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ADVANCED ARCHITECTURE DESIGN STRATEGY BASED ON BIOMIMICRY TOWARDS HIGH-PERFORMANCE DESIGN IN HIGH-RISE BUILDINGS

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ABSTRACT

ADVANCED ARCHITECTURE DESIGN STRATEGY BASED ON BIOMIMICRY TOWARDS HIGH-PERFORMANCE DESIGN IN HIGH-RISE BUILDINGS

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A large share of worldwide energy utilization connects with the built environment and buildings' demand. The fundamental objective of buildings is to deliver a suitable internal environment for the inhabitants, whatever the external environment situations are. Which requires a series of practical and technological procedures to make buildings suitable for occupants. Therefore, the efficiency of the building determined by the provision of the required comfortable level of the indoor environment with the least energy usage, which means mitigate the carbon emission levels. However, to attain a reasonable balance between the level of energy usage and the provision of the required comfortable level of the indoor environment, many approaches have emerged to achieve the goal. Performance-based building designs have become a desirable comprehensive approach for more sustainable architecture, which is one of the primary methods to cope with climate change. The performance-based design consists of multiple approaches or strategies that enhance the principle of energy efficiency and assist the architect in design process and decision making.

Biomimicry strategy which is a novel design approach offers potential link with the concept of energy efficiency and high-performance buildings. The experience of nature to find the best solutions and confront the environmental conditions through the continuous adaptation to the dynamic surrounding conditions, has been derived. In other details, the adaptation of the organism, its fitness, and its homogeneity with its surrounding environment can be applied in buildings design to make buildings more sustainable and adaptive. Generally, Biomimicry is a term used to characterize the brilliant used in nature. Which simply seeks to make the most efficient way of using resources for fulfilling human needs. For instance, mimic the brilliant systems in

nature such as forms, materials, processes, constructions, and functions, which are invested in the research process and proposed design. In practice, the process of applying bio-inspiration in building design requires advanced technology and some costs. Therefore, the application of it must have a potential content of success. For this reason, analysis, simulations, and test operation should be carried out at the early stages of design to ensure the outputs.

Computation tools and software offer the ability to simulate the applied bio-inspired concepts and construction technologies to extract the estimated results of the building behavior in the built environment. Also, some computation tools derive their logical philosophy from nature. However, the environmental computation tools are the major computational tools that contribute to the performance-based designs to improve building efficiency and reduce energy usage. The improvement process by using environmental computation tools made design decision-making much easier by contributing in form, materials used, and choosing the best options available.

From all of the above, new design concepts can be combined to create a comprehensive and integrated design strategy within the potential to serve energy efficiency and high-performance goals. Biomimicry provides an effective strategy to overcome problems while computational tools have the capability to analyze, simulate, improve, and choose the optimum. The comprehensive design strategy presented a promising design method to achieve energy efficacy improvement by providing workflows based on the adopted approaches and present them as advanced design strategies to develop a new design process that makes the architect and architecture field of study deal with the new approaches which have emerged recently in different science fields. Thus, makes the future architectural design methods based on logical reasons and optimal solutions.

The façade design process adopted the advanced design strategy to develop a new design concept aiming for a high-performance building and energy efficiency. Façade in the perspective of nature is a highly sophisticated and developed membrane that performs various functions including protection, sensation, energy, temperature regulation, and ventilation. It is the first line of defense that protects the inside from the external environment. But from the perspective of building and construction, technology can perform the role of natural organisms to control and regulate different factors and conditions which is called building physics. General knowledge of building physics has been made to direct the design process to better methods and ways. Thus,

integrative façade design has been applied to the proposed building which is a large office in a high rise building located in a hot area. The façade performs multiple operations to regulate the temperature and enhance the comfort thermally and visually and making the balance between energy consumption and conditions required.

