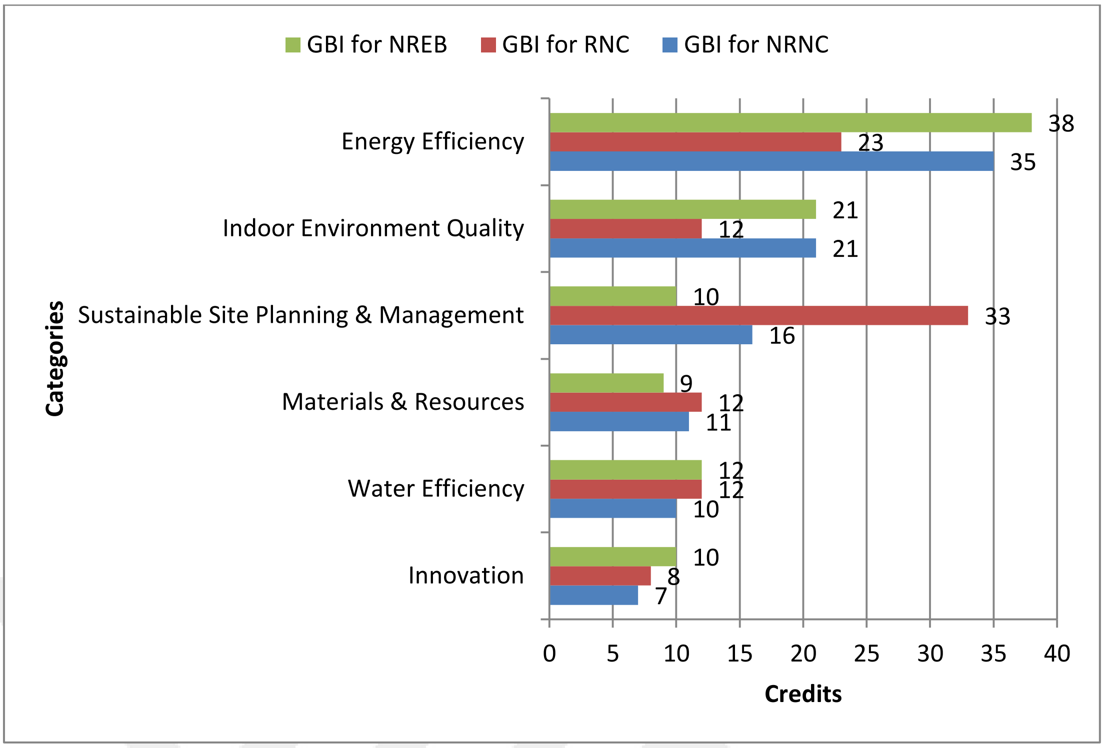


Figure 2.25. GBI credit scoring of categories (Adapted from PAM and ACEM 2016)

According to the result shown in Figure 2.25, it is remarkable that GBI rating systems give important credits for evaluating the energy efficiency of skyscrapers. The credits of indoor environment quality take the second position for evaluating the sustainability of non-residential skyscrapers.

2.3.8. BEAM Plus rating system

Building Environmental Assessment Method Plus (BEAM Plus) is a green building rating system founded in April 2010 by the Hong Kong Green Building Council (HKGBC). According to HKGBC (2016), BEAM Plus projects earn points across six categories that cover key aspects of green buildings ; site aspects, materials aspects, energy use, water use, indoor environmental quality, innovation and additions, management category is found as a main and independent category in the new version of BEAM Plus for existing buildings. The overall rating level of BEAM Plus is determined by the total percentage of the credits which are gained from each category.

It is necessary also to obtain a minimum percentage of credits for the categories in order to qualify for the overall grade. Based on the total percentage achieved, buildings and skyscrapers earn one of the four BEAM Plus rating levels; Platinum, Gold, Silver or Bronze. There is a difference in the minimum percentages of credits for the categories between the BEAM Plus rating systems. Table 2.8 shows BEAM Plus rating levels' minimum scores.

Table 2.8. BEAM Plus rating levels (Adapted from HKGBC 2016)

BEAM Plus New Buildings V1.2 levels' minimum scores						
Level	**Overall**	**SA**	**EU**	**IEQ**	**IA**	**Rating**
Bronze	40 %	40 %	40 %	40 %	-	Above Average
Silver	55 %	50 %	50 %	50 %	1 credits	Good
Gold	65 %	60 %	60 %	60 %	2 credits	Very Good
Platinum	75 %	70 %	70 %	70 %	3 credits	Excellent

BEAM Plus Existing Buildings V2.0 levels' minimum scores							
Level	**Overall**	**MAN**	**SA**	**MWA**	**EU**	**WU**	**IEQ**
Bronze	40	40 %	20 %	20 %	40 %	20 %	20 %
Silver	55	50 %	30 %	30 %	50 %	30 %	30 %
Gold	65	60 %	40 %	40 %	60 %	40 %	40 %
Platinum	75	70 %	50 %	50 %	70 %	50 %	50 %

BEAM Plus has four rating systems; BEAM Plus New Buildings V1.2, BEAM Plus, Existing Buildings V2.0, BEAM Plus Interiors V1.0, and BEAM Plus Neighborhood V1.0. Two of these four rating systems can be used for evaluating the sustainability of skyscrapers; BEAM Plus New Buildings V1.2, and BEAM Plus Existing Buildings V2.0; the first one is BEAM Plus New Buildings V1.2 which is applied to skyscrapers that are being newly constructed or going through a major renovation, and the second one is BEAM Plus Existing Buildings V2.0 which is applied to existing skyscrapers (HKGBC 2016). Figure 2.26 shows the credit scoring of categories of the two BEAM Plus rating systems that can be used for evaluating the sustainability of skyscrapers.

According to the result shown in Figure 2.26, it is remarkable that BEAM Plus rating systems give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment quality take the second position for evaluating the sustainability of skyscrapers.

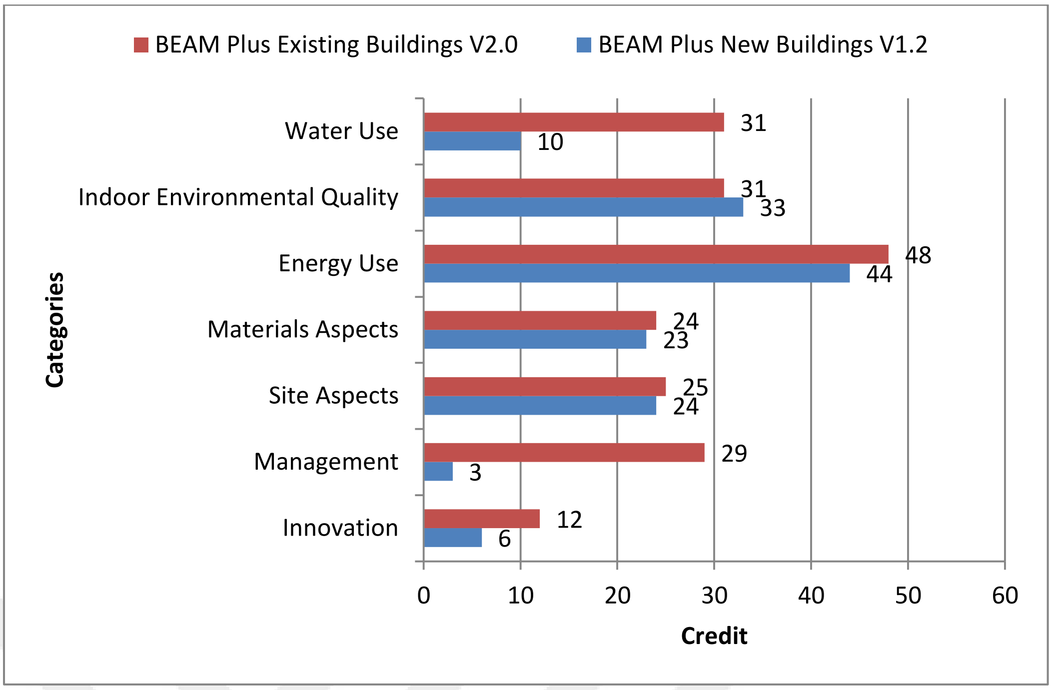


Figure 2.26. BEAM Plus credit scoring of categories (Adapted from HKGBC 2016)

2.3.9. Pearl rating system for Estidama

The Pearl rating system for Estidama is a green building rating system founded in 2010 by Abu Dhabi Urban Planning Council (ADUPC). Estidama is meaning sustainability in the Arabic language, the Pearl rating system provides design guidance and detailed requirements for rating a project's potential performance in relation to the four pillars of Estidama: environmental, economic, cultural and social (ADUPC 2010).

According to ADUPC (2010), Pearl projects earn points across seven categories that covers key aspects of green buildings; integrated development process, natural systems, livable buildings, precious water, resourceful energy, stewarding materials, innovating practice. Pearl rating system is a point-based system in which buildings earn credits for achieving specific green building criteria. There are 177 possible credits distributed across seven credit categories. Within each category, there are both mandatory and optional credits. To achieve a 1 Pearl rating, all the mandatory credit requirements must be earned. To achieve a higher Pearl rating, all the mandatory credit requirements must be earned along with a minimum number of credit points. Based on the credit points achieved, buildings and skyscrapers earn one to five Pearl of the Pearl rating system (Table 2.9).

Table 2.9. Pearl rating levels (Adapted from ADUPC 2010)

Pearl rating level	Requirement
1 Pearl	All mandatory credits
2 Pearl	All mandatory credits + 60 credit points
3 Pearl	All mandatory credits + 85 credit points
4 Pearl	All mandatory credits + 115 credit points
5 Pearl	All mandatory credits + 140 credit points

Pearl has three rating systems; Pearl Community rating system, Pearl Building rating system, and Pearl Villa rating system. One of these three rating systems can be used for evaluating the sustainability of skyscrapers; Pearl Building Rating System V1.0; this system is applied to skyscrapers that are being newly constructed or existing ones (ADUPC 2010). Figure 2.27 shows the credit scoring of categories of Pearl Building V1.0 rating system.

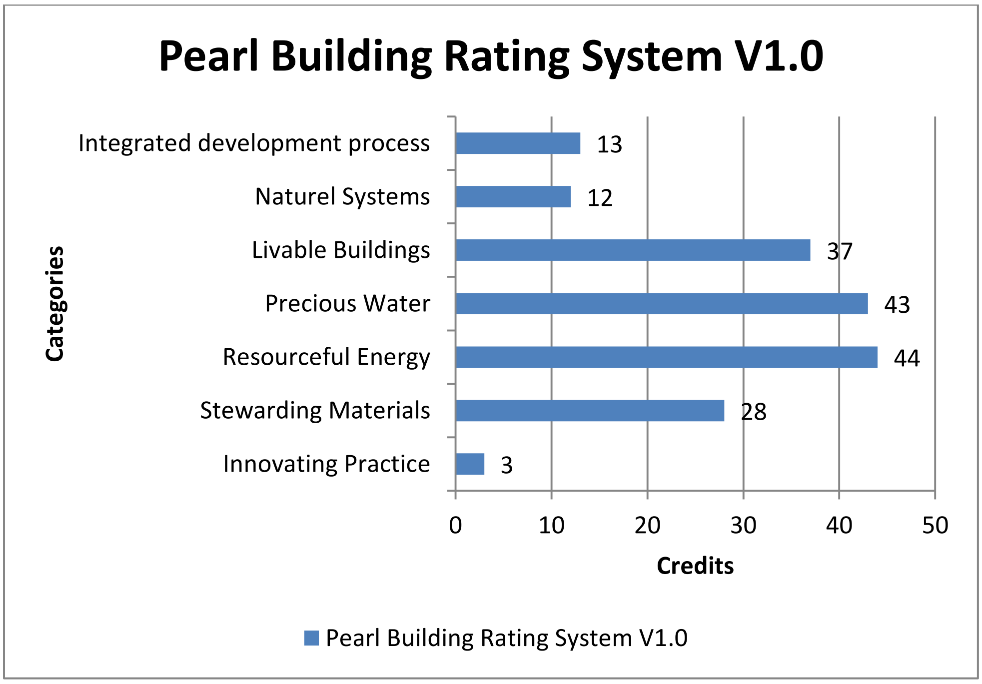


Figure 2.27. Pearl Building credit scoring of categories (Adapted from ADUPC 2010)

According to the result shown in Figure 2.27, it is remarkable that Pearl Building V1.0 rating system gives important credits for evaluating the resourceful energy performance of skyscrapers. The credits of precious water performance take the second position for evaluating the sustainability of skyscrapers.

2.3.10. Comparison between the investigated green building rating systems

This part provides a table of comparison summary between the investigated green building rating systems (Table 2.10), and a table of some examples of certificated skyscrapers with these rating systems (Table 2.11). This part also provides comparisons between the investigated rating systems' scoring charts of categories for new and existing skyscrapers (Figure 2.28, Figure 2.29).

Table 2.10. Comparison summary between the investigated green building rating systems

Rating system	**LEED**	**BREEAM**	**Green Star**	**Green Globes**	**DGNB**	**BCA Green Mark**	**GBI**	**BEAM Plus**	**Pearl**
label	USGBC	UK BRE	GBCA	ECD	DGNB	BCA	PAM and ACEM	HKGBC	ADUPC
Origin	USA	UK	Australia	Canada	Germany	Singapore	Malaysia	Hong Kong	UAE
Year	2000	1990	2003	2000	2007	2005	2009	2010	2010
App	World Wide	World Wide	World Wide	Canada and USA, can be worldwide	Germany and can be worldwide	Singapore and Sur.countries	Malaysia and Sur.countries	Hong Kong and China	UAE
Logo									
Levels	Basic: 40-49 p, Silver: 50-59 p Gold: 60-79 p Platinum: 80+ p	Outstanding ≥ 85% Excellent ≥ 70% Very Good ≥55% Good ≥ 45% Pass ≥ 30% Unclassified < 30%	1 star: Minimum Practice. 2 star: Average practice. 3 star: good practice. 4 star: Best practice. 5 star: Australian Excellence. 6 star: World Leadership	1 Green Globe. 2 Green globes 3 Green globes 4 Green globes 5 Green globes	Bronze ≥ 35% Silver ≥ 50% Gold ≥65% Platinum ≥ 80	Certified ≥ 50% Gold ≥ 75% Gold Plus ≥ 85% Platinum ≥ 90 %	Certified ≥ 50% Silver ≥ 66% Gold ≥ 76% Platinum ≥ 86 %	Bronze ≥ 40% Silver ≥ 55% Gold ≥ 65% Platinum ≥ 75 %	1 Pearl: All mandatory credits. 2 Pearl: All + 60c. 3Pearl: All + 85c. 4 Pearl: All+115c. 5Pearl: All+140c.

Table 2.10. Continued. Comparison between the investigated green building rating

Method	Determined by the total 110 point score summed over all categories	Determined by a final percentage score for the building summed over all categories	Determined by a final percentage score for the building summed over all categories	Based on the percentage of a total points (up to 1000) achieved summed over all categories	Determined by a final percentage score for the building summed over five categories	Based on the percentage of a total points (up to 190) achieved summed over all categories	Determined by a final percentage score for the building summed over all categories	Determined by a final percentage score for the building summed over all categories	Based on the total points (up to 177) achieved summed over all categories
Skyscrapers rating Systems	• LEED v4 BD+C • LEEDv4 O+M	• BREEAM New Construction • BREEAM In-Use.	• Green Star – Design and As Built • Green Star Performance	• Green Globes for NC • Green Globes for EB	• DGNB Core 2014 office	• BCA green Mark for NB. • BCA green mark for EB.	• GBI for NRNC. • GBI for RNC. • GBI for NREB.	• BEAM for NB. • BEAM for EB.	The Pearl Building Rating System for Estidama
Credit scoring of categories	**BD+C**	**New Construc.**	**Design, Built**	**USA NC**	Environm.: 20 Economic: 7 Sociocultu.: 26 Technical: 11 Process: 21 Site: 9	**RB**	**NRNC**	**NB**	Process: 13 Natural: 12 Livable: 37 Water: 43 Energy: 44 Material: 28 Innovation: 3
	Location: 16 Sites: 10 Water: 11 Energy: 33 Material: 13 In. Envir. : 16 Region Pr.: 4 Innovation: 6	Land use: 10 Waste: 9 Transport: 13 Wellbeing: 25 Manage.: 17 Water: 10 Energy: 36 Material: 12 Pollution: 13 Innovation: 10	Manage.: 14 In. Envir.: 17 Energy: 22 Transport: 10 Water: 12 Material: 14 Land use: 6 Emissions: 5 Innovation: 10	Manage.: 50 Site: 115 Energy: 390 Water: 110 Material: 125 Emission: 50 In. Envir.: 160		In. Envir.: 34 Waste: 4 Manage.: 8 Site: 8 Energy: 31 Water: 13 Material: 18 Innovation: 20 Transport: 4	Energy: 35 In. Envir.: 21 Site,Manag: 16 Material: 11 Water: 10 Innovation: 7	Water: 10 In. Envir.:33 Energy: 44 Material: 23 Site: 24 Manage.: 3 Innovat.: 6	
	O+M	**In-Use**	**Performance**	**USA EB**		**ERB**	**NREB**	**EB**	
	Location: 15 Sites: 10 Water: 12 Energy: 38 Material: 8 In. Envir. : 17 Region Pr.: 4 Innovation: 6	Land use: 6 Waste: 4 Transport: 18 Wellbeing: 33 Manage.: 46 Water: 40 Energy: 108 Material: 26 Pollution: 22	Manage.: 17 In. Envir.: 18 Energy: 24 Transport: 7 Water: 12 Material: 10 Land use: 6 Emissions: 6 Innovation: 10	Manage.: 100 Energy: 350 Water: 80 Material: 110 Emission: 175 In. Envir.: 185		In. Envir.: 40 Waste: 8 Manage.: 24 Site: 7 Energy: 65 Water: 18 Material: 10 Innovation: 8 Transport: 2	Energy: 38 In. Envir.: 21 Site,Manag: 10 Material: 9 Water: 12 Innovation: 10	Water: 31 In. Envir.:31 Energy: 48 Material: 24 Site: 25 Manage.: 29 Innovat.: 12	

Rating system	LEED	BREEAM	Green Star	Green Globes	DGNB	Green Mark	GBI	BEAM Plus	Pearl
Name	TAIPEI 101	Warsaw Trade Tower	1 Bligh St., Sydney	Marriott's Gr. Chateau	Deut. Bank Twin Towers	Marina Bay Sands	Menara Kerja Raya	Holiday Inn Express	Al Bahar Tower
Photo									
Place	Taipei, Taiwan	Warsaw, Poland	Sydney, Australia	Las Vegas, NV, USA	Frankfurt, Germany	Singapore	Kuala L., Malaysia	Hong Kong, China	Abu Dhabi, UAE
Height	508 m	208 m	138.8 m	110 m	155 m	193.9 m	174.4 m	115 m	147 m
Function	Office	Office	Office	Hotel	Office	Hotel	Office	Hotel	Office
Designer	C.Y. Lee	RTKL	Architectus Group	MGM architecture	Mario Bellini Architects	Moshe Safdie	GDP Architects	Chau Ku & Leung	Aedas UK
Year	2004	1999	2011	2005	2010	2010	2014	2012	2012
Cer. System	LEED BD+C	In-Use International	Office Design v2	USA GG for EB	New Office	BCA green Mark for NB	NRNC	NB V1.1	Building V1.0
Cer. Year	2011	2001	2010	2016	2011	2010	2016	2012	2012
Rating	Platinum	Very Good	6 Star	Three-globe	Gold	Platinum	Platinum	Platinum	3 Pearl
Score	82/110	63.1%	84/100	70-84%	84,7%	≥ 90 %	≥ 86 %	79.8 %	All + 85c
Description	Energy: 25/35 Material: 5/10 In. Env. 12/15 Sites: 19/26 Water : 15/14 Innovation6/6	**Assessor** Sentient Kft **NSO** BRE Global **Cert. Number** BIU00000046 -1.0	Manag.12/12 In. Env.20/27 Energy 20/24 Transpo.9/11 Water 13/13 Materi.13/20 Land Use 2/8 Emissi.12/14 Innova. 5/15	Achieved a Three-globe rating with USA Green Globes for Existing Buildings	ENV: 81,5% ECO: 92,6% SOC: 86,3% TEC: 75,4% PRO: 91,2% **SITE:84,7%**	**Energy saving** 47,830,000 kWh/yr **Water saving** 60,000 m3/yr	**Certificate No.** GBI-NRNC-0032	SA: 74 % MA: 30 % EU: 84 % WU: 75 % IEQ: 79 % IA: 5	Achieved a Three-Pearl rating with Building V1.0 rating system.

Table 2.11. Examples of certificated skyscrapers

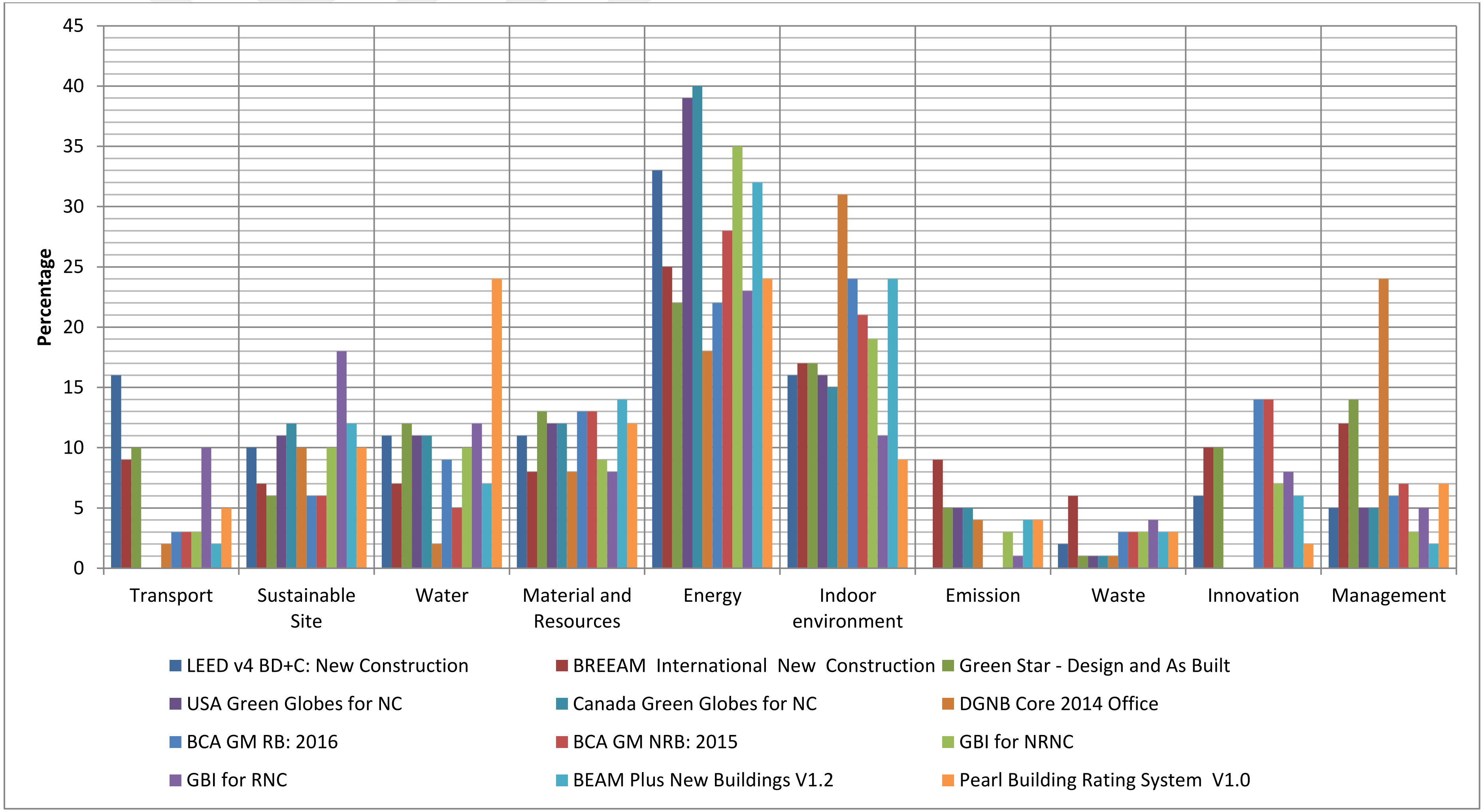


Figure 2.28. Comparison between rating systems' scoring charts of categories for new skyscrapers

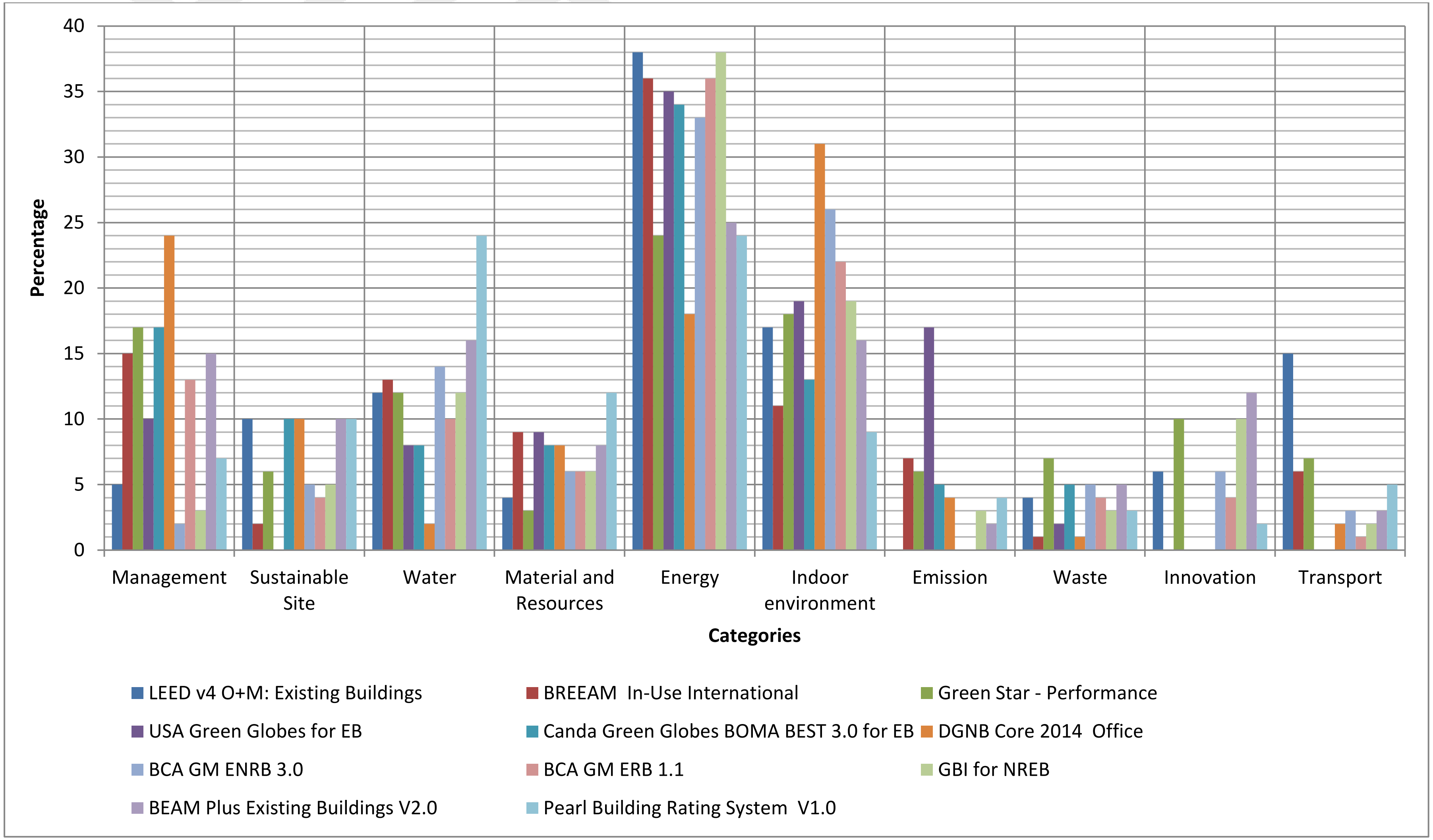


Figure 2.29. Comparison between rating systems' scoring charts of categories for existing skyscrapers

According to the result shown in (Figure 2.28), it is remarkable that Green Globes for NC rating systems have the higher percentage between the investigated rating systems for evaluating the energy performance of new skyscrapers, it is also remarkable that DGNB Core 2014 Office rating system has the higher percentage between the investigated rating systems for evaluating the indoor environment performance of new skyscrapers.

According to the result shown in (Figure 2.29), it is remarkable that LEED v4 O+M: Existing Buildings and GBI for NREB rating systems have the higher percentage between the investigated rating systems for evaluating the energy performance of existing skyscrapers, it is also remarkable that DGNB Core 2014 Office rating system has the higher percentage between the investigated rating systems for evaluating the indoor environment performance of existing skyscrapers.

According to the results shown in (Figure 2.28, Figure 2.29), it is remarkable that green building rating systems give important credits for evaluating the energy performance of skyscrapers. The credits of indoor environment quality take the second position for evaluating the sustainability of skyscrapers.

2.3.11. The importance of energy for evaluating the sustainability of skyscrapers

Skyscrapers demand massive amounts of energy during their life-cycle. Total energy need before their deconstruction consists of embodied energy and operational energy. Embodied energy refers to all the energy required to extract, manufacture, and transport skyscrapers' materials as well as that required to assemble and complete their construction. The raw materials, recycled materials, and waste materials are all significant components of embodied energy. Embodied energy in skyscraper materials can be discussed in terms of material strength, durability, availability, locality, and efficiency. Operational energy refers to all the energy required to heat, cool, illuminate, and to ventilate the skyscrapers. Energy spent on maintenance and repairs should also be included in operational energy (Al-Kodmany and Ali 2013).

Oil, coal, and natural gas are extremely used these days to meet the needs for embodied energy and operational energy in skyscrapers. These non-renewable resources are in limited quantities, and have detrimental environmental impacts. These resources release harmful pollutants and greenhouse gases that contribute to global warming and climate change, reducing air quality on a global scale. Given the fact the skyscrapers consume large amounts of the energy used on daily needs, it is essential to use the alternative renewable resources. The renewable energy systems help to reduce greenhouse gas emissions and improve energy efficiency. It is necessary to mention that the energy efficiency can extremely affect the triple bottom line of sustainability which is summarized in three components: environmental, economic, and social. From an environmental perspective, the use of sustainable energy highly reduces the use of non-renewable resources that have harmful impacts on the environment. From an economic standpoint, investing in renewable energy systems has cost effectiveness, and can actually lessen the burden of the expanding non-renewable energy systems in the future. From a social perspective, the use of sustainable energy can increase community's comfort and satisfaction (Cottrell 2014).

Therefore, the green building rating systems put the most emphasis on the energy category by offering the largest opportunity to earn points from this category, as an attempt to meet the needs for energy in buildings and skyscrapers by using sustainable methods and strategies.

3. ENERGY GENERATION IN SKYSCRAPERS WITH PRODUCTIVE MODE STRATEGIES

This chapter focuses on the energy generation in skyscrapers with productive mode strategies; this chapter examines some strategies for energy generation in skyscrapers from renewable resources which are the sun and the wind. This chapter covers two sections; the first section researches on the solar energy and solar PVs, the second section researches on the wind energy and wind turbines. This chapter examines some examples of skyscrapers that exist around the world as case studies; the ecological approaches for generating the energy from sun or wind in these examples are analyzed.

Yeang (2006) mentioned that the built environment may become a producer of sustainable energy instead of becoming a consumer of non-renewable energy. What can be inferred from these is that the ecological design must use productive modes from renewable resources such as sun and wind in the design of skyscrapers so that skyscrapers can generate their own energy from their surrounding environment. These lead towards a skyscraper of zero or partial use of non-renewable resources of energy. The following sections analyze the ecological approaches for generating the energy with productive mode strategies from two renewable resources of energy; solar energy and wind energy.

3.1. Solar Energy and Solar PVs

The Sun has always held the attention of humanity and has been an element of worship and devotion by many cultures over thousands of years, such as the Egyptians, Incans, Greeks, and Mayans. Solar energy has been used for centuries by ancient people’s harnessing solar energy for heating and drying. Solar energy is considering as a renewable and sustainable energy because it is available and useful as long as the sun continues to shine. Solar energy is the energy that sustains life on the earth for all plants, animals, and people. Solar energy can be converted into useful forms of energy such as heat and electricity by using the solar photovoltaic (PV) technologies which are used to generate the energy from the sun (Foster et al. 2010). This section focuses on the only way to generate the energy from the sun in skyscrapers, which is by using the solar PVs. The following parts explain this system in details and provide case studies of skyscrapers incorporating solar PVs.

3.1.1. Overview on solar PVs

Electricity can be produced from sunlight through a system called the solar PV system, where 'Photo' refers to light and 'Voltaic' to voltage (Foster et al. 2010). Solar PV system is an electrical and ecological productive mode system that can supply a clean and non-pollutive energy from the sun by converting light into electrical energy (Pank et al. 2002, Yeang 2006). Solar PVs can generate electrical power without any noise, without any pollution, and without consuming any fuel (Sillah 2011).

The essential principles for modern PV cells were first discovered in 1839 by Alexander Edmond Becquerel. He observed the PV effect via an electrode in a conductive solution exposed to light. After this original discovery, a number of scientists tried to improve Becquerel's observations in practical ways. In 1883s, Charles Fritts developed a solar cell using selenium on a thin layer of gold to form a device. This device was only around 1% efficient but was the first to demonstrate that solid material with no moving parts could be used to convert sunlight directly into electrical energy (Fraas 2014). Figure 3.1 shows Charles Fritts and his first design of a PV cell.

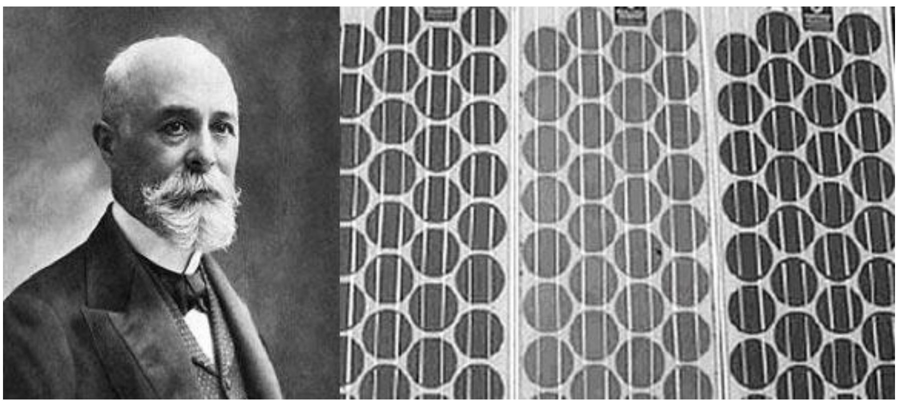


Figure 3.1. Charles Fritts's design of PV cell (Haleakala Solar Inc. 2017)

In the 1950s, Bell Labs produced the first modern piece of PV silicon solar cells for space activities. In 1954, Bell Labs announced this invention; these cells have about 6 % efficiency. From that time the New York Times predicted that these solar cells will eventually lead to a source of limitless energy of the sun (Fraas 2014).

Solar PV cells are made from a variety of semi-conductor materials and coated with special additives. The most used material for the PV cells is the crystalline silicon, representing over 90% of the global commercial PV module production in its various forms (Foster et al. 2010). A typical solar PV module consists of 33 to 40 cells; typical components of a module are aluminum, glass, tedlar, and rubber. The cell is usually silicon, with trace amounts of boron and phosphorus (Lawrence et al. 2013). According to Al-Kodmany and Ali (2013), solar PVs are increasingly in demand worldwide; these give skyscrapers a great opportunity to adapt these systems which can generate the energy for them. Figure 3.2 shows the increasing in solar PVs production worldwide between 1990 and 2006. The cost of solar PVs can be four to five times of producing electricity from conventional sources (Yeang 2006), but actually producing electricity from solar PVs is a sustainable process that has cost effectiveness, and can lessen the burden of the expanding non-renewable energy systems in the future.

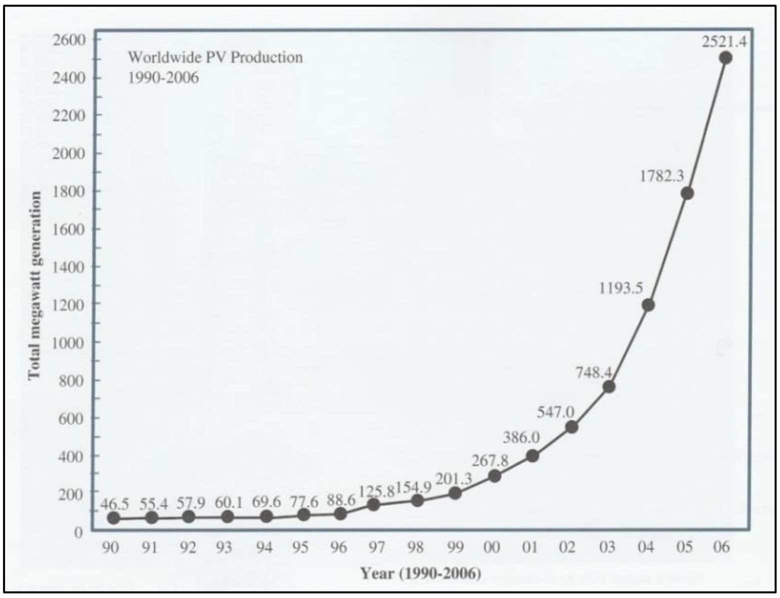


Figure 3.2. The increasing in solar PVs production worldwide between (1990-2006) (Al-Kodmany and Ali 2013)

3.1.2. The working mechanism of solar PVs

Yeang (2006) and Renewable Energy Hub Group (2017) summarize the process of working mechanism of solar PVs as the following; when solar light falls on the solar PVs, PV cells absorb the photons of light and convert it to Direct Current (DC) electrical stream of energy, which is not suitable for feeding the building by electricity, so that DC electrical stream of energy needs to convert into Alternating Current (AC) electrical stream of energy, which is suitable for feeding the building by electricity, by passing through the inverter, after this the electrical streams are collected and saved in the collector and storage, finally the electrical streams go over the distributor to distribute the electrical power. Figure 3.3 summarizes this process.

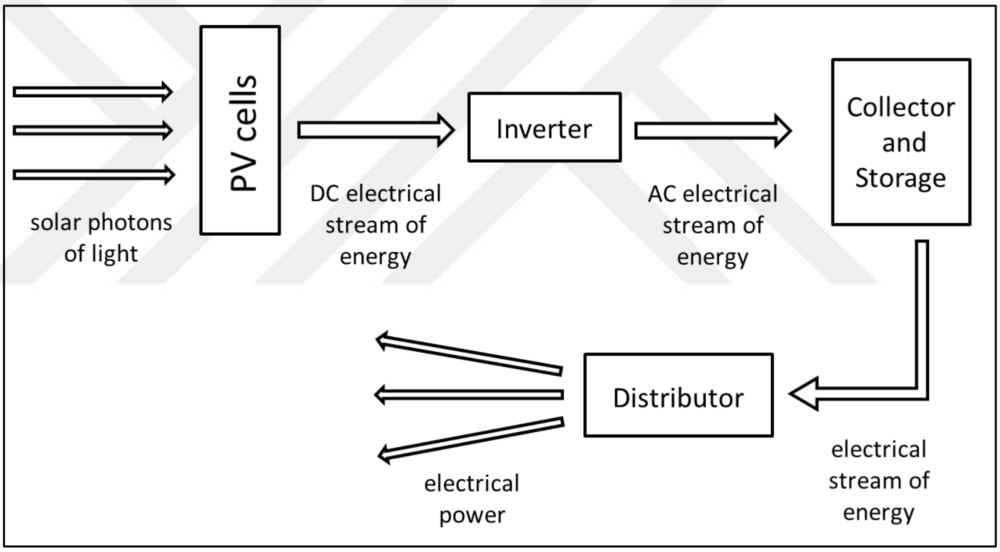


Figure 3.3. The working mechanism of solar PVs
(Adapted from Yeang 2006, Renewable Energy Hub Group 2017)

Generally, solar PVs have two thin layers of silicon. The top layer, facing the sun, has atoms that are unstable so that when an energy source hits them, electrons fly off. The lower layer has a number of gaps in the atoms that are in need of an electron or two. Exactly what happens is that when sunlight hits the top layer, the unstable electrons get excited and are attracted down to the bottom layer. This movement of electrons causes a stream, with adding two metal contacts above and below; a circuit and a system of electricity can be produced (Renewable Energy Hub Group 2017). Figure 3.4 and

Figure 3.5 show solar PVs layers' working and typical small-scale solar PVs installation.

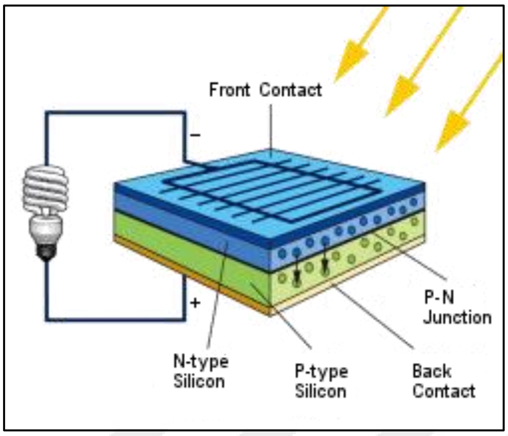


Figure 3.4. Solar PVs layers' working (Renewable Energy Hub Group 2017)

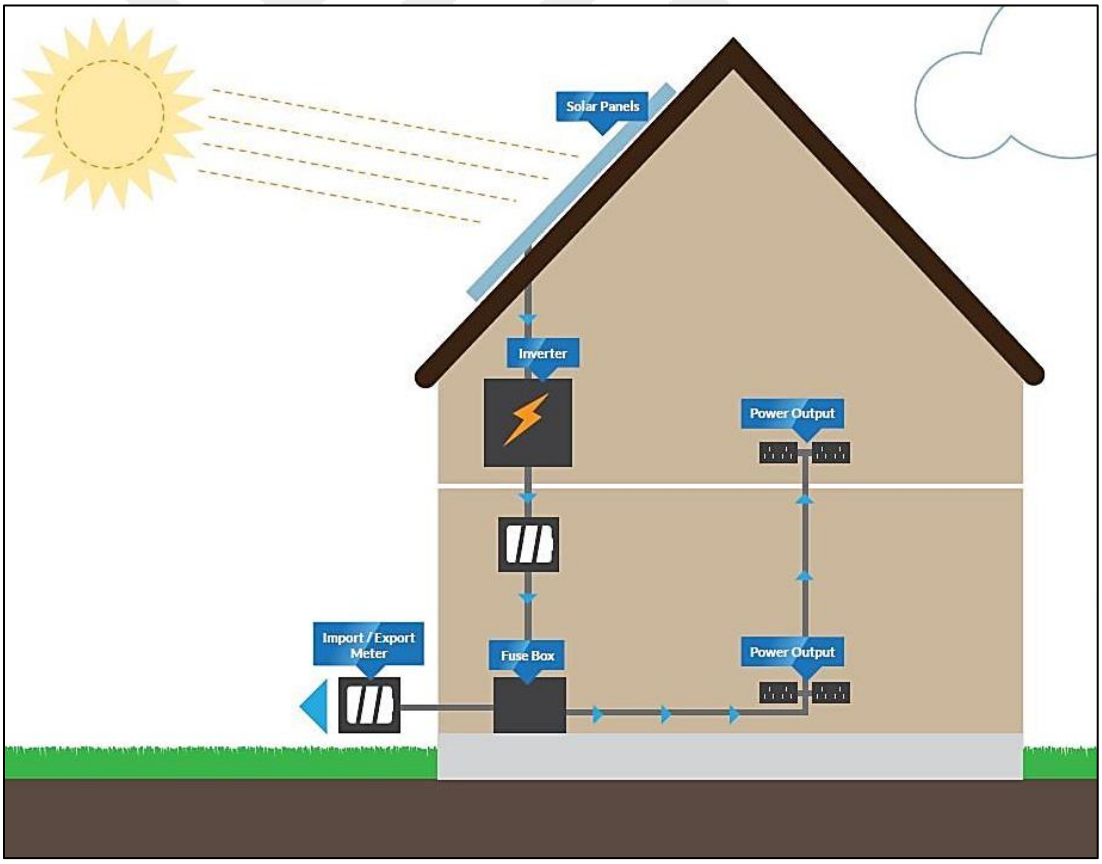


Figure 3.5. Typical small-scale solar PVs installation
(Renewable Energy Hub Group 2017)

A typical silicon cell, with a diameter of 4 inches, can produce more than 1 Watt of DC electrical power in full sun. Individual solar PV cells must be connected in parallel and series to gain the desired energy. These groups of solar PV cells are packaged into modules that protect the solar PV cells from the environment while providing the useful electrical energy (Foster et al. 2010). According to Yeang (2006), generally 1 m^2 of normal solar PV cells can generate an average of 200-300 Watts per month; typically 40-story office skyscraper can consume an average of 240 KW (240000 watts) per month. Although it must be considered that the geographic location makes a difference in performance and electrical output of solar PVs, for example; if a kind of solar PVs were to be placed on a skyscraper in London, they would only generate half of the energy of the same solar PVs placed on a skyscraper in Delhi (Al-Kodmany 2015).

3.1.3. Types of solar PV cells

There are many types of solar PV cells. The most used PV cells are presented in Table 3.1.

Table 3.1. Types of PV Cells (Adapted from Foster et al. 2010, Alnasser 2010, Renewable Energy Hub Group 2017)

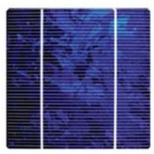
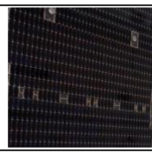
1	Conventional PV Cells (Mono-crystalline Silicon Cells)	
	Most cells these days are mono-crystalline silicon cells. These cells are made from a single crystal of silicon. These silicon cells provide a great balance of cost-effectiveness, reliability, and efficiency. The efficiency of these cells is typically range from about 15–20%. The main disadvantage of these cells is their costs.	
2	Spherical Solar Cells	
	A spherical cell is operationally the same as a conventional solar cell, but differs in its geometry. A spherical cell consists of many small spheres of silicon covered with aluminum foil to provide electrical contacts. The advantages of spherical cells are that the manufacturing process is simple, and that low cost, low purity silicon feedstock material can be used.	
3	Polycrystalline (or Multi-crystalline) Solar PV Cells	
	Poly-crystalline silicon cells are also made of purified silicon, but are not formed of a single crystal. These cells are made up of various silicon crystals. While the cells made in this way are less efficient than single-crystal cells, they are much cheaper to produce. The efficiency of these cells is typically range from about 13 to 15%.	

Table 3.1. Continued. Types of PV Cells (Adapted from Foster et al. 2010, Alnasser 2010, Renewable Energy Hub Group 2017)

4	Amorphous/Thin Film Solar Cells	
	The term amorphous refers to the lack of any geometric cell structure. These cells are made from non-crystalline silicon that can be transferred in a thin film into another material such as glass. These cells are less expensive than silicon-based cells, but there are less efficient from silicon cells. The efficiency of these cells is typically range from about 5 to 10%.	
5	Hybrid Silicon Solar Cells	
	Hybrid solar cells are made from a mix of amorphous and mono-crystalline cells to generate maximum efficiency. There is the most expensive PV cell type, but also the most efficient. The efficiency of these cells is typically 18%.	
6	Multi-junction PV Cells	
	Multi-junction PV cells employ multiple layers of semi-conducting materials; different layers in the cell absorb different parts of the solar spectrum, so the overall efficiency of the cell can be high.	

3.1.4. Types of solar PVs systems

Two types of solar PVs systems can be considered for skyscrapers; PV panels and Building Integrated Photovoltaic system (BIPV). PV panels can be placed on the ground area or on the roofs of the skyscrapers, the large area that is required for placing the PV panels can be considered as a disadvantage for panels' system type (Gonçalves 2010). Figure 3.6 shows the solar PV panels on the roof of 1 Bligh Street Tower which is located in Sydney, Australia.

Figure 3.6. PV panels on the roof of 1 Bligh Street, Sydney (CTBUH's Database 2017)

The other type of solar PVs systems is BIPV. BIPV is a new development that works on the integration of PV systems with building materials and building construction (Sillah 2011). In this system some parts of traditional building material can be replaced by electricity producing material which is the PV solar cells (Yeang 1999), as an example; PV wall cladding can be replaced the normal glass and concrete facades of skyscrapers. BIPV options can be used in retrofits or new construction (Kubba 2012). Figure 3.7 shows examples of BIPVs developed by the National Renewable Energy Laboratory (NREL), and Figure 3.8 shows an example of a skyscraper with BIPVs which is the Federation of Korean Industries (FKI) Tower in Seoul, South Korea.

Figure 3.7. Examples of BIPVs developed by the NREL (Lawrence et al. 2013)

Figure 3.8. BIPVs in FKI Tower, South Korea (CTBUH's Database 2017)

3.1.5. Advantages and disadvantages of solar PVs

The advantages of solar PVs can be summarized as the followings (Pank et al. 2002, Yeang 2006, Foster et al. 2010, Lawrence et al. 2013, Renewable Energy Hub Group 2017);

- Providing systems that can generate the energy from a renewable resource of energy which is the solar energy.
- Completely environmentally friendly system that can generate electrical power without any noise, without any pollution, and without consuming any fuel.
- Reducing non-renewable energy consumption, and it is an alternative to the probably expensive non-renewable energy resources (oil, gas, electricity).
- High-reliability systems which have good design, and long and useful life (from 20+ years).
- Solar PVs can be utilized almost everywhere around the world.
- Leading to gain green building certificates.
- Enhancing the environmental performance of the skyscrapers.
- Using the solar PVs and the wind turbines in the same skyscraper can supply a sufficiently clean and non-pollutive energy for skyscrapers.
- Economic systems that have cost-effectiveness, and can lessen the burden of the expanding non-renewable energy systems in the future.
- The process of installation is quick, easy and has low operating costs.
- These systems don’t need much maintenance.

The disadvantages of solar PVs can be summarized as the followings (Pank et al. 2002, Yeang 2006, Foster et al. 2010, Lawrence et al. 2013, Renewable Energy Hub Group 2017);

- Electrical energy production relays on the sun and therefore the energy can be sometimes not available.
- Expensive systems at the beginning.

3.1.6. Case studies

This part examines two examples of skyscrapers that incorporate and utilize solar PVs to take the advantage of the sun to generate green and sustainable energy. The first example is the Condé Nast Building at Four Times Square which is located in New York City, USA. The second example is the CIS Solar Tower which is located in Manchester, United Kingdom. These case studies had been chosen because of that these skyscrapers are considering as the most ideal tall buildings' examples of mega-scale utilization of solar PVs around the world.

3.1.6.1. The Condé Nast Building at Four Times Square, USA

The Condé Nast Building at Four Times Square (Figure 3.9, Figure 3.10) is located in New York City, USA. This skyscraper was built in 1999 and it is 246.5 m in height; it was designed by Fox & Fowle Architects Firm (CTBUH's Database 2017).

Figure 3.9. The Condé Nast Building at Four Times Square, USA (Gissen 2002)

All of Condé Nast Building's systems and construction technologies were evaluated for their ecological performance, their ability to generate energy from the sun, their impact on user health and satisfaction, and their ability to reduce energy consumption. These made this skyscraper one of the largest buildings in the USA to set up standards for energy conservation, indoor air quality, recycling systems, and sustainable manufacturing processes (Gissen 2002), this building is considering also one of the earliest green skyscrapers in the USA (Al-Kodmany and Ali 2013).