The final design decision produced integrative shading units with four potential functions as main purposes (shading, Daylight, Ventilation, energy generation). The integrative shading units have a mutual effect with the gazing type. Therefore, the study focusing on this mutual connection between shading and glazing systems on the proposed building as an integrative facade system to conduct the research process. Moreover, there are many limitation factors (computational tools capability, research limitation, etc…) that prevent the research process to include all the potential functions that the integrative shading units have. Therefore, the improvement process covers two potential functions (Shading, Daylight) with its related issues as major determining factors. While, the other two potential functions (Ventilation, energy generation) detailed as potential concepts for future studies. But, the adoption of the wind profile in the research improvement process as another determination factor related to both of the (Ventilation, energy generation), gives an estimation vision to evaluate the potential functions of future studies.

Key Words: Performance-based design, Biomimicry, Environmental computation tools, Energy efficiency, Advanced design strategy, Façade design, Transformable shading system, High-performance building, renewable energy.

ÖZ

YÜKSEK BİNALARDA YÜKSEK PERFORMANSLI TASARIMA YÖNELİK BİYOMİMİKRİ TEMELLİ İLERİ MİMARİ TASARIM STRATEJİSİ

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Dünya genelinde enerji tüketiminin büyük bir bölümü, imar edilmiş çevre ve binaların enerji talebiyle bağlantılıdır. Binaların temel amacı ise, dışarıdaki çevre koşulları ne olursa olsun, içinde yaşayanlar için uygun bir kapalı ortam sunmaktır. Bu doğrultuda, binaları içinde yaşayanlar için uygun hale getirmek üzere bir dizi pratik ve teknolojik prosedürün devreye sokulması gerekmektedir. Bu çerçevede, iç ortamda ihtiyaç duyulan konforun, mümkün olan en düşük enerji tüketimiyle temin edilme düzeyi ile belirlenen bina verimliliğinin artırılması, karbon emisyon seviyelerinin aşağı çekilmesi anlamına gelmektedir. Öte yandan, iç ortamda ihtiyaç duyulan konforun temini ile enerji tüketimi arasında makul bir dengenin kurulması yönünde pek çok yaklaşım geliştirilmiştir. Performans odaklı bina tasarımları, iklim değişikliğiyle mücadelede öne çıkan yöntemlerden biri haline gelecek şekilde, daha sürdürülebilir bir mimarinin ortaya çıkmasında kapsamlı bir yaklaşıma dönüşmüştür. Performans odaklı tasarım, enerji verimliliği ilkesini destekleyen ve tasarım süreci ile karar alma aşamalarında mimara yardımcı olan çeşitli yaklaşım veya stratejilerden oluşmaktadır.

Özgün bir tasarım yaklaşımı olarak kendini gösteren biyomimikri stratejisi, enerji verimliliği anlayışı ile yüksek performanslı binalar arasında bağlantı kurma olanağını sunmaktadır. Dinamik çevre koşullarına kesintisiz bir biçimde uyum sağlayarak en iyi çözümleri bulma ve çevresel koşullarla mücadele etme yolunda doğanın ortaya koyduğu deneyimler, bu yaklaşımın geliştirilmesine temel oluşturmuştur. Daha ayrıntılı bir ifadeyle, organizmanın çevresine uyumu ve uygunluğu, ayrıca çevre koşulları ile kurduğu homojen ilişki, binaları daha sürdürülebilir ve uyum sağlayabilir kılma yolunda bina tasarımlarında da uygulanabilmektedir. Biyomimikri, genel olarak, doğadaki faydalı kullanım şekillerini tanımlamak için kullanılan bir terimdir. Basit bir ifadeyle, insan ihtiyaçlarını karşılamak için kaynakların en verimli şekilde kullanılması arayışıdır. Örnek olarak, doğadaki faydalı sistemlerin kalıplar,

malzemeler, süreçler, inşa ve işlevler gibi unsurların oluşturulmasında araştırma ve tasarım çalışmalarına uygulamak üzere taklit edilmesini içerir. Uygulamaya gelindiğinde, biyolojik esinlenmelerin bina tasarımlarında hayata geçirilmesi, ileri teknolojiler gerektirir ve belli maliyetler ortaya çıkarır. Dolayısıyla, uygulamanın belli bir başarı potansiyeli ortaya koyması gerekir. Bu nedenle, elde edilecek çıktıları belirlemek üzere, erken tasarım aşamalarında analizler, simülasyonlar ve testlere yer verilmesi gerekmektedir.