Figure 3.10. The Condé Nast Building at Four Times Square, USA (Al-Kodmany and Ali 2013)

Condé Nast Building incorporates solar BIPV system as an innovative wall cladding system (Al-Kodmany and Ali 2013), in this skyscraper the Amorphous type of PVs wall cladding replaces some parts of the normal glass and concrete facades. On the issue of energy performance and consumption, Condé Nast Building has an ability to consume a percentage of 40 percent less energy consumption than similar traditional office skyscrapers in New York (Gonçalves 2010). When sunlight falls on the BIPV, PV cells absorb the photons of light and convert it to DC, the DC electrical stream of energy converted into AC electrical stream of energy by passing through the transformer; finally this electrical stream distributes all over the skyscraper to feed it by electrical power. Figure 3.11 shows this process.

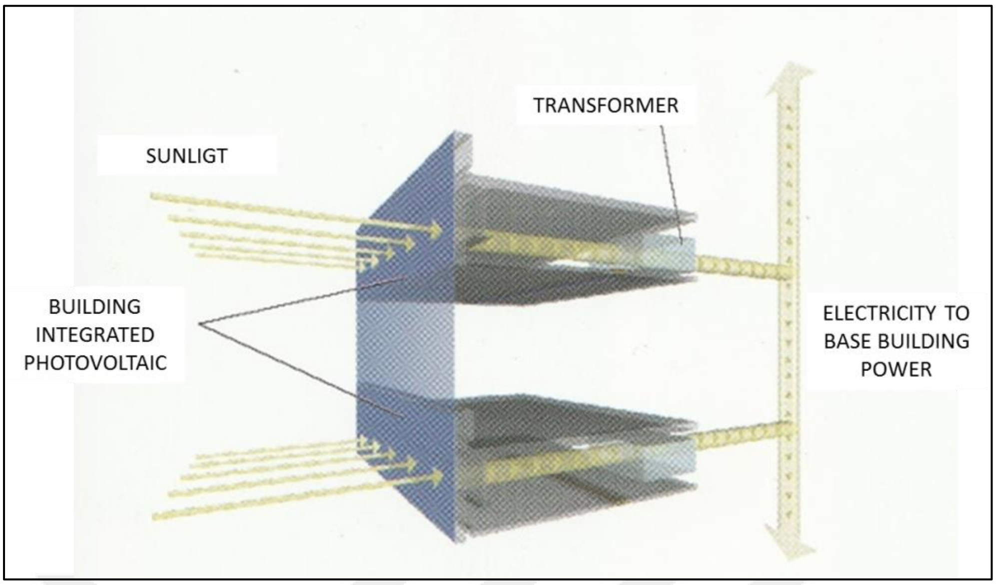


Figure 3.11. Solar PVs system in Condé Nast Building (Gissen 2002)

There are also many other environmental features in the design of Condé Nast Building. Gissen (2002) and Gonçalves (2010) summarize some these features as the followings:

- The skyscraper utilizes environmentally efficient gas-fired absorption chillers.
- Curtain wall façades are clad with energy efficient glass to block direct solar radiation while allowing diffuse light through.
- There are basement fuel cells which produce electricity by extracting hydrogen from natural gas.
- The air delivery system supplies 50 percent more fresh air.
- A network of recycling chutes serves all the building.
- Ability to take advantage of daylight illumination.
- Higher floor to ceiling heights (2.85m in high, or 15cm higher than the traditional height used in commercial buildings) permitting daylight penetration into deeper parts of the floor plate.
- Ability to water conservation and reuse.
- Using of renewable materials and using of local or regional materials.
- Working spaces are fully air-conditioned.
- Sealed façades are clad in energy efficient glass to reduce heat gains in summer and heat losses in winter.

3.1.6.2. CIS Solar Tower, UK

Cooperative Insurance Society (CIS) Solar Tower (Figure 3.12) is an office skyscraper located in Manchester, UK; the skyscraper was completed in 1962 and renovated with solar PVs in 2006. This tower was designed by Gordon Tait and G. S. Hay; the tower is with 25 floors and 118 m in height (CTBUH's Database 2017).

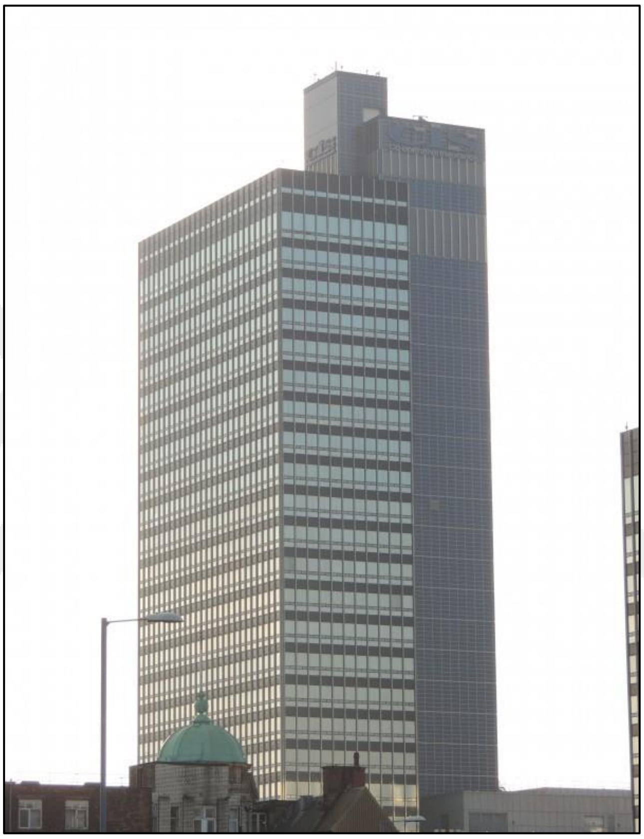


Figure 3.12. CIS Solar Tower, Manchester, UK (CTBUH's Database 2017)

According to Solar Design and Green Building Professionals Group (2009) and Solar Century firm (2017), which is the firm that was responsible to develop a solution for cladding CIS Tower with solar PV panels, CIS Tower was firstly built in 1962 to host the British Cooperative Insurance group CIS Ltd. headquarters, the CIS Tower was suffering over 40 years from the exposure to pollution. The skyscraper had a lot of small mosaic tiles covering its non-window façade, but because of time and pollution, these tiles were falling off. After that CIS paying out over $ 8 million for the enhancement of this skyscraper, three faces of the skyscraper were cover with a total of 7,244 PV panels that generating 390kW of energy (around 181,000 units of renewable electricity every year), this equal in value to the energy wanted to 55 full-power houses for a year. The PVs started feeding with electricity to the skyscraper in November 2005, and with its PVs system, CIS tower became the largest renewable energy skyscraper in the UK. Figure 3.13 and Figure 3.14 show the cladding of CIS Tower with the solar PV panels.

Figure 3.13. The PV panels of CIS Solar Tower
(Solar Design and Green Building Professionals Group 2009)

Figure 3.14. The cladding of CIS Tower with the solar PV panels
(Solar Design and Green Building Professionals Group 2009)

The CIS Solar Tower (Figure 3.15) has three of its four sides completely covered with PV cells. This permits the skyscraper to gather and take the advantage of the solar power over the day. The front wall façade is facing the south direction that is the main receiving of sunlight, the east and west wall facades receive far less light; the north wall façade is not covering with any of the PV cells. This skyscraper is an ideal example of mega-scale utilization of solar PV panels (Solar Design and Green Building Professionals Group 2009). According to Solar century firm, the CIS Tower project is one of the largest solar installations in the UK, this project shows how solar PV technology can be easily combined into any skyscraper renovation to offer a highly cost-effective alternative to traditional skyscraper materials (Solar Century firm 2017).

Figure 3.15. CIS Solar Tower, UK (Solar Century firm 2017)

There are also many other environmental features in the design of CIS Solar Tower. Solar Design and Green Building Professionals Group (2009) and Solar Century firm (2017) summarize some of these features as the followings:

- CIS Solar Tower has 24 wind turbines on the roof that provide 10 percent of the total energy used by the skyscraper.
- The renewable energy that is generated in CIS Tower saves the equivalent of 100 tons of CO_2 emissions.

3.2. Wind Energy and Wind Turbines

The use of wind as an energy resource began in the ancient past and before the middle ages. The wind was being used for grinding grain in Persia in the 10^{th} century and in China in the 13^{th} century. The wind was also a main source of energy for transportation to power ships and sailboats, and pumping water. Humans were seeking to develop new and smart ways to utilize the energy of the wind in the form of converting wind movement into electricity that feeds homes; they found that the only way for that is by using the wind turbines (Nelson 2014).

This section focuses on the only way to generate the energy from the wind in skyscrapers, which is by using the wind turbines. The following parts explain this system in details and provide case studies of skyscrapers incorporating wind turbines.

3.2.1. Overview on wind turbines

The wind turbine is a mechanical and ecological productive mode system that can supply a clean and non-pollutive energy from the wind (Lawrence et al. 2013). Wind turbines are one of the most important resources of renewable energy that meet our future energy needs.

The first wind turbine used to produce electricity was built in 1887 in Scotland. This wind turbine (see Figure 3.16) is created by Prof James Blyth of Anderson's College, Glasgow (now known as Strathclyde University). This wind turbine was installed in the garden of his holiday cottage at Marykirk in Kincardineshire and was used to power the lighting in the cottage, so this made it the first house in the world to have its electricity supplied by wind power. The first known US wind turbine created for electricity production was built in 1888 (see Figure 3.17) by inventor Charles Brush to provide electricity for his mansion in Ohio (Shahan 2014).

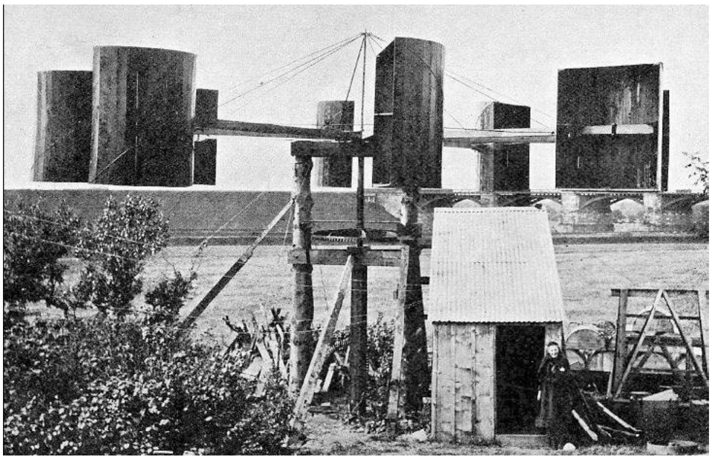


Figure 3.16. Blyth's wind turbine at his cottage in Marykirk (Shahan 2014)

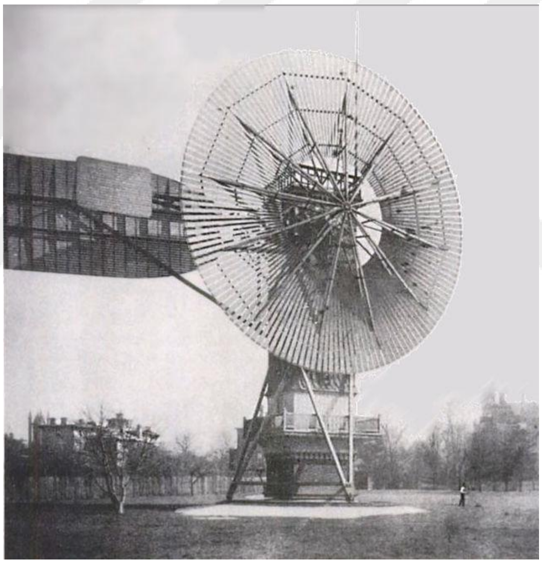


Figure 3.17. Brush's wind turbine for his mansion in Ohio (Shahan 2014)

Energy generation with wind turbines has become more dependable over the last 30 years. According to the Global Wind Energy Council (GWEC), global wind energy installations reached about 282 Giga Watt (GW) at the end of 2012, and wind turbines are increasingly in demand worldwide these years. Wind turbines should first be evaluated by looking at the wind resource and wind speed at the site (Lawrence et al. 2013). According to Al-Kodmany (2015), if there is little wind to start with, employing turbines will not gain much energy power, so that the wind speed in the area must be taken into consideration before integrating wind turbines in skyscraper design.

According to the Storm Prediction Center (SPC) in the National Oceanic and Atmospheric Administration (NOAA), the most widely used system to measure wind speed and strength is the Beaufort scale (Table 3.2). Beaufort scale was created in 1805 by the Britain's Admiral Sir Francis Beaufort. He developed the scale to help the sailors for evaluating the winds via visual observations. The scale begins with 0 and goes to a force of 12 (NOAA 2017).

Table 3.2. Beaufort scale (Adapted from Yeang, 2006, NOAA 2017)

Beaufort Force Number	Wind Speed (m/s)	Description	Land Condition	Comfort
0	0 – 0.5	Calm	Smoke rises vertically	No noticeable wind
1	0.5 – 1.5	Light Air	Smoke drift indicates wind direction	
2	1.6 – 3.3	Light Breeze	leaves rustle	Wind felt on face
3	3.4 – 5.4	Gentle Breeze	wind extend flags	Hair disturbed, clothing flaps
4	5.5 – 7.9	Moderate Breeze	Dust, leaves, and loose paper raise, small tree branches move	Hair disarranged
5	8.0 – 10.7	Fresh Breeze	Small trees in leaf begin to sway	Force of wind felt on the body
6	10.8 – 13.8	Strong Breeze	Larger tree branches moving, whistling in wires	Umbrellas used with difficulty, Difficult to walk steadily, Noise in ears
7	13.9 – 17.1	Near Gale	Whole trees moving	Resistance felt while walking against the wind
8	17.2 – 20.7	Gale	Twigs broken from trees	progress impedes, balance difficulty in gusts
9	20.8 – 24.4	Strong Gale	Slight structural damage occurs, slate blows off from roofs	People blown over in gusts
10	24.4 – 28.5	Storm	Trees broken or uprooted, considerable structural damage	
11	28.6 – 32.6	Violent Storm	Violent structural damage	
12	> 32.6	Hurricane	Catastrophic damage	

Sillah (2011) mentioned that concerns that may become apparent in relating to the use of wind turbines include noise, aesthetics, potential harm to birds, and interference with television and radio signals, these had been considered as worries or disadvantages for the use of wind turbines. Beginning from the concerns about the noise; actually, the average noise level of turbines is around (52–55 decibels), they are able to be heard outdoors but no noisier than the average refrigerator. Coming to the concerns about aesthetics; actually adding wind turbines in the design of buildings especially skyscrapers become a new ecological trend in architecture that can give an aesthetic element for the skyscraper indeed. Coming to the concerns about the potential harm to birds; birds can collide with any structure, actually, reports and researches show that killing birds a cause of colliding with skyscrapers having wind turbines are very rare in comparison to killing birds a cause of colliding with skyscrapers with only glass facades. Coming to the concerns about the interference with television and radio signals; actually, wind turbines have not been found to interfere with TV or radio reception, the rotors are usually made of fiberglass; this material is transparent to electromagnetic waves, such as radio or TV.

According to Yeang (2006), generally for an area where the average of wind speed is 4.0 m/s like Europe, the wind turbine with the diameter of 10 meters can generate an average of 150 Kilo Watt (KW) per month; typically 40-story office skyscraper can consume an average of 240 KW per month.

The cost of wind turbines can be expensive but actually producing electricity from the wind turbine is a sustainable process that that has cost effectiveness, and can lessen the burden of the expanding non-renewable energy systems in the future.

3.2.2. The working mechanism of wind turbines

Yeang (2006) and Renewable Energy Hub Group (2017) summarizes the process of working mechanism of wind turbines as the following; when wind power go over the wind turbine, the blades of wind turbine starts to turn, the mechanical movement of the turbine goes to the generator, this movement rotate the axis which feeds into a generator and the generator convert these mechanical movement to DC electrical stream of energy, which is not suitable for feeding the building by electricity, so that DC electrical stream of energy needs to convert into AC electrical stream of energy, which is suitable for feeding the building by electricity, by passing through the inverter, after this the electrical streams are collected and saved in the collector and storage, finally the electrical streams go over the distributor to distribute the electrical power. Figure 3.18 summarizes this process, and Figure 3.19 shows a typical small-scale wind turbine installation.

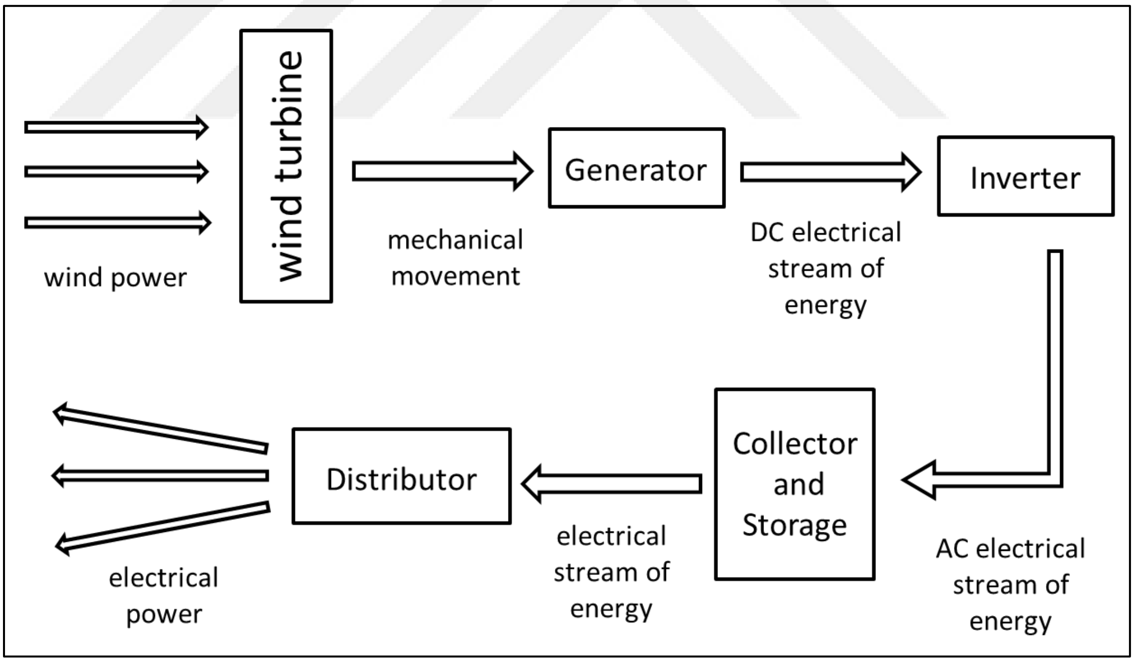


Figure 3.18. The working mechanism of wind turbines
(Adapted from Yeang 2006, Renewable Energy Hub Group 2017)

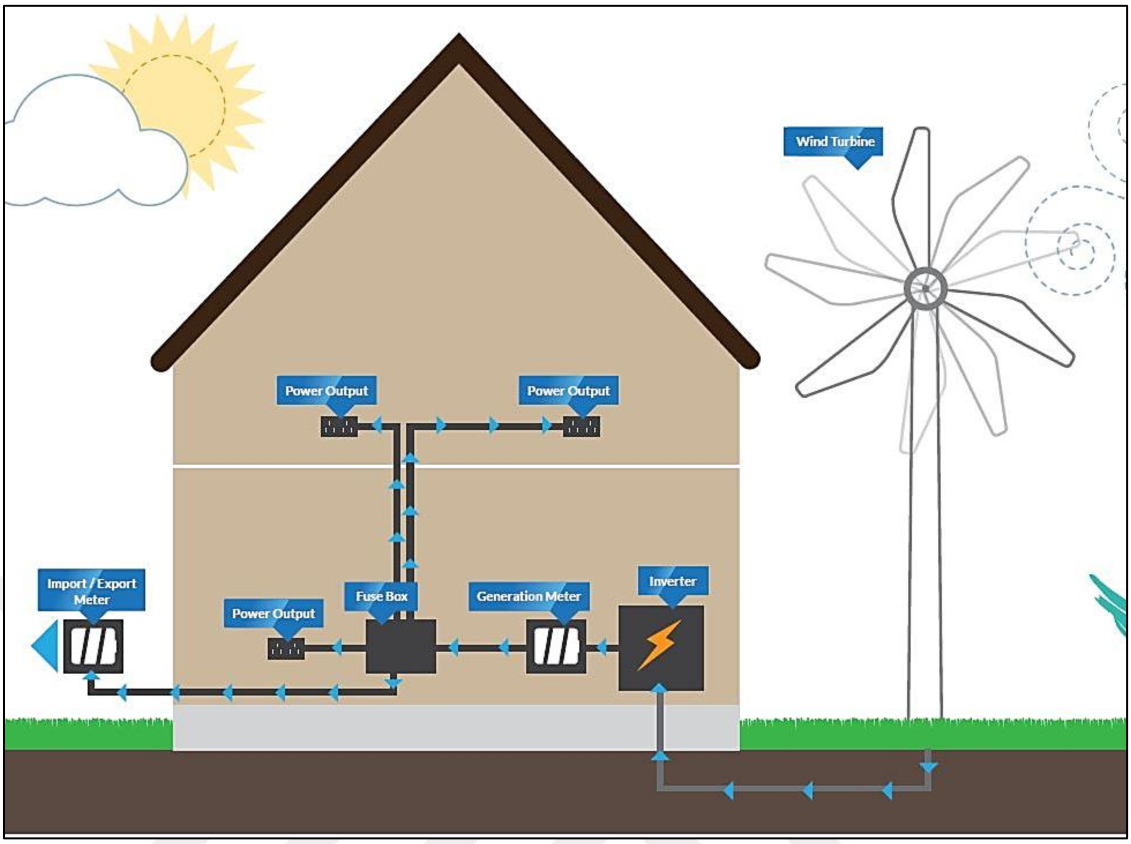


Figure 3.19. Typical small-scale wind turbine installation
(Renewable Energy Hub Group 2017)

3.2.3. Types of wind turbines

The wind turbines kinds that can always be used for skyscrapers are the Building Integrated Wind Turbines (BIWT); According to Bussel and Mertens (2005), there are two types of wind turbines and BIWTs that can be considered for skyscrapers (see Figure 3.20); Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The first type of wind turbines is HAWT (see Figure 3.21); in this turbine, the main rotor shaft and generator arranged horizontally, the blades always moves perpendicularly to the wind, receiving power through the whole rotation, the high transportation and installation costs for skyscrapers because of their difficulties can be considered as a disadvantage of these turbines. The second type of wind turbines is VAWT (see Figure 3.22); in this turbine, the main rotor shaft and generator arranged vertically, these turbines have the ability to take the wind from any direction, the disadvantages of these turbines can be concluded in that these turbines are hard to start, hard to stop and have lower efficiency than HAWT. The following figures show these two types.

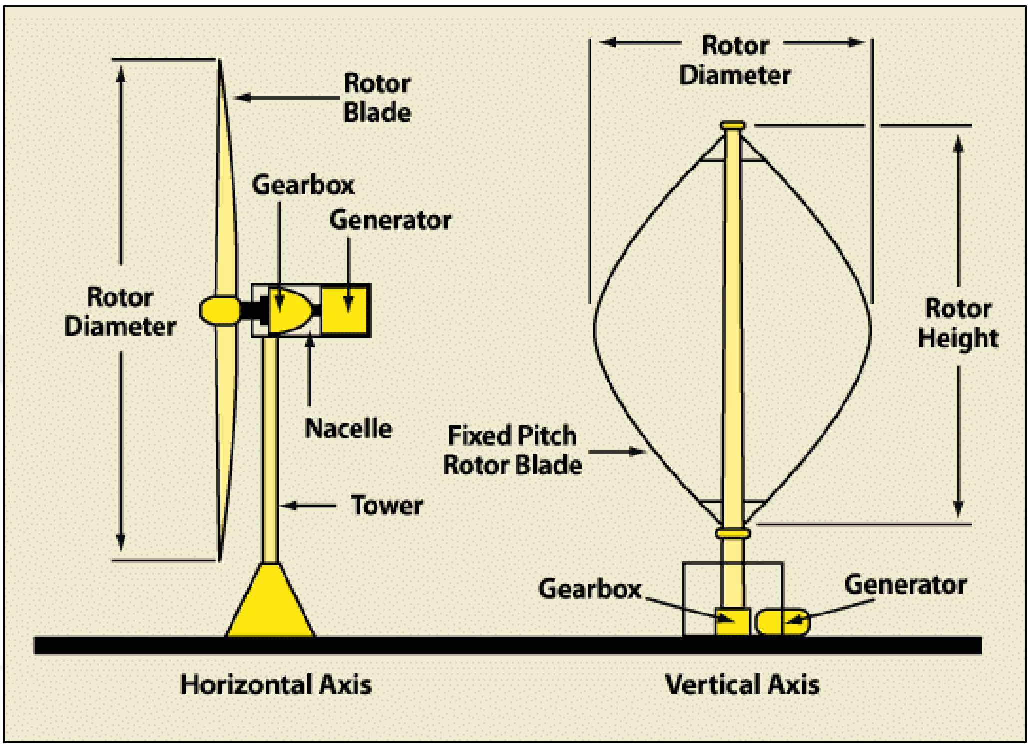


Figure 3.20. HAWT and VAWT (http://www.windturbineworks.com, 2017)

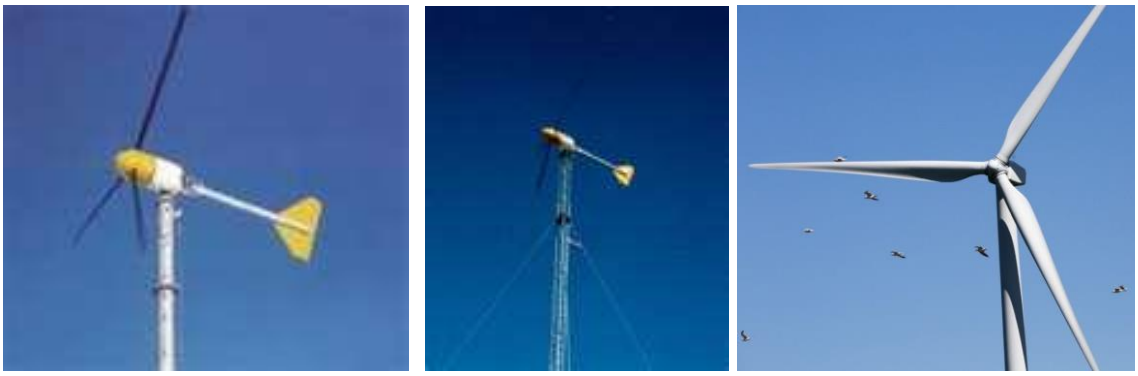


Figure 3.21. Examples of HAWTs (http://www.windturbineworks.com, 2017)

Figure 3.22. Examples of VAWTs (http://www.windturbineworks.com, 2017)

Table 3.3 summarizes a comparison between the two turbine types (HAWT and VAWT);

Table 3.3. Comparison between HAWT and VAWT
(Adapted from Bussel and Mertens 2005, Beller 2011)

HAWT	VAWT
The main rotor shaft and generator arranged horizontally	The main rotor shaft and generator arranged vertically
The blades always move perpendicularly to the wind	Independent of wind direction (the ability to take the wind from any direction)
The generator can only be located horizontally beside the blades	The generator can be located on the ground or under the blades (structural advantage and maintenance accessibility)
More noise	Less noise
Resist high turbulence but not as VAWT	Resist high turbulence
Symmetric and aesthetic	Symmetric and aesthetic
Self-starting	Not self-starting (hard to start, hard to stop)
Turning always in one direction	Changing angle of rotation
Fixation of the upper end of the axis is not needed	Fixation of the upper end of the axis is needed
High transportation and installation costs because of their difficulties	Less transportation and installation costs
Have more energy production efficiency than VAWT	Have lower energy production efficiency than HAWT

3.2.4. Advantages and disadvantages of wind turbines

The advantages of wind turbines can be summarized as the followings (Bussel and Mertens 2005, Beller 2011, Lawrence et al. 2013);

- Providing systems that can generate the energy from a renewable resource of energy which is the wind energy.
- Reducing the non-renewable energy consumption by converting renewable energy to electrical power.
- An alternative to the probably expensive non-renewable energy resources (oil, gas, electricity).
- Leading to gain green building certificates.
- Enhancing the environmental performance of the skyscrapers.
- The turbine system can be canceled out the long transmission lines for energy transportation that can link to significant losses.
- Using the solar PVs and the wind turbines in the same skyscraper can supply a sufficient clean and non-pollutive energy for skyscrapers.
- Economic systems that have cost-effectiveness, and can lessen the burden of the expanding non-renewable energy systems in the future.

The disadvantages of wind turbines can be summarized as the followings (Bussel and Mertens 2005, Beller 2011, Lawrence et al. 2013);

- Electrical energy production relays on the wind and therefore the energy it can be not always reliable and available.
- New surrounding buildings can affect coordinately the local wind conditions and they must be part of the project as well.
- Wind velocities in cities are lower than in rural sites, and the most integrated wind turbines needed for the skyscrapers in cities.
- They can be expensive systems at the beginning.

3.2.5. Case studies

This part examines two examples of skyscrapers which incorporate and utilize wind turbines to take the advantage of the wind to generate green and sustainable energy. The first example is the Bahrain World Trade Center which is located in Manama, Bahrain. The second example is the Pearl River Tower which is located in Guangzhou, China. These case studies had been chosen because of that these skyscrapers are considering as the most ideal tall buildings' examples of mega-scale utilization of BIWTs systems around the world.

3.2.5.1. Bahrain World Trade Center, Bahrain

Bahrain World Trade Center (BWTC) (Figure 3.23) is located on the main King Faisal Highway in Manama, Bahrain, it was completed in 2008, the site giving opening views over the Arabian Gulf. The towers' positioning on the sea-side facing location of prevailing wind direction and their aerodynamic design is helping to create greater power generation efficiency (Beller 2011). BWTC having innovative features such as wind turbines to generate electricity, intelligent building technology, and high fire safety standards, which make it a highly innovate construction project on a global scale (Alnasser 2010).

Figure 3.23. Design illustration of the Bahrain World Trade Center (Smith and Killa 2007)

The project is designed by Atkins International firm and the project's design was made by the architect Shaun Killa. The concept design of the BWTC was inspired by the traditional Arabian wind towers (Figure 3.24) in that the shape of the buildings take advantage of the unstopped prevailing onshore breeze and air from the Gulf, providing a renewable resource of energy for the project (Smith and Killa 2007).

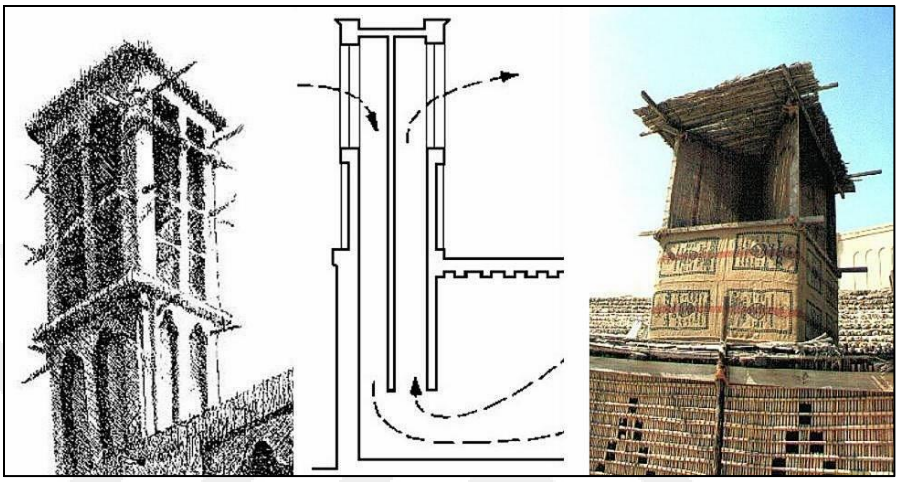


Figure 3.24. Al-Barjeel or Al-Kashteel, traditional wind towers in the United Arab Emirates (Al-hassani 2009)

BWTC (see Figure 3.25) is a Mixed-use (office, commercial) skyscraper with Shear walled frame system and reinforced concrete material structural system (Günel and Ilgin 2014). BWTC is consisting of two 50-story sail-shaped office towers with 240 m in height. There are three massive HAWTs, measuring 29 meters in diameter, which are supported by bridges spanning between BWTC's two towers (Beller 2011). The bridge is a shallow V-shape in the plan to avoid the unexpected dangerous collisions with the turbines. The towers are integrated on top of a three-story podium and basement which accommodate a new shopping center, restaurants, business centers and car parking (Smith and Killa 2007).

According to Smith and Killa (2007), the elliptical plan forms and the sail-shaped form of the towers act as aero-foils which can help for passing the onshore breeze and having a function of air flow dynamics between the two towers as well as creating a negative pressure behind, thus accelerating the wind speed between the two towers (see Figure

3.26). Because of the increasing speed of the onshore breeze at increasing heights, as the towers go upwards, their aero-foil plan forms reduce, this effect can create a near-equal flow of wind speed on each of the three turbines.

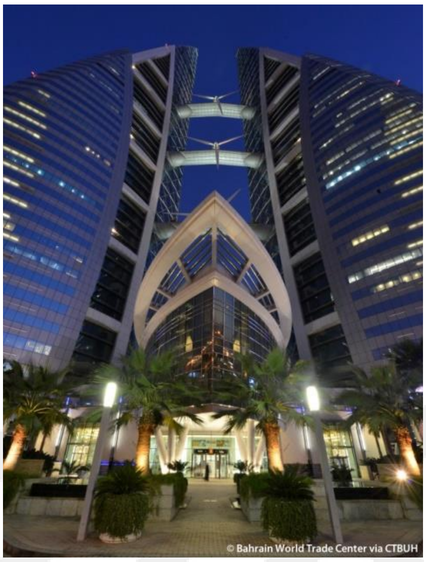


Figure 3.25. Bahrain World Trade Center, Bahrain (CTBUH's Database 2017)

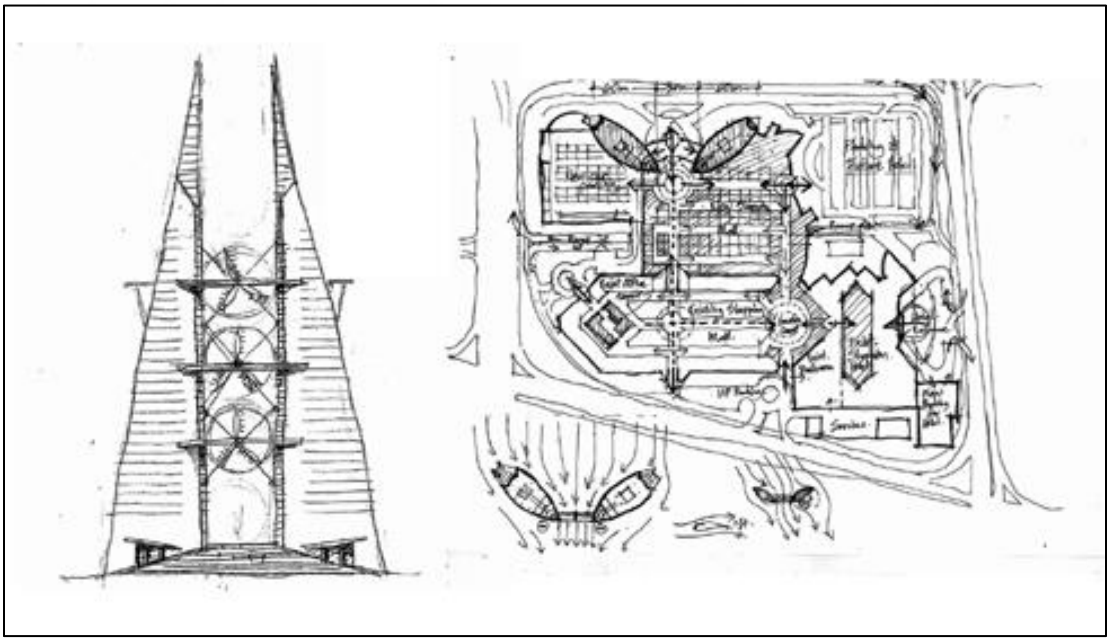


Figure 3.26. Initial sketches by Shaun Killa for BWTC (Günel and Ilgin 2014)

The three horizontal axis wind turbines are integrated into the building to generate electric power, the turbines turn to face the direction of the wind, thus maximizing energy yield. According to Smith and Killa (2007), extensive wind tunnel modeling that was recently proved by Computational Fluid Dynamics (CFD) modeling has shown that the incoming wind is in effect deflected by the towers in the form of an S-shaped streamline which passes through the space between the towers. Figure 3.27 shows CFD study of airflow patterns near and around the BWTC, these air patterns are used to optimize the shape of the skyscraper in relation to wind harnessing (Al-Kodmany and Ali 2013).

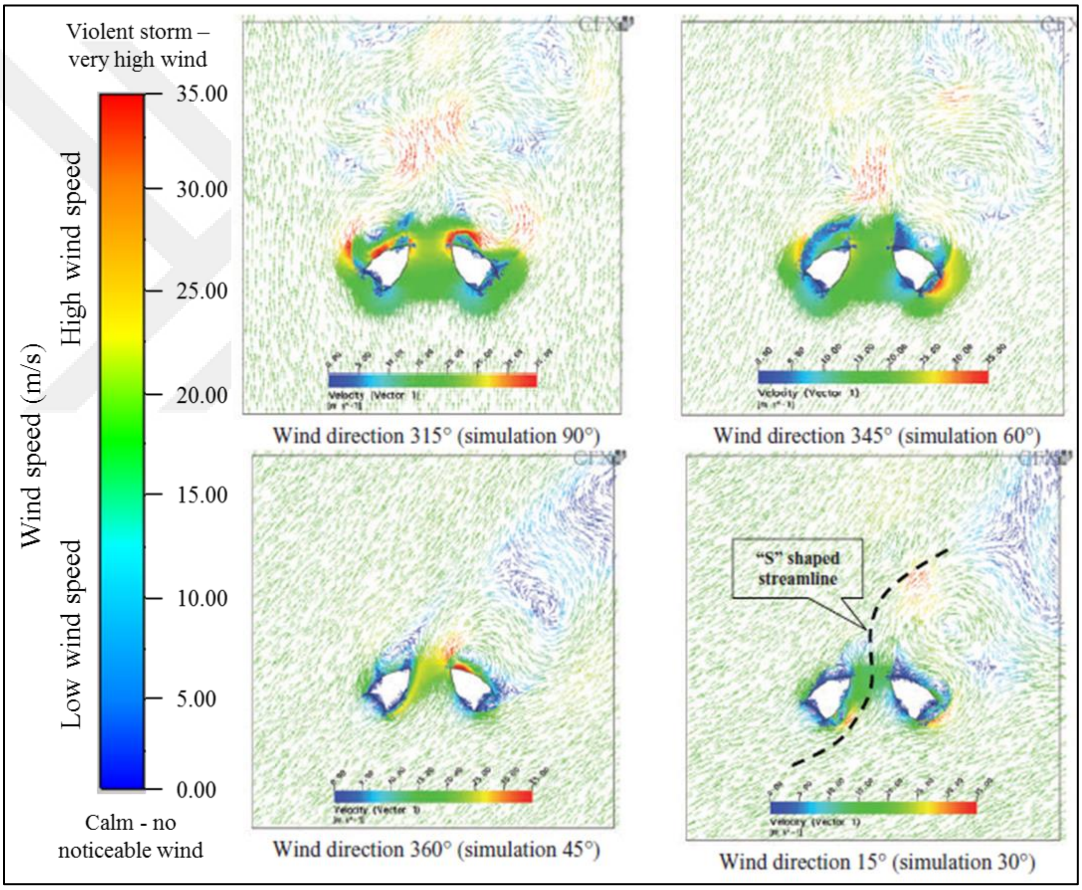


Figure 3.27. CFD Images showing airflow patterns near BWTC (Adapted from Smith and Killa 2007)

Each turbine (see Figure 3.28) can generate between 1.1 and 1.3 Giga Watt hours (GWh) annually which deliver approximately 11 to 15 % of the office tower's electrical energy consumption, eliminating around 55 tons of carbon emissions every year, BWTC’s turbines are considering as the largest contemporary BIWT in the world. The speed of the blades is reduced to a favorable condition as compared to standard wind turbines. Besides this, the sound insulation of the cladding next to the line of the blades is fortified and the thickness of the glass close to the wind turbines is also increased (Alnasser 2010).

Figure 3.28. BWTC’s turbine (CTBUH’s Database 2017)

There are also many other environmental features in the design of BWTC towers. Smith and Killa (2007) summarize some of these features as the followings:

- Insulated spaces between the external environment and air-conditioned spaces, this have the effect of reducing solar air temperature and reducing conductive solar gain.
- Deep gravel roofs in some locations to provide dynamic insulation.
- Balconies to the sloping elevations to provide shading.
- A high-quality solar glass is used with low shading degree to minimize solar gains.

- Low-leakage open-able windows to allow mixed-mode operation in winter months.
- Enhanced thermal insulation for opaque fabric elements.
- Enhanced chilled water transport systems.
- Energy-efficient, high-efficacy, high-frequency fluorescent lighting with zonal control.
- Double drainage systems that separate waste and water and allow gray water recycling to be added at a later date.
- Connection to the district cooling system to improve the levels of energy conversion efficiency.
- Solar-powered road and amenity lighting.
- Windows that can be opened to allow for natural ventilation.

3.2.5.2. Pearl River Tower, China

Pearl River Tower (Figure 3.29) is located in Guangzhou, China, the skyscraper was completed in 2013 and it was designed by SOM firm, the building is 309.4 m in height (CTBUH's Database 2017). The design of this building aims to harness wind power and achieving the title of a net zero-energy skyscraper. Wind turbines are located in the building to enlarge the wind speed (Al-Kodmany and Ali 2013).

Figure 3.29. Pearl River Tower, China (CTBUH's Database 2017)

The aerodynamic shape of this skyscraper carefully formed to use the wind natural resource to maximize the skyscraper's energy efficiency. The tower's sculpted body and its curved glass façade have the ability to direct the wind to a pair of openings in the facade at its mechanical floors, pushing the large VAWTs to generate electrical energy for the skyscraper. The east and the west facades of the skyscraper are straight (see Figure 3.30), while the south facade is concave, the north facade is convex. The south side of the skyscraper is sculpted to direct the wind through the four openings (see

Figure 3.31) where there are four VAWTs (see Figure 3.32), two at each mechanical level (CTBUH's Database 2017). Isolating the vertical axis wind turbines on these mechanical floors minimizes noise and vibration and simplifies maintenance (El-Hassan and Gharib 2008).

Figure 3.30. One of the straight facades of Pearl River Tower (CTBUH's Database 2017)

Figure 3.31. One of the VAWT openings in Pearl River Tower (CTBUH's Database 2017)

Figure 3.32. One of the VAWTs of Pearl River Tower (Drew 2014)

Figure 3.33 shows the CFD study of airflow patterns near and around the Pearl River Tower, these air patterns are used to optimize the shape of the skyscraper in relation to wind harnessing (Al-Kodmany and Ali 2013).

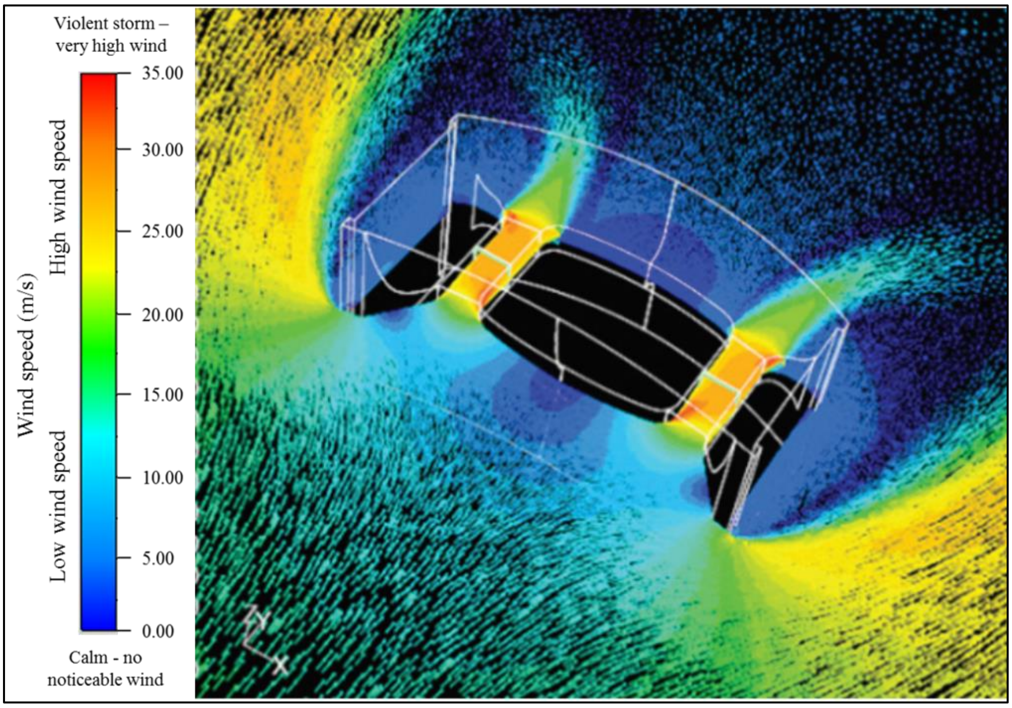


Figure 3.33. Image showing airflow patterns near Pearl River Tower (Adapted from El-Hassan and Gharib 2008)

The skyscraper's site orientation has the advantage of reducing the skyscraper energy consumption; this is by rotating to the east so the skyscraper takes the advantage of the mid-day sun while the effects of the late-day sun on the larger southern horizontal exposure are minimized. Figure 3.34 shows the sun path diagram of Pearl River Tower. The energy consumption in this skyscraper can be reduced by about 40 percent (El-Hassan and Gharib 2008). The combination of turbines, shading systems, a double-skin façade with energy-efficient lighting, ventilation, mechanical design and the other ecological features makes this building one of greenest skyscrapers in the world (CTBUH's Database 2017).

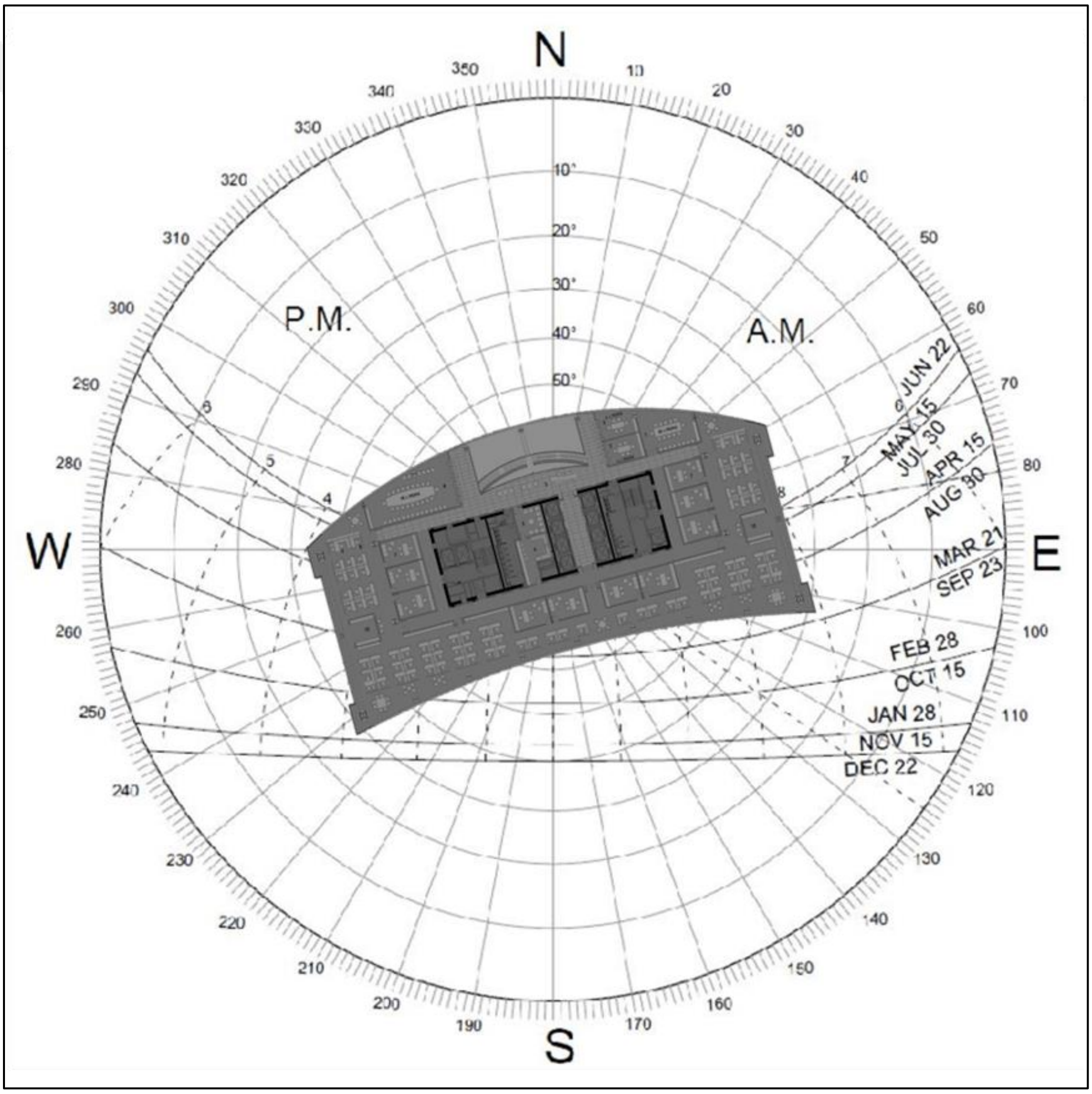


Figure 3.34. Sun path diagram of Pearl River Tower
(Adapted from El-Hassan and Gharib 2008)

There are also many other environmental features in the design of Pearl River Tower. El-Hassan and Gharib (2008), and CTBUH's Database (2017) summarize some of these features as the followings:

- Basement fuel cells which produce electricity by extracting hydrogen from natural gas.
- Façade integrated photovoltaic and better capture the sun's energy through the strategic location of the PVs.
- Water retention and conservation area.
- A condensate reclamation system that collects water and reuses it.
- The skyscraper's shading system uses automated, daylight-responsive blinds set within the building's double-skin facade, as a result of that the building management's operational needs can be reduced.
- The skyscraper's ventilation/dehumidification system uses heat collected from the double-skin facade as an energy source.
- The integrated facade provides very good thermal performance as well a high level of natural daylight to the space.
- Low-energy, high-efficiency lighting systems use radiant panel geometry to assist in the distribution of light.
- The double-skin facade reduces the amount of internal mechanical proceedings that are required for ventilation, heating and cooling.
- A high-performance building envelope, the skyscraper contains double wall construction which offers insulation and a critical way station between indoors and outdoors.
- The radiant cooling, chilled ceiling and decoupled ventilation system provides improved human thermal comfort, efficient heat exchange, and improved office acoustics.
- The ventilation system is providing improved indoor air quality and air change effectiveness.

Pearl River Tower awarded LEED Platinum certification within LEED for BD+C rating system. This skyscraper earned 33 out of 37 points in the energy category of LEED (USGBC 2017). Figure 3.35 shows the LEED Scorecard of Pearl River Tower.

1000025970, Guangzhou, Guangdong

Pearl River Tower

LEED BD+C: Core and Shell (v2009)

PLATINUM, AWARDED DEC 2013

SUSTAINABLE SITES		AWARDED: 20 / 28
SSc1	Site selection	1 / 1
SSc2	Development density and community connectivity	5 / 5
SSc3	Brownfield redevelopment	0 / 1
SSc4.1	Alternative transportation - public transportation access	6 / 6
SSc4.2	Alternative transportation - bicycle storage and changing rooms	0 / 2
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	3 / 3
SSc4.4	Alternative transportation - parking capacity	2 / 2
SSc5.1	Site development - protect or restore habitat	0 / 1
SSc5.2	Site development - maximize open space	1 / 1
SSc6.1	Stormwater design - quantity control	0 / 1
SSc6.2	Stormwater design - quality control	0 / 1
SSc7.1	Heat island effect - nonroof	1 / 1
SSc7.2	Heat island effect - roof	0 / 1
SSc8	Light pollution reduction	0 / 1
SSc9	Tenant design and construction guidelines	1 / 1

WATER EFFICIENCY		AWARDED: 7 / 10
WEc1	Water efficient landscaping	4 / 4
WEc2	Innovative wastewater technologies	0 / 2
WEc3	Water use reduction	3 / 4

ENERGY & ATMOSPHERE		AWARDED: 33 / 37
EAc1	Optimize energy performance	19 / 21
EAc2	On-site renewable energy	4 / 4
EAc3	Enhanced commissioning	2 / 2
EAc4	Enhanced refrigerant Mgmt	2 / 2
EAc5.1	Measurement and verification - base building	3 / 3
EAc5.2	Measurement and verification - tenant submetering	3 / 3
EAc6	Green power	0 / 2

MATERIAL & RESOURCES		AWARDED: 4 / 13
MRc1	Building reuse - maintain existing walls, floors and roof	0 / 5
MRc2	Construction waste Mgmt	2 / 2
MRc3	Materials reuse	0 / 1

MATERIAL & RESOURCES		CONTINUED
MRc4	Recycled content	1 / 2
MRc5	Regional materials	1 / 2
MRc6	Certified wood	0 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 7 / 12
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	1 / 1
EQc3	Construction IAQ Mgmt plan - during construction	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	0 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	0 / 1
EQc5	Indoor chemical and pollutant source control	1 / 1
EQc6	Controllability of systems - thermal comfort	0 / 1
EQc7	Thermal comfort - design	1 / 1
EQc8.1	Daylight and views - daylight	0 / 1
EQc8.2	Daylight and views - views	1 / 1

INNOVATION		AWARDED: 6 / 6
IDc1	Innovation in design	5 / 5
IDc2	LEED Accredited Professional	1 / 1

REGIONAL PRIORITY		AWARDED: 4 / 4
EAc1	Optimize energy performance	1 / 1
EAc3	Enhanced commissioning	1 / 1
EAc5.2	Measurement and verification - tenant submetering	0 / 1
WEc1	Water efficient landscaping	1 / 1
WEc2	Innovative wastewater technologies	0 / 1
WEc3	Water use reduction	1 / 1

TOTAL 81 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Figure 3.35. LEED Scorecard of Pearl River Tower (USGBC 2017)

4. ENERGY LOSS REDUCTION IN SKYSCRAPERS WITH PASSIVE MODE STRATEGIES

This chapter focuses on the reducing of energy loss in skyscrapers with passive mode strategies; this chapter examines some strategies that can improve the ecological performance of skyscrapers and reduce the non-renewable energy consumption, this chapter focuses on two passive design strategies; passive solar concepts for natural solar gain and daylight, and passive wind concepts for natural ventilation. This chapter also examines some examples of skyscrapers that exist around the world as case studies; the ecological approaches for reducing the energy loss with the investigated passive design strategies in these examples are analyzed.

The word passive means that the architectural elements can operate as a system without the need for power input from mechanical and electrical equipment (Sillah 2011). Passive design can be defined as the design that considers the advantage of the surrounding environment and tries to optimize the use of the renewable resources of energy and minimize the use of non-renewable resources of energy. Eco-design or ecological design starts by optimizing the passive design strategies to ensure an effective low energy design and produce improved internal comfort conditions without the use of any non-renewable resources of energy (Yeang 1999, 2006).

Passive mode design can be considered as the bioclimatic design that needs an understanding of the local climate to enable the advantage of the surrounding energies and climatic characteristics (Yeang 2006). For reaching the maximum advantage from the surrounding environment, it is important to take into consideration the climatic conditions of the site. Each climatic sites and regions have their own characteristics. There are four main climatic zones in the world; tropical, arid, temperate, and cool (Yeang 2000, Wood and Salib 2013). These different climate zones are shown in Figure 4.1. Thereby for ecological skyscrapers, it is important to examine the unique conditions of the site to reach the objective of passive design.

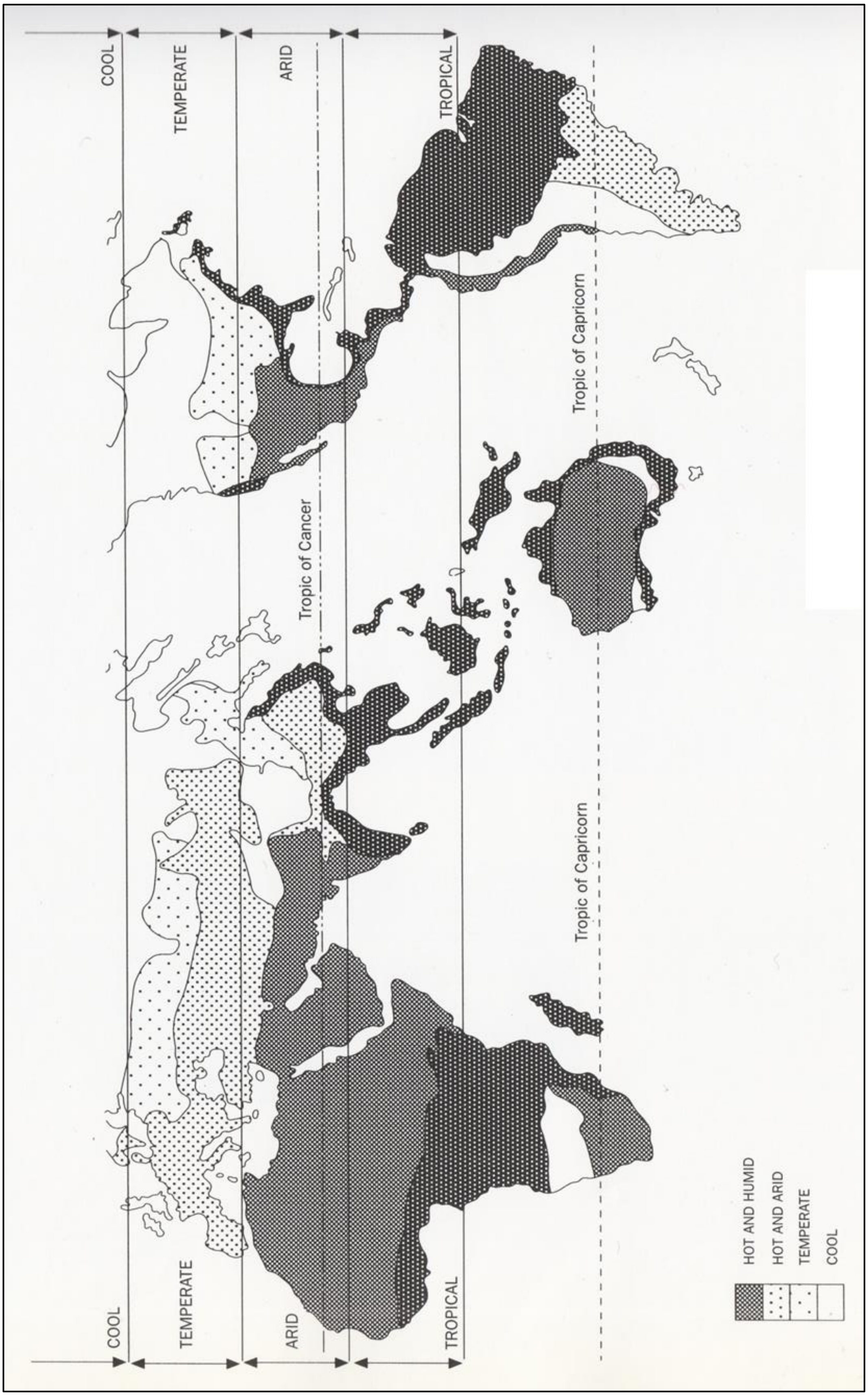


Figure 4.1. The world's different climate zones (Yeang 2000)

Different climate zones mean different environmental requirements, and different design strategies and considerations that can be adopted to achieve human comfort. For example, the strategies those aim to particular energy savings and better energy performance in the skyscraper. The following points give some information about the specific features of each climate zone (Wood and Salib 2013);

- Tropical Climates; these climates are characterized by relatively high air temperatures, high humidity levels, high precipitation, and high solar radiation. Two important considerations can be used while designing in these climates: protection from solar radiation and ventilating with a high air change rate to remove unneeded humidity.

- Arid Climates; these climates are hot and dry, and they are characterized by high air temperatures that exceed 37 °C, low humidity levels, and almost no precipitation. Reducing solar heat gain is an important consideration in these climates.

- Temperate Climates; these climates are characterized by un-excessive temperature and precipitation. The changes between summer and winter without being extreme are noticeable in these climates. These climates generally need the design to have the best adaptability over the year.

- Cool Climates; cool or cold climates are characterized by low average air temperatures and low solar radiation. The most important consideration in these climates is the conservation of heat.

Passive design concepts are more and more important in planning and designing sustainable buildings especially sustainable skyscrapers because of their consumption of a large amount of energy and much of this energy are used for artificial lighting, cooling, ventilating and heating (Al-Kodmany 2015). The following sections focus in two of the most important passive design strategies which are the passive solar concepts for natural solar gain and daylight, and the passive wind concepts for natural ventilation.

4.1. Passive Solar Concepts for Natural Solar Gain and Daylight

This section focuses on the passive solar concepts which depend on the solar energy that is a renewable resource of energy. The ecological approaches for reducing the non-renewable energy consumption in skyscrapers by providing maximum natural solar gain and daylight are investigated in this part. The following parts examine passive solar concepts in details and provide case studies of skyscrapers designed with passive solar concepts.

4.1.1. Overview on passive solar concepts

Over time, concepts and strategies have been in developing to harness the solar energy especially the concepts and the strategies for natural solar gain to provide maximum natural heating and cooling for the buildings and for daylight which is the controlled allowing for natural light to provide maximum natural lighting for the buildings.

According to France International Office of Exhibitions (Bureau International des Expositions- BIE) (2017), one of the first buildings integrating sustainable design with passive solar concepts was “The House of Tomorrow” in Chicago (see Figure 4.2), this building designed by the American modernist architect George Fred Keck; it was built in 1933, the building is known as the first building with passive solar principles in contemporary architecture, it was including some design consideration such as solar orientation and insulated glass windows. Keck benefited from the glass walls by introducing a passive solar heating system for the winter. The House of Tomorrow took the advantage of the power of radiant heat from the sun passing through large expanses of glass to warm the interior. The circular twelve-sided glass and steel model of the building challenged the traditions and made the building to obtain the title of America’s first glass house. Unluckily, in summer the building presented overheating caused by the all-glass facades that strained the cooling system and had to be closed off during the summer. Lessons learned from the House of Tomorrow led to the rise of passive solar buildings to provide natural heating in winter and recycled cool air in summer.

Figure 4.2. The House of Tomorrow, Chicago (BIE 2017)

Generally, it can be observed that it is important to consider passive solar concepts in the design of buildings and skyscrapers especially to reach the objective of passive design which is to reduce the energy requirement from non-renewable resources to generate artificial heating and lighting, for these reasons, designing skyscrapers with considering passive solar concepts is an important factor in ecological and bio-climatic design (Al-Kodmany 2015).

4.1.2. Principles for passive solar concepts

There are many principles for passive solar concepts in skyscrapers; the followings mention some of these principles;

According to the American Institute of Architects (AIA) and the Society of Building Science Educators (SBSE) (2012), understanding solar geometry and movement is the determining element of solar heat gain, shading, and daylight penetration.

In his works in the principles and strategies for passive solar concepts, Yeang (1999, 2000) proposed 4 diagrams (Figure 4.3) that provide an overview of the sun's influence in the world's different climate zones.

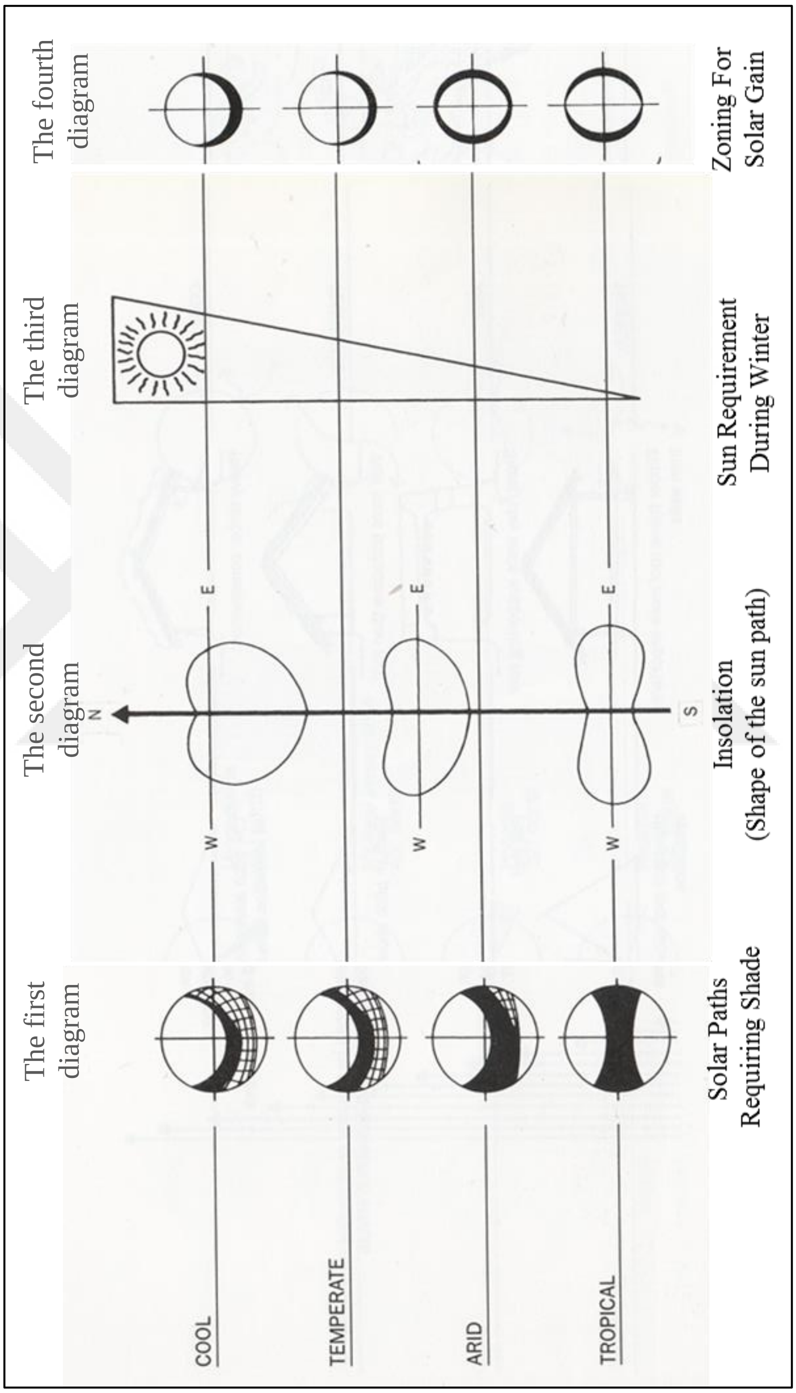


Figure 4.3. Diagrams on the sun's influence in the world's different climate zones (Adapted from Yeang 1999, 2000)

According to Yeang (1999, 2000), the first diagram (see Figure 4.3) shows the solar paths requiring shade in the world's different climate zones. In this diagram, it can be observed that the shading requirement depends on the sun path in each season. In the lower latitudes, there is a problem of overheating related to unwanted solar gain, but in higher latitudes, overheating only take places during the summer and it really wanted in winter. The second diagram shows the shape of the sun path in the world's different climate zones. In this diagram, it can be observed that the sun path is more southerly in cool zones, changing to a 'bow tie' pattern in tropical zones. The third diagram in the same figure shows the sun requirement during winter in the world's different climate zones. In this diagram, it can be observed that this needing increase in higher latitudes and decrease in lower latitudes during winter. The fourth diagram shows the zoning for solar gain in the world's different climate zones. This diagram indicates the location of spaces which can be used for solar heat gain. From the diagram, it can be observed that the location follows the sun path in each climate zone. These locations are on the south facing side in temperate and cool zones, and on the west and east facing sides in tropical and arid zones.

Generally, in cold climates, the principle for solar gain is to capture and store as much solar heat as possible, while in hot climates the principle is to keep heat out. The ideal passive solar concepts must perform and consider both functions by using solar heat in winter and rejecting it in summer (Sillah 2011).

According to Bainbridge and Haggard (2011), one of the main principles of passive solar design is the solar radiation transfer of heat, generally, radiation flow from a warmer object to a cooler object and outcome to thermal balance. In general, when solar radiation hit a surface, this radiation can be reflected, absorbed, or transmitted (see Figure 4.4). The angle at which solar radiation hit the surface is known as the angle of incidence. This is most important while considering the absorption, reflection, and transmission of solar energy. Generally, the more acute angle of incidence is the greater in reflection and the lower in absorption and transmission.

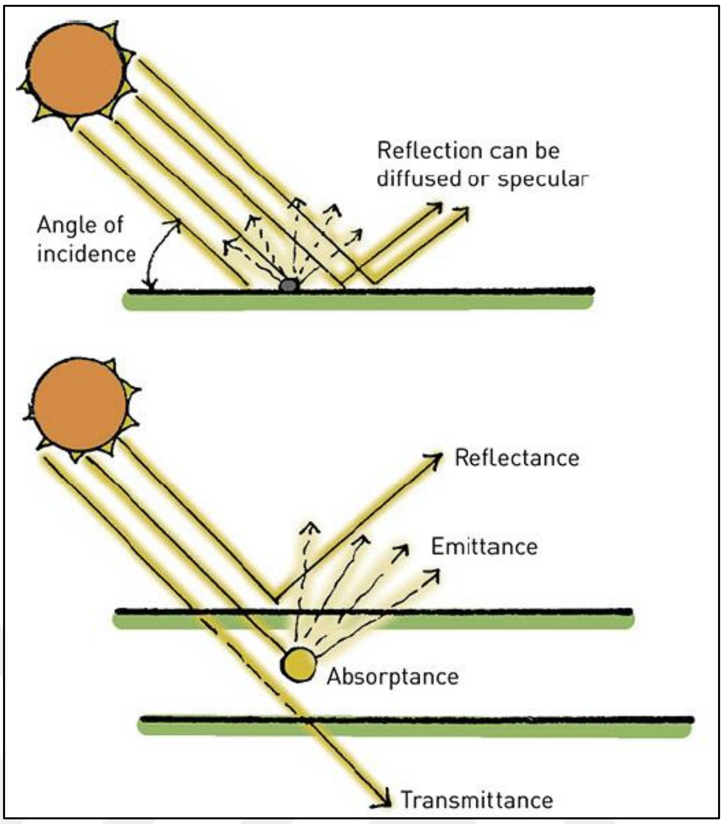


Figure 4.4. Reflectance, absorbance, and transmittance of solar radiation (Bainbridge and Haggard 2011)

Taking benefit from natural lighting and daylight in skyscrapers is also one of the important elements of passive solar concepts. Daylight utilizes sunlight and spread the radiation from the sky to provide natural lighting inside the skyscrapers. Daylight has a great impact on user's satisfaction by providing movement, change, and connection to the outdoor environment. Global gas emissions and the environmental impacts of power production and power distribution can be significantly minimized by integrating daylight in buildings (Bainbridge and Haggard 2011).

Daylight availability is highly affected by climatic conditions. In areas with hot climates and lower latitudes, the reaching of the wanted lighting levels is related to the control and moderation of the intensity of daylight and the avoidance of glare and overheating. In areas with higher latitudes and colder climates, daylight availability during the year is lower, for this, the aim here is to reach of maximum daylight incoming into the skyscrapers (Gonçalves 2010).

The main source of daylight is the sun, parts of the solar radiation used for natural lighting is received as direct sunlight, the other parts of the solar radiation is received as indirect or reflected radiation bounced off other buildings or the surrounding landscape. The proportion of each reflected radiation varies according to building orientation and design, variation in the ground surface, cloudiness and type of clouds, atmospheric clarity, and the sun's daily and seasonal path and position (Bainbridge and Haggard 2011). According to Al-Kodmany (2015), there are three main sources to provide natural daylight for skyscrapers (Figure 4.5);

- Direct Sunlight (DS); it is the main source of natural light and solar gain.
- Internal Reflection (IR); internal walls, interior parts of the floor roofs and floors reflect of the main direct sunlight into interior spaces of skyscrapers (for example, the use of highly reflective surfaces such as glossy and smooth surfaces and mirrors to reflect direct sunlight).
- External Reflection (ER); Ground surfaces and the near surrounding buildings reflect the main direct sunlight into interior spaces of skyscrapers.

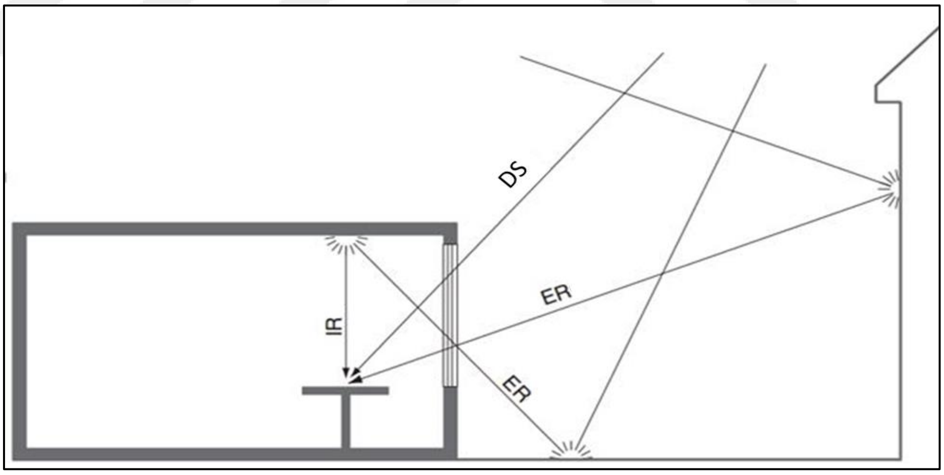


Figure 4.5. The main sources to provide natural daylight (Adapted from Iitvegar 2013)

This part examined some of the most important principles for passive solar concepts for natural solar gain and daylight. Table 4.1 summarizes and concludes the investigated principles in this part.

Table 4.1. Summarizing of the investigated principles for passive solar concepts

The principles for passive solar concepts		Climate zones	Description
Understanding solar movement and diagrams	Solar paths requiring shade	Lower latitudes (tropical and arid zones)	There is a problem of overheating related to the unwanted solar gain
		Higher latitudes (temperate and cool zones)	Overheating only take places during the summer and it really wanted in winter
	The sun path and the zoning for solar gain	Lower latitudes (tropical and arid zones)	The solar gain is more in west and east facing sides
		Higher latitudes (temperate and cool zones)	The solar gain is more in the south facing side
	The sun requirement during winter	Lower latitudes (tropical and arid zones)	Needing for solar gain is decreased
		Higher latitudes (temperate and cool zones)	Needing for solar gain is increased
Understanding the solar radiation transfer of heat	The absorption, reflection, and transmission of solar energy	Lower latitudes (tropical and arid zones)	More reflection and absorption, less transmission are required
		Higher latitudes (temperate and cool zones)	More transmission and absorption, less reflection are required
	Solar heat gain	Lower latitudes (tropical and arid zones)	The principle for solar gain is to keep heat out as much solar heat as possible
		Higher latitudes (temperate and cool zones)	The principle for solar gain is to capture and store as much solar heat as possible.
Understanding the principles and the sources for providing natural daylight	Daylight providing	Lower latitudes (tropical and arid zones)	The reaching of the wanted lighting levels is related to the control and moderation of the intensity of daylight and the avoidance of glare and overheating
		Higher latitudes (temperate and cool zones)	Daylight availability during the year is lower, for this, the aim here is to reach of maximum daylight incoming

4.1.3. Design considerations for passive solar concepts

There are many design considerations for passive solar concepts in skyscrapers; the followings mention some of these design considerations;

One of the most important design considerations for passive solar concepts is by giving importance for skyscraper layout and configuration. The built form, its spatial arrangement, and orientation must be configured and planned in relation to the performance of the surrounding environment and the climatic conditions of the locality. This configuration and planning must be according to the sun paths of the locality. All these are to reduce the energy requirement from non-renewable resources and to reach the maximum solar shading, solar gain, and daylight (Yeang 1999, 2006). For these, skyscraper layout and configuration require being made in such a way on the site as to perform in a low energy way.

In his works in the area of design considerations for passive solar concepts by skyscrapers layout and configuration, Yeang (1999, 2000) proposed 5 diagrams (Figure 4.6) that provide an overview of the favorable skyscraper layout and configuration in the world's different climate zones.

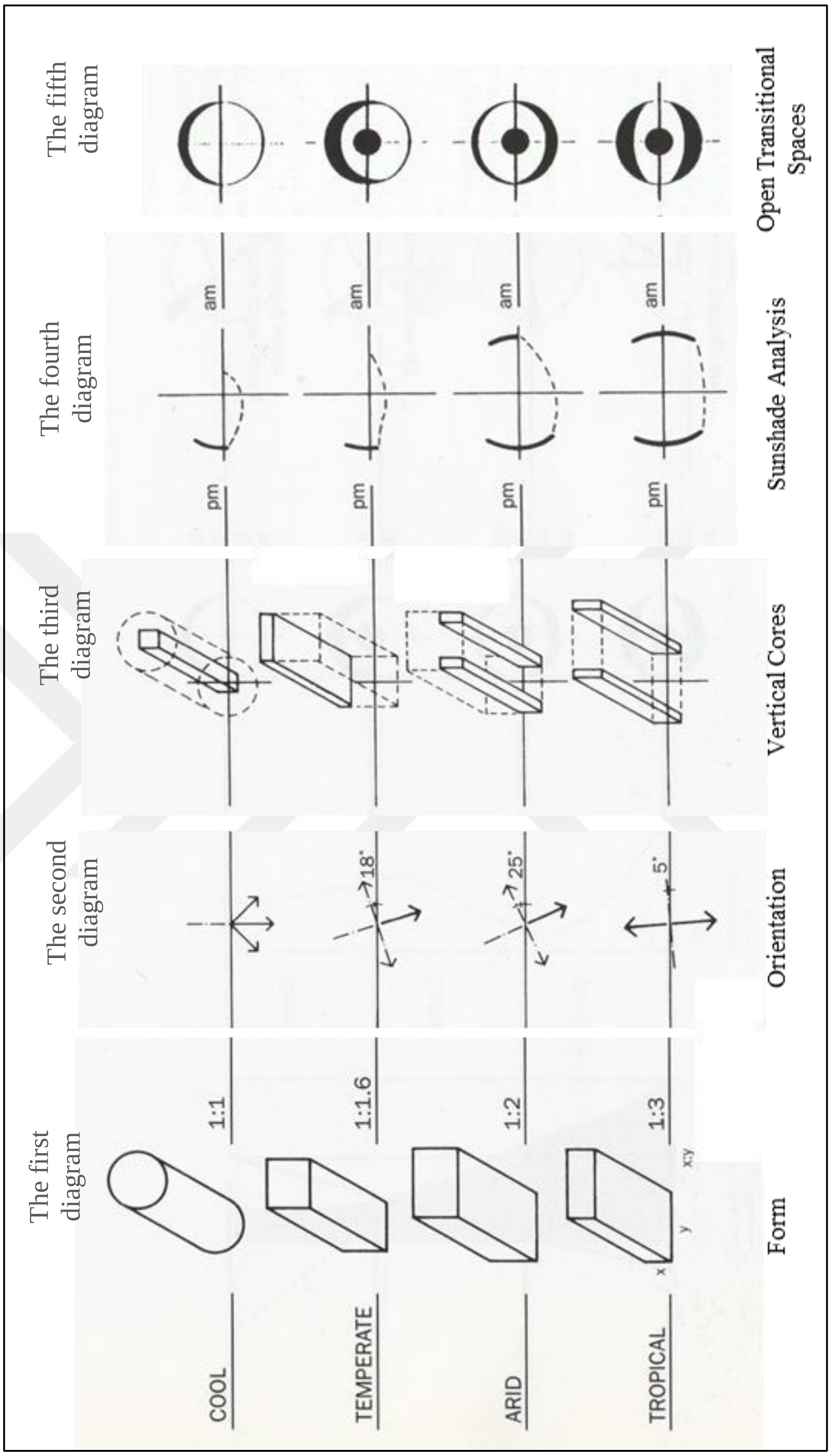


Figure 4.6. Diagrams on the optimum and favorable skyscraper layout and configuration for passive solar concepts in the world's different climate zones (Adapted from Yeang 1999, 2000)

According to Yeang (1999, 2000), the first diagram (see Figure 4.6) shows the optimum and favorable aspect ratios of skyscrapers in the world's different climate zones. This diagram indicates the favorable length of the sides of the skyscrapers, here the sides are of length x:y, these favorable length of the sides are;

- Cool zone 1:1
- Temperate zone 1:1.6
- Arid zone 1:2
- Tropical zone 1:3

In this diagram, it can be observed that lower latitude climate zones which are hot and humid need a prolonged form to reduce the east and west exposure, reduce the shading impact, and reduce solar penetration into the skyscraper, here it must be included that the long axis of the skyscraper must be oriented east-west so that long faces of the building are north and south. This prolonged form develops gradually into 1:1 in the higher latitude climate zones to enlarge the capable surface for utilizing of solar gain. The diagram doesn't only mean that the forms of the skyscrapers must be with rectangle or circle base, the other bases forms can be also considered here with respecting the providing ratios and lengths. The second diagram in the same figure shows the optimum and favorable orientation of a skyscraper and the placement of its main facades in the world's different climate zones. It must also be careful about the difference between the true north (solar north) and magnetic north, that is not the same, the true north is approximately 11° west of magnetic north, here it must be considered the true north in the designing of skyscrapers, misunderstandings can seriously affect shadow diagrams. Table 4.2 shows Yeang's propositions for the optimum skyscraper's orientation and directional emphasis in the world's different climate zones. The directional emphasis is important to help keep heat in and out the building.

Table 4.2. The optimum skyscraper's orientation and directional emphasis in the world's different climate zones (Adapted from Yeang 1999, 2000)

Zone	Skyscraper's main orientation	Directional emphasis
Cool	On an axis facing south	Facing South
Temperate	On an axis facing 18° north of east	South – South-east
Arid	On an axis facing 25° north of east	South-east
Tropical	On an axis facing 5° north of east	North - South

The decision taken in relation to the orientation of the skyscraper on the site is very important and can affect every other later decision. Every skyscraper's site is unique by its local climate and the environmental impact of the skyscraper on the site. The skyscraper's perfect orientation can take advantage of free energy from the sun in terms of heat and light, and from the wind in terms of natural ventilation (Yeang 2006).

The third diagram in the same figure (see Figure 4.6) shows the optimum and the favorable placement of the skyscraper's masses (cores, shafts, stairwells) in the world's different climate zones. In this diagram, it can be observed that the cool zone needs the maximum faces of the skyscraper must be opened to the sun for heat penetration, for this, the main mass preferred to be placed in the center of the skyscraper to not block out the sun's rays and to keep heat within the skyscraper. The main mass in the temperate zone preferred to be placed on the north face of the skyscraper to leave the south face available for solar heat gain during the winter. In the arid zone, the cores preferred to be located on the east and west sides mainly on the south face of the skyscraper a cause to the major shading needed during the summer. The core in the tropical zone preferred to be placed on the east and west faces of the skyscraper to control shading impact and to serve as a solar buffer.

The fourth diagram shows the vertical and horizontal sunshade analysis in the world's different climate zones. This diagram indicates the favorable locations of vertical sun shading (there are with solid line in the diagram) which can protect the skyscraper from low sun angles in the morning and evening, and also the favorable locations of horizontal sun shading (there are with broken line in the diagram) which can protect the skyscraper from high mid-day sun. Tropical climate zones need both types of shading during the year. In higher latitudes, these types of shading only needed during summer.

The fifth diagram shows the optimum and favorable placement of the skyscraper's open transitional spaces (e.g. balconies, open lobbies, open hallways) in the world's different climate zones. In this diagram, it can be observed that the open transitional spaces in tropical and arid zones are preferred to be located on the north and south sides of the skyscraper where the sun doesn't penetrate too far into the internal spaces. In cool and temperate zones the open transitional spaces are preferred to be located on the north side of the skyscraper where the sun doesn't penetrate too far into the internal spaces. Atriums also can be used also to provide natural heating and daylight for the inner parts of the skyscraper.

According to Sillah (2011), an understanding of solar radiation and of the position of the sun in the sky is fundamental to efficient skyscraper design. Winter sun is at its maximum on the south side of the skyscraper, so this is the façade most affected by passive solar gain design. The skyscraper floor plan must be laid out to provide sufficient southern solar exposure, with the long axis of the skyscraper going from east to west (Figure 4.7). According to Wood and Salib (2013), skyscrapers in hot and dry climates especially must be oriented with the main façade openings positioned toward the north and south, and the east and west facades must be reduced to minimize east-west exposure and to reduce solar gain during periods of lower-angle sun in the mornings and afternoons. Generally, the skyscraper with south façade orientation and with long axis stretched out in the east-west direction can take the advantage of minimizing solar heat gain in summer and maximizing solar heat gain in winter.

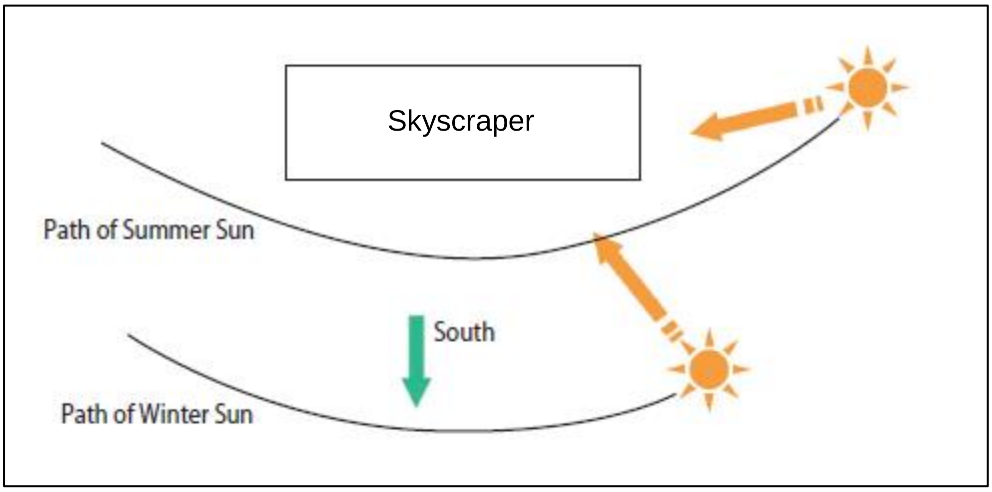


Figure 4.7. The position of the sun in summer and winter (Sillah 2011)

Figure 4.8 provides some examples of typical skyscrapers in the different climate zones; tropical, arid, temperate, and cool climate.

Different climate zones				
Zone	Tropical climate	Arid climate	Temperate	Cool climate
Photo				
Name	The Met	ADNOC Headquarters	New York Times Tower	Absolute Towers
Location	Bangkok, Thailand	Abu Dhabi, UAE	New York, USA	Mississauga, Canada
Height	230.6 m	342 m	318.8 m	175.6 m
Floors	69 floors	65 floors	52 floors	62 floors
Material	Concrete	Concrete	Steel	Concrete
Function	Residential	Office	Office	Residential
Arch. Design	WOHA Architects	HOK, Inc.	FXFOWLE	MAD Architects
Orientation				

Figure 4.8. Examples of typical skyscrapers in the different climate zones (Adapted from CTBUH's Database 2017, Google Maps 2018)

Another design consideration for skyscraper layout and configuration is by giving importance to the lease span of the skyscrapers; this term refers to the distance between the core and the exterior wall (see Figure 4.9), and it changes relying on the site configuration and the use of the skyscraper. According to Al-Kodmany (2015), generally, lease spans must be shorter in overcast or cloudy climatic areas and must be longer in sunny climatic areas for maximum solar gain and daylight providing.

Generally, four types of lease span can be considered for skyscrapers based on the depth of space;

- Very deep space, over 20 m.
- Deep space, 11 to 19 m.
- Medium, 6 to 10 m.
- Shallow space, 4 to 5 m.

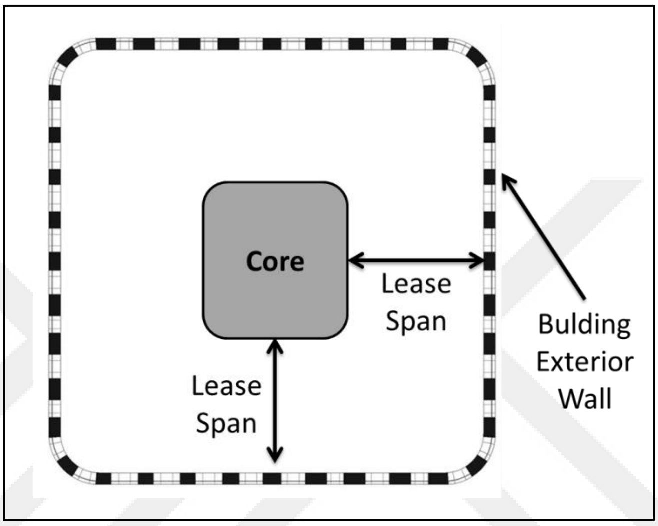
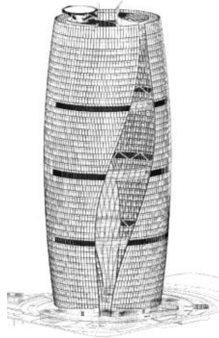


Figure 4.9. Lease span in the skyscraper

The use of sky courts and atriums in skyscrapers is another important design consideration for passive solar concepts. Atriums and sky courts utilized for authorizing the light and the heat of the sun to penetrate too far into the internal spaces of the skyscraper for providing natural solar gain, heating, cooling and daylight for the inner parts of the skyscraper (Yeang 1999, Al-Kodmany 2015). An example of a skyscraper with sky courts and atrium is the SOHO Li Ze Tower (see Figure 4.10) which is located in Beijing, China. This skyscraper contains a huge twisting atrium that is considering as one of the world's tallest atriums with 190 m in height. As it rises, the atrium twists at 45 degrees to orientate the higher floors with the east-west axis of Lize Road which one of west Beijing's main streets. The shape of the atrium and the sky courts create convex openings that run up either side of the tower to allow for plenty of daylight and views of the city from the center of each floor (Gibson 2017).

SOHO Li Ze Tower (Leeza SOHO Tower)	
City	Beijing
Country	China
Height	207 m
Floors	50
Function	office
Structural Material	composite
Architectural Design	Zaha Hadid Architects
Energy Label	LEED Gold



Sky courts and atrium

Figure 4.10. SOHO Li Ze Tower, China
(Adapted from CTBUH’s Database 2017, Gibson 2017)

Another important design consideration for passive solar concepts is by using sunshades. According to Al-Kodmany (2015), one of the main discomfort things in the skyscrapers is the problem associated with glare and unpleasant direct sunlight, sunshades are effective for solving this problem, solar heat gain and rays through the window can be reduced also by sunshades. Yeang (1999) mentioned that the shading providing by the sunshades should be designed to reduce glare, at the same time to enable the passive transmission of light to provide better daylight entry to internal spaces which then can reduce the artificial lighting and cooling energy loads.

AIA and SBSE (2012) categorized the types of exterior fixed sunshade devices as horizontal, vertical and egg crate. Fixed horizontal sunshades are suitable for southern exposures, fixed vertical and egg crates sunshades are suitable for east and west exposures. Figure 4.11 shows the different types of fixed sunshades and their ideal orientation.

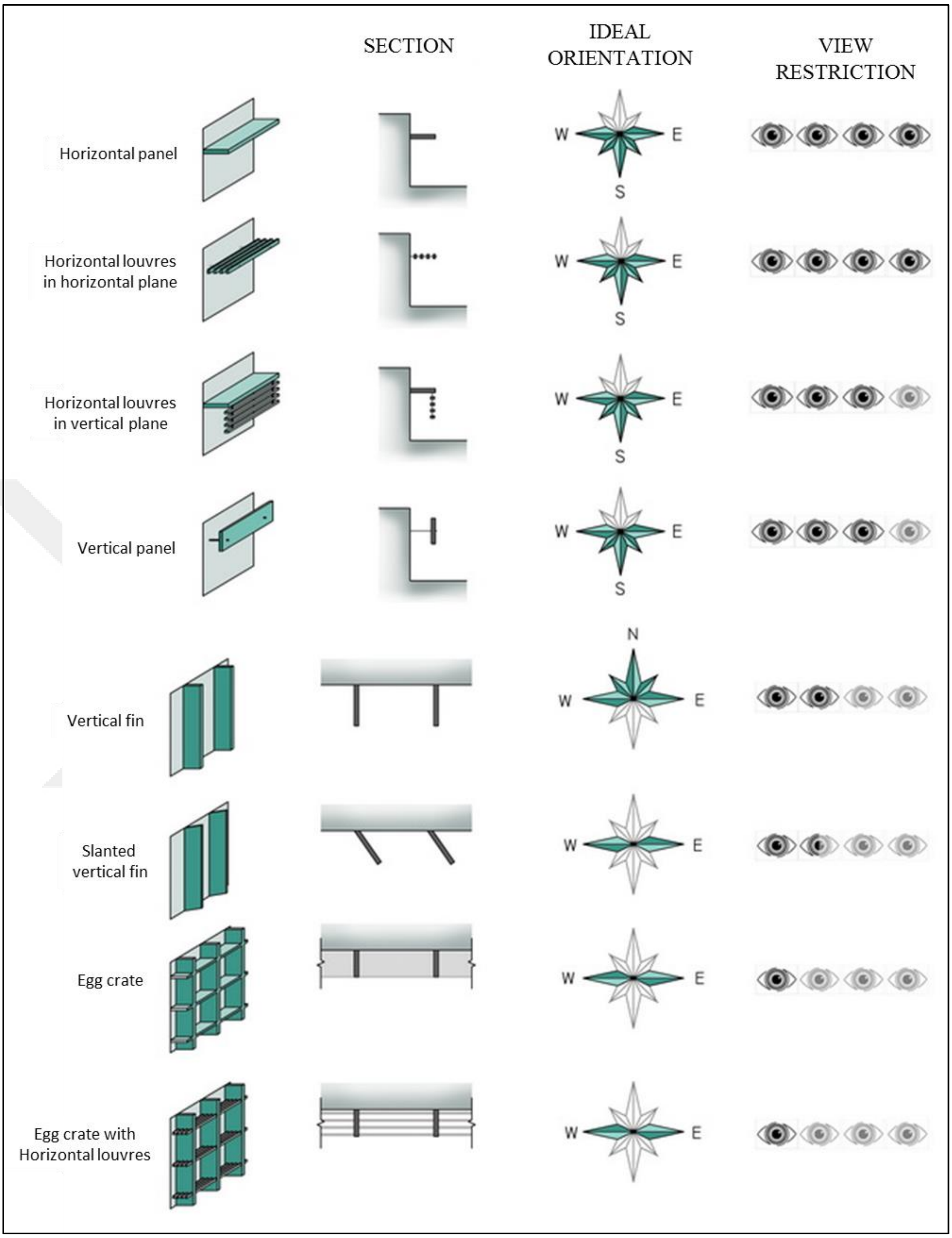


Figure 4.11. The different types of fixed sunshades (AIA and SBSE 2012)

Generally, fixed horizontal sunshades are effective for south facade windows, and fixed vertical sunshades are effective for east and west facades' windows (Yeang 2006). An example of a skyscraper with fixed sunshades is the 20 Fenchurch Tower (Figure 4.12) which is located in London, UK. One of the world's largest fixed sunshades has been draped over this skyscraper. The entire south side of the tower covered with black netting to reduce the glare caused by its unique facade focusing solar beams onto streets below (CTBUH 2017).

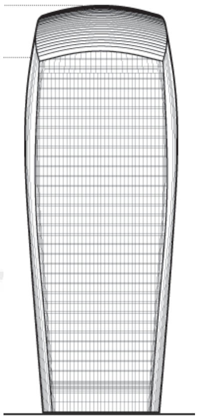
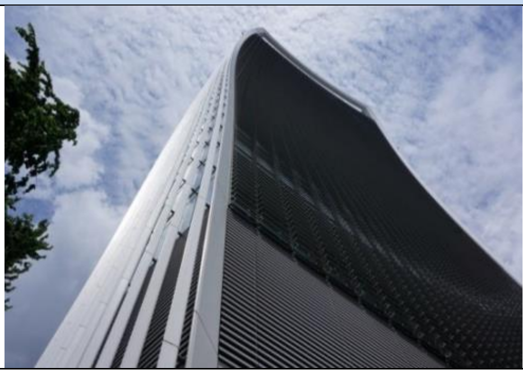
20 Fenchurch Tower (The Walkie Talkie)			
	City	London	
	Country	UK	
	Height	160.1 m	
	Floors	38	
	Function	Office	
	Structural Material	steel/concrete	
	Architectural Design	Rafael Viñoly Architects	
	Energy Label	BREEAM Excellent	
Fixed sunshades			
			

Figure 4.12. 20 Fenchurch Tower, UK (Adapted from CTBUH's Database 2017)

Using the light shelves (see Figure 4.13) is also another design consideration for solving the problem of glare. Light shelves are acting as horizontal sunshades that facilitate additional benefits of providing protection from glare and direct sunlight by reflecting them. An example of a skyscraper with light shelves is the National Library of Singapore (see Figure 4.14) which located in Singapore. In this building, the usage of artificial indoor lighting is minimized by light shelves that reflect daylight deeper into the building to help in lighting interior spaces. Sun-shading blades have been fitted onto the building's facades to prevent excessive heat and glare (Richards 2007, Hart 2011).

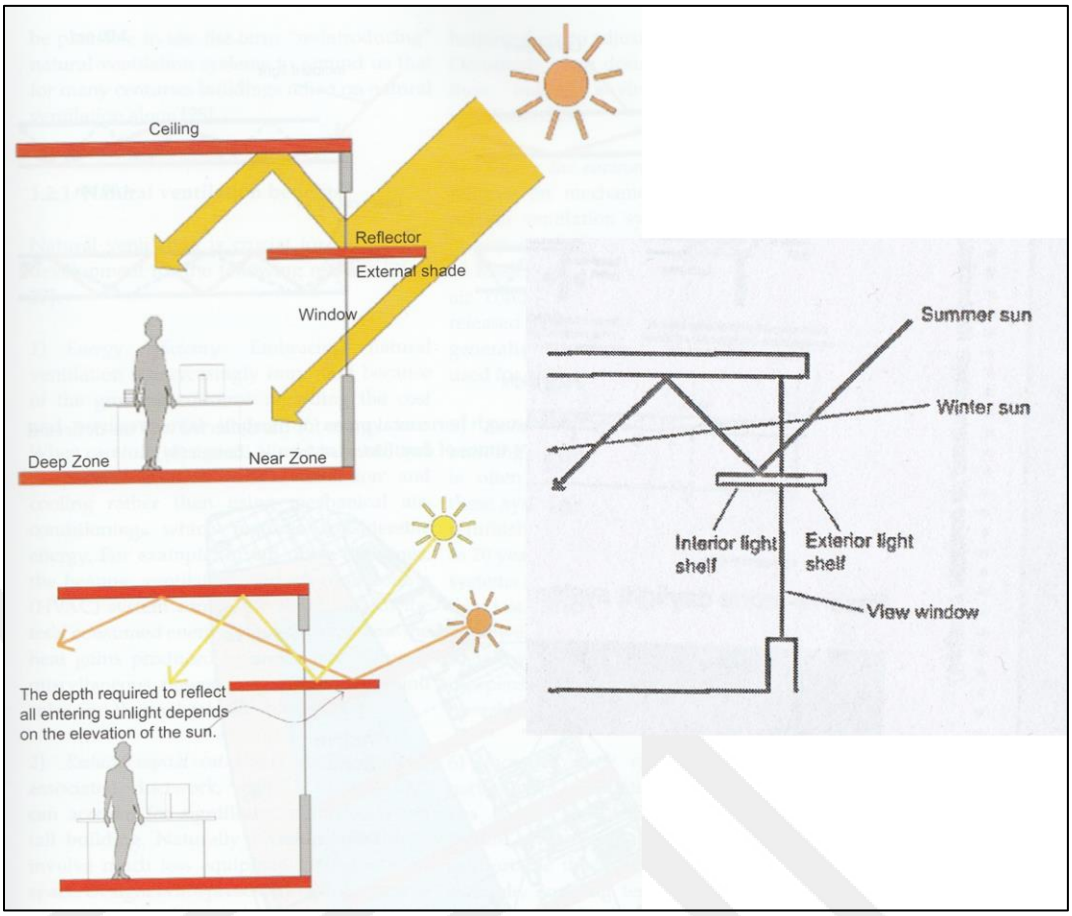


Figure 4.13. The using of light shelves for natural daylight
(Adapted from Yeang 2006, Al-Kodmany 2015)

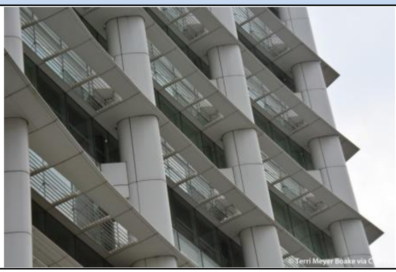
<table>
<tr><th colspan="4">National Library of Singapore</th></tr>
<tr><td rowspan="8"></td><td>City</td><td>Singapore</td><td rowspan="8"></td></tr>
<tr><td>Country</td><td>Singapore</td></tr>
<tr><td>Height</td><td>102.8 m</td></tr>
<tr><td>Floors</td><td>19</td></tr>
<tr><td>Function</td><td>Library</td></tr>
<tr><td>Structural Material</td><td>steel</td></tr>
<tr><td>Architectural Design</td><td>TR Hamzah & Yeang</td></tr>
<tr><td>Energy Label</td><td>Green Mark Platinum</td></tr>
<tr><td colspan="4">Light shelves</td></tr>
<tr><td colspan="4">  </td></tr>
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Figure 4.14. National Library of Singapore (Adapted from CTBUH’s Database 2017)

The use of greenery and vegetation in skyscrapers is another important design consideration for passive solar concepts. Greenery and vegetation can be used to improve the skyscraper’s surrounding air temperature. This design consideration has aesthetic, ecological, energy conservation benefits, and effective solutions to benefit from the sun to ideal and maximum natural solar gain. The use of greenery and vegetation in skyscrapers can reduce the surrounding hot temperature in summer, at the same time heat loss in winter can be reduced with this strategy. In this design consideration, the vegetation at the facade absorbs and reflects a high percentage of solar radiation in summer the rest passes through the vegetation and reach the skyscraper surface, this can reduce the artificial cooling energy load from non-renewable energy resources in skyscrapers. In winter, the vegetation at the facade stores a percentage of solar radiation and working as a semi-insulator to reduce the heat loss inside the skyscraper; this can reduce the artificial heating energy load from non-renewable energy resources in skyscrapers. Shading of the exterior wall of the skyscraper from incoming solar radiation is also one of the important benefits of the use of greenery and vegetation in skyscrapers (Yeang 1999, Al-Kodmany 2015).

According to Wood et al. (2014), the types for the use of greenery and vegetation in skyscrapers can be grouped into four types; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies. The following points provide some information and examples about these types.

- Facade supported green walls is one of the four types for the use of greenery and vegetation in skyscrapers; here the planting medium is not integrated into the facade, the planting medium is carried in horizontal farmers that can be found at various intervals over the height of the facade. This system is usually contained of steel, wood, or plastic trellises externally attached to the skyscraper facade where the vegetations are supported by them. An example of a skyscraper with facade supported green walls is Consorcio Santiago Tower (Figure 4.15) which is located in Chile. This tower contains a double facade: an inner with curtain wall and an outer with vegetation. This facade supported green walls transforms the building into a vertical garden of about 2700 m² (Afrin 2009).