Hesaplama araçları ve yazılımlar, uygulanacak biyolojik esinlenme konseptlerinin ve inşaat teknolojilerinin önceden simüle edilmesini, böylece inşa edilmiş çevrede bina davranışına ilişkin tahminî sonuçlara ulaşılmasını sağlamaktadır. Bunun yanında, bazı hesaplama araçları da kendi işleyiş felsefesini doğadan almaktadır. Çevresel hesaplama araçları, bina verimliliğini yükseltmeye ve enerji tüketimini düşürmeye dönük performans odaklı tasarımlara katkıda bulunan temel hesaplama araçları olarak öne çıkmaktadır. Çevresel hesaplama araçlarının kullanıldığı geliştirme süreci, kalıplara, malzeme kullanımına ve en iyi seçeneklerin belirlenmesine katkıda bulunarak, tasarımda karar almayı çok daha kolay hale getirmektedir.

Her şeyden önce, enerji verimliliği ve yüksek performans hedeflerine destek verecek kapsamlı ve bütünlüklü bir tasarım stratejisi oluşturmak için, yeni tasarım konseptleri birleştirilebilmektedir. Biyomimikri, sorunların açılması yolunda etkin bir strateji temin ederken, hesaplama araçları da analiz ve simüle etme, iyileştirme ve en iyi seçeneği belirleme olanaklarını getirmektedir. Kapsamlı tasarım stratejisi, benimsenen yaklaşımlar temelinde iş akışları temin ederek, enerji verimliliğini yükseltmek için umut verici bir tasarım yöntemi sunmaktadır. İleri tasarım stratejileri şeklinde sunulan bu yöntemler, mimarın ve mimarlık saha çalışmasının, farklı bilim alanlarında son dönemde ortaya çıkmış yeni yaklaşımlarla çalışmasını olanaklı kılan bir tasarım süreci geliştirmeye olanak tanımaktadır.

Cephe tasarım sürecinde, yüksek performanslı bina ve enerji verimliliği hedefleyen yeni bir tasarım konsepti geliştirme doğrultusunda ileri tasarım stratejisi benimsenmiştir. Bina cephesi, doğanın perspektifi açısından bakıldığında, koruma, duyuşla bildirimler alma, enerji, sıcaklığı düzenleme ve havalandırma gibi çeşitli işlevleri yerine getiren, son derece sofistike ve gelişkin bir çeperdir. İçerideki ortamı dış ortamdan koruyan ilk savunma hattıdır. Ancak, bina ve inşaat perspektifinden bakıldığında, farklı etmen ve koşulları kontrol altında tutup düzenlemek üzere, yapı

fiziği çerçevesinde doğal organizmaların rolünü teknoloji üstelenebilmektedir. Yapı fiziğine ilişkin genel bilgimiz, tasarım sürecini daha iyi yola ve yöntemlerle şekillendirme olanağını sunmaktadır. Böylece, sıcak iklimde yer alan yüksek bir binadaki büyük bir ofis alanı şeklinde tasarlanmış yapı için entegre cephe tasarımı uygulanmıştır. Yapı cephesi, sıcaklığı düzenleyerek, ısıl ve görsel konforu yükselterek, enerji tüketimi ile ihtiyaçlar arasında bir denge kurarak çeşitli işlevleri yerine getirmektedir.