Consorcio Santiago Tower	
City	Biobío
Country	Chile
Height	75 m
Floors	17
Function	Office
Architectural Design	
Enrique Browne Arquitectos	

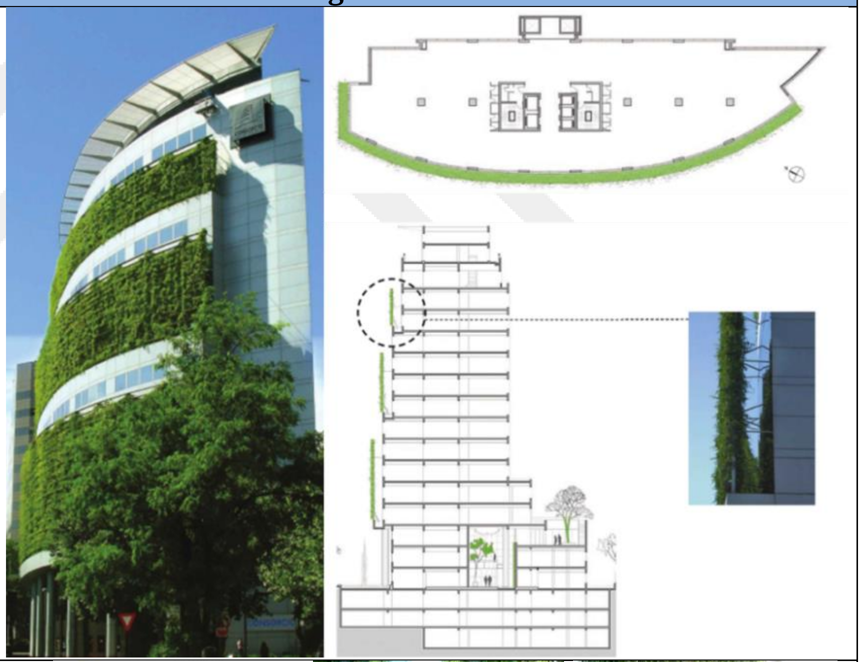


Figure 4.15. Consorcio Santiago Tower, Chile
(Adapted from Afrin 2009, Wood et al. 2014, CTBUH’s Database 2017)

- Facade integrated living walls is another type for the use of greenery and vegetation in skyscrapers; here the vegetation is not only attached to the skyscraper facade but is fully integrated into the facade construction in which vegetation and planting medium are both placed on the vertical surface of the exterior wall. Generally, living walls are separated from the facade surface by a waterproof layer planned to protect the rest of the facade construction from unneeded humidity. An example of a skyscraper with facade integrated living walls is the Athenaeum Hotel (Figure 4.16) which is located in London, UK. The eight-story tall living wall of Athenaeum Hotel covers approximately 260 m^2. In this building, pre-grown plants are inserted into holes cut in fabric, where they establish their root system in between the layers that serve as a planting medium (Susorova and Bahrami 2012).

Athenaeum Hotel					
City	London	Country	UK	Height	48 m
Function	hotel	Structural Material	Concrete	Floors	9
Facade integrated living walls					

Figure 4.16. Athenaeum Hotel, UK
(Adapted from Wood et al. 2014, CTBUH's Database 2017)

- Integrated green terraces are another type for the use of greenery and vegetation in skyscrapers; this type generally consists of concrete floors holding planting medium much like the terraced agricultural planting fields. This type is most often used when the vegetation and their planting medium are required a large amount of soil (Wood et al. 2014). An example of a skyscraper with integrated green terraces is the Park Royal on Pickering (Figure 4.17) which is located in Singapore. In this skyscraper, a total of 15,000 m² of sky gardens, reflecting pools, waterfalls, planter terraces and green walls were designed. A diverse variety of species ranging from shade trees, tall palms, flowering plants, leafy shrubs and overhanging creepers come together to create the integrated green terraces of this tower (Frearson 2013).

Park Royal on Pickering					
City	Singapore	Country	Singapore	Height	89 m
Function	hotel	Structural Material	Precast	Floors	16
Architectural Design		WOHA Architects		En. Label	LEED
Integrated green terraces					

Figure 4.17. Park Royal on Pickering, Singapore
(Adapted from Frearson 2013, Wood et al. 2014, CTBUH's Database 2017)

- Integrated tree balconies is another type for the use of greenery and vegetation in skyscrapers; in this type, trees and vegetation are placed in front of the facades of the skyscraper using a projecting balcony. This platform generally contains planters of a depth sufficient to support a root structure and the required soil. An example of a skyscraper with integrated tree balconies is the Bosco Verticale (Figure 4.18) in Italy. There are about 20,000 specimens, including about 700 trees up to six meters high, installed on both towers. All the plants take root in containers located on the external side of deep cantilevered terraces, which are directly accessible from each residential apartment (Giacomello and Valagussa 2015).

Bosco Verticale					
City	Milan	Country	Italy	Height	115.9 m
Function	residential	Structural Material	concrete	Floors	30
Architectural Design		Stefano Boeri Architetti		En. Label	LEED Gold
Integrated tree balconies					

Figure 4.18. Bosco Verticale, Italy
(Adapted from Giacomello and Valagussa 2015, CTBUH’s Database 2017)

Another design consideration for passive solar concepts is by using different types of glasses in the facade design of skyscrapers which can provide natural lighting, cooling and heating from taking these advantages from the sun. The following points show some types of these glasses.

- The use of Tinted glasses is one consideration for the façade design of skyscrapers, Tinted glasses can reduce thermal transmission to about 20%, these types of glasses absorb some of the unneeded heat to make the internal spaces cooler which then can reduce the artificial cooling energy load (Al-Kodmany 2015). An example of a skyscraper with Tinted glasses is the 333 Wacker Drive Building (Figure 4.19) which is located in Chicago, USA.

333 Wacker Drive Building					
City	Chicago	Country	USA	Height	148.6 m
Function	office	Structural Material	steel	Floors	36
Architectural Design		Kohn Pedersen Fox Associates and Perkins+Will			

Figure 4.19. 333 Wacker Drive, USA (Adapted from CTBUH’s Database 2017)

- The use of solar-reflective glasses is another consideration for the façade design of skyscrapers, Solar-reflective glass can be used to reduce solar penetration with providing a good quality of natural lighting which then can reduce the artificial lighting energy load. In addition to that, they can be useful in places where heat gain is not needed and the use of sunshades is not physically possible (Yeang 2006). An example of a skyscraper with solar-reflective glasses is the Bank of America Plaza (Figure 4.20) which is located in Dallas, USA.

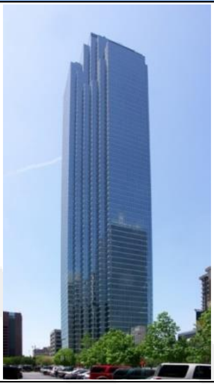
Bank of America Plaza			
	City	Dallas	
	Country	USA	
	Height	280.7 m	
	Floors	72	
	Function	office	
	Structural Material	composite	
	Architectural Design	JPJ Architects	

Figure 4.20. Bank of America Plaza, USA (Adapted from CTBUH's Database 2017)

- The use of Low emissivity (Low-E) glasses is another consideration for the façade design of skyscrapers, Low-E glass is more effective than solar-reflective glass, this type of glasses can be used to reduce direct heat gain and to provide maximum benefit from natural daylight which then can reduce the artificial lighting energy load. In addition to that, they can be useful in places where daylight is needed and solar heat gain should be reduced (Pank et al. 2002). An example of a skyscraper with Low-E glasses is the Dual Towers (Figure 4.21) which is located in Bahrain.

Dual Towers (Bahrain Financial Harbour)			
	City	Manama	
	Country	Bahrain	
	Height	260 m	
	Floors	52	
	Function	office	
	Structural Material	concrete	
	Architectural Design	Ahmed Janahi Architects	

Figure 4.21. Dual Towers, Bahrain (Adapted from CTBUH's Database 2017)

- Tinted glasses can be utilized in combination with Low-E glasses coatings to control the unpleasant glare. These types of combination glasses can take the advantage of Tinted glasses to provide maximum natural heating and cooling, and take the advantage of Low-E glasses to provide maximum natural daylight (Al-Kodmany 2015). The artificial heating, cooling and lighting energy loads can be reduced with these types of glasses. An example of a skyscraper with these glasses is the Swiss Re Tower (Figure 4.22) which is located in London, UK.

30 St Mary Axe (The Gherkin, Swiss Re Tower)					
City	London	Country	UK	Height	179.8 m
Function	office	Material	steel	Floors	41
Architectural Design		Foster + Partners			

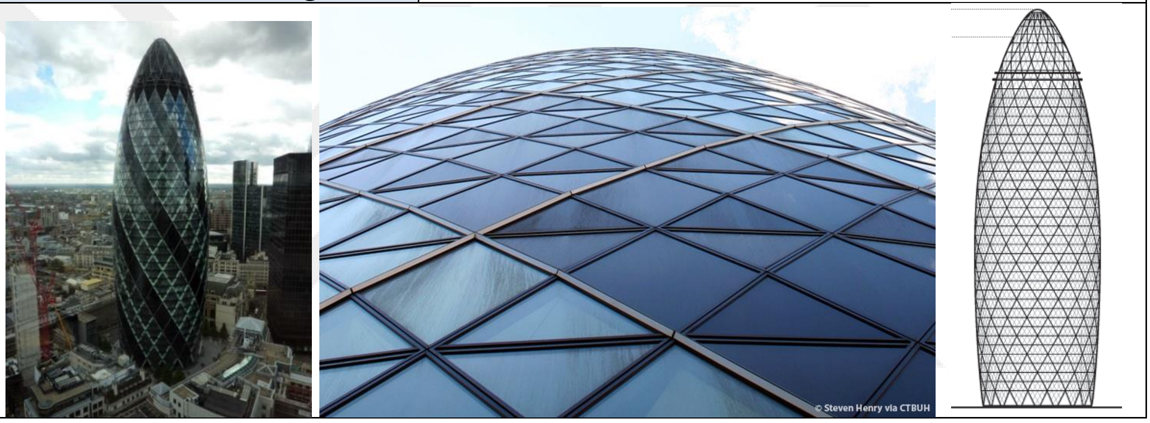


Figure 4.22. 30 St Mary Axe Tower, UK (Adapted from CTBUH's Database 2017)

Another design consideration for passive solar concepts is by the use of double skin façade in the façade design of skyscrapers; this type of facades provides maximum natural heating, cooling, daylight and natural ventilation. Double skin façade can act as a thermal buffer that can equivalence the temperatures between the interior and exterior. During the summer, the solar gain in the gap of the double skin can help to take the sufficient natural heating and reduce the extreme solar gain before it enters the skyscraper. During winter, the gap of the double skin can help to save the solar heat gain and reduce heat loss. The double skin facade also provides an extra advantage of reflecting solar heat gain before it enters the skyscraper. An example of a skyscraper with double skin façade is the Shanghai Tower (see Figure 4.23) which is located in China. This tower contains a double skin façade that creates nine atrium sky gardens, stacked one atop the other, that are being used as plazas and reunions. Both skin facades are transparent establishing a connection between the buildings' interior and Shanghai's urban fabric. By having two skin layers forming the building façade, the tower creates thermal buffer zones, which improves the indoor air quality (Letízia Lau 2015).

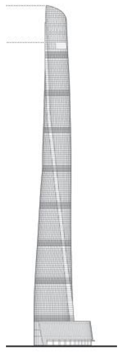
<table>
<tr><th colspan="4">Shanghai Tower (Shanghai Center)</th></tr>
<tr><td rowspan="8"></td><td>City</td><td>Shanghai</td><td rowspan="8"></td></tr>
<tr><td>Country</td><td>China</td></tr>
<tr><td>Height</td><td>632 m</td></tr>
<tr><td>Floors</td><td>133</td></tr>
<tr><td>Function</td><td>hotel / office</td></tr>
<tr><td>Material</td><td>composite</td></tr>
<tr><td>Architectural Design</td><td>Gensler and Tongji Architectural Design</td></tr>
<tr><td>Energy Label</td><td>LEED Platinum BD+C: Core and Shell</td></tr>
<tr><td colspan="4">Double skin façade</td></tr>
<tr><td colspan="4"></td></tr>
</table>

Figure 4.23. Shanghai Tower, China
(Adapted from Letízia Lau 2015, CTBUH's Database 2017)

This part examined some of the most important design considerations for passive solar concepts for natural solar gain and daylight. Table 4.3 summarizes and concludes the investigated design considerations in this part.

Table 4.3. Summarizing of the investigated design considerations for passive solar concepts

Design consideration		Climate zone	Optimal consideration and placement	Benefits and Aims
Considering the local climate and optimal form, spatial arrangement, and orientation	Considering optimal forms for skyscrapers	Tropical and arid zones	• Designing the skyscraper with a prolonged form (the long axis of the skyscraper must be oriented east-west so that long faces are north and south). • The main façade openings are preferred to be positioned toward the north and south, and the east and west facades must be reduced.	• Reducing the east and west exposure. • Reducing the shading impact. • Reducing solar penetration into the skyscraper during periods of lower-angle sun in the mornings and afternoons.
		Temperate and cool zones	Designing the skyscraper with a square or round geometry forms.	Enlarging the capable surface for utilizing of solar gain.
	Considering optimal orientation for skyscrapers	Tropical zone	The optimal orientation is on the axis facing 5° north of east and the directional emphasis is on the north and south faces.	Taking advantage of free energy from the sun in terms of heat and light, and from the wind in terms of natural ventilation.
		Arid zone	The optimal orientation is on the axis facing 25° north of east and the directional emphasis is on the south and east faces.	
		Temperate zone	The optimal orientation is on the axis facing 18° north of east and the directional emphasis is on the south and south-east faces.	
		Cool zone	The optimal orientation is on the axis facing south and the directional emphasis is on the south face.	
	Considering optimum placement of the skyscraper's masses (cores, shafts, stairwells)	Tropical zone	The core is preferred to be placed on the east and west faces of the skyscraper.	Controlling shading impact and serving as a solar buffer.
		Arid zone	The cores are preferred to be located on the east and west sides mainly on the south face of the skyscraper.	A cause to the major shading needed during the summer.
		Temperate zone	The main mass is preferred to be placed on the north face of the skyscraper.	Leaving the south face available for solar heat gain during the winter.
		Cool zone	The main mass is preferred to be placed in the center of the skyscraper.	• Don't block out the sun's rays and keeping heat within the skyscraper. • Making maximum faces of the skyscraper to be opened to the sun for heat penetration.
	Giving importance to the lease span of the skyscrapers	Tropical and arid zones	The distance between the core and the exterior wall is preferred to be long.	Providing maximum solar gain and daylight.
		Temperate and cool zones	The distance between the core and the exterior wall is preferred to be short.	
	Considering optimum placement of the open transitional spaces (e.g. balconies, open lobbies, open hallways)	Tropical and arid zones	The open transitional spaces are preferred to be located on the north and south sides of the skyscraper.	Making the sun to penetrate too far into the internal spaces to provide natural solar gain and daylight for the inner parts of the skyscraper.
		Temperate and cool zones	The open transitional spaces are preferred to be located on the north side of the skyscraper.	

Table 4.3. Continued. Summarizing of the investigated design considerations for passive solar concepts

The use of sky courts and atriums in skyscrapers	Lower and higher latitudes	The inner spaces of the skyscraper.	Authorizing the light and the heat of the sun to penetrate too far into the internal spaces of the skyscraper for providing natural solar gain, heating, cooling and daylight for the inner parts of the skyscraper.
The use of vertical and egg crates sunshades in skyscrapers	Lower and higher latitudes	There are preferred to be located on the east and west faces of the skyscraper.	• Protecting the skyscraper from east and west exposures. • Protecting the skyscraper from low sun angles in the morning and evening. • Solving the problem of glare.
The use of horizontal sunshades and light shelves in skyscrapers	Lower and higher latitudes	There are preferred to be located on the south face of the skyscraper.	• Protecting the skyscraper from southern exposures. • Protecting the skyscraper from high mid-day sun. • Solving the problem of glare.
The use of greenery and vegetation in skyscrapers	Lower and higher latitudes	Utilizing one or more of these four types; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies.	• Reducing the surrounding hot temperature in summer, at the same time reducing heat loss in winter. • Shading of the exterior wall of the skyscraper from incoming solar radiation.
The use of different types of glasses: Tinted glasses	Lower and higher latitudes	In the façade design of skyscrapers	Absorbing some of the unneeded heat to make the internal spaces cooler which then can reduce the artificial cooling energy load.
The use of different types of glasses: Solar-reflective glasses	Lower and higher latitudes	In the façade design of skyscrapers	Reducing solar penetration by providing a good quality of natural lighting which then can reduce the artificial lighting energy load.
The use of different types of glasses: Low-E glasses	Lower and higher latitudes	In the façade design of skyscrapers	Reducing direct heat gain and providing maximum benefit from natural daylight which then can reduce the artificial lighting energy load.
The use of different types of glasses: Tinted glasses in combination with Low-E glasses coatings	Lower and higher latitudes	In the façade design of skyscrapers	Controlling the unpleasant glare to provide maximum natural heating, cooling and daylight.
The use of double skin façade in the façade design of skyscrapers	Lower and higher latitudes	In the façade design of skyscrapers	• Providing maximum natural heating, cooling, daylight and natural ventilation. • Acting as thermal buffers that can equivalence the temperatures between the interior and exterior. • Taking the sufficient natural heating, and reducing the extreme solar gain during the summer. • Saving the solar heat gain and reduce heat loss during winter.

4.1.4. Advantages and disadvantages of passive solar concepts

The advantages of passive solar concepts can be summarized as the followings (Yeang 2000, 2006, Al-Kodmany 2015);

- Providing concepts that can reduce the energy by taking the advantage from renewable resource of energy which is the sun.
- Reducing non-renewable energy consuming and requirement.
- Minimizing the high percentage of using the artificial Heating, Ventilation, and Air-Conditioning (HVAC) systems.
- Economic concepts because they provide significant savings on energy use by minimizing electrical loads.
- Healthy concepts because of their maximum profiting from natural lighting and heating, and their positive psychological effects on the humans.
- Improving the indoor environmental quality.
- Increasing the range of thermal comfort.
- Leading to gain green building certificates.
- Reducing maintenance and replacement operations which can occur a lot with artificial and mechanical systems.
- Reducing carbon dioxide emissions.
- Enhancing the environmental performance of the skyscrapers.

The disadvantages of passive solar concepts can be summarized as the followings (Yeang 2000, 2006, Al-Kodmany 2015);

- Passive solar concepts are not sufficient and cannot be taken alone in the design of the skyscraper, the other solar modes concepts; (e.g., mixed mode, full mode) must be also undertaken in the design of skyscrapers due to some practical reasons in some regions such as the extremely hot weather conditions.

4.1.5. Case studies

This part examines two examples of skyscrapers which utilize passive solar concepts to take the advantage of the sun for natural solar gain and daylight. The first example is Menara Mesiniaga which is located in Selangor, Malaysia. The second example is Solaris which is located in Singapore. These case studies had been chosen because of that these skyscrapers incorporate more design considerations for passive solar concepts in comparison to the other investigated skyscrapers examples around the world.

Table 4.4 shows the utilized table to determinate which skyscrapers incorporate more design considerations for passive solar concepts. The investigated skyscrapers examples and their related information had been collected from different sources (see Appendix 2). This table can be also used as a checklist for determining some of the important design considerations for passive solar concepts in skyscrapers.

Table 4.4. Design considerations for passive solar concepts for some skyscrapers examples around the world

N	Skyscraper example	Location	Considering local climate	Considering the solar paths	Perfect form, orientation	Sunshades and light shelves	Greenery and vegetation	Sky courts and atriums	Different types of efficient glasses	Double skin façade	Total points
1	**Menara Boustead**	Malaysia	X	X	X	X	X		X		6
2	**IBM Plaza**	Malaysia	X	X	X	X	X			X	6
3	**Plaza Atrium**	Malaysia	X	X	X	X		X			5
4	**Menara Mesiniaga**	Malaysia	X	X	X	X	X	X	X	X	8
5	**Central Plaza**	Malaysia	X	X	X		X	X	X	X	7
6	**Budaya Tower**	Malaysia	X	X	X			X	X		5
7	**MBf Tower**	Malaysia	X	X	X	X	X	X			6
8	**Menara UMNO**	Malaysia	X	X	X	X		X		X	6
9	**Commerzbank**	Germany	X	X	X		X	X		X	6
10	**RWE Tower**	Germany	X	X	X		X		X	X	6
11	**Deutsche Messe AG**	Germany	X	X	X				X	X	5
12	**GSW Headquarters**	Germany	X	X	X				X	X	5
13	**Post Tower**	Germany	X	X	X	X		X	X	X	7
14	**Highlight Towers**	Germany	X	X	X			X	X	X	6
15	**KfW Westarkade**	Germany	X	X	X	X			X	X	6
16	**Edificio Malecon**	Argentina	X	X	X	X	X	X		X	7
17	**Consorcio Santiago**	Chile	X	X	X	X	X			X	6
18	**Swiss-Re Tower**	UK	X	X	X			X	X		5
19	**Heron Tower**	UK	X	X	X				X	X	5
20	**Leadenhall Tower**	UK	X	X	X				X	X	5
21	**1 Bligh Street**	Australia	X	X	X	X	X	X		X	7
22	**Council House 2**	Australia	X	X	X	X	X				5
23	**Bosco Verticale**	Italy	X	X	X		X	X			5
24	**New York Times**	USA	X	X	X	X				X	5
25	**SF Federal Building**	USA	X	X	X	X		X		X	6
26	**Manitoba Hydro**	Canada	X	X	X			X		X	5
27	**Solaris**	Singapore	X	X	X	X	X	X	X	X	8
28	**National Library**	Singapore	X	X	X	X	X	X			6
29	**Newton Suites**	Singapore	X	X	X	X	X	X			6
30	**Torre Cube**	Mexico	X	X	X		X	X		X	6
31	**The Met**	Thailand	X	X	X	X	X	X			6
32	**IDEO Morph 38**	Thailand	X	X	X	X	X	X			6

4.1.5.1. Menara Mesiniaga, Malaysia

Menara Mesiniaga (Figure 4.24) is an office skyscraper located in Subang Jaya, Selangor, Malaysia; the skyscraper was completed in 1992. This skyscraper was designed by TR Hamzah & Yeang firm; the building is with 16 floors and 63 m in height (CTBUH's Database 2017). This skyscraper is considering as one of the most successful eco-towers of Ken Yeang. Menara Mesiniaga is the model of new climate responsive skyscraper which is suitable for tropical zones (Pank et al. 2002). This skyscraper is won the Aga Khan Award for Architecture in 1995 for its successful approach to the design of multi-story structure in a tropical climate zone (Hart 2011).

Figure 4.24. Menara Mesiniaga, Malaysia (CTBUH's Database 2017)

According to Hart (2011), this skyscraper brings together and combined a series of ideas and elements of Ken Yeang's preceding bioclimatic and ecological skyscrapers, such as: the solar buffer, the multiple sky courts and the solar responsive sun shading (which are made in Menara Bousted Tower); the continuous stepped planters (which are made in IBM Plaza); the multi-story wind catcher boxes (which are made in Plaza Atrium). The skyscraper is located in Selangor which is a suburb near to Kuala Lumpur in Malaysia. Malaysia has a high relative humidity in the range of 80% - 85%. It has a tropical wet climate with no dry or cold season as it is permanently wet due to year-round rainfall (Zaas 2014). There is a problem of overheating related to unwanted solar gain in the site. To solve this problem, design and facade studies that analyze the solar path (Figure 4.25) were affected to determine the form of the skyscraper and the location of sunshades (Powell 1999).

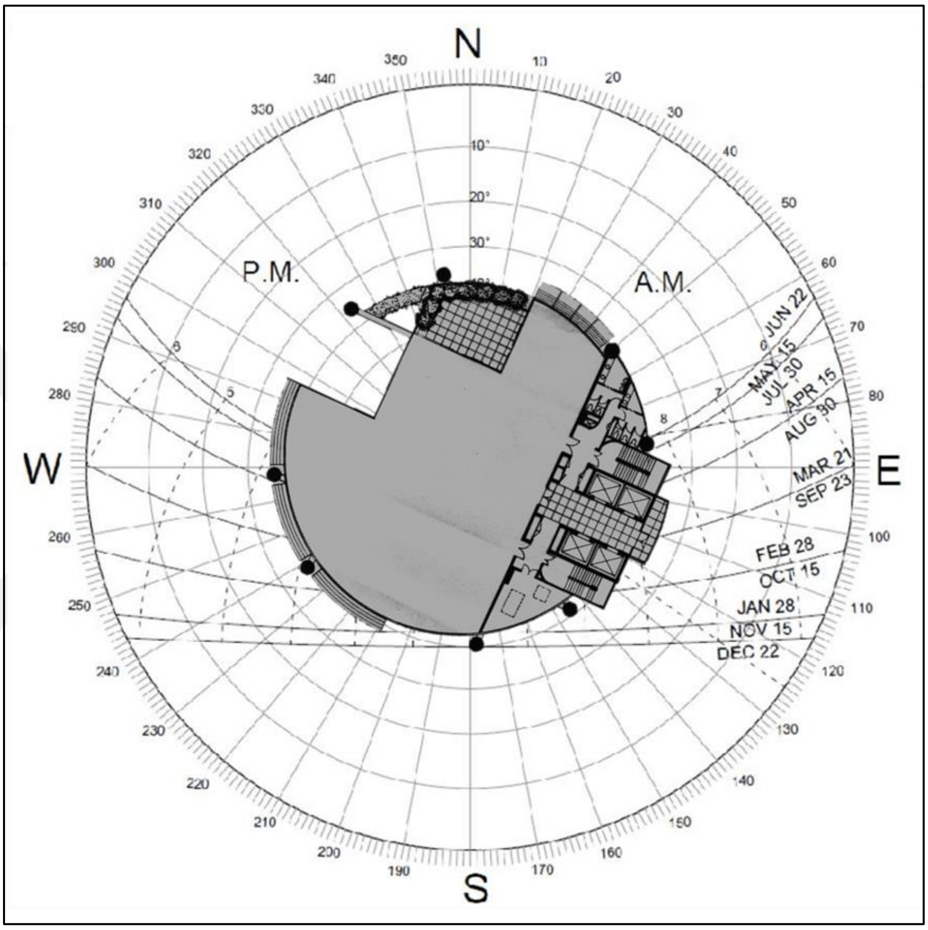


Figure 4.25. The sun path of Menara Mesiniaga (Adapted from Powell 1999)

Menara Mesiniaga has a cylindrical form. This circular shape enables daylight, solar gain and natural ventilation to reach the internal parts of the skyscraper. Because the skyscraper is circular in plan (see Figure 4.26), there are no dark corners (Yeang 2000). There are balconies which are located in a spiraling configuration around the exterior of the skyscraper. There is a sun-roof on top of Menara Mesiniaga that works as a sun and wind scoop to direct daylight and natural ventilation to the inner parts of the skyscraper as well as a way out for rising hot air (Pank et al. 2002).

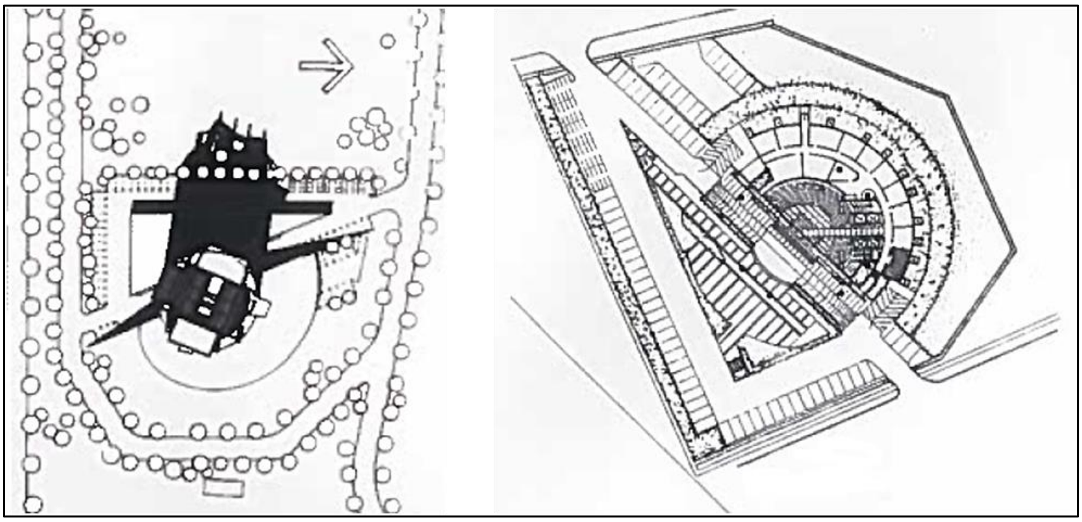


Figure 4.26. The site plan of Menara Mesiniaga (Hart 2011)

The cylindrical skyscraper comprises un-continuous atriums that found from the ground floor to the top of the skyscraper. These atriums enable the directing of the cool flow of air throughout the skyscraper's transitional spaces, also to enable maximum lighting for the skyscraper (Yeang 2000). There are also sky courts (Figure 4.27, Figure 4.28) to allow for maximum favorable solar gain and natural ventilation. The sky courts here are terraced spaces which provide spaces in the skyscraper that can be viewed as transitional areas between the inside and the outside of the skyscraper (Pank et al. 2002).

Figure 4.27. Sky court near to the atrium of Menara Mesiniaga (Hart 2011)

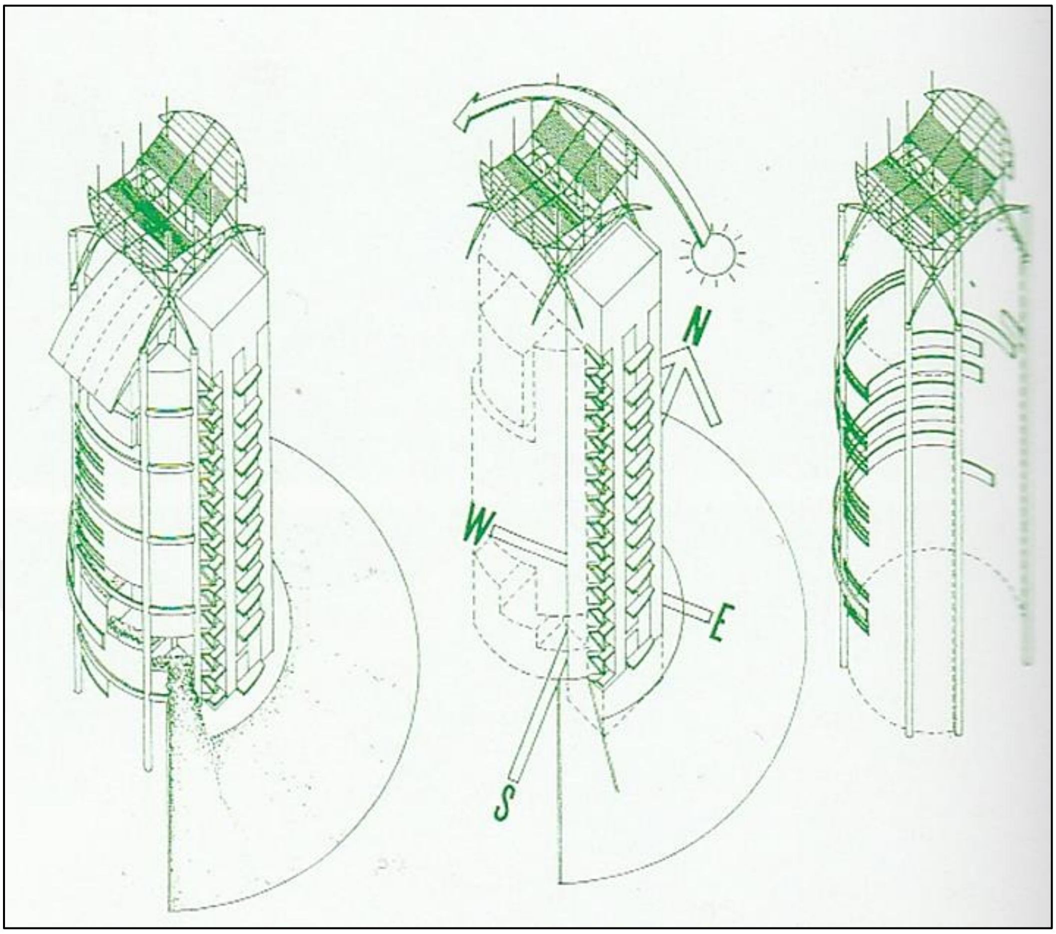


Figure 4.28. The concept of sky courts and sunshades of Menara Mesiniaga (Gissen 2002)

The skyscraper contains two forms of sun shades (Figure 4.28): the first is the horizontal external sun shades (see Figure 4.29) which are located over the façade of the skyscraper; the second is the curved sun shade (the solar canopy) (see Figure 4.30) which extends over the upper floor (Hart 2011). These sunshades have an important role to reduce solar heat gain and to cut the unneeded glare. All the shaded windows of Menara Mesiniaga are facing the east and west sides (which are the hot sides of the skyscraper) to reduce east and west exposure, all the windows areas facing the hot east and west faces have external aluminum fins and louvres to provide sun shading, the north and south sides have unshielded windows to improve natural lighting. Curtain wall glazing is used on the north and south sides to moderate solar gain (Yeang 2000, Gissen 2002).

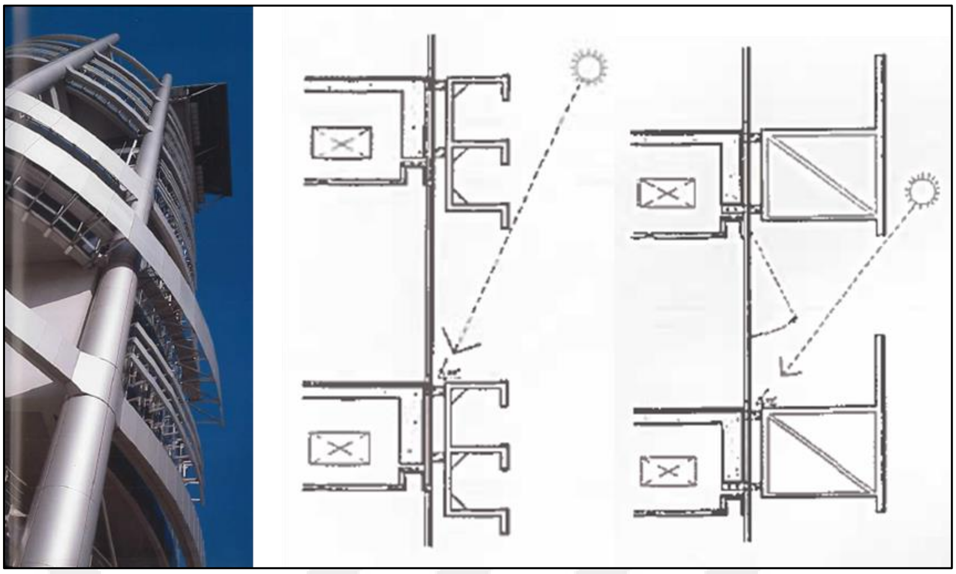


Figure 4.29. The horizontal sun shades of Menara Mesiniaga (Adapted from Hart 2011)

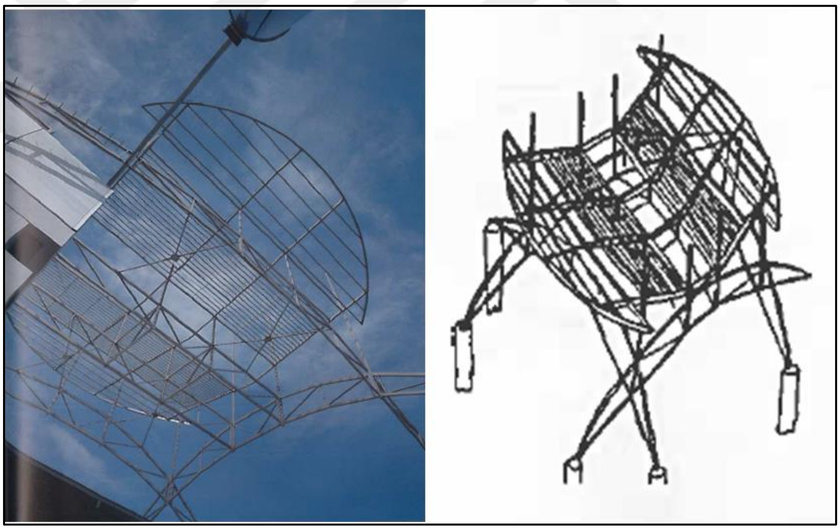


Figure 4.30. The solar canopy of Menara Mesiniaga (Adapted from Hart 2011)

Menara Mesiniaga has spiraling vertical landscaping (see Figure 4.31) that includes green balconies (see Figure 4.32) (Pank et al. 2002). According to Gissen (2002), the vertical landscaping concepts is one of the most successful features in this skyscraper, it is used here on different floors in a spiral pattern, allowing the vegetation to receive maximum sunlight and rainwater. The vegetation cools the skyscraper and provides to the users a sense of connection to the outdoors and natural environment.

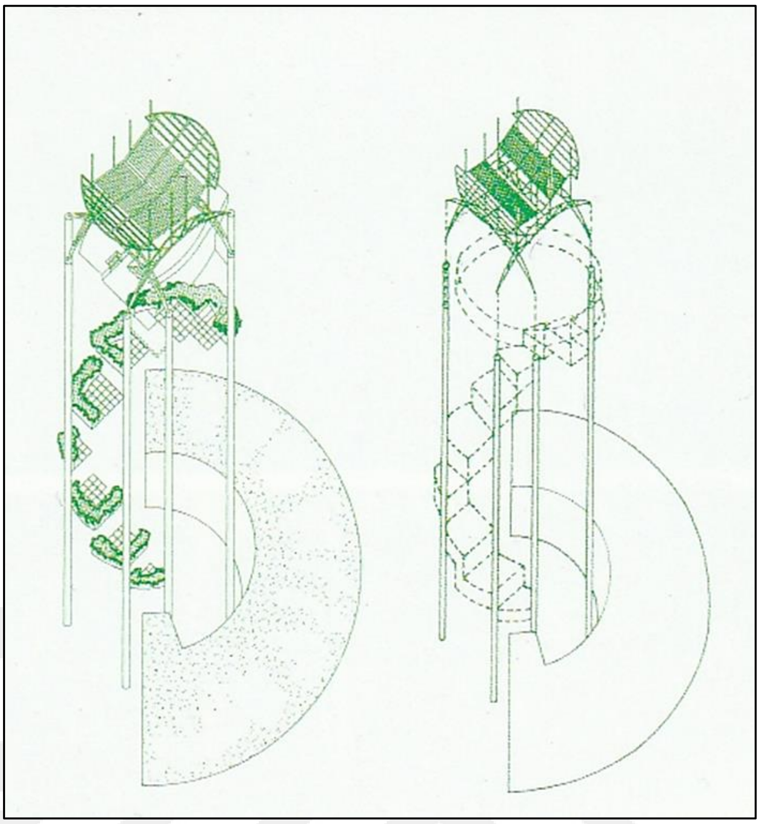


Figure 4.31. The vertical landscape concept of Menara Mesiniaga (Gissen 2002)

Figure 4.32. Integrated green balconies of Menara Mesiniaga (Gissen 2002)

Table 4.5 summarizes the design considerations for passive solar concepts for Menara Mesiniaga according to the investigated design considerations for passive solar concepts in the previous part of this chapter.

Table 4.5. The design considerations for passive solar concepts for Menara Mesiniaga

The design considerations for passive solar concepts for Menara Mesiniaga	
Considering the local climate and the solar paths	• Menara Mesiniaga is located in a tropical wet climate with no dry or cold season. • Vertical landscaping concept and sunshades for solving the problem of overheating related to unwanted solar gain.
Considering optimal forms, spatial arrangement and orientation	• The skyscraper has a cylindrical form. • There are balconies which are located in a spiraling configuration. • There is a sun-roof on the top of the skyscraper.
The use of sky courts and atriums in skyscrapers	• The skyscraper comprises un-continuous atriums that found from the ground floor to the top of the skyscraper. • There are sky courts and open ceilings.
The use of sunshades and light shelves	• The skyscraper contains two forms of sun shades: horizontal external sun shades and curved sun shade (solar canopy). • There are shaded and unshielded windows.
The use of greenery and vegetation in skyscrapers	• Menara Mesiniaga has spiraling vertical landscaping that includes green balconies.
The use of different types of glasses	• Solar reflective glasses are used.
The use of double skin facades	• Double glazing curtain wall is used to the north and south sides of the skyscraper.

There are also many other environmental features in the design of Menara Mesiniaga (see Figure 4.32). Yeang (2000), Pank et al. (2002), and Hart (2011) summarize some of these features as the followings:

- Users can experience comfort from the heat and humidity through natural ventilation through opening windows.
- The whole skyscraper, from stairways and lift lobbies to the toilet areas, is naturally ventilated.
- Over 60 percent of the workers have access to the opening windows.

- The balconies are entered through sliding doors which admit the natural ventilation and daylight into the work spaces.
- The curved sun shade (solar canopy) contains the facility to retrofit PV panels in the future.
- Terraces have sliding full height glass doors to control the extent of natural ventilation.

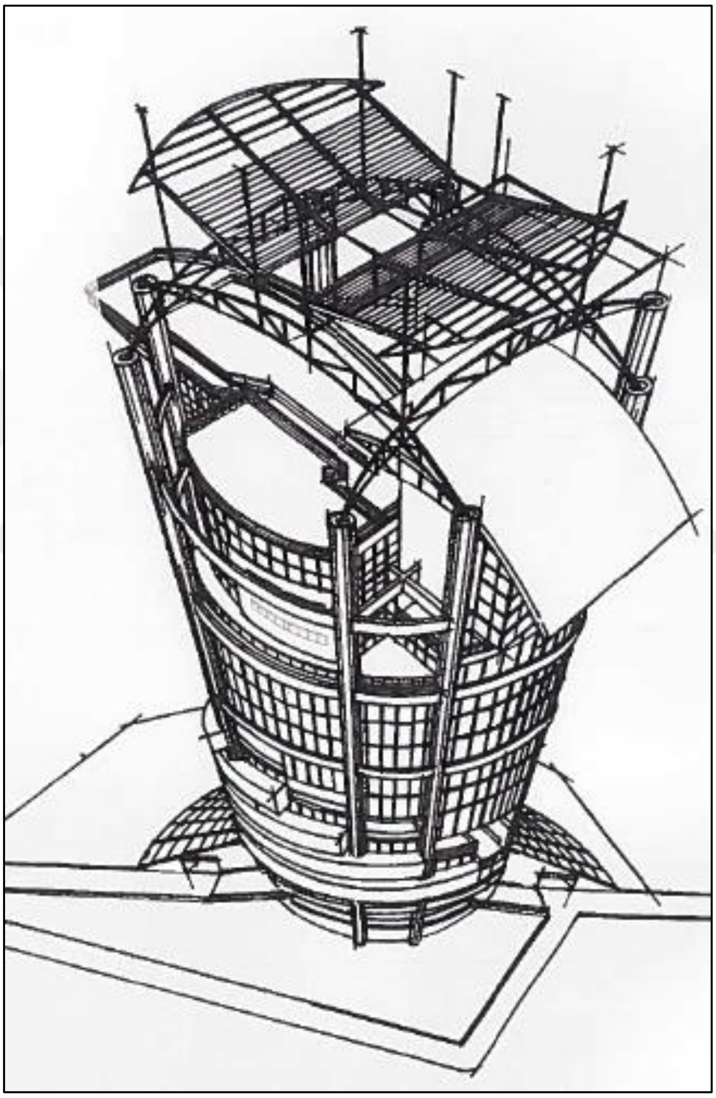


Figure 4.33. Sketch perspective of Menara Mesiniaga (Hart 2011)

4.1.5.2. Solaris, Singapore

Solaris (Figure 4.34) is an office skyscraper located in Singapore; the skyscraper was completed in 2011. This skyscraper was designed by TR Hamzah & Yeang firm; the building is with 18 floors and 79.2 m in height. The approach for designing the Solaris office tower was to create a totally ecological site. Rather than replacing natural habitat with a built environment, the design aims to create a maximum amount of habitable green spaces in addition to a sustainable tower. Two towers were designed to contain research and development facilities, connected with an atrium. Owing to Solaris' passive solar strategies for solar gain and daylight providing, the skyscraper has a 36% reduction in overall energy consumption compared to the other skyscrapers. Solaris received a 97.5 rating from Singapore's BCA GM program, obtaining a Platinum level in BCA GM for New Non-Residential Buildings (NRB) rating system (CTBUH's Database 2017).

Figure 4.34. Solaris, Singapore (CTBUH's Database 2017)

The site of Solaris Tower is located at the edge of Singapore's Central Business District in the Fusionopolis development (see Figure 4.35), an area dedicated to research and development in a diversity of fields (CTBUH's Database 2017). Solaris Tower is located in a tropical equatorial climate zone, and classified as a fully humid zone; Singapore has little temperature and humidity variation between seasons, but usually high temperatures over the year. The relatively high rate of humidity, the stable air temperatures, and the considerable rainfall makes Singapore an excellent location for growing plants. The average temperatures range from 23 C° to 32 C°, with May being the hottest month of the year. A high relative humidity of near 90% in the morning generally moves to around 60% in the mid-afternoon (Wood et al. 2014).

Figure 4.35. Site plan of Solaris Tower (Bullivant 2011)

Solaris Tower's climate responsive design made with analysis of the site's sun path (Figure 4.36). Singapore is on the equator and the sun path is almost exactly east-west, these mean that there is a problem of overheating related to unwanted solar gain in the site. To solve this problem, design and facade studies that analyze the solar path were affected to determine the form of the skyscraper and the location of sunshade (Bullivant 2011).

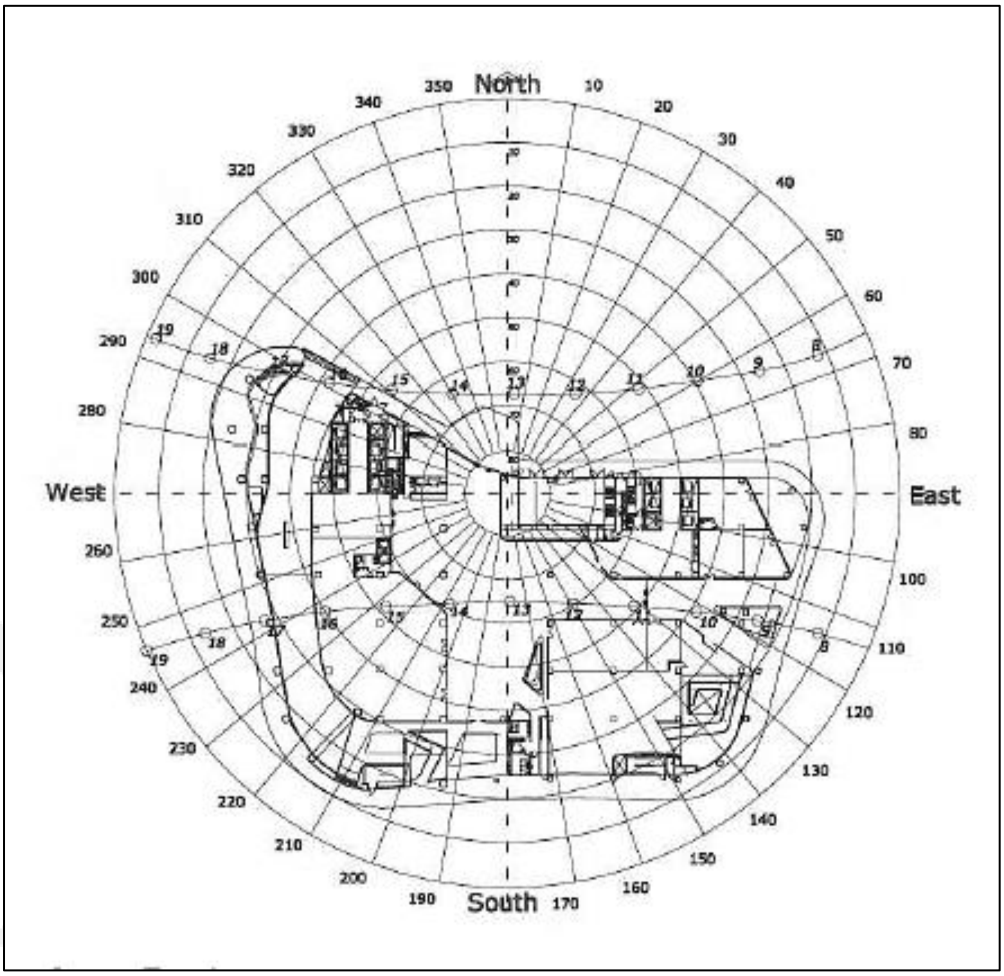


Figure 4.36. Solar path of Solaris Tower (Bullivant 2011)

Solaris is consisting of two tower blocks which are separated by a central atrium (see Figure 4.37); office floors are connected by a series of sky terraces that extent with the atrium to upper floors. The atrium permits for daylight of the internal spaces in the skyscraper. Sky bridges were added to cross and join between towers through the atrium. There is a large diagonal light shaft (see Figure 4.37) that cuts through the upper floors of the taller tower, allowing daylight and sun to penetrate deep into the skyscraper's interior (Wood et al. 2014). The internal spaces connected with the light shaft have automatic sensors to control lighting when daylight proves adequate. CFD modeling was also used to refine the design of the atrium to ensure optimal conditions (CTBUH's Database 2017).

Figure 4.37. The atrium and solar shaft of Solaris Tower (Xing 2014)

For solving the problem of overheating related to unwanted solar gain in the site and the problem of glare, the skyscraper was designed with sun shades (see Figure 4.38), facade studies were affected to determine the favorable location of sunshades (Bullivant 2011). It can be observed that the sunshades are located mostly in the east and the west facades of the skyscraper.

The horizontal sun shades serve as light shelves that deflect sun penetration and daylight into the skyscraper's interiors. These horizontal sun shades are featured elements within the skyscraper's overall aesthetic (Hart 2011). The combined length of the skyscraper's sun shades exceeds 10 km (Bullivant 2011). Solar shades were incorporated with a double-glazed wall system to further minimize the effects of solar exposure. There are sunshades which are controlled by climate responsive sensors to regulate them when necessary (CTBUH's Database 2017).

Figure 4.38. The sun shades of Solaris Tower (Wood et al. 2014)

Solaris is designed with more than 8,000 square meters of landscaping, greater than the area of the site. This ecological skyscraper replaced the original site with a landscape to site ratio of 108%. The greenery strategy of Solaris is presented in the form of an exterior planted ramp that spirals up around the surrounding of the skyscraper, connecting with the integrated green terraces (Wood et al. 2014).

The integrated green terraces (see Figure 4.39) provide spaces for the skyscraper users to enjoy during breaks, or to use for events. These areas are not only participating in the improvement of the user satisfaction, but they also create a buffer between the skyscraper envelope and the elements, reducing solar gain and reflection (CTBUH's Database 2017).