Nihai tasarım kararı doğrultusunda, ana amaç olarak dört olası işlev (gölgeleme, günışığı, havalandırma, enerji üretimi) yerine getiren entegre gölgeleme elemanları oluşturulmuştur. Entegre gölgeleme elemanları, kaplama tipi ile ortak etki göstermektedir. Bu nedenle, tasarlanan yapıda, söz konusu araştırma sürecini yürütmek için, entegre bir cephe sistemi olarak, gölgeleme ve kaplama sistemleri arasındaki bu karşılıklı ilişkiye odaklanılmıştır. Bunun yanında, entegre gölgeleme elemanlarının tüm olası işlevlerini araştırma sürecine dahil etmeye izin vermeyen pek çok sınırlayıcı etmen (hesaplama araçlarının kabiliyetleri, araştırma sınırlılıkları vb.) bulunmaktadır. Dolayısıyla, iyileştirme sürecinde, temel belirleyici etmenler olarak iki olası işlev (gölgeleme, günışığı) ve bunlarla bağlantılı unsurlar ele alınmıştır. Diğer iki olası işlev (havalandırma, enerji üretimi) ise gelecekteki çalışmalar için olası konseptler şeklinde detaylandırılmıştır. Bununla birlikte, rüzgâr profilinin, hem havalandırma hem de enerji üretimi ile bağlantılı bir başka belirleyici etmen olarak araştırma iyileştirme sürecinde dikkate alınması, gelecekteki çalışmalarda olası işlevlere dönük değerlendirmeler için tahminî bir bakış açısı temin etmektedir.

Anahtar Sözcükler: Performans odaklı tasarım, Biyomimikri, Çevresel hesaplama araçları, Enerji verimliliği, İleri tasarım stratejisi, Cephe tasarımı, Dönüştürülebilir gölgeleme sistemi, Yüksek performanslı bina, yenilenebilir enerji.

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ZIYAD AMER MAJEED ALYASIRI
İzmir, 2020

TEXT OF OATH

I declare and honestly confirm that my study, titled **“ADVANCED ARCHITECTURE DESIGN STRATEGY BASED ON BIOMIMICRY TOWARDS HIGH-PERFORMANCE DESIGN IN HIGH-RISE BUILDINGS”.** and presented as a Master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

ZIYAD AMER MAJEED ALYASIRI

Signature

……………………

June 17, 2020

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

GHGs	Greenhouse_gases
CH2	The Council House 2, Melbourne
CAD	Computer_aided_design
BIM	Building_information_modelling
GAs	Genetic_algorithms
PBD	Performance-based design
PCA	Principal component analysis
HVAC	Heating_ventilation_and air conditioning
U value	Thermal_transmittance
SHGC	Solar_Heat_Gain_Coefficient
VT	Visible_Transmittance
LSG	The ratio between (VT) and (SHGC)
CIE	International_Commission on Illumination
VAV	Variable_Air_Volume
UFAD	Under_floor air distribution system
IES	The Illuminating_Engineering_Society
DF	Daylight_factor
DA	Daylight _Autonomy
UDI	Useful_Daylight_Illuminance
cDA	Continuous_Daylight-Illuminance
sDA	Spatial_Daylight_Illuminance
PV	Photovoltaic
HDD	Heating_Degree_Days
CDD	Cooling_Degree_Days
VLT	Visible_Light_Transmittance
Sgl	Single_pane
Dbl	Double_pane
Trp	Triple_pane
Clr	All panes are clear glass
LoE	Low_Emissivity_metallic_coating on one or more panes

U	Nominal_Center_of_glass U_value (W/m2-K) calculated
SHGC	Solar_heat_gain_coefficient_of the construction calculated
TSOL	Solar_transmittance at normal incidence of the construction
TVIS	Visible_transmittance at normal incidence of the construction
DT	Diffuse_transmission
ST	Specular_transmission

SYMBOLS:

PH	The measurement of hydrogen ion concentration in a liquid solution.
CO_2	Carbon dioxide
SiO_2	Silicon dioxide
%	Percentage
º	Angle Degree
°C	Centigrade Degree