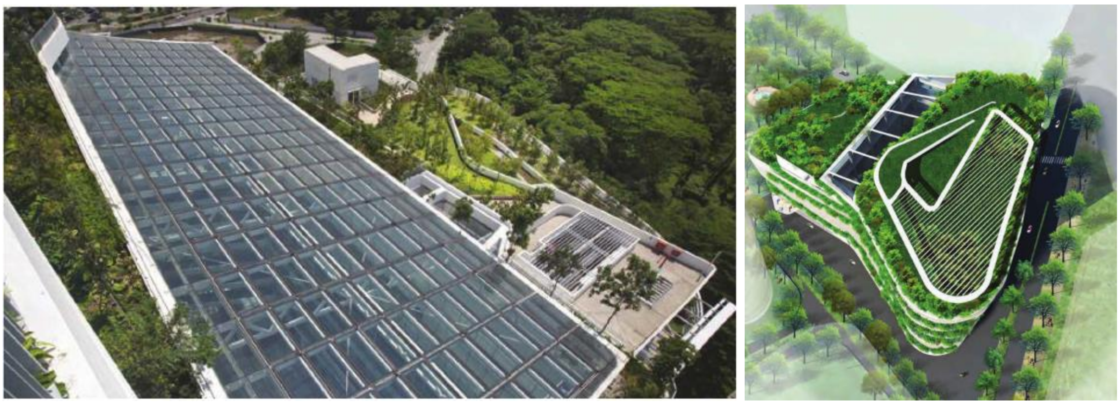


Figure 4.39. The integrated green terraces of Solaris Tower (Bullivant 2011)

The linear green ramp at Solaris (Figure 4.40) was designed to link the ground level with the upper levels of the skyscraper (CTBUH's Database 2017). The 1.5 km long linear ramp is considering as one of the most outstanding ecological features of Solaris Tower, this green ramp begins within a basement eco cell level and rises upwards, wrapping itself around the skyscraper in a continuous way that makes it one of the world's longest vertically spiraling vegetated ramps (Hart 2011). The green ramp benefits from deep overhangs from the floor above, with a large density of shade plants as an overall strategy for ambient cooling of the skyscraper façade (Wood et al. 2014). Figure 4.41 shows the different types of vegetation in Solaris.

Figure 4.40. The linear green ramp of Solaris Tower (Wood et al. 2014)

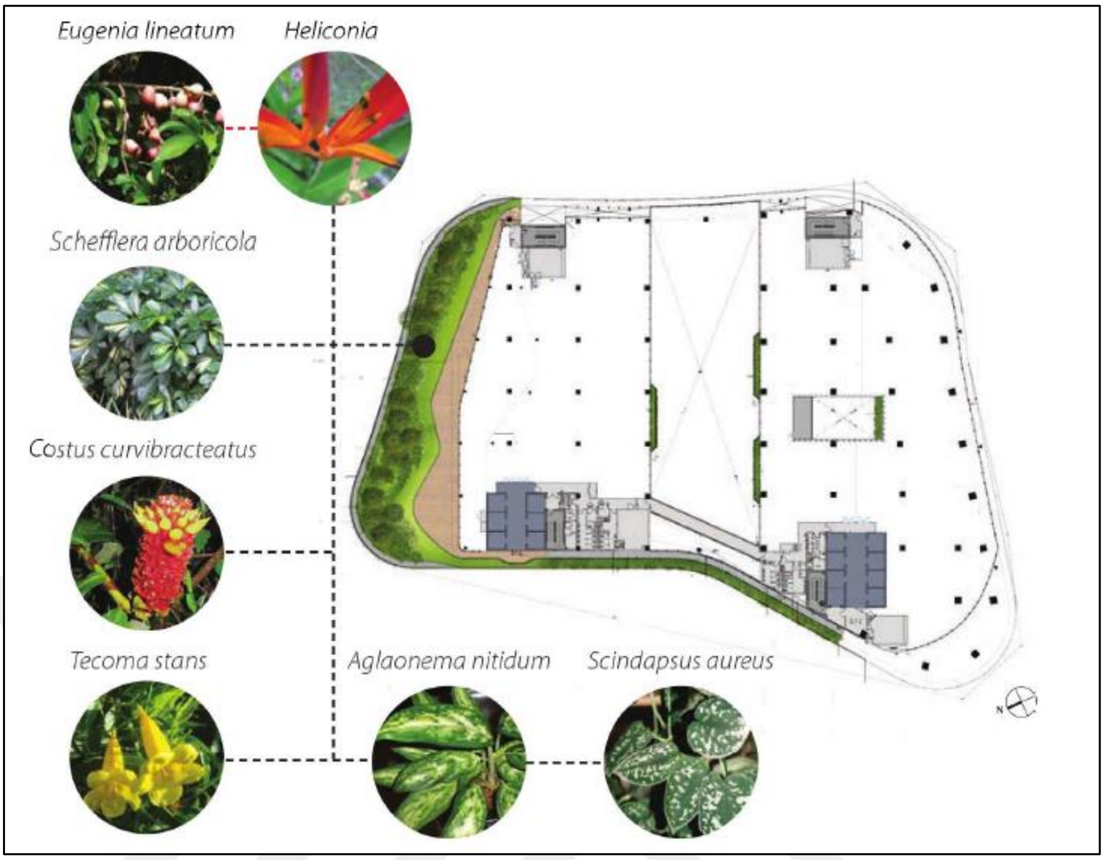


Figure 4.41. The different types of vegetation in Solaris (Wood et al. 2014)

Ground level landscaping is also connecting to One North Park which is across the street; this permits for cross ventilation of the ground floor plaza and offers a place for social and interactive events. The ramp is an extension of One-north Park across the street. Together they create an ecological connection that connects with the rising series of roof gardens and sky terraces that present the green concept of the skyscraper (see Figure 4.42) (Bullivant 2011).

The green ramp and the integrated green terrace landscaping (see Figure 4.43) works as a thermal buffer and create places for relaxation and event spaces. These wide gardens permit skyscraper users to interact with nature and offer chances to face the external environment and enjoy views of the treetops of the near One-North Park. These vegetated spaces, therefore, provide social spaces for users and perform very real sustainable functions (Hart 2011).

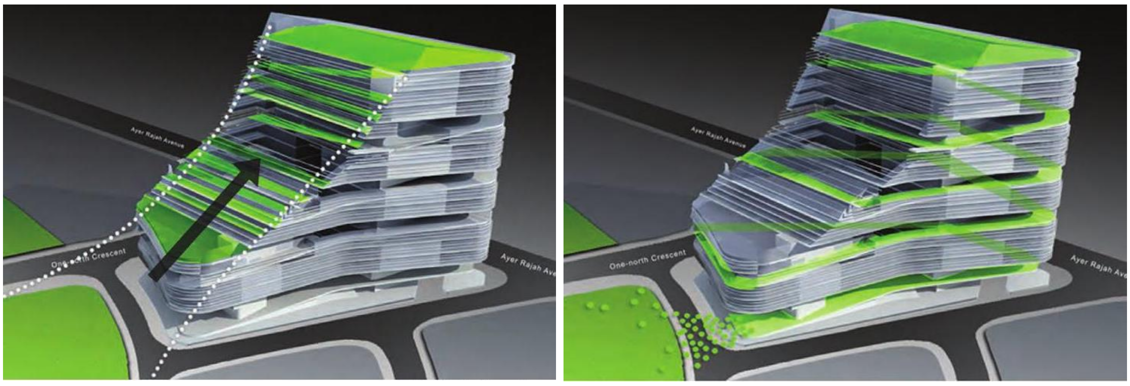


Figure 4.42. The green concept of Solaris Tower (Hart 2011)

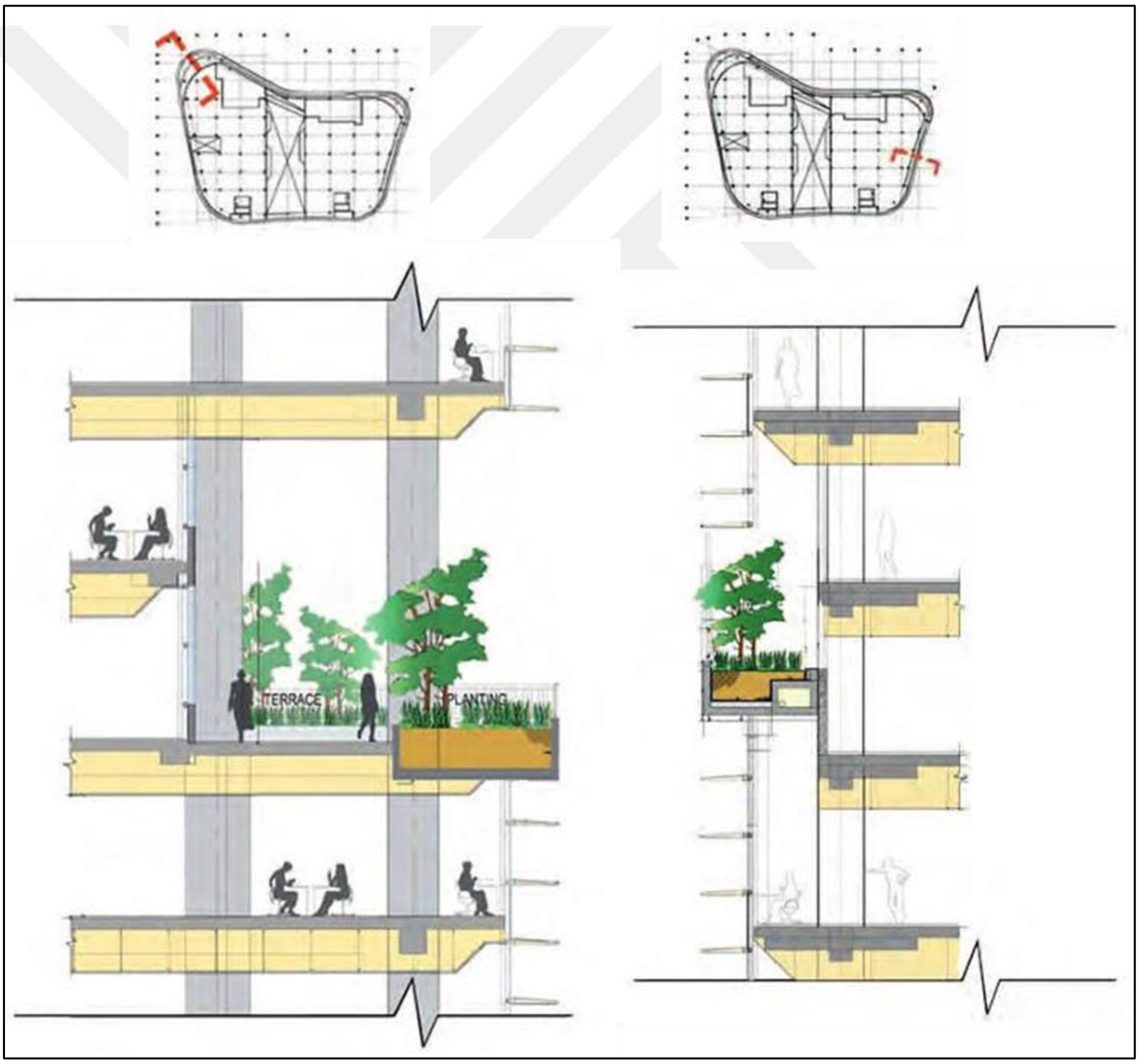


Figure 4.43. Green traces and green ramp sections (Adapted from Bullivant 2011)

Solaris utilize Low-E glass faced to reduce heat transfer across the skyscraper and to provide maximum natural lighting inside the skyscraper. Facade studies in this skyscraper proved that the Low-E glass double glazed façade, participating to a low External Thermal Transfer Value (ETTV) of 39W/m2 (Wood et al. 2014).

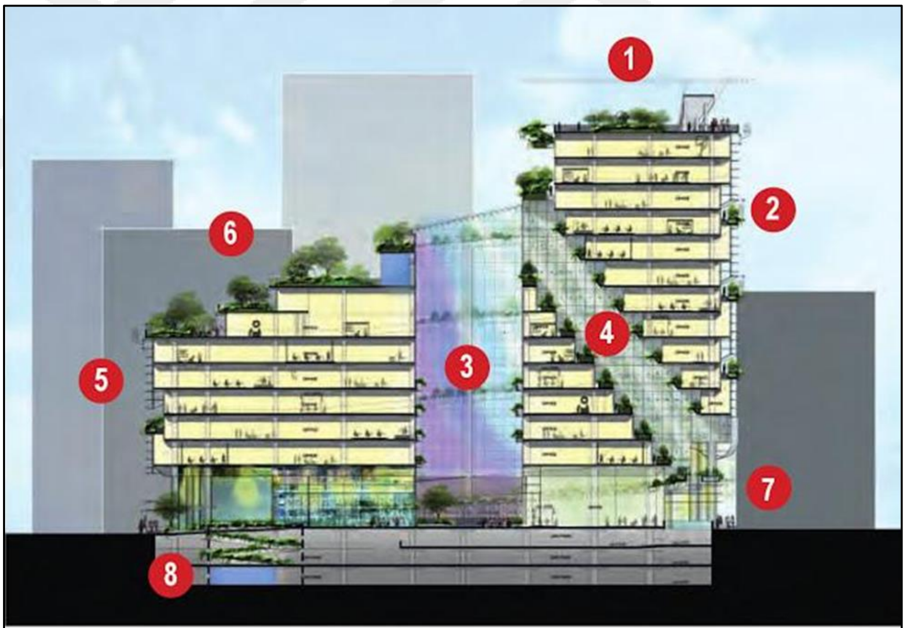
Table 4.6 summarizes the design considerations for passive solar concepts for Solaris Tower according to the investigated design considerations for passive solar concepts in the previous part of this chapter.

Table 4.6. The design considerations for passive solar concepts for Solaris Tower

The design considerations for passive solar concepts for Solaris Tower	
Considering the local climate and solar path	• Solaris Tower is located in a tropical equatorial climate zone. • The sun path is almost exactly east–west. • Green concepts and sunshades for solving the problem of overheating related to unwanted solar gain.
Considering optimal forms, spatial arrangement and orientation	• Two tower blocks separated by a central atrium. • A large diagonal light shaft cuts through the upper floors of the taller tower. • Optimal form for the solar path.
The use of sky courts and atriums in skyscrapers	• An atrium that separates the two tower of Solaris. • Sky bridges that connect between towers through the atrium.
The use of sunshades and light shelves	• The existence of horizontal sun shades that serve as light shelves.
The use of greenery and vegetation in skyscrapers	• Integrated green traces. • Linear green ramp. • Atrium planter boxes. • Ground level landscaping.
The use of different types of glasses	• The utilization of Low-E glasses.
The use of double skin facades	• The utilization of double-glazed wall system.

There are also many other environmental features in the design of Solaris Tower. Wood et al. (2014) and CTBUH’s Database (2017) summarize some of these features as the followings:

- An elaborate network of drainage trenches and subsoil pipes ensure effective water discharge.
- An overall rainwater harvesting system is utilized throughout the skyscraper, using siphoned drainage to hold up to 700 cubic meters of water for irrigation of the green spaces. The system also ensures the recycling of water.
- The atrium is fully passively ventilated and cooled.
- The design of the building responds directly to its environment and user needs.
- A rain-check wall is utilized to allow for ventilation during conditions of precipitation,
- There are vented roofs that take the advantage of the stack effect for cooling.
- The basement Eco-cell allows daylight and natural ventilation to extend into the car park levels below. Figure 4.44 concludes some of the ecological design features of Solaris Tower.



1. Roof Garden
2. Continuous Vertical Landscaping (1.5 km Urban Ecosystem)
3. Naturally-Ventilated Day-Lit Atrium
4. Solar Shaft
5. Climate-Responsive Façade
6. Sky Terraces
7. Verandahway (Semi-Enclosed Tropical Walkway)
8. Ecocell and Rainwater Harvesting

Figure 4.44. Ecological design features of Solaris Tower (Bullivant 2011)

4.2. Passive wind concepts for natural ventilation

This section focuses on the passive wind concepts which depend on the wind energy which is a renewable resource of energy. The ecological approaches for reducing the non-renewable energy consumption in skyscrapers by providing maximum natural ventilation are investigated in this part. The following parts examine passive wind concepts in details and provide case studies of skyscrapers designed with passive wind concepts.

4.2.1. Overview on passive wind concepts

The wind can be used to provide natural free ventilation rather than using mechanical air conditionings which need large amounts of energy (Al-Kodmany and Ali 2013). Natural ventilation is the process of providing and removing air from interior spaces through natural means. Natural ventilation is used to increase comfort from air movement, for health from air change, and for building cooling from wind speed (Yeang 2006). Natural ventilation contains some ways in which external wind and air can be used to benefit the building’s and skyscraper’s users and to assure a fresh air supply to the interiors and to improve personal thermal comfort (Al-Kodmany 2015).

Over time, concepts and strategies have been in developing to harness the wind energy especially the concepts and the strategies for natural ventilation to provide maximum natural ventilating and cooling for the buildings. One of the first buildings that designed with passive wind concepts is the traditional wind towers (Bâdgir in Persian or Barjil in Arabic). These towers contained wind catchers to create natural ventilation in the buildings. It is not known who first invented these towers, but until now it can be seen in many countries especially in the Middle East (see Figure 4.45). The wind tower is a tall construction with vertical openings in all directions, and with internal walls arranged diagonally to force any breeze downwards and up again before it can escape, and to accelerate the air descending into the rooms, this made a circulation of air in rooms used in summer and provide natural ventilation in the building (Al-hassani 2009). Figure 4.46 shows the working mechanism of the traditional wind tower.

Figure 4.45. Wind towers in the Middle East (Al-hassani 2009)

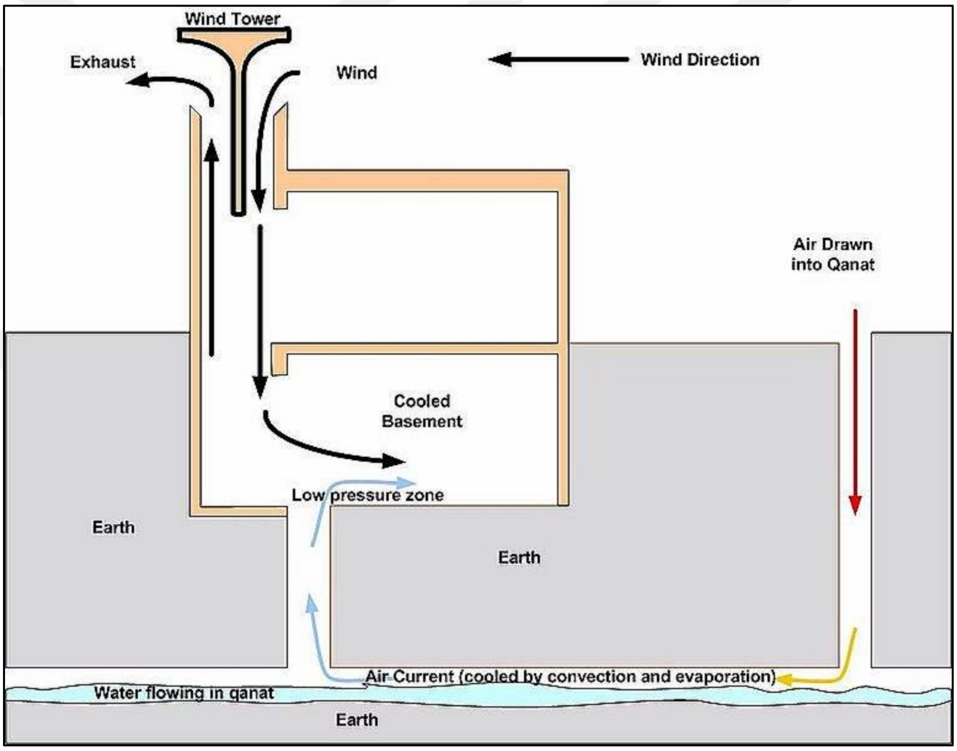


Figure 4.46. The working mechanism of the traditional wind tower (Al-hassani 2009)

Generally, it can be observed that it is important to consider passive wind concepts in the design of buildings and skyscraper to reach the objective of passive design and to reduce the energy requirement from non-renewable resources for mechanical ventilation and air-conditioning systems to generate artificial ventilating and cooling, for these reasons, designing skyscrapers with considering passive wind concepts are an important factor in ecological and bioclimatic design (Gonçalves 2010).

4.2.2. Principles for passive wind concepts

There are many principles for passive wind concepts in skyscrapers; the followings mention some of these principles;

Gonçalves (2010) mentioned that the reaching of comfort levels in natural ventilation needs an optimized design based on passive principles and strategies which aim to optimize air gains by looking at the design of the facades according to wind orientations and their performance in relation to the perfect configuration of the skyscraper's internal spaces, including plan depth, room floor to ceiling height and even occupation parameters, such as density and periods of use.

The driving forces for natural ventilation in skyscrapers are the same as the driving forces for natural ventilation in the other buildings. The techniques for natural ventilation depend on the pressure differences generated over the cover openings of the building. The pressure differences are generated by three sources (Irving et al. 2005, Ghiaus and Allard 2005, Etheridge 2012, Wood and Salib 2013, Chenvidyakarn 2013):

- The effects of wind.
- Temperature differences between inlet and outlet of air.
- A combination of both.

For these, natural ventilation can be classified into wind-caused and buoyancy-caused ventilation according to the technique that drives the air. Wind-caused ventilation takes place when the wind makes a pressure of distribution around the skyscraper with considering the atmospheric pressure (see Figure 4.47). The pressure differences drive the air into the skyscraper's cover on the windward side (positive pressure zone) and drive the air out of the skyscraper via the openings on the leeward side (negative pressure zone). The pressure impact of the wind on a skyscraper is firstly controlled by the skyscraper's shape, the wind direction and velocity, and the influence of the surroundings. The average pressure difference over a skyscraper's cover is dependent upon the average wind velocity at upwind skyscraper height, and the indoor air concentration as the role of atmospheric pressure, temperature, and humidity (Irving et al. 2005, Etheridge 2012).

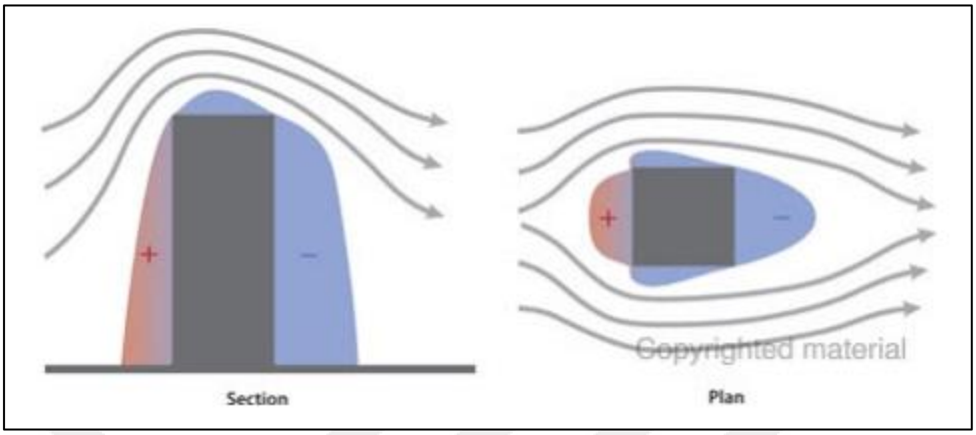


Figure 4.47. Pressure of distribution around the skyscraper a cause of wind flow (Wood and Salib 2013)

Buoyancy-caused ventilation which is also known as stack effect or the chimney effect takes place a cause of the concentration differences caused by variations in temperature and height between the inside and the outside or between certain zones within the skyscraper (see Figure 4.48). The pressure differences made by buoyancy primarily rely on the stack height which is the height difference between the air intakes and extract openings, and the air concentration difference as the role of temperature and humidity in the air. To ensure internal airflow in the absence of wind, it needs to guarantee that outdoor temperatures are lower than indoor temperatures to reach the buoyancy-caused ventilation. When the indoor air temperature exceeds the outdoor temperature, an under-pressure is shaped in the lower section of the skyscraper, pulling the air insides via the openings in the skyscraper’s cover (even if the outdoor temperatures are similar to the indoor temperatures, buoyancy can still happen a cause of the internal loadings) (Chenvidyakarn 2013). According to Wood and Salib (2013), the concentration difference caused by the indoor and outdoor temperature difference happens in a different pressure gradient in the skyscraper. The over-pressured zones at the top of the skyscraper drive air out of the openings since air flows from areas of high pressure to areas of low pressure. At a particular height of the skyscraper, the indoor pressure and the outdoor pressure are equal to each other; this level is named as the neutral plane or the neutral pressure level. It also important to consider that a reverse stack effect can happen when outside air temperatures are very higher than internal skyscraper temperatures, in this condition, air can enter skyscrapers from high elevations and go out from lower elevations, this reverse stack effect can be hard to control.

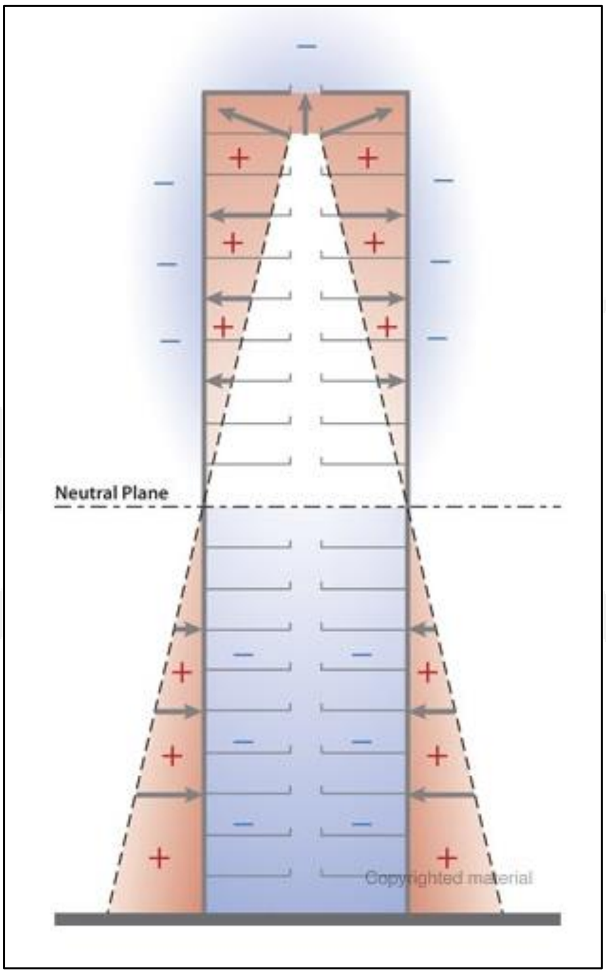


Figure 4.48. Buoyancy-caused ventilation in skyscrapers (Wood and Salib 2013)

According to Ghiaus and Allard (2005), Wood and Salib (2013), it is important to consider that the two driving forces for natural ventilation in skyscrapers (which are wind-caused and buoyancy-caused ventilations) can take place separately, but it is more preferred to take place at the same time. Buoyancy-caused ventilation is generally the controlling of driving force on a calm day with virtually no wind, and wind-caused ventilation is generally the controlling of driving force on a windy day.

In his works in the principles and strategies of passive wind concepts for natural ventilation, Yeang (2000) proposed 3 diagrams (Figure 4.49) that provide an overview of the wind's influence in the world's different climate zones.

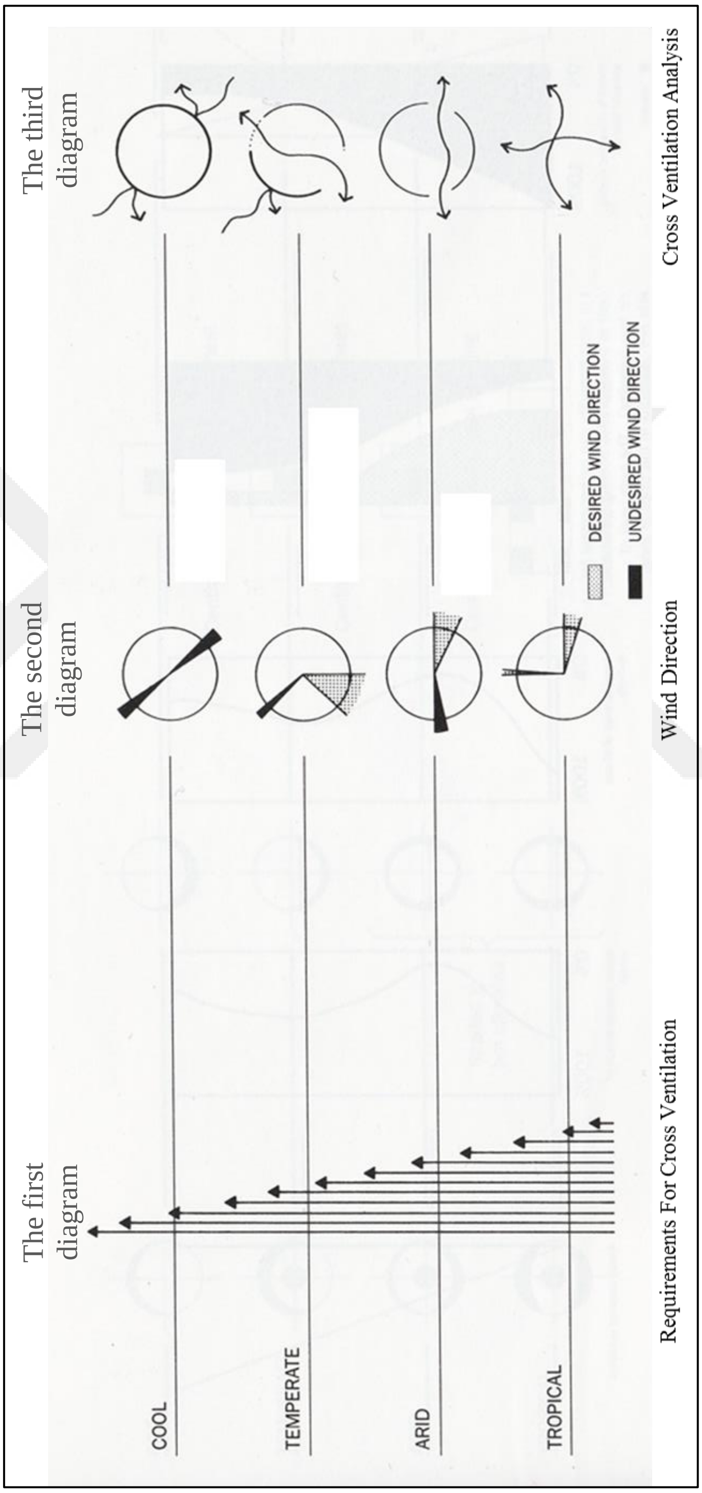


Figure 4.49. Diagrams on the wind's influence in the world's different climate zones (Adapted from Yeang 2000)

According to Yeang (2000), the first diagram (see Figure 4.49) shows the requirement for cross ventilation in the world's different climate zones. In this diagram, it can be observed that the cross ventilation is more required in tropical zones than in cool zones. The second diagram shows the main wind direction in the world's different climate zones. In this diagram, it can be observed that the desired and undesired wind directions rely mainly on local conditions. Any breeze in lower latitudes is favorable while in higher latitudes most wind is unfavorable.

The third diagram in the same figure shows the cross ventilation analysis in the world's different climate zones. In this diagram, it can be observed that for tropical zones as much natural ventilation as possible is needed. For arid zones cross ventilation is needed but care must be taken to filter out high-velocity winds. In temperate zones, cross ventilation and shielding are both required. In cool zones, the skyscraper should be protected from cold, high-velocity winds, although cross ventilation is still required.

Another important principle for passive wind concepts is by considering the basic concepts of natural ventilation. For perfect design consideration and to reach maximum natural ventilation in skyscrapers, it is important to understand the basic concepts of how air can go inside the skyscraper, and how it can go out of it. The different basic concepts used to ventilate skyscrapers can be classified into three main categories (Irving et al. 2005, Etheridge 2012, Wood and Salib 2013, Al-Kodmany 2015);

- Single-sided ventilation.
- Cross ventilation.
- Stack ventilation.

In single-sided ventilation; fresh air and wind go in and out from the openings on the same side. The driving force for single-sided ventilation is wind occurring with the temperature difference between low-level air inlets and high-level air outlets, buoyancy impact can also help single-sided ventilation if the ventilation openings are located at different heights. Generally, residential skyscrapers and office skyscrapers with floor plates divided into cellular offices require single-sided ventilation (Irving et al. 2005). Figure 4.50 shows an example of single-sided ventilation of isolated rooms with large and small openings. Rooms (i) and (iii) are buoyancy alone, (ii) and (iv) are wind alone and (v) is for any combination of wind and buoyancy caused ventilation.

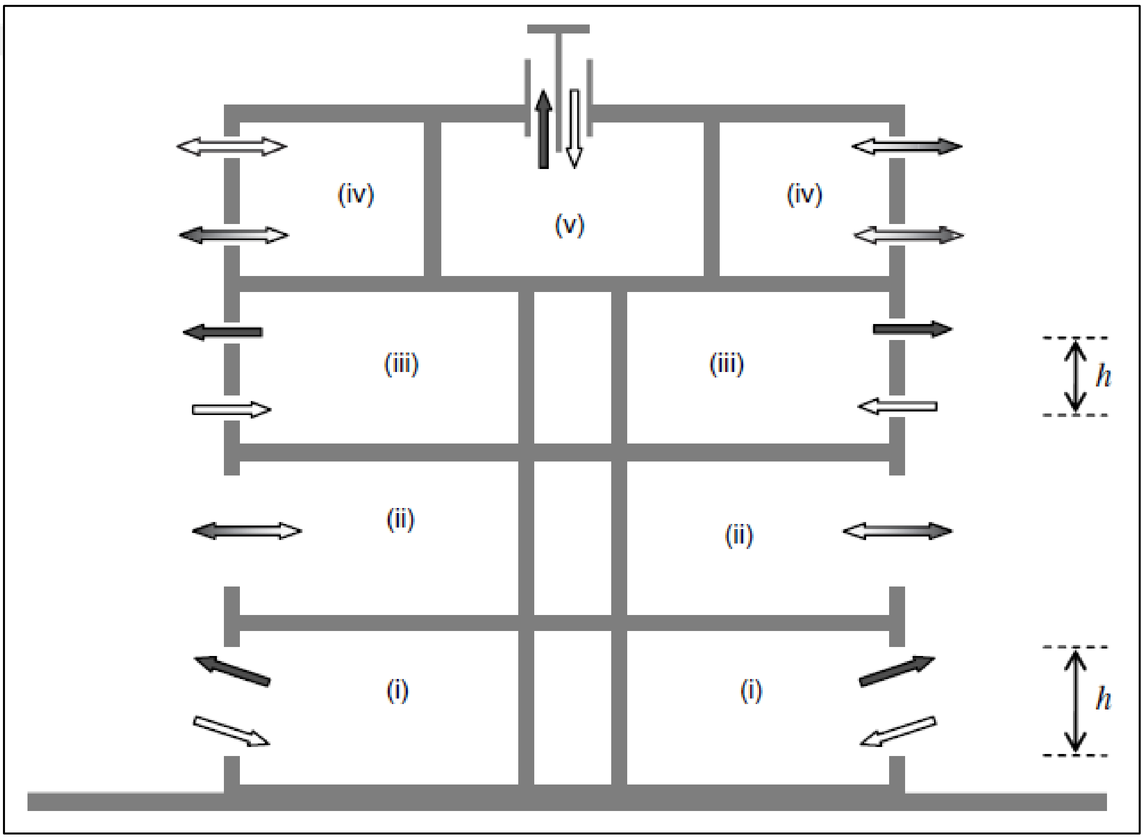


Figure 4.50. Single-sided ventilation (Etheridge 2012)

In cross ventilation, fresh air and wind go in from one side and go out from the opposite side. The driving force for cross ventilation is the wind occurring with the pressure differentials between openings in the two sides, buoyancy impact can also help cross-ventilation if the spaces are facing tall open spaces such as atriums. Generally, office skyscrapers with landscape type of floor plates require cross-ventilation (Wood and Salib 2013). Figure 4.51 shows an example of cross ventilation of isolated floors with large and small openings. (i) and (iii) are buoyancy alone, (ii) and (iv) are wind alone caused ventilation.

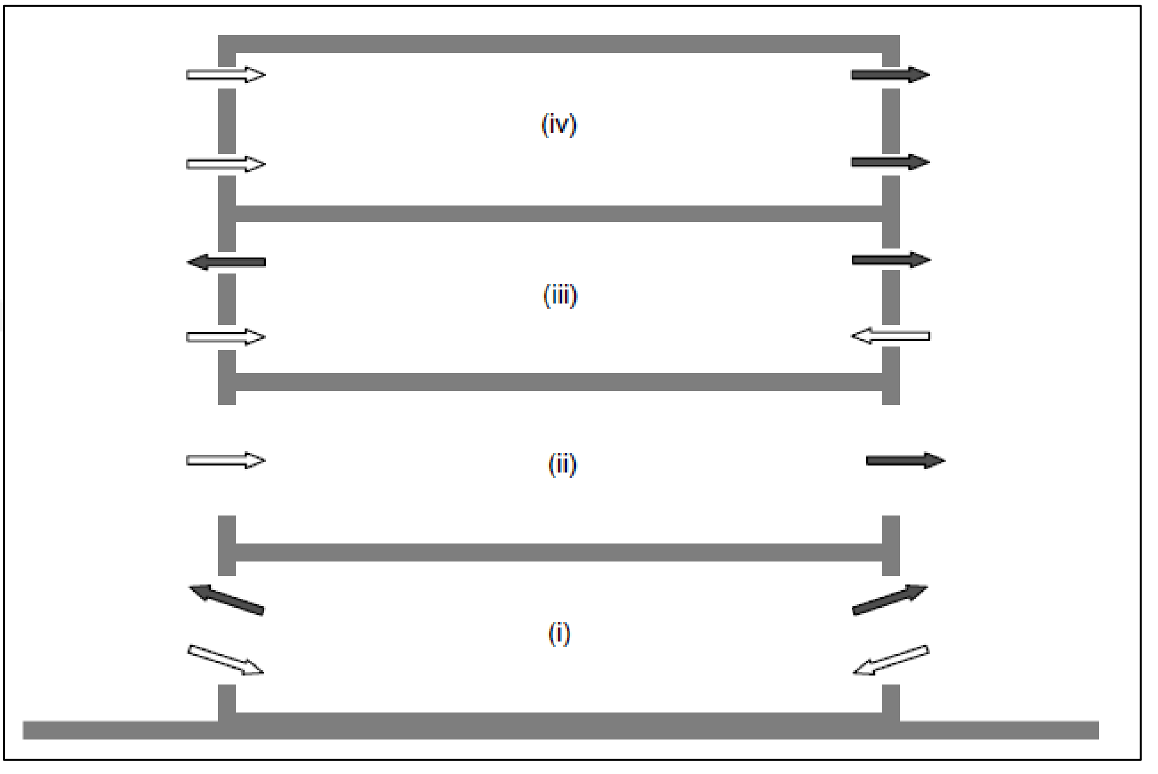


Figure 4.51. Cross ventilation (Etheridge 2012)

In stack ventilation, fresh air and wind go in from low points of the skyscraper, rising up and then go out from the top of the central space of the building, this method can be used for designing skyscraper with atriums, these atriums can be utilized to save energy and to provide fresh air and natural ventilation for skyscrapers. The driving force for stack ventilation is the buoyancy impact a cause to the taking place of temperature, concentration, and pressure differences between the interior and exterior or between certain zones within the skyscraper (Irving et al. 2005). Figure 4.52 shows examples of stack ventilation. (i) and (ii) shows upward flow stack ventilation by a chimney in a single-cell building (i); and four-cell building includes chimney as a cell (ii). (iii) shows upward flow stack ventilation by an atrium in a single-cell building. (iv) shows upward flow stack ventilation by chimneys with the use of an underground duct to provide internal fresh-air entry. (v) shows top-down stack ventilation by cooling of air at top of lightwell and possibly heating of chimneys (Etheridge 2012).

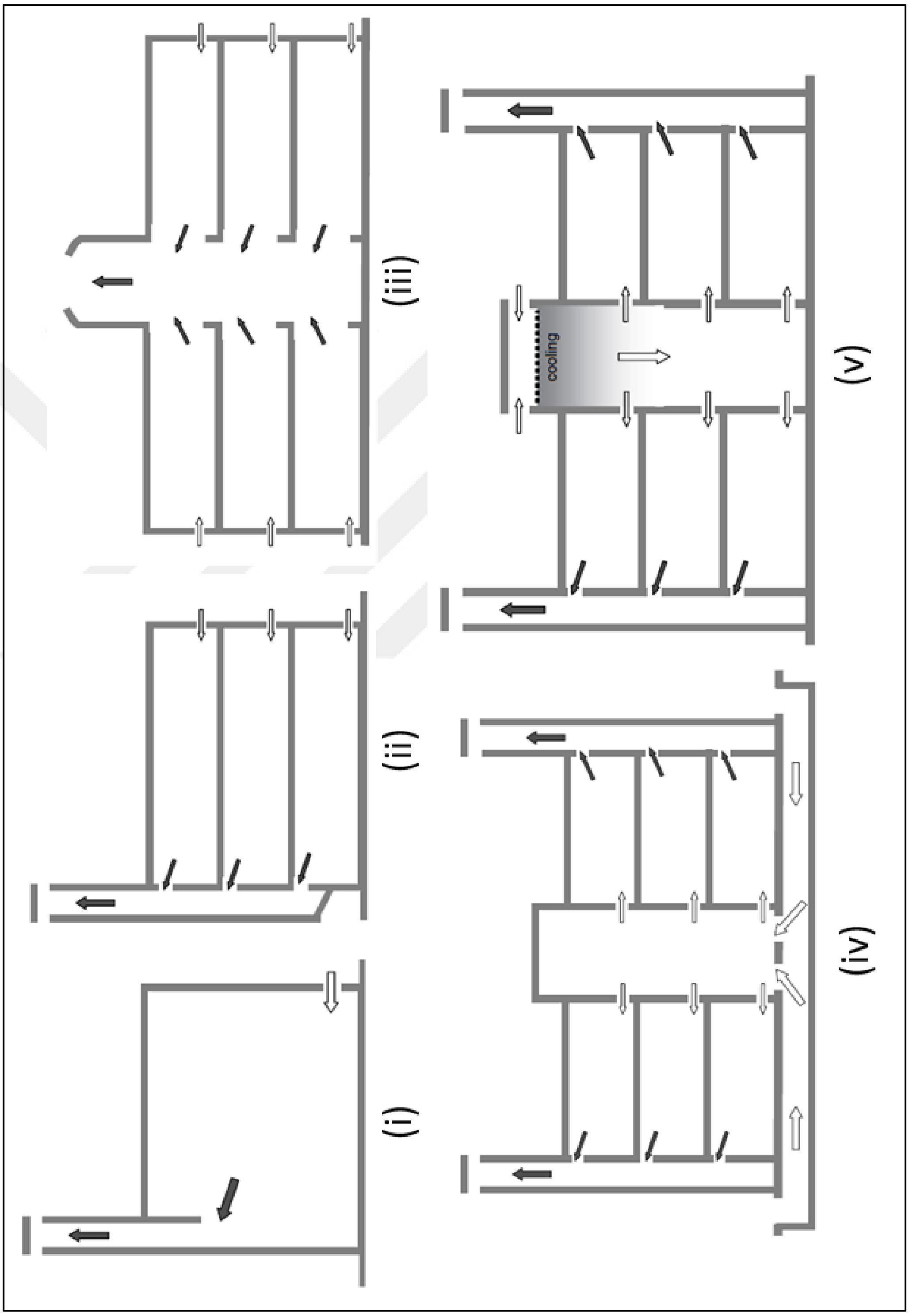


Figure 4.52. Stack ventilation (Adapted from Etheridge 2012)

Depending on the local climatic conditions stack ventilation for skyscrapers can be segmented and un-segmented (Figure 4.53), un-segmented skyscrapers can create extreme stack flows; this can be reduced by introducing segmentation in the skyscrapers. Segmentation can present an ideal solution to allow the operation of natural ventilation for the skyscrapers. Each segment in the skyscraper can behave as an individual unit independent of the ventilation strategy of the segment above or below. Because of that, each segment acts independently; the natural ventilation strategy can be vertically extruded by adding additional segments to create the skyscrapers (Al-Kodmany 2015).

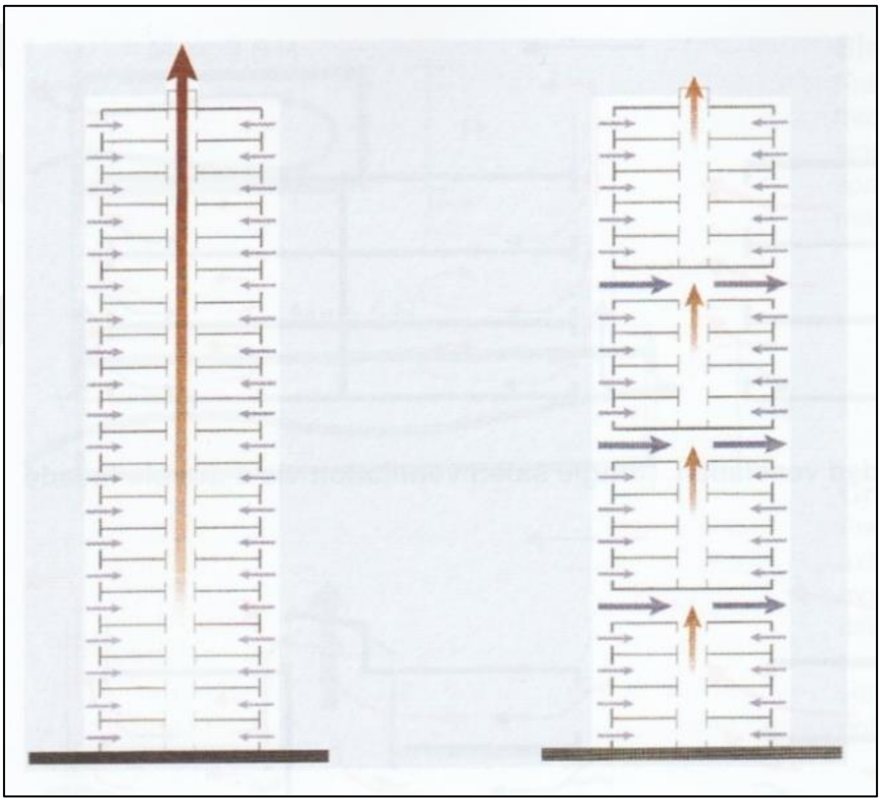


Figure 4.53. Stack ventilation in segmented and unsegmented skyscrapers (Al-Kodmany 2015)

The three concepts of natural ventilation (single-sided ventilation, cross ventilation, and stack ventilation) can be combined and used in the same skyscraper for reaching the aim of maximum natural ventilation (Wood and Salib 2013). Figure 4.45 shows some examples of these combination natural ventilation concepts.

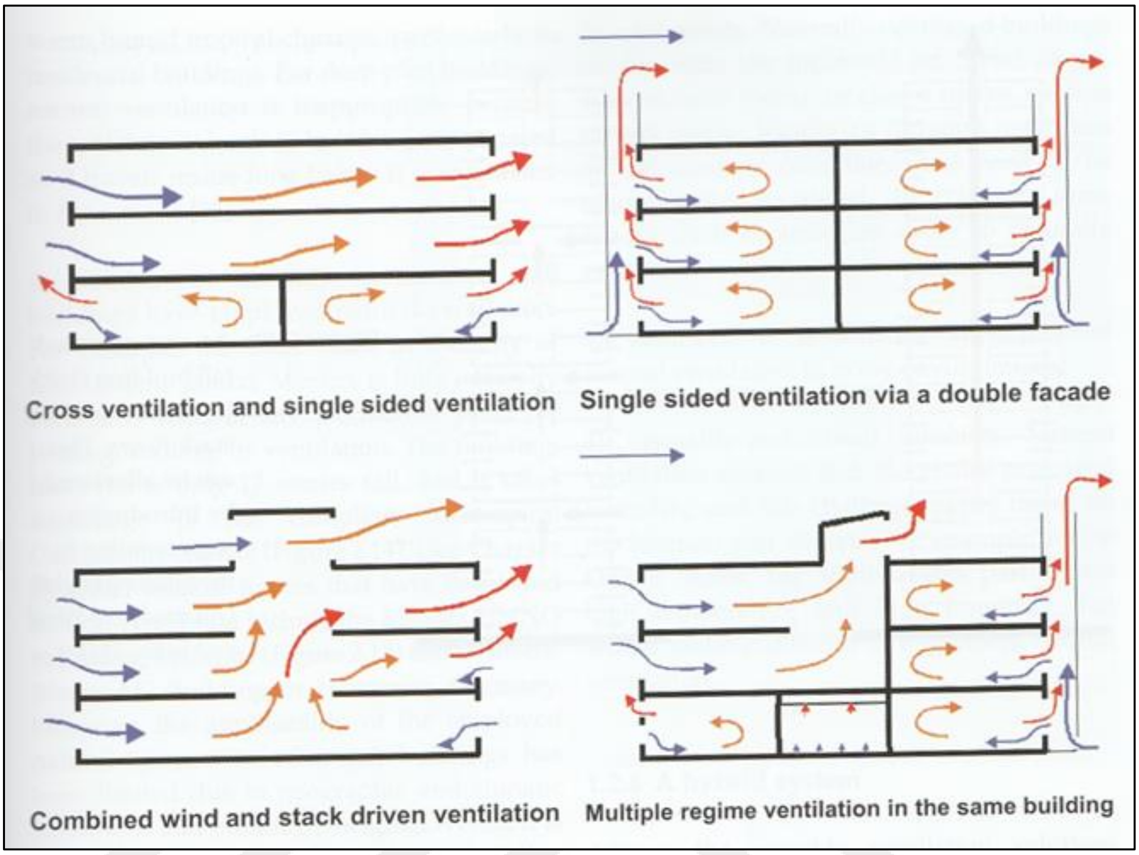


Figure 4.54. Combinations of natural ventilation systems (Al-Kodmany 2015)

This part examined some of the most important principles for passive wind concepts for natural ventilation. Table 4.7 summarizes and concludes the investigated principles in this part.

Table 4.7. Summarizing of the investigated principles for passive wind concepts

The principles for passive wind concepts		Climate zones	Description
Understanding the driving forces for natural ventilation in skyscrapers	Wind-caused ventilation	Lower and higher latitudes	• It takes place when the wind makes a pressure of distribution around the skyscraper with considering the atmospheric pressure. • The pressure impact is controlled by the skyscraper's shape, the wind direction and velocity, and the influence of the surroundings. • It is generally the controlling of driving force on a windy day.
	Buoyancy-caused ventilation	Lower and higher latitudes	• It takes place a cause of the concentration differences caused by variations in temperature and height between the inside and the outside or between certain zones within the skyscraper. • The pressure impact is controlled by the skyscraper's shape, the wind direction and velocity, and the interior design of the skyscraper. • It is generally the controlling of driving force on a calm day with virtually no wind.
Understanding wind movement and diagrams	Requirement for cross ventilation	Lower latitudes (tropical and arid zones)	• The cross ventilation is more required.
		Higher latitudes (temperate and cool zones)	• The cross ventilation is less required.
	The main wind direction (the desired and undesired wind)	Tropical zone	• Any wind is favorable especially that come from the east and the north.
		Arid zone	• The wind coming from the east is favorable while the wind coming from the west is unfavorable.
		Temperate zone	• The wind coming from the south-west is favorable while the wind coming from the north-west is unfavorable.
		Cool zone	• The most wind is unfavorable especially that come from the south-east and the north-west.
	The cross ventilation analysis	Tropical zone	• Here as much natural ventilation as possible is needed.
		Arid zone	• Here cross ventilation is needed but care must be taken to filter out high-velocity winds.
		Temperate zone	• Here cross ventilation and shielding is both required.
		Cool zone	• Here the skyscraper should be protected from cold, high-velocity winds. Cross ventilation is still required.
Understanding the basic concepts of natural ventilation	Single-sided ventilation	Lower and higher latitudes	• Fresh air and wind go in and out from the openings on the same side.
	Cross ventilation	Lower and higher latitudes	• Fresh air and wind go in from one side and go out from the opposite side.
	Stack ventilation	Lower and higher latitudes	• Fresh air and wind go in from low points of the skyscraper, rising up and then go out from the top of the central space of the building.

4.2.3. Design considerations for passive wind concepts

There are many design considerations for passive wind concepts in skyscrapers; the followings mention some of these design considerations;

One of the important design considerations for passive wind concepts is by considering the local climate in the design of skyscrapers. The following points give some information about some of the design considerations in different local climates (Wood and Salib 2013);

- In the tropical climate, the natural ventilation strategy has the main impact on the form of the skyscraper. Narrow floor plates are helpful to guarantee sufficient cross ventilation over the space. High floor-to-ceiling heights can be used to keep the air warmer, and to increase natural ventilation through stack impact.