CHAPTER 1
INTRODUCTION

The built environment is a complex system that consumes natural resources like materials used for construction, energy which negatively impact the natural environment for decades if not centuries (Sustainable and Energy Efficient Design Principles in Vernacular Architecture, 2017). Energy consumption is one aspect that affects many issues we are facing today. The most influential issue is the fact of climate change. Many of the clear signs that occur on our planet such as Ice solubility, flood and global warming emphasize the importance of taking serious and strict positions to seek real solutions(Oguntona & Aigbavboa, 2017)

"Energy presents in nature; it cannot be destroyed, it cannot be produced from nothing and existing energy cannot be destroyed. However, it can be transformed from one form to another. This is the principle of conservation of energy. It may occur in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms" (Britannica, 2018). Energy is a central issue for every challenge or opportunity facing humanity. Development, security, food production, and increased income all depend on energy as a basic issue. Energy contributes heavily to climatic changes, as it contributes 60% of greenhouse gas emissions (United Nations Development Programme, 2000).

Before the industrial era, energy consumption was primitive and dependent on available resources in the surrounding environment. But, after the industrial era, materials that are used for energy completely changed. Coal and other fossil fuels, mineral oil, and natural gas propellants are the most used resources. Consumption has become more sophisticated. And energy sources have become a necessity for the national security of nations (Maggio & Cacciola, 2012). The tremendous technological development has produced many alternative methods for us that have less negative effects on the environment. Traditional methods of energy production have their environmental problems, which confiscate the right of future generations to live in an environment that is sustainable and prosperous (Karaman, 2019).

Energy resources are the fuel that can be used to produce energy. Energy is produced during various physical processes on fuel or by relying on other forms of energy transforming operations. But energy sources can be classified into three categories: renewable, fossil, and nuclear (Novakovic & Nasiri, 2016). In more specifically, the classification could be divide into renewable and non-renewable. In the past 50 years, energy consumption has tripled. And it is also expected that it will triple another again in the next thirty years (Boundless Physics, n.d.). With this level of excessive increase in energy consumption, the emission level will reach very high limits, cities will be polluted and become somewhat uninhabited. Therefore, environmentally friendly sources must be seriously considered and developed to increase their effectiveness and include it among the priorities of developing the built environment.

Non-renewable Energy Resources are the sources that can be depleted over time and not compensated. It is often accompanied by a negative impact on the environment due to its conversion to other forms of compounds when used to produce energy. These resources include nuclear energy, coal, oil, and natural gas, etc. Nonrenewable energy accounts for 85% of all energy sources and oil makes up the largest proportion. It is expected that non-renewable energy sources will continue to lead the energy sources in the coming years.

(see Figure 1.1.) shows the largest proportion of the energy sources used are non-renewable .(Boundless Physics, n.d.)

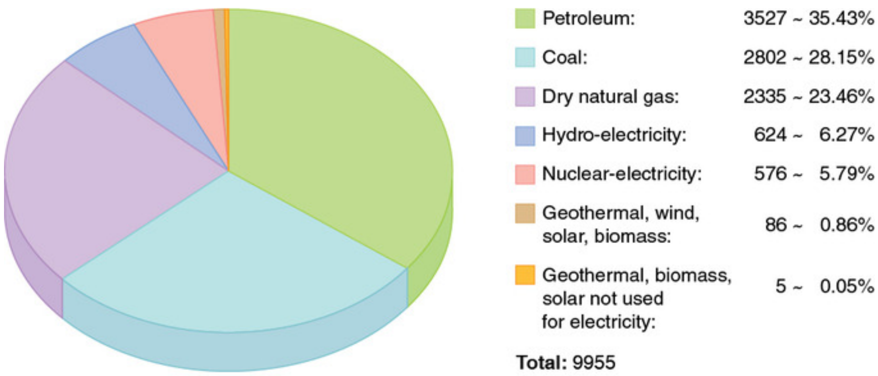


Figure 1.1. Pie Chart of Resource Consumption Rates; Adapted from Boundless (Boundless Physics, n.d.)

While Renewable energy is the energy that can be naturally replenished at the same rate as it is used in our planet such as hydropower and biomass. In general, it is a source found in nature and restores itself whenever it used. After the 2000s, the issue of alternative energy and its sources became more serious. Studies and researches have begun to be carried out in various fields of sustainable energy. Its renewable and eco-friendly properties have made it one of the most effective solutions to combat climate change and global warming. There are different types of renewable energies. Renewable and sustainable energy sources are grouped as sunlight based, wind, geothermal, hydraulic, biomass, and wave, and hydrogen energies (see Table 1.1.) (Karaman, 2019).

Table 1.1. Types and Source of Renewable Energy; Adapted from (Karaman, 2019)

RENEWABLE ENERGY TYPES	SOURCE OF ENERGY
Solar energy	Sun
Wind power	Wind
Geothermal energy	Groundwater
Hydraulic Energy	Rivers
Biomass Energy	Biological wastes
Wave Energy	Oceans and seas
Hydrogen Energy	Water and Hydroxides

"Sustainable development is the development that meets the needs of the present without compromising the needs of future generations". The initial model of sustainability appeared with vernacular and local architecture, which include many sustainable principles like spatial design analysis, climate responsiveness, indigenous technologies, locally available materials, etc. (Sustainable and Energy Efficient Design Principles in Vernacular Architecture, 2017).

"Architectural sustainability includes three aspects: environmental, economic and cultural". Recently, architecture design has the potential of integrating the building with its environment through a series of proactive processes that can achieve positive mutual results between the environment and buildings (Vermesan & Flueckiger, 2016). Energy usage in the building industry expanded to somewhere around one-third of the global total energy consumption, producing about one-sixth of CO_2 releases. The evolution of construction and industry influenced by the continued growth of population and the expansion of human activities, which cause more environmental damage and an excessive increase in consumption. Therefore, the challenge of the future is how to re-manage the existent policies toward sustainability and reduce carbon emission. The fact that energy demand in building sector expected to increase needs new way of addressing and new way of invention. Innovation is an expression must take an important place in our thinking and producing. The process and strategies must be developed and new ideas should be created innovatively, Sustainability, permanency, performance and efficiency. The future demand should be managed in sustainable way influenced by environment, economic and social demands(Press, n.d.).

In the long-term, the concept of building performance must be further developed to reach a stable state of given and taken concept between built environment and natural environment. The potential of harmony between architecture and nature in term of energy efficiency is one criteria for evaluation. Recently, serious attempts have been made to develop a novel approach in science. Architecture has a great share of this new approach by applying it in architectural designs. This approach based on imitate nature behavior aiming for inspiration ideology is called Biomimicry (Maglic, 2014). Biomimicry offering new methods based on nature inspiration to tackle climate change and energy efficiency. Biomimicry has the potential to emulate natural forms, processes, and strategies to develop efficient alternatives of human activities. By inspiring the most efficient principles of nature to create connections between natural world and the built environment (Vermesan & Flueckiger, 2016). Mimicking nature is not just by implementing shapes or material, but to understand the nature applications and the philosophy behind the organism, the behavior or the ecosystem. Biomimicry seeking a solutions to develop humankind in sustainable way (Maglic, 2014). In general, Scientists, engineers and designers contributes the exploration process of the nature potential to provide solutions and make balance between human activities and nature. Effective designs and maintenance strategies in the building industry need to be applied to decrease the total waste for future generations. The emergence of the concept of sustainability is an inevitable consequence of the conservation of natural resources. Industry leaders are looking for real solutions that can be inspired from nature to achieve the desired goals. Each organism provides unique adaptation lessons. Nature contains a range of potential approaches, from desert’s insects to mammals in the tundra that can be adapted into the sustainable building industry (Bayhan & Karaca, 2019).