- In the arid climate, skyscrapers must be oriented along an east-west axis with the main façade openings positioned toward the north and south. This orientation can reduce solar gain and maximize the cross ventilation coming from the desired east wind during the summer. The use of aerodynamic elements is also effective to increase the natural ventilation in this climate.

- In the temperate climate, the use of double skin facades is the most effective consideration for natural ventilation. Stack ventilation is also effective to increase the natural ventilation in this climate.

- In the cool climate, compact and curvilinear shapes can reduce the facade heat loss and have also a better aerodynamic performance which can help in the natural ventilation strategies in the skyscraper

Some examples of typical skyscrapers in the different climate zones have been shown in Figure 4.8.

Considering the basic concepts of natural ventilation which are investigated in the previous part is another important design consideration for passive wind concepts. The design considerations for the basic concepts of natural ventilation can be concluded as the followings (Figure 4.55) (Irving et al. 2005);

- Single-sided ventilation; this method can ventilate the space effectively if the space depth is a maximum of 2.5 times of its height.
- Cross ventilation; this method can ventilate the space effectively if the space depth is a maximum of five times of its height.
- Stack ventilation; this method can be used for designing the skyscrapers with atriums.

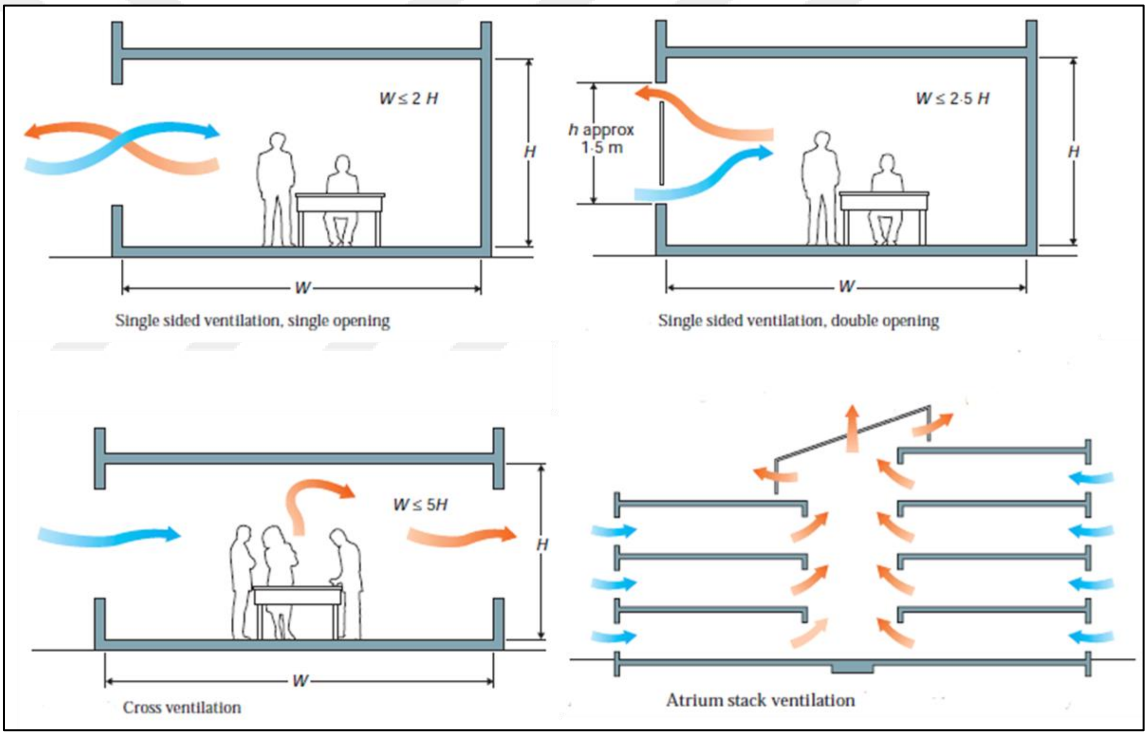


Figure 4.55. The basic concepts of natural ventilation (Adapted from Irving et al. 2005)

One of the important design considerations for passive wind concepts is by giving importance for skyscraper layout and configuration; the careful configuration of the skyscraper in relation to the existing wind improves the effect of natural ventilation. Al-Kodmany (2015) give some considerations and recommendations for achieving the maximum natural ventilation in skyscrapers, it is recommended to adopt shapes such as

E, H, O, Y and U for the floor plan layout, it is recommended also to design skyscrapers with narrow plan depths to facilitate the flow of air across interior spaces and enhance the effectiveness of natural ventilation. It is also important to orient the skyscraper and the main windward openings toward the prevailing wind direction particularly summer winds, especially if cross ventilation is the primary natural ventilation strategy. Tehran International Tower (Figure 4.56) is an example of a skyscraper with the previous features with its adopting of Y shape for the floor plan layout and its narrow plan depths, and its orientation toward the prevailing wind direction especially from the east.

Tehran International Tower					
City	Tehran	Country	Iran	Height	162 m
Function	residential	Material	concrete	Floors	54

Figure 4.56. Tehran International Tower, Iran
(Adapted from CTBUH’s Database 2017, Google Maps 2018)

Another important design consideration for skyscraper layout and configuration to improve natural ventilation in skyscrapers is by considering floor to ceiling heights. According to Gonçalves (2010), the floor to ceiling heights of skyscrapers is recommended to be higher than 2.7 m for residential skyscrapers and 3 m for office skyscrapers to enable more air flow via the interior spaces, and creating the chance for openings and windows at different heights to increase pressure differences and air change rates.

The use of aerodynamic elements and forms is one of the most important design considerations for skyscraper layout and configuration. These elements and forms can enhance the flow of the wind and the natural ventilation around the skyscrapers.

Aerodynamic elements and forms encourage the flow of the wind around the exterior and into the skyscraper from a wide range of directions, creating pressure differentials between the windward and leeward sides. An example for aerodynamic elements is by the use of wing walls, wing roofs and aero-foil sections which can capture the wind from a wider range of directions, encourage the wind for more effective natural ventilation, and increase the airflow rates in the interior spaces. An example of a skyscraper with this feature is the Menara UMNO (Figure 4.57) which is located in Malaysia with its wing walls which direct winds into the building from a wide range of directions and to capture and create greater positive pressure on the windward side of the building (Hart 2011, Liu 2012).

Menara UMNO					
City	Penang	Function	office	Height	93.5 m
Country	Malaysia	Arch. design	Hamzah & Yeang	Floors	21

Figure 4.57. Menara UMNO, Malaysia
(Adapted from Liu 2012, CTBUH’s Database 2017)

The use of sky courts and atriums in skyscrapers is another important design consideration for passive wind concepts. Atriums and sky courts utilized for air intake, air outtake, and the combination of the two operations to encourage the natural ventilation, they are used as taking out channels for the exhaust air from the skyscraper via the stack effect (Yeang 1999, Al-Kodmany 2015). An example of a skyscraper with sky courts and atrium is the National Commercial Bank (Figure 4.58) which is located in Saudi Arabia. The design of this tower was oriented around a central courtyard at the center of the V-shaped office tower. The courtyard framed with a staggered arrangement of seven and nine-story blocks of office space, allowing for large apertures for light and air to enter the courtyard, filled with a series of outdoor gardens within the center of the structure (CTBUH’s Database 2017).

National Commercial Bank					
City	Jeddah	Function/Material	office /concrete	Height	126 m
Country	Saudi Arabia	Arch. design	SOM	Floors	27

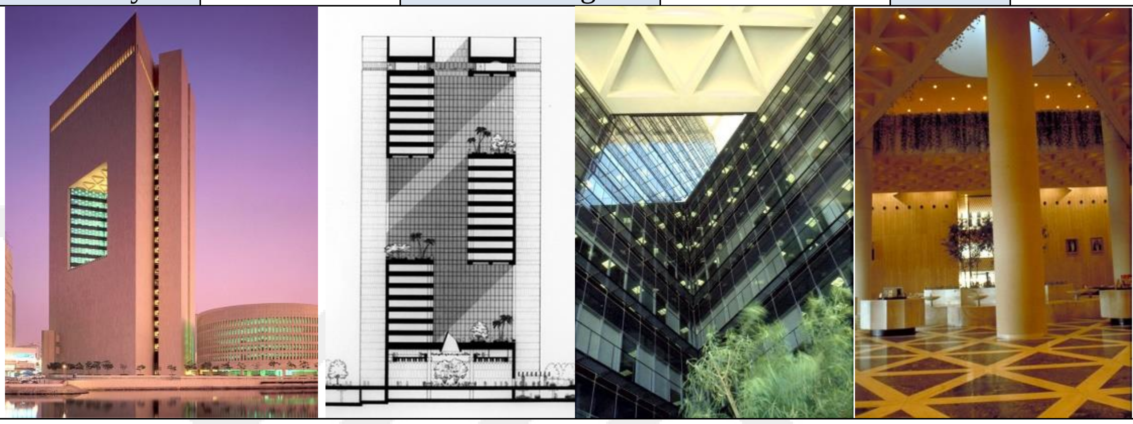
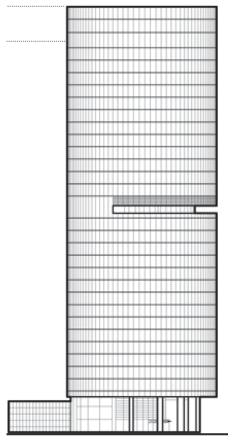


Figure 4.58. National Commercial Bank, Saudi Arabia
(Adapted from CTBUH’s Database 2017)

The use of double skin facades in skyscrapers is another important design consideration for passive wind concepts which are very important for natural ventilation. Skyscrapers face different wind speeds and pressures at different heights and locations across the façade, the double skin openings take account for these. These facades are designed to respond to the specifics of air-speed, noise generated by air movement, solar protection, and assisting with the natural ventilation. Double skin facades provide maximum natural heating, cooling, daylight and natural ventilation. Double skin facades have different modes during the winter and summer. During winter, the gap in double skin façades can preheat the cold air before it enters the skyscraper. During summer, the gap in double skin façades can warm and reduce the hot air before it enters the skyscraper (Poirazis 2004). An example of a skyscraper with double skin façade is the 1 Bligh Street (Figure 4.59) which is located in Australia. The double skin façade is consisting of a double-glazed insulating layer with a very high-performance low-E coating and a single-glazed laminated low-iron glass. To keep heat out, the space between the two layers of the façade contains a flexible sun-screen that functions as glare protection. Made of low-iron glass, the outer façade protects the sun-screen (Yudelson and Meyer 2013).

1 Bligh Street (Space Tower)

City	Sydney
Country	Australia
Height	138.8 m
Floors	32
Function	office
Structural Material	concrete
Architectural Design	Ingenhoven architects and Architectus
Energy Label	6 Star Green Star



Double skin façade

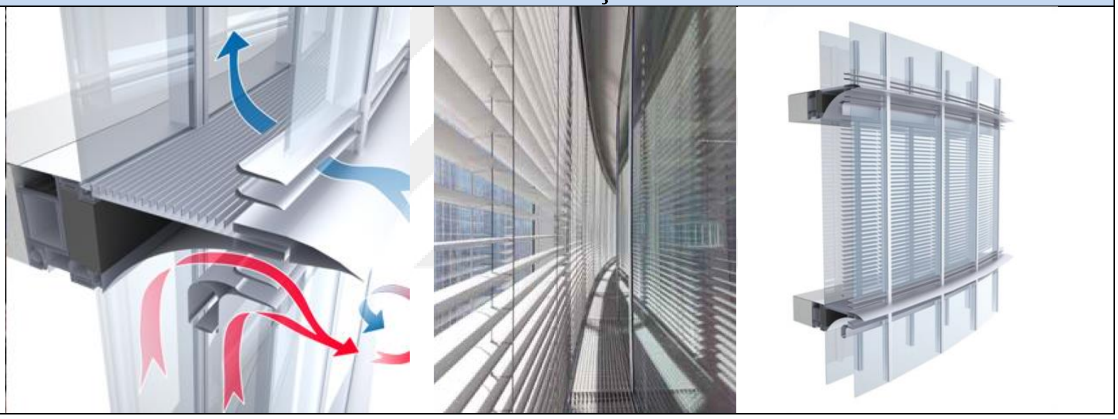


Figure 4.59. 1 Bligh Street, Australia
(Adapted from Yudelson and Meyer 2013, CTBUH's Database 2017)

Another important design consideration for natural ventilation is by building some parts of the skyscraper with large areas of exposed thermal mass (e.g., exposed concrete, ceiling slabs), this can improve the night-time ventilation. According to Etheridge (2012), and Wood and Salib (2013), night-time ventilation is an effective passive strategy due to its benefiting from the lower external air temperatures during the night to cool down the skyscraper and reduce the internal heat loads gained during the day because the wanted air and heat are saved inside and stored in the fabric of the skyscraper. It is important to consider that night time ventilation is only effective in particular climates that show particular day and night temperature variations, and a high relative humidity in the climate can affect this strategy in a negative way. An example of a skyscraper having night-time ventilation strategy is the Liberty Tower of Meiji University (Figure 4.60) which is located in Japan. The tower's concrete structure and exposed ceilings could be used to exploit the material's thermal capacity and to cool down the building at night.

Liberty Tower of Meiji University					
City	Tokyo	Country	Japan	Height	119 m
Function	education /office	Material	concrete	Floors	26
Architectural design		NIKKEN SEKKEI LTD			

Figure 4.60. Liberty Tower of Meiji University, Japan
(Adapted from Wood and Salib 2013, CTBUH's Database 2017)

The use of vegetation and greenery in skyscrapers is another important design consideration for passive wind concepts. This design consideration has aesthetic, ecological, energy conservation benefits, and effective solutions to benefit from the wind to ideal and maximum natural ventilation. This vegetation in skyscrapers has a function as buffer zones which can protect against unwanted weather conditions, noise, and high wind speeds. The use of vegetation in skyscrapers has different modes in hot and cold climates. In cold climates, the vegetation can preheat the cold air before it enters the skyscraper. In hot climates, the vegetation can warm and reduce the hot air before it enters the skyscraper. Studies have shown also that the use of vegetation in skyscrapers removes formaldehyde, benzene, and airborne microbes, which means contributing to healthier internal ventilation. There are four types of the use of vegetation and greenery in skyscrapers which were investigated in the last part; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies. An example of a skyscraper using vegetation and greenery is the Newton Suites (Figure 4.66) which is located in Singapore. This tower features with its façade supported green wall, and its tree planters and gardens on communal cantilevering balconies. The surface area of green coverage is approximately 1,274 square meters (Wood et al. 2014).

Newton Suites			
	City	Singapore	
	Country	Singapore	
	Height	120 m	
	Floors	36	
	Function	residential	
	Structural Material	concrete	
	Architectural Design	WOHA Architects	
The vegetation and greenery			
 			

Figure 4.61. Newton Suites, Singapore
(Adapted from Wood et al. 2014, CTBUH's Database 2017)

This part examined some of the most important design considerations for passive wind concepts for natural ventilation. Table 4.8 summarizes and concludes the investigated design considerations in this part.

Table 4.8. Summarizing of the investigated design considerations for passive wind concepts

Design consideration		Climate zone	Optimal consideration and placement	Benefits and Aims
Considering the local climate (specific considerations)		Tropical climate	Narrow floor plates	• Helpful to guarantee sufficient cross ventilation over the space.
			High floor-to-ceiling heights	• To keep the air warmer, and to increase natural ventilation through stack impact.
		Arid climate	Skyscrapers preferred to be oriented along an east–west axis with the main façade openings positioned toward the north and south	• To reduce solar gain and maximize the cross ventilation coming from the desired east wind during the summer.
			The use of aerodynamic elements	• To enhance the flow of wind and the natural ventilation around the skyscrapers.
		Temperate climate	The use of double skin facades	• To increase the natural ventilation.
			The use of atriums	• To encourage the natural ventilation via the stack effect.
		Cool climate	The use of compact and curvilinear shapes	• To reduce the facade heat loss.
Considering the basic concepts of natural ventilation	Single-sided ventilation	Lower and higher latitudes	This method can ventilate the space effectively if the space depth is a maximum of 2.5 times of its height	• To increase the natural ventilation.
	Cross ventilation	Lower and higher latitudes	This method can ventilate the space effectively if the space depth is a maximum of five times of its height.	
	Stack ventilation	Lower and higher latitudes	This method can be used for designing the skyscrapers with atriums	
Considering optimal forms, spatial arrangement and orientation		Lower and higher latitudes	Adopting shapes such as E, H, O, Y and U for the floor plan layout	• To improve the effect of natural ventilation.
			Designing skyscrapers with narrow plan depths	• To facilitate the flow of air across interior spaces and enhance the effectiveness of natural ventilation.
			Orienting the skyscraper and the main windward openings toward the prevailing wind direction particularly summer winds.	• To improve the effect of natural ventilation.
			The floor to ceiling heights of skyscrapers is recommended to be higher than 2.7 m for residential skyscrapers and 3 m for office skyscrapers	• To enable more air flow via the interior spaces and creating the chance for openings and windows at different heights to increase pressure differences and air change rates.

Table 4.8. Continued. Summarizing the investigated design considerations for passive wind concepts

The use of aerodynamic elements	Lower and higher latitudes	The use of wing walls, wing roofs and aero-foil sections	• To capture the wind from a wider range of directions. • To increase the airflow rates in the interior spaces.
The use of sky courts and atriums in skyscrapers	Lower and higher latitudes	The inner spaces of the skyscraper	• Atriums and sky courts utilized for air intake, air outtake, and the combination of the two operations to encourage the natural ventilation.
The use of double skin facades	Lower and higher latitudes	In the façade design of skyscrapers	• During winter, the gap in double skin façades can preheat the cold air before it enters the skyscraper. During summer, the gap in double skin façades can warm and reduce the hot air before it enters the skyscraper.
The use of large areas of exposed thermal mass (e.g., exposed concrete, ceiling slabs)	Lower and higher latitudes	Building some parts of the skyscraper with large areas of exposed thermal mass that can improve the night-time ventilation.	• This can improve the night-time ventilation which is an effective passive strategy due to its benefiting from the lower external air temperatures during the night to cool down the skyscraper.
The use of vegetation and greenery in skyscrapers	Lower and higher latitudes	Utilizing one or more of these four strategies; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies.	• In cold climates, the vegetation can preheat the cold air before it enters the skyscraper. In hot climates, the vegetation can warm and reduce the hot air before it enters the skyscraper.

4.2.4. Advantages and disadvantages of passive wind concepts

The advantages of passive wind concepts can be summarized as the followings (Yeang 2000, 2006, Wood and Salib 2012, Al-Kodmany 2015);

- Providing concepts that can reduce the energy by taking the advantage from renewable resource of energy which is the wind.
- Reducing non-renewable energy consumption and the requirement for mechanical ventilation.
- Minimizing the high percentage of using the artificial HVAC systems.
- Economic concepts because they provide significant savings on energy use by minimizing electrical loads.
- Reducing noise problems which can happen with the artificial and mechanical systems.
- Healthy concepts because their maximum profiting from natural cooling and ventilating, and their positive psychological effects on the humans. In contrast, artificial cooling and ventilating can have negative effects on human health.
- Improving the indoor environmental quality.
- Providing acceptable thermal comfort conditions for users.
- Leading to gain green building certificates.
- Reducing maintenance and replacement operations which can occur a lot with artificial and mechanical ventilation systems.
- Reducing carbon dioxide emissions.
- Enhancing the environmental performance of the skyscrapers.

The disadvantages of passive wind concepts can be summarized as the followings (Yeang 2000, 2006, Al-Kodmany 2015);

- Passive wind concepts are not sufficient and cannot be taken alone in the design of skyscraper, the other wind modes concepts; (e.g., mixed mode, full mode) must be also undertaken in the design of skyscrapers due to some practical reasons in some regions such as the high-velocity of the wind in higher altitudes.

4.2.5. Case Studies

This part is analyzing two examples of skyscrapers which incorporate and utilize passive wind concepts to take the advantage of the wind for natural ventilation. The first example is Commerzbank Tower which is located in Frankfurt am Main, Germany. The second example is Torre Cube which is located in Guadalajara, Mexico. These case studies had been chosen because of that these skyscrapers incorporate more design considerations for passive wind concepts in comparison to the other skyscrapers around the world.

Table 4.9 shows the utilized table to determinate which skyscrapers incorporate more design considerations for passive wind concepts. The investigated skyscrapers examples and their related information had been collected from different sources (see Appendix 2). This table can be also used as a checklist for determining some of the important design considerations for passive wind concepts in skyscrapers.

Table 4.9. Design considerations for passive wind concepts for some skyscrapers examples around the world

N	Skyscraper example	Location	Considering local climate	Considering basic wind concepts	Perfect form, orientation	Aerodynamic elements and forms	Greenery and vegetation	Sky courts and atriums	Exposed thermal mass	Double skin façade	Total points
1	**Menara Boustead**	Malaysia	X	X	X	X	X		X		6
2	**IBM Plaza**	Malaysia	X	X	X		X		X	X	6
3	**Plaza Atrium**	Malaysia	X	X	X			X	X		5
4	**Menara Mesiniaga**	Malaysia	X	X	X	X	X	X		X	7
5	**Central Plaza**	Malaysia	X	X	X	X	X	X		X	7
6	**Budaya Tower**	Malaysia	X	X	X	X		X			5
7	**MBf Tower**	Malaysia	X	X	X	X	X	X	X		7
8	**Menara UMNO**	Malaysia	X	X	X	X		X		X	6
9	**Commerzbank**	Germany	X	X	X	X	X	X	X	X	8
10	**RWE Tower**	Germany	X	X	X	X	X			X	6
11	**Deutsche Messe AG**	Germany	X	X	X				X	X	5
12	**GSW Headquarters**	Germany	X	X	X	X			X	X	6
13	**Post Tower**	Germany	X	X	X	X		X		X	6
14	**Highlight Towers**	Germany	X	X	X			X		X	5
15	**KfW Westarkade**	Germany	X	X	X	X				X	5
16	**Edificio Malecon**	Argentina	X	X	X	X	X	X		X	7
17	**Consorcio Santiago**	Chile	X	X	X	X	X		X	X	7
18	**Swiss-Re Tower**	UK	X	X	X	X		X			5
19	**Heron Tower**	UK	X	X	X					X	4
20	**Leadenhall Tower**	UK	X	X	X	X				X	5
21	**1 Bligh Street**	Australia	X	X	X	X	X	X		X	7
22	**Council House 2**	Australia	X	X	X		X		X		5
23	**Bosco Verticale**	Italy	X	X	X		X	X	X		6
24	**New York Times**	USA	X	X	X					X	4
25	**SF Federal Building**	USA	X	X	X	X		X	X	X	7
26	**Manitoba Hydro**	Canada	X	X	X			X		X	5
27	**Solaris**	Singapore	X	X	X	X	X	X		X	7
28	**National Library**	Singapore	X	X	X	X	X	X			6
29	**Newton Suites**	Singapore	X	X	X		X	X	X		6
30	**Torre Cube**	Mexico	X	X	X	X	X	X	X	X	8
31	**The Met**	Thailand	X	X	X		X	X	X		6
32	**IDEO Morph 38**	Thailand	X	X	X		X	X	X		6

4.2.5.1. Commerzbank Tower, Germany

Commerzbank Tower (Figure 4.62) is an office skyscraper located in Frankfurt am Main, Germany; the skyscraper was completed in 1997. This tower was designed by Foster + Partners firm; the tower is with 56 floors and 259 m in height (CTBUH's Database 2017). This skyscraper is considered as one of the most ecological skyscrapers ever built. The main strategy in Commerzbank Tower is to meet the challenges of environmental quality and energy efficiency by the introduction of natural ventilation according to the possibilities of the local climate and the limits of thermal comfort. Its design utilizes many of the passive design strategies found in the early modern skyscrapers, including natural day-lighting and ventilation. This tower also introduces new characteristics of sustainability, such as sky gardens, water conservation systems and foundation reuse. The existence of this building has brought the sustainability agenda forward for many architectural practices, especially those in Europe, and, because of its overall focus, it is to date still considered one of the most environmentally sensitive completed building (Pank et al. 2002, Fazlic 2013).

Figure 4.62. Commerzbank Tower, Germany (CTBUH's Database 2017)

The ecological and structural innovations were the major success factors in the design of this skyscraper. According to Wood and Salib (2013), the skyscraper's energy consumption from non-renewable and mechanical systems is reduced by 38 % by adopting passive wind concepts by taking the advantage from the wind to provide maximum natural ventilation; the approximate percentage of year natural ventilation that can be utilized is 80 %.

As it is mentioned above Commerzbank Tower is located in Frankfurt am Main, Germany. Frankfurt is located in a warm temperate climate which relatively moderate weather over the year, in spite of the fact of the occasional occurrence of fairly uncommon and short-lived extremes. Typically summers in Frankfurt are warm and sunny with a possibility of light rain occurrence. In summer, the temperature often rises above 24 °C, even topping 30 °C, and drops to around 15 °C in the evenings. In winter, the weather in Frankfort is cold and snowy, daytime temperatures are around 4 °C and at night drop just below freezing (Figure 4.63) (Wood and Salib 2013).

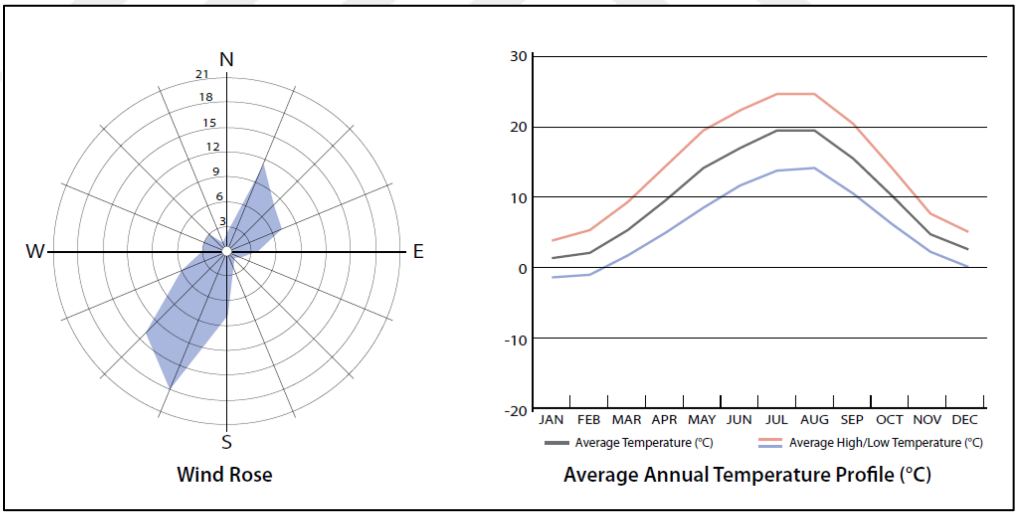


Figure 4.63. The wind rose and the average annual temperate profile of Frankfort (Wood and Salib 2013)

The skyscraper has a triangular plan with a central atrium divided into four segments around which office spaces and sky gardens are organized in a spiraling configuration (see Figure 4.64). The three corners of the triangle skyscraper are the main structural elements and they contain vertical circulation, toilets, and other service facilities. The structural system consists of three atrium columns with peripheral girders and six mega columns at the corners of the skyscraper, connected by eight-story girders. The triangular plan of the Commerzbank Tower helps the skyscraper to perform better against wind pressure in comparison to the other skyscrapers with the rectangular plan (Günel and İlgin 2014). From these, it can be observed that the ecological strategies of the architectural approach for Commerzbank Tower brought challenges for the structural design. The objective of taking natural ventilation via lateral voids combined with the central atrium removed the central core solution, heading to a tubular peripheral structural solution, with three cores placed on the heads of the triangular shape (Gonçalves 2010).

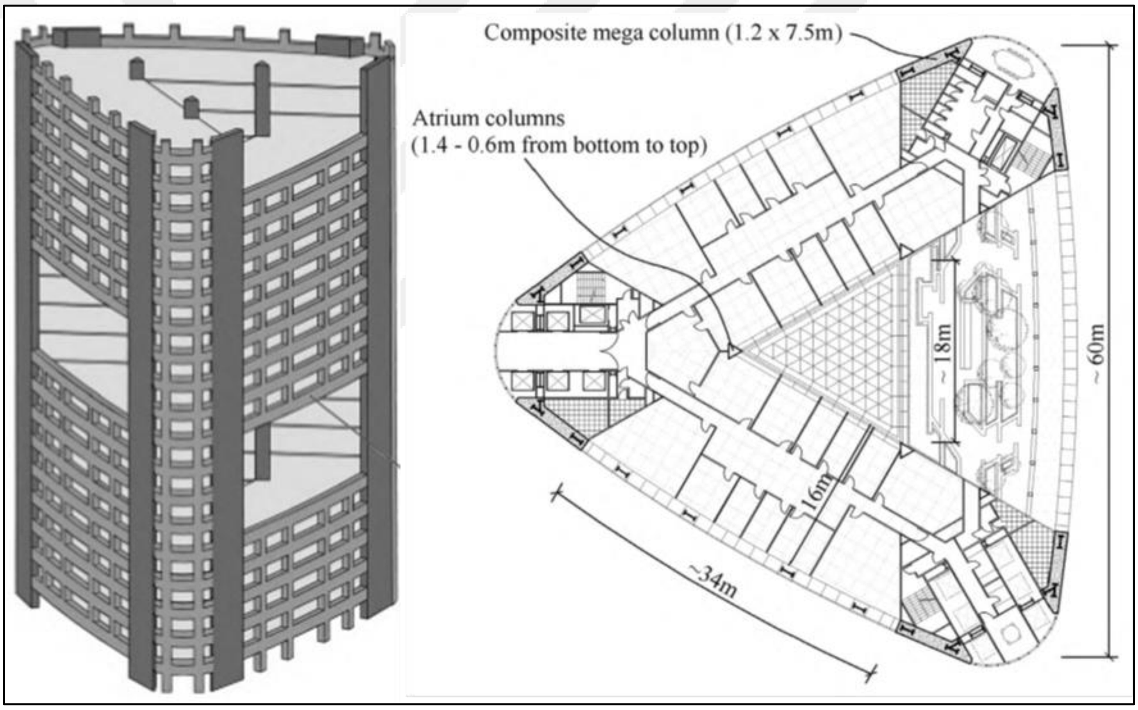


Figure 4.64. The plan and the structural system of Commerzbank Tower (Günel and İlgin 2014)

Natural ventilation is facilitated by the skyscraper layout and configuration that go away from the traditional central core and surrounding office arrangement. Moving typical core functions to the outer corners of the skyscraper gives more flexibility in space planning, permitting for the creation of a central atrium and spiraling sky gardens which allow the entrance of fresh air into the skyscraper. Commerzbank Tower is also with narrow floor plates allow cross ventilation, while the offices cellular layout allows single-sided ventilation (Wood and Salib 2013).

Commerzbank Tower is divided into four vertical villages, each one composed of 12 stories, and these villages are arranged on top of each other. The three sides of the triangular floor plate of the skyscraper face a central atrium with two sides occupied by offices and one by the sky gardens. The concept of the villages with the central atrium surrounded by the sky gardens is the basis for the natural ventilation strategy of the internal zone of offices facing the atriums, combined with the effects of cross ventilation from the stack effect (Liu 2012).

Figure 4.65. The central atrium of Commerzbank Tower (CTBUH's Database 2017)

The central atrium is segmented by a metallic structure (closed in glass) at the end level of each village (Figure 4.65). This segmentation prevents the development of extreme stack flows, and reduces wind pressures and smoke spread in the central atrium, without blocking daylight penetration from the top. Each of the 12 story villages includes three sky gardens, one on each face of the skyscraper, each sky garden has four stories placed on each of the three faces of the skyscraper, the sky gardens are organized in a spiraling configuration, this optimize the natural ventilation strategy by allowing efficient cross ventilation to take place regardless of wind direction and the orientation of the skyscraper as there is always a windward garden to allow the air to enter the central atrium and a leeward garden to exhaust it (Fazlic 2013). The sky gardens and atrium can be considered as enclosed spaces that moderate between external and internal environments and assist in the first degree in the natural ventilation strategy.

According to Pank et al. (2002), the offices of Commerzbank Tower are divided by a wide central corridor with half of the offices facing the central atrium and the other half facing the exterior. This allows each office in the skyscraper, regardless of inward or outward orientation, to have inlet to outside air, light, and views.

The external facing offices of Commerzbank Tower are ventilated directly from the external envelope through a double skin façade (Figure 4.66). The outer layer of the double skin façade deflects the strong wind and rain, the inner layer of the double skin façade consists of double-glazed windows that open inwards at the top, thus permitting air from the cavity to flow directly into the inner spaces of the skyscraper. The double skin façade works generally as a buffer to control wind driven air into the office spaces, and as a thermal flue by stack buoyancy of rising warmer air in the façade cavity extracting unpleasant air from the offices. Commerzbank Tower utilizes small aero-foil sections at the top and the bottom of the double skin façade openings to improve airflow through the ventilated cavity and avoid the short-circuiting of air (Poirazis 2004).

Figure 4.66. The external facing offices of Commerzbank Tower (Wood and Salib 2013)

The internal facing offices of Commerzbank Tower which are facing the atrium are ventilated via the air movement through the sky gardens through windows facing the atrium (Figure 4.67). The sky gardens are an important element of the natural ventilation strategy, working as extraction chimneys that use stack effect to exhaust air from the skyscraper. The sky gardens also work as solar collectors and thermal buffers between the interior and exterior, preheating the air before it enters the office spaces in the winter. Also, they work as transition and rest spaces that facilitate user circulation and satisfaction inside the skyscraper (Liu 2012). The glass curtain wall enclosed sky gardens help to improve the environmental conditions inside the skyscraper by bringing fresh air and daylight into the central atrium that works as a natural ventilation chimney for the skyscraper (Günel and İlgin 2014).

Figure 4.67. The internal facing offices of Commerzbank Tower (Wood and Salib 2013)

The natural ventilation strategies for the inward facing offices and the outward facing offices work independently of each other. Generally, the natural ventilation strategy of the offices can be characterized as single-sided ventilation, and the natural ventilation strategy for the atrium can be characterized as a combination of cross and stack ventilation, which are providing favorable natural ventilation conditions for the internal offices of Commerzbank Tower (see Figure 4.68) (Wood and Salib 2013). As a result, all the offices of Commerzbank Tower can collect fresh natural air and direct sunlight because of the availability of sky gardens, the central atrium and the double skin façade which can improve the working environment inside the skyscraper (Fazlic 2013).

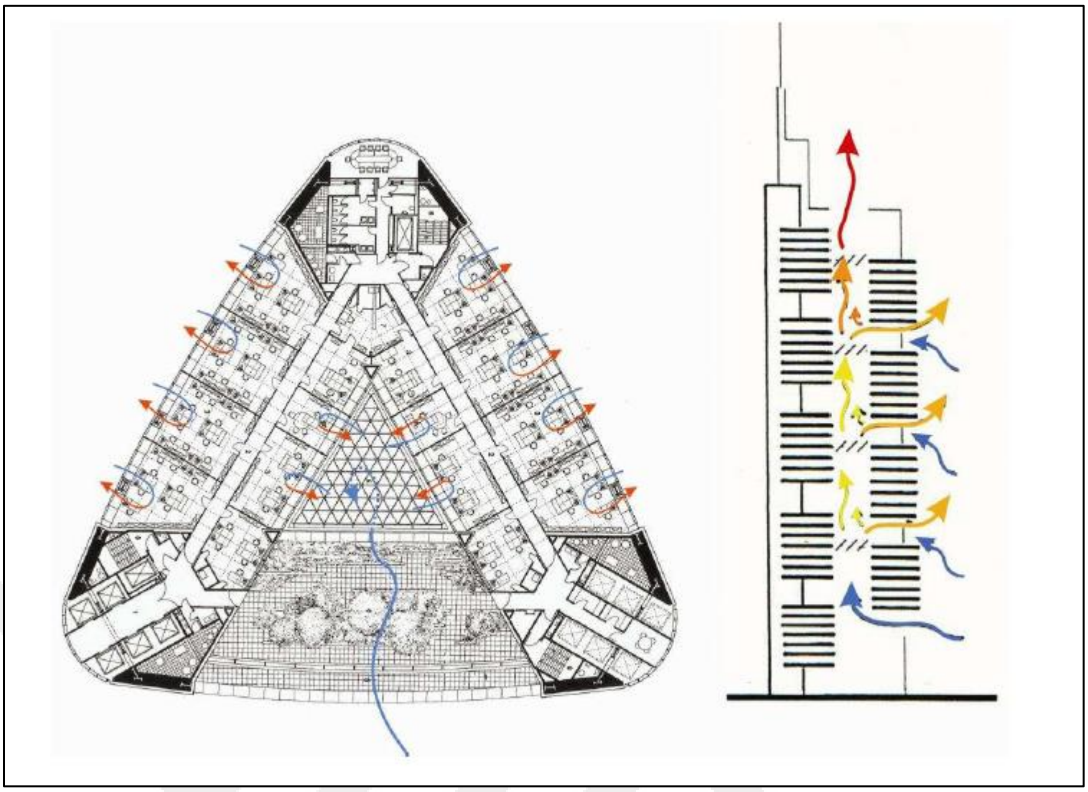


Figure 4.68. The natural ventilation strategy of Commerzbank Tower (Liu 2012)

In the sky gardens, it is remarked the existing of enclosed green terraces (Figure 4.69). In cold climates, this vegetation can preheat the cold air inside the skyscraper. In hot climates, this vegetation can warm and reduce the hot air inside the skyscraper (Gissen 2002).

Figure 4.69. Enclosed green terraces in the sky gardens (Wood and Salib 2013)

Table 4.10 summarizes the design considerations for passive wind concepts for Commerzbank Tower according to the investigated design considerations for passive wind concepts in the previous part of this chapter.

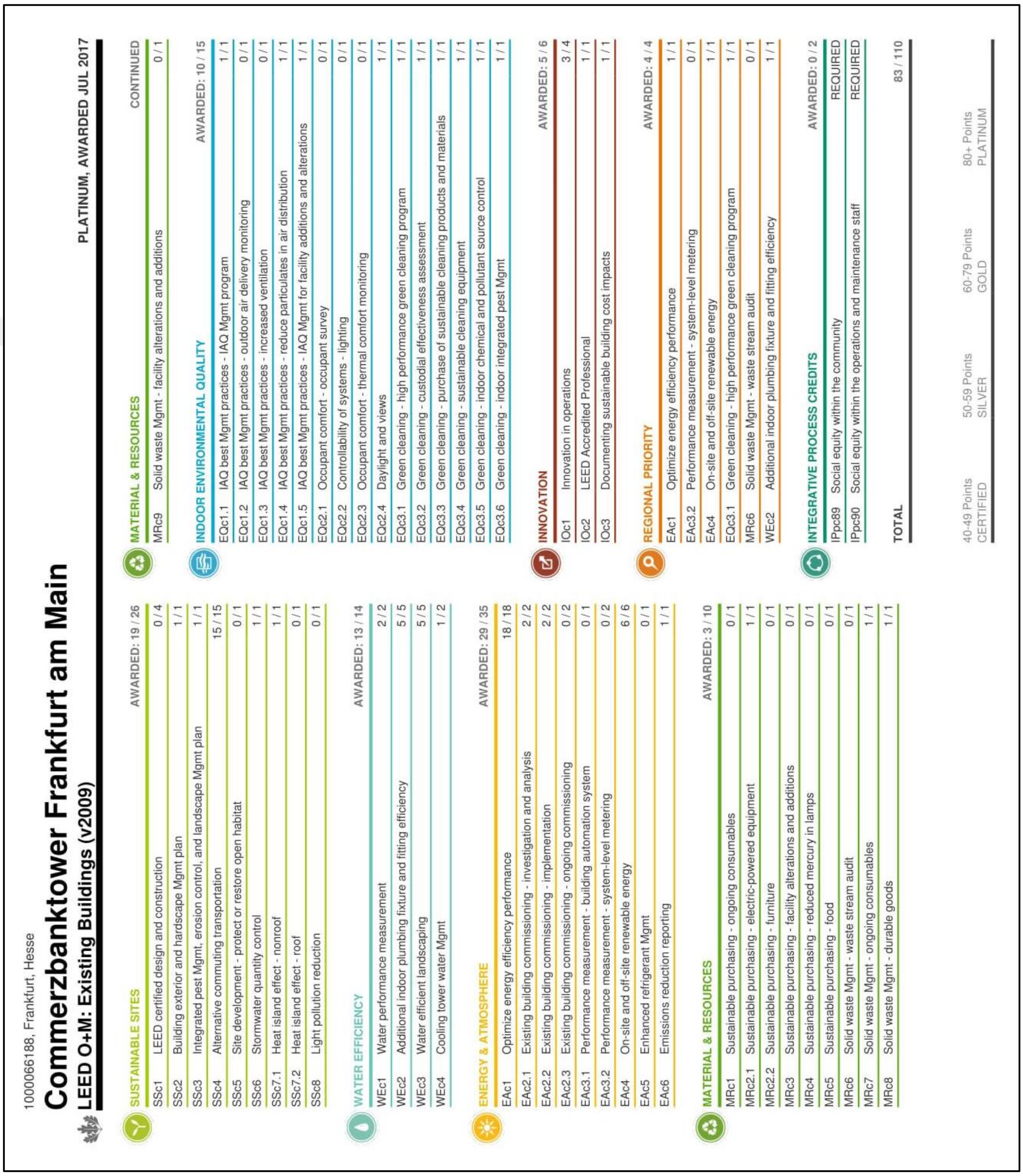
Table 4.10. The design considerations for passive wind concepts for Commerzbank

<table>
<tr><th colspan="3">The design considerations for passive wind concepts for Commerzbank Tower</th></tr>
<tr><td colspan="2">Considering the local climate</td><td>• Warm temperate climate (considering the double skin facades and the atrium).</td></tr>
<tr><td colspan="2">Considering the basic concepts of natural ventilation</td><td>• Single-sided ventilation for the cellular offices.
• Cross ventilation by the narrow floor plates.
• Stack ventilation by the segmented atrium.
• Combination of cross and stack ventilation by the spiraling configuration of the sky gardens.</td></tr>
<tr><td rowspan="4">Considering optimal form, spatial arrangement and orientation</td><td>Considering optimal forms</td><td>• Triangular building form.
• Dividing the office spaces by a wide central corridor with half of the offices facing the central atrium and the other half facing the exterior.
• The movement of typical core functions to the outer corners of the skyscraper.</td></tr>
<tr><td>Designing the skyscrapers with narrow floor plates</td><td>• The existence of narrow floor plates.</td></tr>
<tr><td>Considering high floor to ceiling heights</td><td>• The floor to ceiling heights is higher than 3m.</td></tr>
<tr><td>Orienting toward the prevailing wind direction</td><td>• The optimization of the natural ventilation strategy on the three facades of the skyscraper is allowing efficient cross ventilation to take place regardless of wind direction and the orientation as there is always a windward garden to allow the air to enter to the central atrium and a leeward garden to exhaust it.</td></tr>
<tr><td colspan="2">The use of aerodynamic elements and forms</td><td>• The utilization of small aero-foil sections at the top and the bottom of the double skin façade openings.</td></tr>
<tr><td colspan="2">The use of sky courts and atriums</td><td>• Central atrium divided into four segments.
• Sky gardens are organized in a spiraling configuration.</td></tr>
<tr><td colspan="2">The use of double skin facades</td><td>• Double skin facades that ventilating the external facing offices.</td></tr>
<tr><td colspan="2">The use of exposed thermal mass for night-time ventilation</td><td>• Exposed thermal mass also exists in this skyscraper.</td></tr>
<tr><td colspan="2">The use of vegetation and greenery</td><td>• Sky gardens organized in a spiraling configuration.
• The existing of enclosed green terraces.</td></tr>
</table>

There are also many other environmental features in the design of Commerzbank Tower. Wood and Salib (2013), and Gonçalves (2010) summarize some of these features as the followings:

- Providing perfect solar access and daylight availability in all the spaces inside the skyscraper.
- According to the design, the maximum acceptable temperature in the working spaces is 26°C in summer and the minimum is 18°C in winter.
- When it is necessary, artificial cooling is provided to the working spaces by means of chilled ceilings coupled with mechanical ventilation.
- Heating is provided by the technical systems in the coolest periods of the year, coupled with mechanical ventilation.
- Garden spaces are naturally ventilated the whole year with the provision of under-floor heating during the coolest period of the year.
- The users have the chance for changing environmental conditions when moving from the formal working spaces to the seating areas in the sky gardens.
- Users have views towards the outside from any point in the working areas, either via the windows directly facing outside or via the sky gardens and atrium.
- The sky gardens provide panoramic views of the city in all orientations.
- All working spaces are well served by acceptable levels of daylight during the year.
- Direct sunlight is blocked and reflected into diffuse light by horizontal blinds installed within the double glazed windows.
- Narrow floor plates permit all working spaces to receive daylight and obtain good daylight uniformity rates.
- The layout of cellular office cells is more favorable to acoustic comfort than the open-plan layout.
- CFD Simulations were done at the design stage to model airflow patterns through and around the skyscraper, as well as to predict the velocity, the direction, and the temperature of the air in the atrium and sky gardens at different times of the year and under a diversity of weather conditions.
- Chilled ceilings perform the double role of cooling and providing absorption of noise generated in the spaces.

Commerzbank awarded LEED Platinum certification within LEED for O+M rating system. This skyscraper earned 29 out of 35 points in the energy category of LEED (USGBC 2017). Figure 4.70 shows the LEED Scorecard of Commerzbank Tower.



1000066188, Frankfurt, Hesse

Commerzbanktower Frankfurt am Main

LEED O+M: Existing Buildings (v2009) — PLATINUM, AWARDED JUL 2017

SUSTAINABLE SITES		AWARDED: 19 / 26
SSc1	LEED certified design and construction	0 / 4
SSc2	Building exterior and hardscape Mgmt plan	1 / 1
SSc3	Integrated pest Mgmt, erosion control, and landscape Mgmt plan	1 / 1
SSc4	Alternative commuting transportation	15 / 15
SSc5	Site development - protect or restore open habitat	0 / 1
SSc6	Stormwater quantity control	1 / 1
SSc7.1	Heat island effect - nonroof	1 / 1
SSc7.2	Heat island effect - roof	0 / 1
SSc8	Light pollution reduction	0 / 1

WATER EFFICIENCY		AWARDED: 13 / 14
WEc1	Water performance measurement	2 / 2
WEc2	Additional indoor plumbing fixture and fitting efficiency	5 / 5
WEc3	Water efficient landscaping	5 / 5
WEc4	Cooling tower water Mgmt	1 / 2

ENERGY & ATMOSPHERE		AWARDED: 29 / 35
EAc1	Optimize energy efficiency performance	18 / 18
EAc2.1	Existing building commissioning - investigation and analysis	2 / 2
EAc2.2	Existing building commissioning - implementation	2 / 2
EAc2.3	Existing building commissioning - ongoing commissioning	0 / 2
EAc3.1	Performance measurement - building automation system	0 / 1
EAc3.2	Performance measurement - system-level metering	0 / 2
EAc4	On-site and off-site renewable energy	6 / 6
EAc5	Enhanced refrigerant Mgmt	0 / 1
EAc6	Emissions reduction reporting	1 / 1

MATERIAL & RESOURCES		AWARDED: 3 / 10
MRc1	Sustainable purchasing - ongoing consumables	0 / 1
MRc2.1	Sustainable purchasing - electric-powered equipment	1 / 1
MRc2.2	Sustainable purchasing - furniture	0 / 1
MRc3	Sustainable purchasing - facility alterations and additions	0 / 1
MRc4	Sustainable purchasing - reduced mercury in lamps	0 / 1
MRc5	Sustainable purchasing - food	0 / 1
MRc6	Solid waste Mgmt - waste stream audit	0 / 1
MRc7	Solid waste Mgmt - ongoing consumables	1 / 1
MRc8	Solid waste Mgmt - durable goods	1 / 1

MATERIAL & RESOURCES		CONTINUED
MRc9	Solid waste Mgmt - facility alterations and additions	0 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 10 / 15
EQc1.1	IAQ best Mgmt practices - IAQ Mgmt program	1 / 1
EQc1.2	IAQ best Mgmt practices - outdoor air delivery monitoring	0 / 1
EQc1.3	IAQ best Mgmt practices - increased ventilation	0 / 1
EQc1.4	IAQ best Mgmt practices - reduce particulates in air distribution	1 / 1
EQc1.5	IAQ best Mgmt practices - IAQ Mgmt for facility additions and alterations	1 / 1
EQc2.1	Occupant comfort - occupant survey	0 / 1
EQc2.2	Controllability of systems - lighting	0 / 1
EQc2.3	Occupant comfort - thermal comfort monitoring	0 / 1
EQc2.4	Daylight and views	1 / 1
EQc3.1	Green cleaning - high performance green cleaning program	1 / 1
EQc3.2	Green cleaning - custodial effectiveness assessment	1 / 1
EQc3.3	Green cleaning - purchase of sustainable cleaning products and materials	1 / 1
EQc3.4	Green cleaning - sustainable cleaning equipment	1 / 1
EQc3.5	Green cleaning - indoor chemical and pollutant source control	1 / 1
EQc3.6	Green cleaning - indoor integrated pest Mgmt	1 / 1

INNOVATION		AWARDED: 5 / 6
IOc1	Innovation in operations	3 / 4
IOc2	LEED Accredited Professional	1 / 1
IOc3	Documenting sustainable building cost impacts	1 / 1

REGIONAL PRIORITY		AWARDED: 4 / 4
EAc1	Optimize energy efficiency performance	1 / 1
EAc3.2	Performance measurement - system-level metering	0 / 1
EAc4	On-site and off-site renewable energy	1 / 1
EQc3.1	Green cleaning - high performance green cleaning program	1 / 1
MRc6	Solid waste Mgmt - waste stream audit	0 / 1
WEc2	Additional indoor plumbing fixture and fitting efficiency	1 / 1

INTEGRATIVE PROCESS CREDITS		AWARDED: 0 / 2
IPpc89	Social equity within the community	REQUIRED
IPpc90	Social equity within the operations and maintenance staff	REQUIRED

TOTAL	83 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Figure 4.70. LEED Scorecard of Commerzbank Tower (USGBC 2017)

4.2.5.2. Torre Cube, Mexico

Torre Cube (Figure 4.71) is an office skyscraper located in Guadalajara, Mexico; the skyscraper was completed in 2005. This tower was designed by Estudio Carme Pinós firm; the tower is with 16 floors and 55 m in height (CTBUH's Database 2017). This skyscraper is a rare example of a tall office building which is naturally ventilated over the whole year with no dependence on air-conditioning, mechanical ventilation or mixed-mode systems (Liu 2012).

Figure 4.71. Torre Cube, Guadalajara, Mexico (McManus 2014)

As it is mentioned above Torre Cube is located in Guadalajara in Mexico. Guadalajara is located in a comparatively humid sub-tropical climate, characterized by dry and moderate-mild winters, and warm and humid summers. Although the temperature is warm over the year, it faced a strong seasonal variation in precipitation. There is plenty of sun over the year, summer temperatures averaging around 30 °C while the daytime winter weather tends to be moderate and averaging around 25 °C, the temperature drops at night, falling to around 5 °C (Figure 4.72). The moderate Guadalajara climate allows for natural ventilation throughout the whole year for the buildings which are designed in an ecological way, without dependence for much mechanical ventilation, cooling, or heating (Wood and Salib 2013).

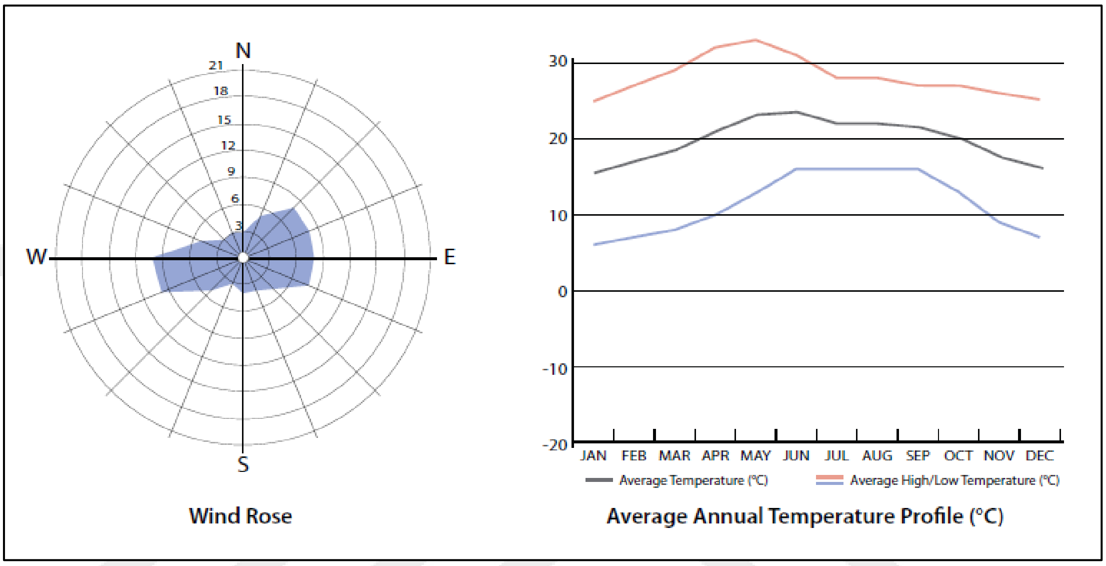


Figure 4.72. The wind rose and the average annual temperate profile of Guadalajara (Wood and Salib 2013)

The main ecological aim to design Torre Cube is to create well-ventilated offices with natural light and taking the advantage of the moderate weather of Guadalajara with making air-conditioning unnecessary for the skyscraper. The client searched for a singular structure building because it is located on a site with a dense office district (MacManus 2014).

Torre Cube is totally dependent on natural ventilation and solar shading devices to cool down the skyscraper. For this, there is no mechanical ventilation or mixed-mode systems operating within the skyscraper. Even during winter, the climate is moderate enough that there is no wanted for heating to warm up the interior spaces. This reduces energy consumption and eliminates the space needed to place mechanical HVAC equipment (Liu 2012).

The skyscraper consists of three chimney-shaped, wooden cladding office wings (Figure 4.73). The three office wings show a difference in size, they are 105, 125 and 175 square meters in floor area. The office spaces are a maximum of 12 m in depth and an average 12 m in width. These wings are supported by three concrete cores which include all the service facilities and vertical circulation elements for the skyscraper (e.g., elevators, stairwells, and toilets) (see Figure 4.74). This configuration of the skyscraper allows for open plan and column-free interiors within the office areas and provides maximum air movement and natural ventilation within the skyscraper (Wood and Salib 2013). These concrete cores act as columns and they are the only structural support for the skyscraper. Largely supported beams of different dimensions support column-free slabs. Thus both, office modules and the parking area, are free from obstacles (MacManus 2014).

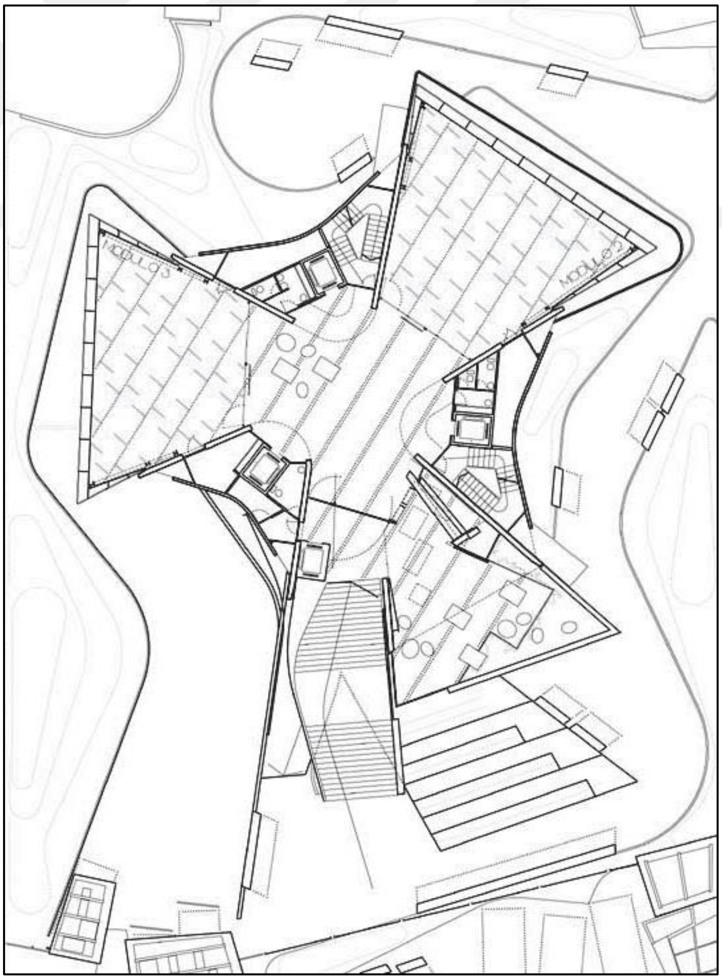


Figure 4.73. The plan of Torre Cube (McManus 2014)

Figure 4.74. One of the service cores of Torre Cube (Wood and Salib 2013)

The offices and service cores are arranged around a central atrium (Figure 4.75) which is an important part of the natural ventilation strategy of the skyscraper. The central atrium is linked to the exterior by the removal of some office floors which creates sky gardens in each office wing. These sky gardens serve to earn maximum natural ventilation and daylight into the central atrium (Liu 2012).

Figure 4.75. The atrium of Torre Cube (McManus 2014)

The office spaces have a double skin façade (see Figure 4.76) which facilitate natural ventilation and employ sunshades to provide protection against glare and solar heat gain. The inner skin is comprised of a floor-to-ceiling glazed curtain wall with operable sliding windows. The outer skin consists of a wooden cladding made from thin treated pine battens on a steel frame acting directly as sunshades. In addition, this outer skin acts as a buffer against wind-driven ventilation into the offices for reducing the speed of the air flow. The wooden cladding panels can slide horizontally by the occupants, giving a degree of flexibility to the amount of shade and controlling the flow of air into the offices. Since both elements can be manually controlled (the wooden cladding and the sliding glazed windows), the occupants have direct control over the amount of sun, light and air entering the office. The intermediate zone between the two façade layers has grated floor panels which permit access to this space, but does not impede vertical air flow in the space itself (Liu 2012).

Figure 4.76. The double skin façade of Torre Cube (Wood and Salib 2013)

The overall natural ventilation strategy of Torre Cube relies on the air movement between the outer windows and the central atrium (see Figure 4.77). Cross ventilation is performed by the fresh air entrance to the offices through the sliding glass windows in the exterior façade of the skyscraper. The warm air from the offices is exhausted into the central atrium which is completely open at the top through stack effect ventilation.

Stack effect in the atrium offers extra rising, through negative pressure that pulls air out of the offices to be exhausted at the top of the skyscraper (Liu 2012, Wood and Salib 2013). The ventilation strategy of Torre Cube can be summarized as a combination of cross ventilation supported by stack ventilation in the central atrium.

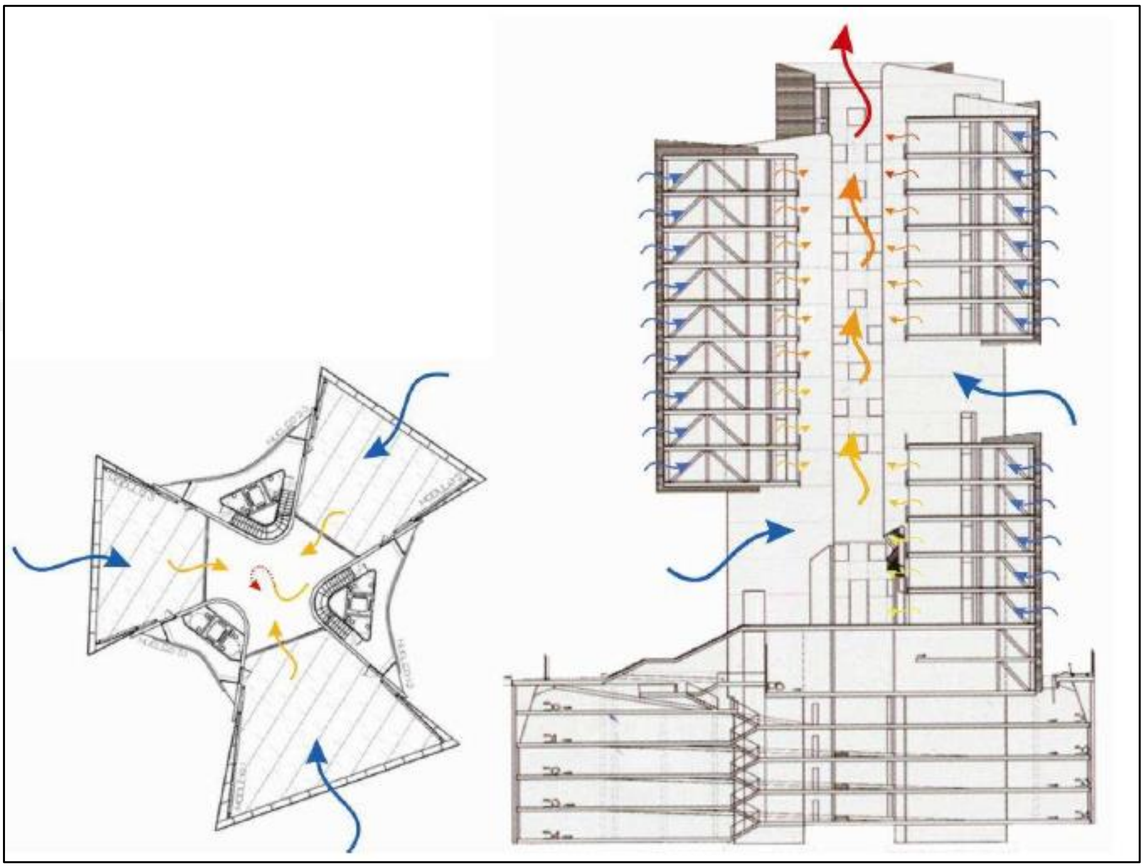


Figure 4.77. The natural ventilation strategy of Torre Cube (Liu 2012)

Table 4.11 summarizes the design considerations for passive wind concepts for Torre Cube according to the investigated design considerations for passive wind concepts in the previous part of this chapter.

Table 4.11. The design considerations for passive wind concepts for Torre Cube

The design considerations for passive wind concepts for Torre Cube		
Considering the local climate		• Humid sub-tropical climate (considering narrow floor plates and high floor to ceiling heights).
Considering the basic concepts of natural ventilation		• The ventilation strategy of Torre Cube can be summarized as a combination of cross ventilation supported by stack ventilation in the central atrium.
Considering optimal form, spatial arrangement and orientation	Considering optimal shapes and forms	• The skyscraper consists of three chimney-shaped, wooden cladding office wings. These wings are supported by three concrete cores which include all the service facilities and vertical circulation elements for the skyscraper.
	Designing the skyscrapers with narrow floor plates	• The skyscraper is designed with narrow floor plates.
	Considering high floor to ceiling heights	• The floor to ceiling heights is higher than 3m.
	Orienting toward the prevailing wind direction	• The optimization of the natural ventilation strategy on the office wings of the skyscraper is allowing efficient cross ventilation to take place regardless of wind direction and orientation, the office wing facing the prevailing wind may be better ventilated than the others, but the stack buoyancy in the central atrium is sufficient to draw air to the other office wings.
The use of aerodynamic elements and forms		• The office wings with the three concrete cores have an aerodynamic form.
The use of sky courts and atriums		• The offices and service cores are arranged around a central atrium and there are sky gardens in each office wing.
The use of double skin facades		• The external façades of the three office wings consist of two layers: a wooden cladding and floor-to-ceiling sliding glass windows with an intermediate zone between the two façade layers.
The use of exposed thermal mass for night time ventilation		• Some parts of the skyscraper are building with large areas of exposed thermal mass to cool down the skyscraper at night.
The use of vegetation and greenery		• The existing of some green plants.

There are also many other environmental features in the design of Torre Cube (Figure 4.78). Wood and Salib (2013) summarized some of these features as the followings:

- The sky gardens provide favorable shade and act as communal terraces for social gatherings.
- The wooden cladding can slide horizontally (operated and manually controlled by the office users) for perfectly controlling the amount of shade and the flow of air into the skyscraper.
- The position of the service facilities in the concrete cores permits for open-plan office spaces.
- The central atrium offers daylight to the back side of the office areas.

Figure 4.78. View and elevation of Torre Cube (McManus 2014)

5. CONCLUSION

This chapter summarizes the main points of this thesis, mentions the broader implications of the thesis, and gives the importance of this topic for our environment.

The skyscraper is a relative term for building that seems to reach the sky and characterized by tall and extensive facades and small roofs. According to CTBUH, the building's height is a poor indicator for defining tall buildings, tall buildings are buildings that show some aspects of tallness in one or more of these three categories; height relative to context, proportion, and containing technologies which made buildings tall.

The ecological design can be defined as the design that aims to build with minimal ecological and environmental impact and to create a positive reaction to the building's surrounding natural environment. The necessity of ecological design for skyscrapers depends on the facts that these buildings consume high amounts of energy. For enhancing the ecological performance of skyscrapers, it is necessary to make them capable of generating and reducing energy loss by using renewable resources.

Green building rating systems generally are point-based systems in which buildings and skyscrapers earn points for satisfying green buildings criteria. The awarding of points relative to performance which covered under sustainable categories like management, sustainable sites, water, material and resources, energy and indoor environmental quality. Based on the achieved points, buildings and skyscrapers earn one of the rating levels of these systems. These rating systems were developed to address all buildings and skyscrapers everywhere, from existing ones to those still in design phase. Generally, it is remarkable that green building rating systems give important credits for evaluating the energy performance of skyscrapers.

This thesis focuses on the ecological approaches for generating the energy in skyscrapers with productive mode strategies by using solar and wind energy, and reducing the energy in skyscrapers with passive mode strategies by using solar and wind concepts. In terms of solar energy generation; solar PVs are considered as the only way to generate green and sustainable energy from the sun in skyscrapers by converting light into electrical energy. Solar PVs can generate electrical power without any noise, without any pollution, and without consuming any fuel. There are many types of solar PV cells such as; mono-crystalline, spherical, polycrystalline, amorphous, and hybrid silicon solar PVs. Two types of solar PVs systems can be considered for skyscrapers; PV panels and BIPVs. PV panels can be placed on the ground area or on the roofs of the skyscrapers, BIPVs works on the integration of PV systems with skyscrapers materials and construction.

In terms of wind energy generation; wind turbines are considered as the only way to generate green and sustainable energy from the wind in skyscrapers by converting wind movement into electrical energy. Wind turbines must first be evaluated by looking at the wind resource and wind speed at the site. Two types of BIWTs systems can be considered for skyscrapers; HAWT and VAWT. The first type of wind turbines is HAWT; in this turbine, the main rotor shaft and generator arranged horizontally, the blades always moves perpendicularly to the wind. The second type of wind turbines is VAWT; in this turbine, the main rotor shaft and generator arranged vertically, these turbines have the ability to take the wind from any direction. Wind turbines and solar PVs can be expensive systems at the beginning, but actually, they are economic systems that have cost-effectiveness, and can lessen the burden of the expanding non-renewable energy systems in the future.

Passive design can be defined as the design that considers the advantage of the surrounding environment and tries to optimize the use of the renewable resources of energy and minimize the use of non-renewable resources of energy. According to Yeang (2000), for reaching the objective of passive design, it is important to take into consideration the climatic conditions of the site. There are four main climatic zones and sites in the world; tropical, arid, temperate and cool. Passive design strategies include; the passive solar concepts for natural solar gain and daylight, and the passive wind concepts for natural ventilation.

This thesis covers research relating to the passive solar concepts for natural solar gain and daylight. Over time, concepts and strategies have been in developing to harness the solar energy especially the concepts and the strategies for natural solar gain to provide maximum natural heating and cooling and for daylight to provide maximum natural lighting for the buildings and skyscrapers.

The investigated principles for passive solar concepts in skyscrapers can be summarized as the following points (Yeang 1999, 2000, Gonçalves 2010, Sillah 2011, Bainbridge and Haggard 2011, AIA and SBSE 2012, Iitvegar 2013);

- Understanding solar movement and diagrams in the different climate zones of the world.
- Understanding the solar radiation transfer of heat.
- Understanding the principles and the sources for providing natural daylight.

The investigated design considerations for passive solar concepts in skyscrapers can be summarized as the following points (Pank et al. 2002, Yeang 1999, 2000, 2006, Richards 2007, Sillah 2011, Hart 2011, AIA and SBSE 2012, Susorova and Bahrami 2012, Wood and Salib 2013, Wood et al. 2014, Giacomello and Valagussa 2015, Al-Kodmany 2015, Letízia Lau 2015);

- Considering the local climate and solar paths of the skyscrapers.
- Considering optimal form, spatial arrangement and orientation.
- The use of sky courts and atriums in skyscrapers.
- The use of sunshades and light shelves.
- The use of greenery and vegetation in skyscrapers such as; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies.
- The use of different types of glasses in the facade design of skyscrapers such as; tinted glasses, solar-reflective glasses, and low-E glasses.
- The use of double skin façade in the façade design of skyscrapers.

This thesis covers also research relating to the passive wind concepts for natural ventilation. Over time, concepts and strategies have been in developing to harness the wind energy especially the concepts and the strategies for natural ventilation to provide maximum natural ventilating and cooling for the buildings and skyscrapers.

There investigated principles for passive wind concepts in skyscrapers can be summarized as the following points (Yeang 2000, Irving et al. 2005, Ghiaus and Allard 2005, Gonçalves 2010, Etheridge 2012, Wood and Salib 2013, Chenvidyakarn 2013, Al-Kodmany 2015);

- Understanding the two driving forces for natural ventilation in skyscrapers which are wind-caused and buoyancy-caused ventilations.
- Understanding wind movement and diagrams in the different climate zones of the world.
- Understanding the basic concepts of natural ventilation; single-sided ventilation, cross ventilation, and stack ventilation.

There investigated design considerations for passive wind concepts in skyscrapers can be summarized as the following points (Yeang 1999, Poirazis 2004, Irving et al. 2005, Gonçalves 2010, Hart 2011, Etheridge 2012, Liu 2012, Yudelson and Meyer 2013, Wood and Salib 2013, Al-Kodmany 2015);

- Considering the local climate.
- Considering the basic concepts of natural ventilation.
- Considering optimal form, spatial arrangement and orientation.
- The use of aerodynamic elements and forms.
- The use of sky courts and atriums in skyscrapers.
- The use of double skin facades.
- Constructing some parts of the skyscraper with large areas of exposed thermal mass to improve the night-time ventilation.
- The use of greenery and vegetation in skyscrapers such as; facade supported green walls, facade integrated living walls, integrated green terraces, and integrated tree balconies.

Passive wind and solar concepts are healthy, economical and sustainable concepts that can reduce the energy by taking the advantage from the sun and wind, and can improve the indoor environmental quality of the skyscrapers. The only disadvantage of passive wind and solar concepts is that these concepts are not sufficient and can’t be taken alone in the design of skyscraper in the extreme weather condition sites, the other wind and solar modes concepts; (e.g., mixed mode, full mode) must be also undertaken.

Table 5.1 provides a summary table of the case studies which are investigated in this thesis. This table concludes the ecological approaches for generating the energy with productive mode strategies and reducing the energy loss with passive mode strategies in the investigated skyscrapers. This table can be also used as a checklist for determining some of important ecological approaches for generating and reducing the energy loss in the skyscrapers by using renewable resources.

As it is mentioned in the practical implication part of this thesis, researching on the ecological approaches for generating and reducing the energy loss in skyscrapers by using renewable resources are considered among the ways for designing skyscrapers with green design strategies. This thesis is to lead designers, architects and all those involved in skyscrapers design to understand what methods and ecological approaches are used for generating and reducing the energy loss in the skyscrapers in order to improve the performance of skyscrapers and to make these tall buildings to have an excellent impact on their environment.

Table 5.1. Summary table of the case studies

Skyscraper	The Condé Nast Building	CIS Solar Tower	BWTC	Pearl River Tower	Menara Mesiniaga	Solaris	Commerzbank Tower	Torre Cube
Photo								
Country	USA	UK	Bahrain	China	Malaysia	Singapore	Germany	Mexico
Height	246.5 m	118 m	240 m	309.4 m	63 m	79.2 m	259 m	55 m
Function	Office	Office	Office	Office	Office	Office	Office	Office
Designer	Fox & Fowle	G. Tait, G.Hay	Atkins	SOM	TR H. & Yeang	TR H. & Yeang	Foster+Partners	Carme Pinós
Proportional Rate	It Consumes a percentage of 40 percent less energy consumption than similar traditional office skyscrapers in New York.	It Covers with a total of 7,244 PV panels that generate 390 kW of energy (around 181,000 units of renewable energy every year).	Each turbine can generate between 1.1 and 1.3 GWh annually (approximately 11 to 15 % of the office tower's electrical energy consumption).	It consume a percentage of 30-35 percent less energy consumption than similar traditional office skyscrapers in China.	The skyscraper has a 25% reduction in overall energy consumption compared to the other skyscrapers.	The skyscraper has a 36% reduction in overall energy consumption compared to the other skyscrapers.	It consumes 38% less energy. The approximate percentage of year natural ventilation that can be utilized is 80 %.	The approximate percentage of year natural ventilation that can be utilized is 100 %.
Energy generation with productive mode strategies (Solar energy)								
PV panels	-	X	-	-	-	-	-	-
BIPVs	X	X	-	X	-	-	-	-
Energy generation with productive mode strategies (Wind energy)								
HAWT	-	X	X	-	-	-	-	-
VAWT	-	-	-	X	-	-	-	-
Energy loss reduction with passive mode strategies (Passive solar concepts)								
Considering local climate	Temperate climate	Temperate climate	Arid climate	Tropical climate	Tropical climate	Tropical climate	Temperate climate	Tropical climate

Table 5.1. Continued. Summary table of the case studies

Skyscraper	The Condé Nast Building	CIS Solar Tower	BWTC	Pearl River Tower	Menara Mesiniaga	Solaris	Commerzbank Tower	Torre Cube
Perfect form, orientation	X	X	X	X	X	X	X	X
Sunshades and light shelves	-	-	X	X	X	X	-	X
Greenery and vegetation	-	-	-	-	X	X	X	X
Sky courts and atriums	-	-	X	-	X	X	X	X
Different types of efficient glasses	X	X	X	X	X	X	-	-
Double skin façade	-	-	X	X	X	X	X	X
Energy loss reduction with passive mode strategies (Passive wind concepts)								
Considering local climate	Temperate climate	Temperate climate	Arid climate	Tropical climate	Tropical climate	Tropical climate	Temperate climate	Tropical climate
Considering basic wind concepts	X	X	X	X	X	X	X	X
Perfect form, orientation	X	X	X	X	X	X	X	X
Aerodynamic elements and forms	-	-	X	X	X	X	X	X
Greenery and vegetation	-	-	-	-	X	X	X	X
Sky courts and atriums	-	-	X	-	X	X	X	X
Double skin façade	-	-	X	X	X	X	X	X
Exposed thermal mass	-	-	-	-	-	-	X	X

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APPENDICES

Appendix 1. The first collecting and gathering sources for the thesis

Topic	Author	Kind	Lang.	Year	Place	Keywords	Problem (Goal)	Important Contents	The provided examples
The Bioclimatic Skyscraper: A Critical Analysis Of The Theories And Designs Of Ken Yeang.	*PUTERI SHIREEN JAHN KASSIM	PhD's Thesis	English	2004	University of Brighton, England	• Ken Yeang, • Bioclimatic Skyscrapers.	provide a critical analysis of the theories and designs of Ken Yeang - with reference to the phenomenon of the 'bioclimatic skyscraper'.	focusing on case studies representing the main phases of Yeang's work, the performance of key 'bioclimatic features' and the overall 'bioclimatic' envelopes are analyzed.	Ken Yeang projects and theories.
Sustainable Skyscraper - Energy from Immediate Surrounding and Within	* Minnu Srinivasan	Master's Thesis	English	2008	University Of Cincinnati, USA	• Skyscrapers, • Sustainable design • Green and energy	There is no debate that Skyscraper is sustainable if we consider the density of population it supports compared to the building footprint. But if we consider from an energy consumption viewpoint, most of the skyscrapers today are inefficient buildings.	• explores the key issues of sustainable skyscrapers. • explore the state of the renewable energy technologies.	• the mixed used skyscraper in Boston. • Dif. examples of sustaiable skyscrapers around the world.
Green Skyscraper: Integration of Plants into Skyscrapers	* Shahrina Afrin	Master's Thesis	English	2009	KTH, Department of Urban Planning and Environment , Sweden	• Green Skyscraper, • integration of plants, • green roof, • green wall, • biofilter, • ecological impact, • climate, • energy savings, • indoor air quality, • aesthetics, • design technology.	Skyscrapers, though considered as a negative structure over the earth, will remain constructed as the population increased and so their demands. These tall buildings posses a lot of bad effects on our economy, environment and society by their excessive energy consumption, toxic materials using and destroying ecological balance. But as we cannot stop their construction all of a sudden, we need to search for alternative solutions to retrofit these harmful effects.	• studied to establish the necessity of planting to incorporate into skyscrapers. • The provisions of integrating plants into skyscraper include the four possible options like, Green roof, Green wall, Biofilter and Indoor potting plants which can be incorporated into the design. • Green Building Rating System. • Technologies to incorporate Green into Skyscraper.	• Ecological-Skyscrapers. • Some other case studies of designed green structures.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Examination of Integration Architecture in Ecological Architecture Since 1990 in Light of the Works of Ken Yeang and Norman Foster	*Nilay Özeler Kanan	Master's Thesis	Turkish	2010	Eskişehir Osmangazi üniversitesi	• Architectural Integration, • Active and Passive Design Systems, • Energy • Gains, • Norman Foster, • Ken Yeang.	In this study, passive and active building design systems applied to buildings to improve energy performance are considered in architectural and integrative terms. How architects Norman Foster of England and Dr. Ken Yeang of Malaysia, whose buildings most often implement these systems, have approached their design choices and systems in their works since 1990 is examined.	• key concepts are presented in relation to the keywords of sustainability, ecology and energy. • building-integrated active and passive technologies, the intersection of engineering and architecture, are classified in terms of solar and wind energy.	ten example buildings from the works of Ken Yeang and Norman Foster.
An Investigation Of Sustainability Formulating The High Rise Buildings	* Deniz ZİNZADE	Master's Thesis	Turkish	2010	İstanbul Teknik Üniversitesi	• High Rise Buildings. • Sustainability. • Performance strategies.	In order to shape today and the future effectively, and to beat ecological problems, sustainability concept and sustainability politics must be respected especially in tall buildings design.	show the sustainable building design and performance strategies and to state the sustainability strategies shaping the high rise buildings investigated throughout this study.	Dif. Examples of sustainable buildings around the world.
In The Context Of Sustainable Architecture Examining Of High-rise Buildings	* Gözde ÇAKIR	Master's Thesis	Turkish	2011	Mimar Sinan Fine Arts University, Turkey	• sustainability, • ecology, • sustainable architecture, • high-rise building	Energy and resource consumption of the high-rise buildings are considerably higher than other building types in the period of construction, usage and destruction. Thus, the importance of sustainability of high-rise buildings is acute for architecture.	In this study, the term of sustainability and principals of sustainable architecture are defined, high-rise buildings are examined according to these principals and high-rise buildings are researched over the world in the guidance of design criteria that have been put forward.	• Commerzbank, Almanya • Bank of America, NY • İstanbul Sapphire, İstanbul.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Tall Buildings: Search for a New Typology	*Antony Wood	Thesis Abstract	English	2011	University of Nottingham, England	• Tall Buildings. • Sustainability. • Energy Generations	This submitted 'PhD by Publications' –consisting of a Narrative and six published papers – explain how the author's research has contributed to this central thesis; the quest for a new typology for tall buildings which are appropriate to the local, the global and the major challenges of the age.	• New Paradigms in High Rise Design. • Sustainability: A New High Rise Vernacular. • Five Energy Generations of Tall Buildings: A Historical Analysis of Energy Consumption in High-Rise Buildings.	Dif. Examples of skyscrapers around the world.
Tall Buildings And Sustainable Energy	*Nazlı Demir	Master's Thesis	Turkish	2011	Yildiz Technical University	• Tall buildings, • Sustainability, • Wind turbine, • Solar energy, • Photovoltaic cells, • Heat Pumps, • Smart glazing, • Natural ventilation,	In response to exhausting fossil fuel sources, intensive researches on alternative renewable energy have been continued all over the world. Alternative sources instead of fossil energy sources on the production of construction materials have been investigated nowadays. Preventions are necessary not only for construction materials but also for increasing high rise buildings.	demonstrate the compatibility and applicability of renewable energy sources to tall buildings. The building integrated systems using advanced technology enables buildings to save energy via the usage of renewable energy or precautions taken during the design and detailing of the building.	Dif. Examples of skyscrapers around the world.
Bio climatic skyscraper: Possible next step of urban development in polluted megalopolises	* Aija Baumane	Bachelor Dissertati on	English	2012	VIA University College, Horsens, Denmark	• BCS; • urban and • coexisting; • Dalian project; • ecosystem; • Ken Yeang; • biomimicry; • parametric design.	• What could be a solution for existing problems in polluted megalopolises around the world? • What can construction of bioclimatic skyscrapers offer city inhabitant and surrounding ecosystem?	• Eco-design: Biomimicry & BC architecture: drawing parallels. • BCS Eco skyscraper: part of our ecosystem. • BCS Design principles and benefits. Case study: Dalian Project. • Future perspective on BCS development Case study: Dubai miracles	• Ken Yeang projects. • Dalian project, China. • Dubai miracles.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Bioclimatic Design Approach In Ken Yeang's High Buildings	* Tarik Taştan	Master's Thesis	Turkish	2012	MALTEPE ÜNİVERSİTESİ	• Ken Yeang, • Bioclimatic Architecture, • High-rise Buildings, • Ecological Design	As a result of the industrial revolution, the process of rapid urbanization and infrastructure and rapid depletion of natural resources which continuous also today cause major environmental pollution. Therefore, to design friendly high-rise buildings to the ecosystem are gaining greater importance against more energy and material consuming structures.	• high rise building and bioclimatic architectural concepts, processes of historical development and their mutual relationship are examined. • examines Yeang's architectural career and his bioclimatic design approach for high-rise buildings.	inspects Ken Yeang's 8 selected high-rise bioclimatic structures.
Evaluation Of Advanced Building Component Systems According To Environmental Sustainability Criteria For High-Rise Buildings	* Merve Toptaş	Master's Thesis	English	2012	İSTANBUL TEKNİK ÜNİVERSİTESİ	• Component Systems • Sustainability • High-Rise Buildings	investigate the advanced building elements, their applications on high rise buildings and according to this principle, review of the buildings' sustainability degree.	In the context of the thesis, sustainability concept, sustainability criteria, advanced and energy-efficient building element systems, alternative assessment methods are examined, afterward the selected high-rise buildings are profoundly analyzed.	
Sustainability Of High-Rise Buildings: Energy Consumption By Service Core Configuration	* İLKAY GÜRYAY	Master's Thesis	English	2012	Mıddle East Technıcal Unıversıty	• Service core, • high-rise buildings, • sustainability • energy consumption optimization • thermal simulation,	• the effect of different core types and locations on the energy consumption of high-buildings	• evolution of sustainable high-rise buildings. • sixteen alternative configuration models with central, end and split core types are determined as the representative of possible design choices.	• Dif. Examples of skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

RETHINKING THE SKYSCRAPER : THE GREEN SKYSCRAPERS OF KEN YEANG	* H. van Dijk	ArchitectureThesis	English	2012	Delft University of Technology, South Holland	• Green Skyscrapers • Ken Yeang, • Sustainable design	Why and how Yeang started the research how to design buildings ecologically, why skyscrapers, and how he developed the theory from a local (tropical climate) point of view to a world-wide acknowledged ecological design theory.	• Background of Ken Yeang. • The evolution of the skyscraper. • Typology versus ecological design. • What is ecological design? • Design principles - theory and practice.	Ken Yeang projects and theories.
TALL BUILDINGS AND SUSTAINABILITY	* Philip Francis Oldfield	PhD's Thesis abstract	English	2012	University of Nottingham	• Sustainability. • Tall Buildings	identify opportunities and challenges for more sustainable high-rise architecture. In considering the holistic sense of sustainability, including environmental, social and economic issues.	• Global Trends in High-Rise Design. • Five Energy Generations of Tall Buildings: An Historical Analysis of Energy Consumption in High-Rise Buildings. • Aluminium and Double Skin Facades. • Strategies to Reduce Embodied Energy / Carbon in High-Rise	Dif. Examples of Sustainable Skyscrapers around the world.
A modelling study of segmentation of naturally ventilated tall office buildings in a hot and humid climate	* PEI-CHUN LIU	PhD's Thesis	English	2012	University of Nottingham	• Natural Ventilation, • Tall Office Buildings, • Segmentation,	The overall objectives are to determine whether the magnitudes of air flow rates and the resultant flow velocity can achieve the desired comfort ventilation over a range of specified conditions.	• the evaluation of naturally ventilated tall buildings with reference to segmentation in the climatic context.	This research is concerned with the prospect of tall office buildings that are purely naturally ventilated.
Design Strategies For Environmentally Sustainable Residential Tall Buildings In	* Sabina Fazlic	PhD's Thesis	English	2013	Welsh School of Architecture Cardiff University	• Sustainable • Residential Tall Buildings • Cool Temperate	As the aspirations for tall buildings have shifted towards sustainability, architects face newfound challenges in finding sufficient information on	find principles of environmentally sustainable design to contribute to the creation of residential tall buildings in the cool temperate	Dif. Examples of Sustainable Residential Tall Buildings around the world

Appendix 1. Continued. The first collecting and gathering sources for the thesis

The Cool Temperate Climates Of Europe And North America						Climates • Europe And North America	environmental strategies and ways in which to apply them, particularly when specific climatic and functional aspects are considered.	climates of Europe and North America and to organize them to best inform architects during the schematic design stage.	especially in Europe And North America.
Comparison of Different Facades for High-rise Buildings in Hot and Cold Climates in terms of Material Usage	* Salih Ben-Nail Abu Sief	Master's Thesis	English	2014	Eastern Mediterranean University Gazimağusa, North Cyprus	• Construction, • Material, • Climate, Facade, Building Environment • Green Building.	The consideration of appropriate building facade materials is a major factor that is often undermined in the building sectors which relatively decreases the functionality and the overall productivity of buildings.	serve as a guide to both architects and architects‟ industry to get a better solution in cold and hot climate. It will provide a prior knowledge to take a decision on the best quality facade materials with maximum efficiency for building facade construction.	Dif. Examples of Skyscrapers around the world.
Sustainable High-rise Construction in Shanghai	* Gina Letízia Lau	Master's Thesis	English	2015	Tecno Lisbona	• Shanghai; • Sustainable construction; • Green building; • High-rise; • GBEL assessment; • Shanghai Tower.	Shanghai is a mega-city with a population over 24 million people, due to its high density urban morphology and limited land resources, high-rise buildings are likely the first choice to minimize the impact on land use. Although buildings provided amount benefits to society, but they are one of the main consumers of energy, as well as the main sources of environmental pollution. In order to give a better future to next generation, must start investing in sustainable construction, based on best practices that emphasize long-term affordability, quality and efficiency.	• get a better understanding of Evaluation Standard for Green Building in China and the respective assessment system. • incorporates numerous green skyscrapers elements and sustainable practices.	Shanghai Tower

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Tall Buildings and Sustainability	* Will Pank, *Herbert Girardet, *Greg Cox,	Book	English	2002	Economic Development Office Corporation of London	• Sustainability; • development; • carbon, • supply chain	examines the options for tall buildings in the City of London in the context of sustainable development.	• The effect of tall buildings on their local environment and on their occupants is considered. • An analysis of new developments in the design, construction and operation of tall buildings	a discussion of “best practice” examples of new design ideas from around the world.
Big and Green: Toward Sustainable architecture in the Twenty-First Century	* David Gissen	Book	English	2002	Princeton Architectural Press, New York, USA	• Green architecture, • Skyscraper, • Sustainable Design	More than a century after its inception, the skyscraper has finally come of age. Though it has long been lampooned as a venal and inhospitable guzzler of resources, a revolutionary new school of skyscraper design has refashioned the idiom with buildings that are sensitive to their environments, benevolent to their occupants, and economically viable to build and maintain.	• examine the sustainable skyscraper, its history, the technologies that make it possible, and its role in the future of urban development. • examines some important recent sustainable skyscrapers with project descriptions, photographs, and detailed drawings. Interviews with such leaders in the field as Sir Richard Rogers, William McDonough, and Kenneth Yeang are also included.	40 of the most important recent sustainable skyscrapers-including Reuters Buildings in New York, Commerzbank in Frankfurt, and spectacular Dutch Pavilion from Expo 2000 in Hanover.
TALL BUILDINGS: From Engineering to Sustainability	*Y K Cheung *K W Chau	Book	English	2005	World Scientific Publishing Co. Pte. Ltd, Singapore	• tall buildings • sustainability	the book addresses the development and application of knowledge in solving problems related to tall buildings.	A collection of papers presented at the Sixth International Conference on Tall Buildings (ICTB), this volume clearly explains the engineering and socio-economic aspects of tall buildings in specific areas of sustainability.	The papers focus on Asian cities, where tall buildings have become a major feature of the built environment.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

101 of the World's Tallest Buildings	* Georges Binder	Book Ebook	English	2006	Images Publishing, Australia	• Skyscrapers	Since the skyscraper's humble beginnings as a 10-story building in Chicago, more than 100 years ago, the super-tall building has been a source of wonder for the layman, and of inspiration, innovation, and fierce competition for architects, engineers, contractors, and the countless others involved with the complex challenge of constructing increasingly higher buildings.	This book is a fully illustrated snapshot of 101 of today's tallest buildings from around the world. The next wave of super-tall buildings is so impressive that a selection of projects currently under construction is presented in the second part of the book.	101 Examples of Skyscrapers around the world.
Seeking the suitable and sustainable skyscraper	* Antony Wood	Book (Seminar)	English	2009	GACCoM Green Building Seminar, UIC, Urbana-Champaign	• Skyscrapers, • Sustainable design	Challenges: Tall Buildings & Sustainability	• Design Principles for future Tall Buildings.	Dif. Examples of sustaiable skyscrapers around the world.
The Environmental Performance of Tall Buildings	* Joana Carla Soares Goncalves	Book	English	2010	Earthscan, UK	• Green architecture, • Skyscraper, • Sustainable Design	Tall buildings represent one of the most energy-intensive architectural typologies, while at the same time offering the high density work and living conditions that many believe will an important constituent of future sustainable communities. How, then, can their environmental impact be lessened.	• an overview of the tall building and its impacts design principles and the development of the sustainable tall building • global perspectives (covering North and South America, Europe, the Middle East and Asia) • detailed, qualitative case studies of buildings in design and operation • the future for sustainable tall buildings.	Dif. Examples of Skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Skyscraper Green Retrofits Guide	* Sze Ting Tam	Book (research paper)	English	2011	Global Energy Network Institute (GENI)	• Skyscrapers • Green architecture, • Sustainable design	High rise buildings are cool and modern, but they generate 16 percent of the energy consumption worldwide. Due to global population growth, more energy will be consumed annually; hence, the tremendous release of greenhouse gases will further increase exponentially with the population.	• investigates the ways to retrofit high rise commercial buildings into outstanding sustainable buildings. • Introduction of building Rating System • Potential Ways to Retrofit Buildings.	• Empire State Building • Adobe Towers • Willis Tower • Paharpur Business Center • Glastonbury House.
Skyscrapers of the Future	*Carlo Aiello	Book Ebook	English	2010	eVolo Press, NY, USA	• Skyscrapers • architecture, • Evolo, • Future design	• explains the true genetics and economics behind the birth and future of the skyscraper. • the relationship between the natural environment, human activity, and supernatural reality with provocative images of an apocalyptic urban future.	• start off with the history and evolution of building high, from the Egyptian pyramids, Gothic cathedrals, and first American skyscrapers to the contemporary reality in Asia and the Middle East. • some of the latest ideas for skyscraper design by some of the most forward-looking architects	projects from eVolo's Skyscraper Competition
Skyscrapers	* Chris van Uffelen	Book	English	2012	Braun, Schweiz, Switzerland	• Skyscrapers	skyscrapers became the defining features of city scapes with the advent of the 20 th century. Since the turn of the millennium, they are again among the most prestigious and coveted architectural challenges.	presents the most spectacular towers still under construction as well as future-oriented experimental designs. Most current projects are being implemented in the Arab-Asian realm, USA and Europe	Dif. Examples of Skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Guide To Natural Ventilation in High Rise Office Buildings (Ctbuh Technical Guide)	* Antony Wood, * Ruba Salib	Book	English	2013	Routledge, USA	• Heating, Ventilation & Air Conditioning, • Skyscraper, • Sustainable Design	Mechanical HVAC systems (Heating, Ventilation and Air-Conditioning) in tall office buildings typically account for 30-40 percent of overall building energy consumption. The increased efficiency (or possibly even elimination) of these mechanical systems – through the provision of natural ventilation – could thus be argued to be the most important single step we could make in making tall buildings more sustainable.	sets out recommendations for every phase of the planning, construction and operation of natural ventilation systems in these buildings, including local climatic factors that need to be taken into account, how to plan for seasonal variations in weather, and the risks in adopting different implementation strategies.	Dif. Examples of Skyscrapers around the world.
eVolo Skyscrapers, Volume 1	* Carlo Aiello	Ebook	English	2013	eVolo Press, NY, USA	• Skyscrapers • architecture, • Evolo,	What will the skyscrapers of the future look like? Will they be covered in gardens, shaped like rocket ships, submerged in the ocean?	The projects have been organized into six chapters that describe the current position and the future of vertical architecture and urbanism. • *Technological Advances*, • *Ecological Urbanism* • *New Frontiers*. • *Social Solutions*, • *Morphotectonic Aesthetics*, • *Urban Theories and Strategies*.	300 outstanding skyscraper projects that challenge the way we understand architecture and their relationship with the natural and built environments.
eVolo Skyscrapers 2: 150 New Projects Redefine Building High	* Carlo Aiello	EBook	English	2014	eVolo Press, NY, USA	• Skyscrapers • architecture, • Evolo,	This publication is the follow-up to the highly acclaimed book *eVolo Skyscrapers*.	the advances in technology, the exploration of sustainable systems, and the establishment of new urban and architectural methods for skyscrapers	150 new skyscrapers of eVolo Skyscraper Competition

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Green Walls in High-Rise Buildings: An output of the CTBUH Sustainability Working Group	*Antony Wood, * Payam Bahrami, * Daniel Safarik	Book Ebook	English	2014	Images Publishing Dist Ac, Australia	• Sustainablity , • High-Rise Buildings, • Green Design	offers an extensive overview of the use of vertical vegetation in high-rise buildings, an in-depth analysis of green walls, definitions and typology, including standards, policies and incentives.	• delves into architect-design considerations and limitations, the effects of green walls on energy efficiencies and includes recommendations and future research.	features comprehensiv e case studies, along with architectural theories of the public and private benefits of green walls.
Roadmap on the Future Research Needs of Tall Buildings	* Philip Oldfield, *Dario Trabucco *Antony Wood	Book	English	2014	Council on Tall Buildings and Urban Habitat, Chicago, USA	• Research Needs • Tall Buildings	The Roadmap on the Future Research Needs of Tall Buildings aims to identify priority research topics and research gaps in the field of tall buildings	acts as a guide to assist all those concerned with the typology with the necessary planning of future research and the pursuit of research funding in order to advance tall buildings to their optimum level in the coming years.	
Tall Buildings: Structural Systems and Aerodynamic Form	*Mehmet Halis Gunel *Huseyin Emre Ilgin	Book	English	2014	Routledge, USA	• Tall buildings, • Aerodynamic Form • Structural Systems	provide the architectural and structural knowledge which must be taken into account in order to design tall buildings successfully.	shown that wind load has a very important effect on the architectural and structural design.	Dif. Examples of Skyscrapers around the world.
Virtecal Greenery : Evaluating the High-Rise Vegetation of the Bosco Verticale, Milan	*Elena Giacomell o *Massimo Valagussa	Book	English	2015	CTBUH Council on Tall Buildings and Urban Habitat, Chicago, USA	• Skyscrapers, • Sustainability, • green Design.	methods and approaches for evaluating of living green façade technologies, whether applied to tall buildings.	• An Overview of the Bosco Verticale. • Monitoring Bosco Verticale’s Trees: Methodology and Results. • Shading Capacity of Vegetation: Evaluation of the Envelope’s Energy Performance. • Assessment of Tree Maintenance at Bosco Verticale.	the Bosco Verticale, Milan

Appendix 1. Continued. The first collecting and gathering sources for the thesis

ASHRAE Design Guide for Tall, Supertall, and Megatall Building Systems	* Peter Simmonds	Book	English	2015	ASHRAE, 1791 Tullie Circle, N.E. Atlanta, GA, USA	• Tall buildings, • Architecture • design	Tall buildings present unique and formidable challenges to architects and engineers because of their size, location in major urban areas, and the multiple, complex occupancies they often contain.	ASHRAE Design Guide for Tall, Supertall, and Megatall Building Systems is a unique reference for owners; architects; and mechanical, structural, and electrical engineers as well as other specialized consultants involved in designing systems for these buildings.	Dif. Examples of Bioclimatic Skyscrapers
Designing with Nature: The Ecological Basis for Architectural Design	*Ken Yeang	doctoral thesis	English	1995	Architectural Association in London, UK McGraw-Hill, Inc. USA	• Ken Yeang, • Sustainability. • Eco design.	In presenting its compelling case for ecological design and its various strategies for achieving it, the book provides a full understanding of the impact that different kinds of built works have on the natural environment, explores what can be done to mitigate damage to a building site and its natural resources, and features examples of ecologically sound building design.	Get state-of-the-art information on such innovative methods as low-energy and bioclimatic design, recycling and disposal of materials, ecological land-use planning, natural resource management, selecting building materials with a long life span and low maintenance costs, designing "low-environmental-impact" buildings.	case studies of "low-environmental impact" building designs from around the world.
The Skyscraper Bioclimatically Considered	*Ken Yeang	Book	English	1996	Wiley Publication, UK	• Ken Yeang, • Bioclimatic Skyscrapers.	Since its invention, there have been many advances in skyscraper design. Malaysian architect Ken Yeang, provides an informative study of this building type, discussing environmental systems, the superstructure and foundations, the changing nature of work and the workplace.	• The geography of the skyscraper. • Sub-structure and super-structure. • İntelligent building systems. • Vertical landscaping. • Wind and ventilation. • External wall and cladding.	• Dif. Examples of Bioclimatic Skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Rethinking the Skyscraper: The Complete Architecture of Ken Yeang	* Robert Powell	Book	English	1999	Whitney libarary of design, Singapore	• Ken Yeang, • green Skyscrapers.	It has long been assumed that skyscrapers, as high consumers of energy and materials, cannot be sensitive to ecological and environmental issues. Yeang's towers, by contrast, use vegetation as a crucial component of the facade and interior, acting both to remove heat and purify the air.	The monograph examines the design elements that characterize Yeang's famous "green skyscrapers": low-energy, passive techniques for lighting and heating, environmentally friendly materials for facades and interiors, well-planned pedestrian linkages, public zones, innovative multiple-use areas, and stunning vistas.	Numerous examples include built projects designed by his Malaysian firm, as well as theoretical case studies. 100 color illustrations.
The green skyscraper: the basis for designing sustainable intensive buildings	*Ken Yeang	Book	English	1999	Prestel, Germany	• Green architecture, • Skyscraper, • Sustainable design.	This book aims to establish a strategy for sustainable design, and for understanding the decisions that need to be made in the design of a complex building type such as the skyscraper.	• examining the fundamental premises of such an approach as well as its practical applications to the contemporary skyscraper. • the use of energy and materials and their physical impact on the ecosystem, illustrated with case studies from Yeang's own projects, experiments and research.	• Ken Yeang projects and theories.
SERVICE CORES	*Ken Yeang	Book	English	2000	WILEY-ACADEMY, UK	• architecture, • Skyscraper, • Service cores.	discusses the historical treatment and development of service cores, and provides an outline guide to the considerations required in their design.	deals with the internal vertical cores of skyscrapers: the parts that are necessary both for environmental servicing and to provide access to the building's usable spaces.	a series of case studies, featuring mainly skyscraper buildings from all over the world

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Bioclimatic Skyscapers Revised Edition	*Ken Yeang	Book	English	2000	Ellipsis London, Limited; Rev Sub edition	• Ken Yeang, • Bioclimatic Skyscrapers.		presents the theoretical framework for Yeang's design work, and looks to the future, to explorations of wind energy and new environmentally-friendly or reactive materials.	Ken Yeang projects and theories.
Hamzah & Yeang : Ecology of the Sky (The Millennium Series)	* Ivor Richards	Book	English	2001	Images Publishing Group, Australia	• Ken Yeang, • Eco Skyscrapers.	looks in-depth at the skyscraper built form and at the ways in which this tall building-type can be designed to be as ecologically-sustainable as possible.	It reviews and illustrates the many eco-towers designed by Ken Yeang of T. R. Hamzah & Yeang Sdn. Bhd. and their experiments trying to design the skyscraper as a man-made ecological system.	many eco-towers designed by Ken Yeang of T. R. Hamzah & Yeang Sdn
Reinventing the Skyscraper: A Vertical Theory of Urban Design	*Ken Yeang	Book	English	2002	Wiley Publication, UK	• Urban & Land Use Planning. • Skyscraper, • Sustainable design.	proposes a new vertical theory of urban design and discusses Yeang's theoretical propositions and design concepts that include those for de-compartment the skyscraper's built form, for urban analysis as a three-dimensional matrix and for a strategy to map the land use of the skyscraper.	Unique treatment of urban design of skyscrapers. * Includes progressive ideas about vertical landscaping. * Provides new mapping techniques useful in both conventional and vertical urban design.	• Ken Yeang projects and theories.
Ken Yeang: Eco Skyscrapers I	*Ivor Richards	Book Ebook	English	2007	Images publishing, Australia	• Ken Yeang, • Eco Skyscrapers.	Ken Yeang makes it clear that the skyscraper building type is probably the most ecologically unfriendly of all building types, but states that they are an economically viable alternative. For that, it is necessary to make them as sustainable as possible.	• presents Ken Yeang's work on the design of ecologically responsive skyscrapers. • includes his essay on applying green-design principles to the skyscraper typology.	• Ken Yeang projects.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Ecodesign: A Manual for Ecological Design	*Ken Yeang	Book	English Turkish	2006	Wiley Publication, UK	• Architecture, • Sustainability, • Green Design.	learn to develop structures and systems that are low consumers of non-renewable resources, built with materials that have low ecological consequences to facilitate disassembly, reuse and recycling.	find clear instructions on how to design, build and use a green sustainable architecture in *Ecodesign*.	Ken Yeang projects and theories.
Dictionary of Ecodesign: An Illustrated Reference	*Ken Yeang, *Lillian Woo	Dictionar y	English	2010	Routledge, USA	• Architecture, • Sustainability, • Eco Design.	The first guide to the terminology of sustainable design. This illustrated dictionary provides over 1500 definitions and explanations of ecodesign terms.	It is an essential reference for all architects, engineers, planners and environmentalists involved in designing and planning projects and schemes in the built environment.	
Vertical Eco infrastructure: The Work of T.R. Hamzah & Yeang	* Leon Schaik	Book	English	2010	Images Publishing Dist Ac, Australia	• Eco infrastructure • T.R. Hamzah & Yeang	Eco-infrastructure is the continuous 'green' subculture which runs throughout a building integrating inorganic mass with the organic content of the green eco-infrastructure, imitating the balance of biotic with the abiotic constituents present in an ecosy.	Eco-infrastructure is the continuous 'green' subculture which runs throughout a building integrating inorganic mass with the organic content of the green ec-oinfrastructure, imitating the balance of biotic with the abiotic constituents present in an ecosy.	Ecoinfrastruct ure designed by Ken Yeang of T. R. Hamzah & Yeang Sdn
Ken Yeang: Eco Skyscrapers II	*Lucy Bullivant	Book Ebook	English	2011	Images publishing, Australia	• Ken Yeang, • Eco Skyscrapers	Tall buildings represent a way of the future which is perceived as necessary despite being environmentally unfriendly. This book demonstrates methods to make these energy-consuming buildings as efficient as possible until a time when the world finds economically viable alternatives.	• presents Ken Yeang's work on the design of ecologically responsive skyscrapers. • includes his essay on applying green-design principles to the skyscraper typology.	• Ken Yeang projects.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Green Design: From Theory to Practice	*Ken Yeang	Book	English	2011	Black Dog Architecture, London, UK	• Architecture, • Sustainability, • Green Design.	discussion of the issues surrounding sustainability, environmental responsibility and the use of natural resources becoming unavoidable. The book looks at what Green Design actually entails and how this can be implemented within today's architectural practice.	• looking at the need to comply with green accreditation systems. • looks in-depth at the way we use buildings, distribution systems of energy, transportation, manufacturing and the food industries, and ultimately at the way we lead our lives, to evaluate and address the true meaning of Green Design and the real causes underpinning today's environmental crisis.	Green Design projects and theories.
Ecoarchitecture : The Work of Ken Yeang	*Sara Hart	Book	English	2011	Wiley Publication, UK	• Ken Yeang, • Eco architecture.	Featuring 22 of Yeang's most significant projects, Eco-Architecture begins with his earliest work on the environmental design, executed as a student at the Architectural Association and then a Phd student at Cambridge in the early 1970s, and with his most recent projects with Llewelyn Davies Yeang in London and TRHY in Kuala Lumpur.	• Bioclimatic Design. • Eco master planning. • Transitional projects. • Vertical Urbanism. • Technical innovation. • Vertical Ecoinfrastructure.	• Ken Yeang projects.
The Future of the City: Tall Buildings and Urban Design	* Kheir Al-Kodmany, *M. M. Ali	Book	English	2013	WIT Press, UK	• Sustainable Design, • Built Environment • Skyscraper, • Urban & Land	Major cities of the world are facing crisis of housing, shortage of workplace, polluted environment, and inadequate and deteriorating infrastructure. Existing cities have a challenge of how to	• enlightens about integrating tall buildings into the cities of the future. • provides a global perspective on the urbanization	Dif. Examples of Skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

						Use Planning	introduce new tall buildings in the urban fabric whereas expanding cities are exploring new schemes about how to select the most appropriate sites and fashion the contextual setting of new tall buildings.	phenomenon and tall building development and examines their underlying logic, design drivers, contextual relationships, and pitfalls. • discusses spatial planning and sustainable strategies as well as offers pragmatic architectural and urban design guidelines to better design tall buildings for future cities.	
Eco-towers: Sustainable Cities in the Sky	* Kheir Al-Kodmany	Book	English	2015	WIT Press, UK Computational Mechanics, USA	• Green Skyscrapers. • LEED Skyscrapers. • Eco iconic towers.	provide solutions to crises the world faces today including climate change, depleting resources, deteriorating ecology, population increase, decreasing food supply, urban heat island effect, pollution, deforestation, and more.	• introduces readers to groundbreaking designs, most progressive projects, and innovative ways of thinking about a new generation of green skyscrapers. • explores new designs that are employing cutting-edge green technologies at a grand scale including water-saving technologies, solar panels, helical wind turbines, sunlight-sensing LED lights, rainwater catchment systems, graywater and blackwater recycling systems, seawater-powered air conditioning,	Dif. Examples of Skyscrapers around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

New Suburbanism: Sustainable Tall Building Development	* Kheir Al-Kodmany	Book	English	2016	Routledge, USA	• Sustainable Design, • Built Environment • Skyscraper	Much of the anticipated future growth in the United States will take place in suburbia. The critical challenge is how to accommodate this growth in a sustainable and resilient manner. This book explores the role of suburban tall as a viable, sustainable alternative to continued suburban sprawl.	• identifies 10 spatial patterns in which tall buildings have been integrated into the American suburbs. • discusses sustainable architectural design and site planning strategies and provides case studies of sustainable tall buildings that were successfully integrated into suburban settings.	The findings are based on analyzing over 300 projects in 24 suburban communities within three major metropolitan areas
Sustainable Building Technical Manual: Green Building Practices for Design, Construction, and Operations.	* David A. Gottfried	Book	English	1996	Public Technology, Inc, USA	• Green building • Architecture • Sustainable design	provide public and private building industry professionals with suggested practices across the full cycle of a building project, from site planning to building design, construction, and operations.	• Economics and Environment. • Green Building Design priciples. • Issues and Trends	Dif. Examples of sustaiable buildings around the world.
Sustainable Architecture Module: Introduction to Sustainable Design	* Jong-Jin Kim	Book	English	1998	National Pollution Prevention Center for Higher Education, USA	• Architecture, • Sustainability, • Eko Design.	Find architectural solutions that guarantee the well-being and coexistence of inorganic elements, living organisms, and humans.	• Principles of Sustainable Design. • Methods for Achieving Sustainable Design.	
Agenda 21 on Sustainable Construction	* Luc Bourdeau	Book	English	1999	CIB Report Publication 237, Rotterdam, Netherlands	• architecture, • Sustainable design		• concepts of sustainable development and sustainable construction. • main issues and challenges of sustainable construction. • resulting challenges and actions.	CIB activities on sustainable construction

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Energy and environment in architecture: a technical design guide	* Nick Baker *Koen Steemers	Book	English	2005	E&FN Spon, New York	• Energy and environment, • Architecture. • LT Method	The book is a technical guide in that it deals with the processes and mechanisms which influence environmental performance and energy use in buildings.	• Low-energy strategies. • The provision of comfort. • Heating and Prevention of overheating. • Daylighting, Ventilation and Energy systems • The LT Method.	Dif. Examples of Sustainable buildings around the world.
Understanding Sustainable Architecture	* Terry Williamson, *Antony Radford *Helen Bennetts	Book	English	2004	Taylor & Francis e-Library, USA	• Sustainablity • Archıtecture	The aim of this book is to be transformative by promoting understanding and discussion of commonly ignored assumptions behind the search for a more environmentally sustainable approach to development.	a review of the assumptions, beliefs, goals and bodies of knowledge that underlie the endeavor to design (more) sustainable buildings and other built developments.	Dif. Examples of Sustainable buildings around the world.
Double Skin Façades for Office Buildings	* Harris Poirazis	Book	English	2004	Lund University, Lund Institute of Technology, Lund, Sweden	• Double Skin Facade, • Active Facade, • Passive Facade, • Curtain Wall, • Supply Air Window, • Office Building.	describe the concept of Double Skin Façades based on different sources of literature.	The advantages and disadvantages of double skin façades found in different literature sources are mentioned and described.	examples of office buildings with Double Skin Façades are presented
Sustainable Design: Ecology, Archıtecture, And Plannıng	* Daniel E. Williams	Book	English	2007	John Wiley & Sons., Canada	• Sustainable Design • Ecology, • Archıtecture	must aggressively commit to designing sustainably—that is, designing within the limits of our natural resources and natural laws. Some choices are obvious and readily available to us.	This book presents multiple scales and a comprehensive overview of sustainable-design principles and practices.	Dif. Examples of Sustainable buildings around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Bright Green Buildings: Convergence of Green and Intelligent Buildings	Scott Walker, Continental Automated Buildings Association, CABA	Book (research paper)	English	2008	Frost & Sullivan, USA	• Bright Green Buildings, • Intelligent Buildings.	provide documented evidence and build tools that can be used to educate and influence end-users, building owners, architects, and contractors that a "greener building" can be achieved using intelligent technology, This concept – intelligent, green, and profitable – is what we call a bright green building.	• Concept Adoption Factor Analysis. • Evaluating the Impact and Benefits of Intelligent and Green Building Technology. • Green Measurement and Rating Systems for Buildings in North America.	Dif. Examples of green buildings around the world.
Green BIM: Successful Sustainable Design with Building Information Modeling	*Eddy Krygiel *Bradley Nies	Book	English	2008	Wiley Publishing, Inc., Indianapolis, Indiana	• BIM. • architecture, • Sustainable design	Meet the challenge of integrating Building Information Modeling and sustainability with this in-depth guide, which pairs these two revolutionary movements to create environmentally friendly design through a streamlined process.	• features practical strategies, techniques, and real-world expertise so that you can create sustainable BIM projects.	
Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide.	* Sue Roaf *David Crichton *Fergus Nicol	Book	English	2009	Elsevier Ltd, USA	• Climate change, • architecture, • Sustainable design	Today we look around and see a world divided between those who are unrestrained in their energy profligacy, building irresponsible cities where cities should never be, vying to see who can build the tallest building in the world and literally unconnected to the fact that they are contributing to the destruction of our common future.	The path to this book passed through nomad tents on tribal roads, and across vast deserts where families, using little more energy than twigs to cook on, lived in comfort, and in some cases luxury, in the extreme climates of what we would see only as barren lands.	Dif. Examples of Sustainable buildings around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Eco-Architecture III : Harmonisation between Architecture and Nature	*S. Hernández *Wessex *W.P. De Wilde	Book	English	2010	WIT Press, UK	• nature, • Eco architecture, • Sustainable design	Decisions have to be taken on ecological grounds concerning locations, siting and orientation, as well as the well-informed choice of materials.	Eco-Architecture implies a new approach to the design process intended to harmonise its products with nature. This involves ideas such as minimum use of energy at each stage of the building process.	Dif. Examples of eco buildings around the world.
Guide To Green Building Rating Systems	* Linda Reeder	Book	English	2010	John Wiley & Sons, Inc., Canada	• Green Building. • LEED, • Green Globes.	Today, sustainability is a growing concern for the architects, designers, builders, and owners of commercial and residential buildings. Meeting the requirements of a rating system provides a metric to evaluate and set priorities.	• An in-depth look at each rating system, including its evolution, objectives, point structure, levels of certification, benefits, and shortcomings .	Illustrated case studies from different climate regions.
Sustainable Tropical Building Design Guidelines for Commercial Buildings	*Cairns Regional Council	Book	English	2011	Cairns Regional Council	• tropical architecture, • Sustainable design	How we design and construct buildings can affect the natural environment, both directly – by placing buildings and paved surfaces on previously vegetated areas, and indirectly – through extracting resources to create building materials.	Sustainable Tropical Building Design Principles in: • Energy and emissions. • Water and wastewater • Indoor environment quality • Waste and construction materials • Local environment	Dif. Examples of sustaiable buildings around the world.
ECOLOGICAL DESIGN (Eco-Design) Architecture, between a design mythology and environmental attitude	*Karwan Taib Fatah	Book	English	2011	Kurd Engineering Union	• Architecture, • Sustainability, • Eco Design.	Buildings are the largest energy consumers, both in the developed and developing countries. The consumption of energy by buildings is not only during or for its construction but also during the period when the building is in use; the energy used for heat, cooling, lighting, ventilation.	• Eco-design's History and Sustainability. • Design guidelines & instructions. • Ecological principals.	Dif. Examples of eco buildings around the world.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

A Green Vitruvius – Principles and Practice of Sustainable Architectural Design	* Vivienne Brophy *J Owen Lewis	Book	English	2011	Ashford Colour Press Ltd., UK	• Marcus Vitruvius • Architecture, • Sustainability, • green Design.	2000 years ago the Roman architect Marcus Vitruvius Pollio wrote the ten books on architecture establishing the concept of the pattern book offering design principles and solutions that is still referred to in every architects education. A Green Vitruvius is intended as a green pattern book for today.	• provides advice suitable for undergraduate and post graduate students on the integration of sustainable practice into the design and construction process. • the issues to be considered, the strategies to be adopted, the elements of green design and design evaluation within the process.	Dif. Examples of sustaiable buildings around the world.
Handbook of Green Building Design, and Construction LEED, BREEAM, and Green Globes	* Sam Kubba	Book	English	2012	Elsevier Inc.	• Green Building Design, • LEED, • BREEAM, • Green Globes	provides a wealth of practical guidelines and essential insights that will facilitate the design of green buildings.	provides a wealth of practical guidelines and essential insights that will facilitate the design of green buildings.	
Sustainable buildings: Go Green	* The International Telecommunication Union (ITU)	Book	English	2012	The International Telecommunication Union (ITU), Switzerland	• Architecture, • Sustainability, • green Design.	Asian countries are expected to contribute a third of worldwide energy and greenhouse gas GHG emissions. Consequently, the challenge to reduce the energy and GHG footprints of new and existing buildings is a very serious one.	standards, guidelines and methodologies that are available for Sustainable buildings.	
ASHRAE Green Guide Design, Construction, and Operation of Sustainable Buildings	* ASHRAE press	Book	English	2013	ASHRAE, 1791 Tullie Circle, N.E. Atlanta, USA	• Architecture, • Sustainability, • green Design.	focus on how to apply Green Building Technology to the design and energy use of a building	Provides information on green-building design. Concerned with sustainable, high-performance projects	

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Sustainable Design and Green Building Toolkit FOR LOCAL GOVERNMENTS	*EPA	Book	English	2013	*EPA (Environment protection Agency), USA	• Architecture, • Sustainability, • green Design.	assist local governments in identifying and removing barriers to sustainable design and green building within their permitting process.	There are two sections to the Toolkit. The first section is an Assessment Tool and Resource Guide. The second section is a guide to developing an Action Plan for implementing changes within a community's permitting process.	
The World's Greenest Buildings : Promise versus performance in sustainable design	* Jerry Yudelson * Ulf Meyer	Book	English	2013	Routledge, USA	• Architecture, • Sustainability, • green Design.	shows "best in class" building performance in North America, Europe, the Middle East, India, China, Australia and the Asia-Pacific region.	a practical reference for how green buildings actually perform at the highest level, one that takes you step-by-step through many different design solutions.	practical examples of best practices for greening both new and existing buildings
The Elements of Modern Architecture: Understanding Contemporary Buildings	* Antony Radford, * Amit Srivastava, * Selen B. Morkoç	Book	English	2014	Thames & Hudson, China	• Modern Architecture, • Sustainability, • Design.	This ambitious publication, organized chronologically, is aimed at a new generation of architects who take technology for granted, but seek to further understand the principles of what makes a building meaningful and enduring.	Each of the fifty works of architecture is presented through detailed consideration of its site, topology, and surroundings; natural light, volumes, and massing; program and circulation; details, fenestration, and ornamentation.	Fifty of the world's greatest modern buildings,
The Ecological Design and Planning Reader	* Forster O. Ndubisi	Book	English	2014	Island Press, USA	• Ecological Design. • Sustainability	bring together classic and important contemporary published works on the history, theory, methods, and practice of ecological design and planning.	Adaptation, biodiversity, bioregionalism, ecological design, ecological urbanism, ecosystem approach, environmental conservation, land ethic, land suitability, landscape, landscape ecology, nature, regionalism, resilience, Smart Growth, urban sustainability	examples from landscape architecture, planning, geography, ecology, environmental science, and green architecture.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Guide to the LEED ®Green Associate V4 Exam	* Michelle Cottrell	Book	English	2014	John Wiley & Sons, Inc.	• LEED exam. • Guide	the resource to prepare for the Leadership in Energy and Environmental Design (LEED) Green Associate exam.	provides a road map to studying for the LEED Green Associate exam as administered by Green Building Certification Institute (GBCI).	
The Ecological (or Green) Approach to Design	* KEN YEANG	Journal paper	English	2000	CTBUH Journal, Spring 2000	• Ecological design. • Green design.		Described here are some of the criteria for ecological design.	
Eco-Design and Planning	* KEN YEANG	Book chapter / Iran: Architecture for Changing Societies.	English	2004	Umberto Allemandi & C.	• Eco Design. • Sustainability	Some of the strategies for eco-design and planning from the viewpoint of Ken Yeang.	• Some of the strategies for eco design and planning from the viewpoint of ken Yeang.	
Linking bioclimatic theory and environmental performance in its climatic and cultural context – an analysis into the tropical highrises of Ken Yeang	*Puteri Shireen Jahnkassim *Kenneth Ip	research paper	English	2006	PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland	• bioclimatic performance, • tropical highrise, • energy simulation, • sustainable theory	This paper presents the outcome of an environmental performance analysis and theoretical study into the bioclimatic highrises of Malaysian architect Ken Yeang – with a focus on the tropical climate.	The study highlights the link between bioclimatic theories and climatic 'performances' and any conflicts between them. A paradox between theories based on critical regionalism and bioclimatic intentions are also described.	Ken Yeang projects and theories. • Plaza IBM • Mesiniaga • Menara UMNO
Designing The Eco skyscraper : Premises For Tall Building Design	*KEN YEANG * ROBERT POWELL	Article	English	2007	John Wiley & Sons, Ltd., UK	• Eco Skyscraper, • Sustainable Design	Designing the eco skyscraper involves configuring about tall building's built form and operational systems so that they integrate with nature in a benign and seamless way over its life cycle	• discusses the theory and premises for the eco-skyscraper. • discusses exemplary projects from Ken Yeang's offices.	Ken Yeang projects and theories.

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Ecoskyscrapers and Ecomimesis: New tall building typologies	*Ken Yeang, *Llewlyn Davies Yeang.	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Skyscraper, • Ecosystems, • Environment, • Exemplary Projects	Designing the eco-skyscraper involves configuring its built form and operational systems so that they integrate with nature in a benign and seamless way over its lifecycle, by imitating the structure, processes and properties of ecosystems, an approach referred to here as ecomimesis.	• Part 1 discusses the theory and premises for the eco-skyscraper. • Part 2 discusses exemplary projects from Ken Yeang's offices.	
Strategies For Green Design	* Ken Yeang	research paper	English	2009	SB10, Seoul	• Green design, • Strategies, • Sustainable	Some of the strategies for green design.	Some of the strategies for green design.	
Tall Buildings, Design, and Technology: Visions for the Twenty-First Century City	* Kheir Al-Kodmany	Article	English	2011	Journal of Urban Technology, USA	• Tall Buildings, • Design, • Technology	• How should cities be regenerated; and how can new cities be built? . • Can cities expand laterally without sprawling and destroying valuable agricultural land? . • Will a vertical expansion be a viable option?	• studying tall buildings and associated technological developments, and their impact on cities. • emphasizing the significant role of tall and supertall buildings in twenty-first-century cities.	examines visionary tall building projects proposed by architects and urban planners from various parts of the world.
Sustainable tall buildings: toward a comprehensive design approach	* Kheir Al-Kodmany	Article	English	2012	Inderscience Enterprises Ltd.	• energy; • social ecology; • green design; • macro-scale; • micro environment.	This paper presents a comprehensive design approach to sustainable tall buildings development. It argues that the true efficiency and success of tall buildings are heightened by their overall relationship with their urban setting and infrastructure.	• The larger sustainable context. • Sustainable design features, technologies, and strategies.	

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Tall Buildings and Urban Habitat of the 21st Century: A Global Perspective.	*Mir M. Ali *Kheir Al-Kodmany	Article	English	2012	MDPI Buildings	• Tall buildings; • new technologies; • urban design; • future cities; • sustainability	a vision of tall buildings and their integration into the cities of the 21st century.	The paper attempts to dispel any discernment about tall buildings as mere pieces of art and architecture by emphasizing their truly speculative, technological, sustainable, and evolving nature.	several tall building case studies.
Green Towers And Iconic Design: Cases From Three Continents	* Kheir Al-Kodmany	Article	English	2014	Archnet-IJAR, International Journal of Architectural Research	• sustainable design; • new technologies, • indigenous forms; • innovative approaches, • green aesthetics.	Recently, massive urbanization, increasingly denser cities and environmental consciousness are pushing architects to build “green” skyscraper. This paper examines the emergence of a notable type of skyscrapers that depart from purely image-driven structures, and emphasizes functionality and energy efficiency.	the paper identifies salient green design strategies that provide new iconicity including: structural efficiencies, renewable energy, façade technology, greeneries, and bioclimatic design.	Reviewing over 30 towers from various parts of the world.
Green Retrofitting Skyscrapers: A Review	* Kheir Al-Kodmany	Article	English	2014	MDPI Buildings	• skyscrapers; • sustainable design; • green retrofit; • energy efficiency; • building’s performance; • holistic approach; • LEED	The existing building stock is substantially large and represents one of the biggest opportunities to reduce energy waste and curb air pollution and global warming. In terms of tall buildings, many will benefit from retrofits.	Investigates innovative trends, practices and goals of tall building retrofits while illustrating green design techniques and implementation strategies.	• Empire State Building,NY • Willis Tower, Chicago. • Taipei 101, Taiwan. • Adobe System Headquarter Complex,US • Glastonbury House,UK. • The Joseph Vance, USA • Hanwha Headquarters,

Appendix 1. Continued. The first collecting and gathering sources for the thesis

THE DRAMATISATION OF 'ECO-TECHNOLOGIES' IN RECENT HIGH-RISE TOWERS	* SANDRA KAJI-O'GRADY	research paper	English	2007	Faculty of Design, Architecture and Building University of Technology, Sydney	• High-towers, • eco-technologies	High-rise towers have become 'the lab benches for sustainable technology innovation'. Major banks and corporations such as Commerzbank and Bank of America are choosing to invest in high-rise projects using a variety of emergent technologies to reduce their environmental impact and energy needs.	examine the ways in ecotechnologies are given a dramatic presence in the high-rise tower independently of requirements for installation and operation and then put to market advantage through strategic media campaigns.	
Emerging Sustainable Green Technologies for Tall Buildings	*Pro.K.Mohan, *Dr.Ajay Gairola, *Dr.Mahua Mukherjee	Article	English	2008	Indian Institute of Technology, Roorkee	• Green architecture, • Skyscraper, • Sustainable Design	The earlier view of tall buildings as Large-scale energy consumers with little regard for sustainable architecture is now changing. The new generation tall buildings are being designed with energy conservation and sustainability as their principal criteria.	• Emerging Trends in Tall Building Design. • Advantages of Enhanced Environmental Performance. • Renewable energy solutions in Tall Buildings. • Role of Nano-materials. • Retrofit Measures for Energy Conservation.	Dif. Examples of Skyscrapers around the world.
The Renewable Energy is the Future of High-Rise Buildings	*Hazem El sayed Hassan, *Mohamed Salah Gharib	research paper	English	2008	King saud university, KSA	• Renewable Energy • High-Rise Buildings	tall buildings have been viewed as mega-scale energy consumers with little regard for sustainable architecture. However, this is changing with a new generation of high-rise buildings that have been designed with energy conservation and sustainability as their principal criteria.	• defining, estimating, and forecasting the Renewable Energy and their applications in high-rise buildings as a case study.	Dif. Examples of Sustainable skyscrapers around the world. • Bahrain World Trade Center • The Pearl River Tower

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Green Skyscrapers What is being built, and why?	*Narie Foster *Samuel Luff *Danielle Visco	A report for CRP 3840: Green Cities	English	2008	Cornell University, New York, USA	• Green Skyscrapers, • Eco-towers.	Skyscrapers in general mean more materials, more money, more time, and more risk. Nonetheless, if building up is a necessity, these skyscrapers certainly are respectable and awe-inspiring. Eco-towers or Green Skyscrapers are shaping the future of tall buildings, and utilizing green technologies on an entirely new scale.	• Get a broad view of the green skyscrapers being built around the world. • Observe trends in the technology and other practices, in a local and a global context. • Analyze and critique the motivations for building these skyscrapers. • Forecast the future of skyscrapers.	Dif. Examples of Skyscrapers around the world.
The role of tall buildings in sustainable cities	* M. M. Ali	Article	English	2008	WIT Transactions on Ecology and the Environment	• sustainable development, • tall building, • city as ecosystem, • skylines, • megacities.	Energy shortage, global warming, urban sprawl, air pollution, overflowing landfills, water shortage, disease and global conflict will be the legacy of the twenty-first century unless we move quickly towards the notion and implementation of sustainability. Both cities and skyscrapers must use fewer natural resources; create less waste; and impact less on the natural world.	• improve the physical systems of the skyscraper and the city. • The concept of sustainable development. • The city as an ecosystem. • Integration of tall buildings and cities • Megacities and urban strategies. • Tall buildings in sustainable cities.	
Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings	* Philip Oldfield, Dario Trabucco, *Antony Wood	research paper	English	2009	The Journal of Architecture, USA	• energy generations • tall buildings • historical analysis	examines the history of energy use in tall buildings, from their origins in North America in the late nineteenth century to the present day.	The five energy generations of tall buildings	

Appendix 1. Continued. The first collecting and gathering sources for the thesis

GREEN SKYSCRAPER S Criteria for Dynamic Sustainable Tall-Buildings	* Dr Abdel-moniem El-Shorbagy	research paper	English	2009	The Third Ain Shams University International Conference, Egypt	• Skyscraper, • Sustainability, • Eco-architecture, • Technology	In the late 20th century, building skyscrapers became a controversial issue among the architectural profession. They questioned the ability of tall buildings to adapt environmental issues as well as to provide a realistic answer to modern environmental problems.	reviews the new generation of progressive green skyscrapers, recently completed or under construction, in order to explore how they embraced sustainability and green building strategies in their dynamic design.	Dif. Examples of Skyscrapers around the world.
Sustainability of tall buildings	* P. de Jong, *J.P. Soeter *J.W.F. Wamelink	research paper	English	2009	Delft University of Technology, Netherlands	• Building costs, • Eco-costs/Value, • Real Estate & • Urban Economics, • Integrated Building • Initiative design phase	The specific land use approach takes away one of the main drivers for the development of tall buildings. The remaining arguments are added value (building performance), political (urban development) or branding (city and/or company).	• compares different ranking tools and benchmarks which are used for indicating sustainability and tall building usability for high rise.	
Sustainable urban life in skyscraper cities of the 21st century	* M. M. Ali	Article	English	2010	WIT Transactions on Ecology and the Environment	• tall buildings, • cities, • urban livability, • sustainability, • urbanization.	In some cities of the industrialized world as well, there is a steady growth of new skyscrapers. The demands for rapid expansion and restructuring of cities often results in poor quality, speedy construction, and the short-term return on investments over livability and a sustainable urban life.	• This paper emphasizes that well-planned skyscrapers in cities can reduce the demands placed on agricultural land and natural resources and create an enjoyable and sustainable living environment. • Tall building design drivers. • Integrating cities and tall buildings. • Greening of existing cities.	• Jakarta • Dubai • Songdo City

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Sustainable Topologies: Qualitative Properties of Geometric Forms in Ecological Buildings	*Dr. Joseph Cory	research paper	English	2010	Sustainable Building conference	• Architecture, • Sustainability, • Green Design.	discuss the qualitative properties of different sustainable projects that are based on multi-disciplinary research studies in Geotectura studio.	A comparison will be made of the topological equivalent between low-rise ecological neighborhood with the World Architecture award winning Contour Museum and the Absolute Green Skyscraper.	• The Van Leer Institute. • The porter School of Environmental Studies, Tel Aviv University.
Vertical sustainability in architecture	*Anna Rydzewska-Szpak	research paper	English	2011	Warsaw University of Technology Poland	• Sustainable • skyscraper, • wellbeing aspects,	There are many points showing that the tower might be the potential solution to the urban problems but can a tower be really sustainable?	• Architecture features for Designing a sustainable tower. • Design principles for Designing a sustainable tower.	
Examples From The Past To The Future For Energy Efficient High Buildings	* Ayşin SEV *Bahar BAŞARIR	research paper	Turkish	2011	Ulusal Tesisat Mühendisliği Kongresi, İzmir	• Tall buildings, • energy-efficiency, • cladding, • mechanical systems, • renewable energy systems	The traditional tall buildings are mass consumers of energy and natural resources. Over the past 120 years, various developments in design methods and models, materials and construction technologies, were accomplished in order to minimize the environmental impact of this building type.	• tends to emphasize the significance of energy efficiency in tall building design, construction and operation. • the design strategies for energy efficiency and utilization of renewable energy systems will be described.	presenting a number of contemporary tall buildings, which utilize these strategies and technologies.
Saving the Environment: Green Skyscrapers, Creating a perfect tower	* Melissa Liu.	research paper	English	2011	University of California, San Diego, USA	• eco-tower, • skyscraper, • environmental impact	the construction of traditional skyscrapers are completely not environmental friendly as it requires great amount of natural materials including steel, concrete and glass, therefore, building eco-towers will be the best solution to this environmental problem.	In this study, the cost and benefit of Green Skyscrapers would be examined by comparing two skyscrapers in San Diego, survey and interviews from professional; showing how green skyscrapers could help to save the environment.	• Executive Complex, the traditional skyscraper. • Union Bank of California, the green skyscraper

Appendix 1. Continued. The first collecting and gathering sources for the thesis

High-rise buildings and environmental factors	* Pooya Lotfabadi	Article	English	2014	ElsevierLtd., USA	• Renewable energies • Energy efficiency • High-rise buildings • Environmental factors	the construction builders and users do not know the excessive energy saving potential of high-rise buildings. So, as a priority, this matter should be more concentrated on while designing by architects. Thus, the overall objective of this study is making tall building architects more aware of the neglected sustainable potential ways to diminish energy consumption.	• this study tries to illustrate the effects of some environmental factors, such as air pressure and density, wind speed and other similar factors in high-rise buildings.	Tehran International Tower, Iran.
Towards a Sustainable Architecture	* Pascual Patuel Chust	Article	English	2014	Servicio de Publicaciones de la Universidad de Murcia. Murcia	• Sustainable architecture, • Ecological architecture, • Green architecture, • Low energy architecture.	The growing awareness of the importance of ecology in the last decades has led many architects to rethink their construction proposals to make them more respectful of the environment and sustainability.	create an architecture that is both sustainable and harmonious with the natural surroundings, the construction materials employed in these buildings, their processes of air conditioning and lighting, and the physical and spiritual health of their occupants.	examples of cities and buildings that have been the object of special ecological attention,
The Integratıon Of Tall Buıldıngs Wıth The Urban Envıronment: Consıderıng The Key Sustaınabılıty Concepts	* Tulû Tohumcu * Ayşem Berrin Zeytun Çakmaklı	research paper	English	2015	ISBS, ankara	• Sustainable Tall Buildings, • Environmental Harmony, • Sustainability Concepts, • Architectural Scale, • Urban Scale.	depending on their large area of influence, design considerations regarding sustainability and environmental integration of tall buildings need to be handled with more care than with other conventional buildings to provide the most positive impact.	This study focuses on the physical and social environmental impacts of tall buildings where these impacts are examined through determined 'key sustainability concepts'.	two tall buildings located in London, 'The Shard' and '30 St Mary Axe (Gherkin)'

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Sustainable High-Rise Buildings And Application Examples	* Hasan Begeç * Darioush BASHİRİ HAMİDA BAD	research paper	English	2015	Dokuz Eylul University, Faculty Of Architecture, Izmir	•Sustainablility; •High-rise buildings; •Energy eficiency; •Active and passive aplications; • Case study.	Development of design and application methods for high rise buildings in accordance with principles of sustainable architecture has a great importance since they have a bigger amount of environmental charge due to their scale and the intense user population.	investigate the concepts of ecological environment, active energy using, energy saving of ecological and sustainable architectural concepts, green construction and sustainable building principles and methods.	case study of Lombardia tower in Milan and De Rotterdam tower in Rotterdam.
Supertall Asia/ Middle East: Technological Responses and Contextual Impacts	* Kyoung Sun Moon	Article	English	2015	MDPI Buildings	•supertall buildings; •tall building technology; •sustainable design	This article reviews the state of tall building developments in Asian and Middle Eastern countries with an emphasis on supertall buildings, with their greater urban and global impacts.	Sustainable design technology transfer and adjustment in Asian and Middle Eastern climates are presented. Further, future prospects on supertall design in Asian and Middle Eastern contexts are discussed.	several tall building case studies.
The Sustainable Tall Building of the Third Millennium	* Harry Blutstein *Allan Rodger	Conference proceeding	English	2001	CTBUH 2001 6th World Congress, Melbourne, Australia	• Sustainable • Tall Building	explores issues that will need to be resolved for a successful sustainable tall building of the Third Millennium. This will not just incorporate sustainable features, like energy efficiency, but a more fundamental change in the systems – technical, economic, organizational – involved in delivering the project	• the need for a sustaınable buıldıng. • defınıng the sustaınable buıldıng. • framework for the sustaınable buıldıng.	
Sustainability: A New High-Rise Vernacular	* Antony Wood	Journal paper	English	2007	CTBUH / Wiley Tal Journal, 2007	• Architecture/ • Design • Sustainability/ • Green/Energy	concludes with a fledgling set of design principles to encourage this new sustainable vernacular in high rise design.	This paper outlines the viability of the tall building as a sustainable element in our future urban centers	several tall building case studies.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Trends, Drivers and Challenges in Tall Buildings and Urban Habitat	* Antony Wood	Book chapter/Part chapter	English	2008	17th Congress of IABSE Chicago 2008	• Tall Buildings, • Challenges, • Sustainability	charts some of the recent trends in tall buildings, and suggests some of the drivers.	• outlines the major influences on tall building design in the early stages of the 21st Century.	
Building Brand Identity: Sustainable yet Iconic High-rise Design for China's Power Companies	* Ming Zhang	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Electric power, • iconic design, • green building, • energy conservation, • branding identity	MG2 has developed several unique design solutions that meet their clients' primary goal: to create a healthy, sustainable working environment in a building symbolic of the modern Chinese power company.	• low cost, energy efficient and green high-rise design; • expression of the clients' high-tech, state-of-art characteristics; • efficient and comfortable interior office environment and public space; • integration and improvement of the urban/cultural context;	MulvannyG2 Architecture (MG2) designed four electric power company headquarters in China.
Towards More Sustainable Tall Buildings	* Ken Dalton, *Richard John,	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Sustainability; • development; • carbon, • supply chain	This paper provides an update on the work published in 2002 "Tall Buildings and Sustainability".	Key recent sustainability drivers and requirements for developments from a planning and regulatory perspective, with a particular focus on lower carbon footprints.	London
From the Tallest to the Greenest - Paradigm Shift in Dubai	* Habiba AlMarashi, *Jasleen Bhinder	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Dubai, Construction industry, • Environmental Impacts, • Green Buildings	discuses the Urban Challenges facing Dubai due to the construction boom, including the social, economic and environmental impacts of the construction industry, Dubai's Economic Gain due to this boom in the economy, and the efforts were undertaken by the government to mandate the construction of green buildings.	• Urban Challenges for Dubai. • Construction Industry. • Economic Gains. • Towards a Greener Emirate- Dubai. • Role of community based organizations.	Dubai large projects.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Sustainable Tall Buildings – Some Introductory Remarks	* Werner Sobek. * Heiko Trumpf	Conference proceeding	English	2008	CTBUH 2008 8th World Congress, Dubai	• Triple Zero, • Integrated Design, • Certification	This paper considers the basic requirements needed to achieve truly sustainable buildings. It discusses possible ways of modifying the cooperation between all project partners responsible for the implementation of a green design.	further identifies the concept of triple zero as a new approach towards vital ecological issues.	
Wanted: Tall Buildings Less Iconic, More Specific	* Jeanne Gang	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Design, • Strategy, • Ownership, • Sustainability, • Labor	Today with the amount of attention being paid to high-rise design, it would appear that progress is being made in this typology, designers have missed an opportunity to address real change in progress.	This paper attempts to point out a few strategies for breaking out of purely image-driven high-rise design and the importance of doing so.	Studio Gang projects.
Design Strategies for Environmentally Sustainable Residential Skyscrapers	* Sabina Fazlic	Conference proceeding	English	2008	CTBUH 2008 8th World Congress, Dubai	• sustainability, • skyscraper, • residential, • temperate climate	The development of residential tall buildings has been accompanied by an increasing interest in the application of sustainability to the building sector. Therefore, this paper will focus on environmentally sustainable residential towers,	consider a range of completed and proposed green high-rises and examine in particular the theoretical and practical work of Dr. Ken Yeang	several tall building case studies.
Towards Zero Energy: A Case Study of the Pearl River Tower, Guangzhou, China	* Frechette, R. *Gilchrist, R.	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• tall buildings, • sustainability, • carbon neutral, • energy consumption, • embodied energy	The goal to achieve 'carbon neutrality' is quite possibly the single most important issue facing architects and engineers today, given the empirical evidence that construction projects far outstrip both industry and transportation as the largest contributors to carbon emissions in the world.	This paper will attempt to both define what is meant by 'carbon neutral' in the context of building design as well as using the case study to demonstrate how such an approach might be achieved it examines the challenges of achieving a net zero energy building.	Pearl River Tower, Guangzhou, China

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Sky-Sourced Sustainability - How Super Tall Buildings Can Benefit From Height	* Luke Leung * Peter Weismantle	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Architecture/ • Design • Sustainability/ • Skyscraper	make tall building designers more aware of the additional sources of sustainability, how these sources change with altitude and how this knowledge can benefit the design and construction of tall buildings.	make tall building designers more aware of the additional sources of sustainability “in the sky”, how these sources change with altitude and how this knowledge can benefit the design, construction and operation of tall buildings.	Burj Dubai
Green or Grey? The Aesthetics of Tall Building Sustainability	* Antony Wood	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• Tall Buildings, • Design, • Environmentalism • Sustainability, • Design Principles	concludes with a fledgling set of design principles to encourage this new sustainable vernacular in high rise design.	This paper outlines the viability of the tall building as a sustainable element in our future urban centres and examines several tall building case studies that have embraced environmental approaches to a lesser or greater degree.	several tall building case studies.
Overview of Sustainable Design Factors in High-Rise Buildings	*M. M Ali, * P. J. Armstrong	Conference proceeding	English	2008	CTBUH 2008, 8th World congress, Dubai	• up alternative • energy, • integration, • sustainable tall buildings, • technology transfer	show how “technology transfers” in the aerospace industry have been applied to tall building systems to achieve high-performance.	examines the critical design factors and strategies that warrant consideration to accomplish sustainable or high-performance tall buildings applying innovative technologies.	several tall building case studies.
Sustainability and the Tall Building: Recent Developments and Future Trends	*M. M Ali, * P. J. Armstrong	Book chapter/ Part chapter	English	2010	AIA Illinois Central Symposium, CTBUH 2010	• Architecture/ • Design • Sustainability/ • Green/Energy	As a major energy consumer, the tall building does not ordinarily conjure images of sustainable design. But a new generation of tall buildings is incorporating new developments in technology and design to produce smarter, energy-efficient buildings.	This paper will show that tall buildings conceived as “vertical garden cities” can use urban space and resources more efficiently and, at the same time, create more user-friendly and habitable buildings.	several tall building case studies.

Appendix 1. Continued. The first collecting and gathering sources for the thesis

Why Tall Buildings? The Potential of Sustainable Technologies in Tall Buildings	* Abdel Rahman Elbakheit	Journal paper	English	2010	International Journal of High-Rise Buildings	• Tall Buildings, • Sustainable designs, • Integration and optimization of building systems	discusses major strengths of tall buildings that distinguish them as sustainable solutions for the built environment.	• Strategies of Sustainable Design in HighRise Buildings. • Sustainable Systems within Buildings' Fabric • Indices of Environmental Performance. • The Need for High Rise Buildings.	
Towards Eco-Tall Buildings in Doha	* Yasser Mahgoub	Conference proceeding	English	2011	CTBUH 2011 Seoul Conference	• Tall Buildings, • Sustainability, • GCC, • Doha, Qatar	discusses the rapid development of tall buildings in Doha due to the rapid urbanization and development that it has been going through since the middle of the 20th century. The paper addresses the importance of developing urban planning legislations for designing eco-tall buildings.	suggests principles that government should include in building legislations and regulations for building a skyscraper in order to achieve ecological and sustainable urban environment.	Doha Towers.
Tall Buildings and Renewable Energy	* Lukia Fais	Book chapter/Part chapter	English	2011	CTBUH 2011 Seoul Conference	• Renewable Energy, • Positive Energy Tall Buildings	focused on the potential capability of tall buildings to be energy-plus buildings in order to contribute to the energy needs of their surrounding context.	addresses the energy issue for tall buildings in terms of energy consumption and the production of energy from renewable sources.	
Delivering and Managing Sustainable Tall Buildings	* Matthew Clifford. * Peter Hilderson. * Chris Wallbank	Journal paper	English	2014	CTBUH 2014 Shanghai Conference Proceedings	• Sustainable Building Management, • Green Building, • Operations	examines best practices to develop a framework for the effective management of high-performance sustainable tall building	Discusses the current and future trends in building construction and design, and their effect on the management of high-performance, sustainable buildings	Utilizes relevant case studies and workshop participation

Appendix 2. The collecting sources for passive concepts' case studies

Kind	Topic / Name	Author	Place	Year	Chapter	Pages		Examples	
						From	To		
Book	Rethinking the Skyscraper: The Complete Architecture of Ken Yeang	* Robert Powell	Whitney libarary of design, Singapore	1999	-	-	-	• Plaza Atrium. • IBM plaza. • Menara Boustead/ • Menara Mesiniaga. • MBf Tower. • Central plaza. • Menara TA1. • Casa-del-sol apartments. • Hitechniaga HQ. UB • Tokyo Nara Tower. • Menara UMNO.	• Menara MISC HQ. • Shanghai Armoury Tower • Gamuda HQ. UB • FACB HQ. • TA2 Service Apartments. • Taman Tun Dr Ismail 6D. • JB 2005, Johor • Signature Tower, BATC. UB
Book	Bioclimatic Skyscapers Revised Edition	*Ken Yeang	Ellipsis London,	2000	-	-	-	• Camera Towers. Malaysia 34 • Ho Chi Minh City Tower. Vietnam 36 • Menara Boustead. Malaysia 42 • IBM plaza. Malaysia 48 • Plaza Atrium. Malaysia 54 • Menara Mesiniaga. Malaysia 58 • Central plaza. Malaysia 64 • Budaya Tower. Malaysia 70 • Autumnland Tower. Malaysia 76 UB • Orchid Tower. Malaysia 82 UB • MBf Tower. Malaysia 86 • BP Tower, Malaysia 90 UB • SCB Tower, Malaysia 94 UB • Penggiran Apartment, Malaysia 96	• Seaacorp Tower, Malaysia 104 UB • 210 Tower, Malaysia 108 UB • Metrolux Tower, Malaysia 110 • Euro Tower 114 UB • Tokyo Nara Tower, Jaban 118 • China Tower, China 122 UB • JB 2005, Johor 134 UB
Book	Tall Buildings and Sustainability	* Will Pank, *Herbert Girardet, *Greg Cox,	Economic Development Office Corporation of London	2002	Ch06. new design concepts for tall buildings	52	61	• Menara Mesiniaga. • Commerzbank Headquarters, Frankfurt • RWE Headquarters, Essen • The Law Courts, Los Angeles UB • The "Flower Tower" UB	

Appendix 2. Continued. The collecting sources for passive concepts' case studies

Book	Big and Green: Toward Sustainable architecture in the Twenty-First Century	* David Gissen	Princeton Architectural Press, New York, USA	2002	Energy	20	34	• Ventiform. UB • The conde nast building at four times square, USA. • Reuters building, USA.	• Experimental solar power. UB • Centre International rogier.UB • Turbine tower, Jaban. UB
					Light and air	48	77	• Deutsche messe AG, Germany. • Edificio Malecon, Argentina. • Highrise RWE AG, Germany • Helicon, London.	• ABN-AMRO bank world HQ, Netherlands • Manulife Financial, Boston UB • Menara UMNO, Malaysia
					Greenery, water and waste	90	113	• Commerzbank HQ, Germany. • Swiss RE HQ, London. • Dutch pavilion, Expo2000, Gr • British pavilion, Expo92, Spain.	• 3D-Garden, Netherlands UB • Menara Mesiniaga, Malaysia. • EDITT Tower, Singapore.
					Construction	128	143	• Lloyds of London. • Carbon Skyscraper. UB	• Industrialized housing system, Korea.
Book	Ken Yeang: Eco Skyscrapers I	*Ivor Richards	Images publishing, Australia	2007	-	-	-	• Editt Tower, Singapore 30 • Tokyo - Nara Tower, Tokyo - Nara 36 • Chongqing Tower, Chongqing 42 • Menara Boustead, Kuala Lumpur 48 • Palomas 2 Tower, Mexico City 54 • Al-Ghorfa Tower, Kuwait 58 • World Science Trade Centre, Beijing 62 • BATC, Germany 66 • Elephant & Castle Tower, London 72 • Ho Chi Minh City Tower, Ho Chi Minh City 78 • IBM Plaza, Kuala Lumpur 82 • National Library Building, Singapore 88 • Shanghai Armoury Tower, Shanghai 94 • Idaman Residence, Kuala Lumpur 100 • MAAG Tower, Zurich 106 • Al-Asima Tower, Kuwait 112 • The Residence, Kuala Lumpur 116 • The Plaza, Kuala Lumpur 120 • UMNO Tower, Penang 124 • EXPO 2005 Tower, Nagoya 130 • Yee Nen Tower, Beijing 136 • Reliance Tower, Mumbai 140 • Santa Fe Tower, Mexico City 146 • Gnome Research Tower, Hong Kong 152	

Appendix 2. Continued. The collecting sources for passive concepts' case studies

Book	The Environmental Performance of Tall Buildings	* Joana Carla Soares Goncalves	Earthscan, UK	2010	Ch04: The environmental paradigm of tall buildings	237	321	• Commerzbank HQ, Frankfurt. • 30 Saint Mary Axe, London • Heron Tower, London • 122 Leadenhall Street, London • Pinnacle, London • 4 Times Square, USA. • Hearst Tower, USA.	• New York Times, USA. • 1 Brian Park, USA.E • ldorado Tower, São Paulo. • Ventura, Rio de Janeiro. • Prosperitas, São Paulo. • Aldar Central, Abu Dhabi. • Pearl River Tower, China
Book	Ken Yeang: Eco Skyscrapers II	*Lucy Bullivant	Images publishing, Australia	2011	-	-	-	• Spire Edge—India 18 • BIDV Tower—Vietnam 28 • Solaris—Singapore 42 • GyeongGi Provincial Government Office—Korea 54 • L Tower—Malaysia 74 • Damansara Garden Residences—Malaysia 82 • Eco Bay Complex—United Arab Emirates 92 • KIA Tower—Kuwait 106 • Plaza of Nations—Canada 114 • P Tower—Malaysia 124 • Shenzhen Garden City—China 132 • DB Tower—Malaysia 142 • G Tower—China 148	
Book	Skyscraper Green Retro. Guide	* Sze Ting Tam	(GENI)	2011	Ch03: Case Studies	22	32	• Empire State Building. 22 • Adobe Towers. 25 • Willis Tower. 28	• Paharpur Business Center. 29 • Glastonbury. 31
Book	Eco architecture: The Work of Ken Yeang	*Sara Hart	Wiley Publication, UK	2011	-	-	-	**Bioclimatic Design** Roof-Roof House Menara Boustead IBM Plaza Menara Mesiniaga **EcoMasterplanning** Soma Masterplan Huanan New City Plaza of Nations **Transitional Projects** National Library Building Mewah Oils Headquarters MAAG Tower **Vertical Urbanism** BATC Tower Nagoya Expo 2005 Tower Tokyo-Nara Tower	**Technical Innovation** Standard Chartered Bank Kiosk UMNO Tower West Kowloon Waterfront **Vertical EcoInfrastructure** EDITT Tower Solaris Spire Edge L Tower DiGi Technical Operations Centre Zorlu Ecocity Gyeong-Gi Complex

Appendix 2. Continued. The collecting sources for passive concepts' case studies

Book	Guide To Natural Ventilation in High Rise Office Buildings (Ctbuh Technical Guide)	* Antony Wood, *Ruba Salib	Routledge, USA	2013	2.0 Case Studies	22	137	• RWE Headquarters Tower, Essen 24 • Commerzbank, Frankfurt 32 • Liberty Tower of Meiji University, Tokyo 42 • Menara UMNO, Penang 50 • Deutsche Messe AG Building, Hannover 58 • GSW Headquarters Tower, Berlin 64 • Post Tower, Bonn 74 • 30 St. Mary Axe, London 84 • Highlight Towers, Munich 92 • Torre Cube, Guadalajara 98 • San Francisco Federal Building, San Francisco 104 • Manitoba Hydro Place, Winnipeg 112 • KfW Westarkade, Frankfurt 122 • 1 Bligh Street, Sydney 132
					Case Study Comparative Analysis Table	142	143	
Book	Green Walls in High-Rise Buildings: An output of the CTBUH Sustainability Working Group	*Antony Wood, * Payam Bahrami, * Daniel Safarik	Images Publishing Dist Ac, Australia	2014	2.0 Case Studies	32	181	Consorcio Santiago, Santiago, 1993 34 ACROS Fukuoka, Fukuoka, 1995 44 Council House 2, Melbourne, 2006 52 Newton Suites, Singapore, 2007 60 Trio Apartments, Sydney, 2009 68 One PNC Plaza, Pittsburgh, 2009 76 The Met, Bangkok, 2009 84 Athenaeum Hotel, London, 2009 92 Pasona Headquarters, Tokyo, 2010 100 School of the Arts, Singapore, 2010 108 Hotel Intercontinental, Santiago, 2011 118 Helios Residences, Singapore, 2011 126 Solaris, Singapore, 2011 134 B3 Hotel Virrey, Bogota, 2011 142 PARKROYAL on Pickering, Singapore, 2012 148 Gramercy Sky Park, Makati, 2013 156 Bosco Verticale, Milan, 2013 164 IDEO Morph 38 Tower, Bangkok, 2013 172
Book	Virtecal Greenery	*Elena Giacomello *Massimo Valagussa	CTBUH	2015	-	-	-	Bosco Verticale, Milan
Master's Thesis	Green Skyscraper: Integration of Plants into Skyscrapers	* Shahrina Afrin	KTH, Sweden	2009	6 Chapter 6: Case Studies	101	106	• The EDITT Tower, Singapore 101 • Tokyo Nara Tower, Tokyo 102 • Chilean Consortia Building, Santiago, Chile 104

Appendix 2. Continued. The collecting sources for passive concepts’ case studies

Master Thesis *TR	Examination of Integration Architecture in Ecological Architecture	*Nilay Özeler Kanan	Eskişehir Osmangazi üniversitesi	2010	4.0 Case Studies	85/69	167/ 151	• Commerzbank, Germany 87 • City Hall-London106 • Swiss Re Genel center (30 St Mary Axe) London 115 • Editt Tower, Singapore 129	• Waterfront, Malaysia 139 • UMNO Tower, Malaysia 145 • Jabal Omar, Mekke 152 • Bishopsgate Towers, London 158
Master Thesis *TR	An Investigation Of Sustainability Formulating The High Rise Buildings	* Deniz Zinzade	İstanbul Teknik Üniversitesi	2010	3.0 Case Studies	43	112	• Menara Mesiniaga: IBM • Commerzbank • Swiss Re • City Hall • Hearst • Co-operative Insurance • Bahrain World Trade Center • Pearl River • MBf • New York Times • Elithis • Newton • Efizia	• Antilla • İstanbul Sapphire • Vertical Village • Lighthouse • Burj al-Taqa • Anara • China Insurance Group • Shanghai • Triangular Project • Urban Cactus • Ultima • COR • Varyap Meridian
Master Thesis *TR	Bioclimatic Design Approach In Ken Yeang's High Buildings	* Tarik Taştan	Maltepe Üniversitesi	2012	4.0 Case Studies	86	140	• Menara Mesiniaga 88 • Menara UMNO Tower 97 • EDITT Tower 102 • National Library Building 113 • Chongqing Tower 118 • BIDV Tower 123 • Solaris 128 • Spire Edge 134	

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