On the other hand, the development of new design methods like software, analytical tools, and optimization tools which enabled to develop the design process, contribute to establish an efficient way to test, evaluate, generate, and extract data of the building. This new approach called design based on computational tools, which has the potential to process complex designs from the initial stage to the final fabrication process (Ashraf Saad El Ahmar, 2011). Moreover, Performance-based design as a concept derived from computation to improve the building construction, manufacturing, and energy consumption during the early conceptual stages of architecture design. Using computer algorithms to process the environmental parameters that affect design in a way of saving time and energy and offering the best logical solutions for design, and that's too complicated for human intelligence to solve. Hence, provide optimum solutions by taking into consideration the sustainability and energy efficiency (Press, n.d.).

There are already many disciplines of design based on energy efficiency as an objective. But, with more cooperation with nature, the design process could address what the otherwise difficult to tackle. Also, using computation methods to find the optimal solution through simulation, modeling, analysis, and optimization, assisting architects in the decision-making process and motivate architects to consider ecological solutions. (Vermesan & Flueckiger, 2016). It might not associate with aesthetic architecture principles with a strong bond but as an additive. Nevertheless, implementing sustainable technologies in architecture design as concepts of energy efficiency do not prevent the application of aesthetic principles (Abdi & Virányi, 2010).

"It may be true that one has to choose between ethics and aesthetics, but whichever one chooses, one will always find the other at the end of the road."

(Jean-Luc Godard)

1.1. Statement of the problem

Energy consumption is one aspect that affects many issues we are facing today. The most influential issue is the fact of climate change. Many of the clear signs that occur on our planet such as Ice solubility and global warming, emphasize the importance of taking serious and strict positions to seek real solutions. Energy usage in the building industry expanded to somewhere around one-third of the global total energy consumption, producing about one-sixth of CO_2 releases. The fact that energy requests in the building industry expected to grow, needs new ways of addressing and new ways of the invention. Innovation is an expression that must take an important place in our thinking and production. The process and strategies must develop and new ideas should be created innovatively. The future demand should be managed in a sustainable way influenced by the environment, economic, and social demands.

A high performance-based design becomes a more desirable concept in architecture especially the performance-based energy consumption by relying on different promising approaches aiming for more innovation principles. Energy efficiency is a primary needed issue for sustainability. Therefore, the research adopted a biomimicry approach with supporting computational tools as an advanced design strategy that provides the architecture field of study and engineering a new method of design that makes the designers' decision more logical-based to find the best innovative solutions that can apply in the building parts. The façade design is one of the most important parts that determine the efficiency level of the building in general. Therefore, convert the facade concept from a rigid barrier membrane to more flexible adaptive part that can control different conditions at the same time, could be a turning point in the efficiency level of the building by making a great balance between energy efficiency and required conditions to keep the internal building environment fits to occupy.

1.2. Research Aims

Examining the potential of the comprehensive design approach (Biomimicry& Environmental computation tools) as an Advanced design strategy. Applying the advanced design strategy to design high rise building façade located in a hot area, within Integrative shading units that have a mutual effect with the glazing system as an integrative façade system and how could improve or optimize it. The integrative system designed with four potential functions (shading, daylight, ventilation, energy generation) towards high performance building design based on energy efficiency issues.

1.3. Scopes and Limitation

The advanced design strategy used for the design process produced integrative shading units with four potential functions as main purposes (shading, daylight, ventilation, energy generation). The integrative shading units have mutual effects with the glazing system and influenced the glass type choice. Therefore, the integrative shading units' concept expands to include the glazing system in the improvement process which makes the research concept sort of façade design. But, the research limitations and design process, focus on the integrative façade system as (shading units and glazing option) only. While the other façade items will not include in the improvement process. Instead, the other façade items will be designed with one option available in the computational tools library to complete the definition of the computational model used for analysis. Therefore, the improvement process will be conducted based on the relative results of the proposed design which gives a logical method to handle the design process of this research at an early stage. In other meaning, the results related to the improvement process within architecture perspective and are not considered as inevitable values for the reality consideration within engineering perspective due to the fact that the research scope, bounds the improvement process with just the integrative shading system and glazing type. So far, the research process will cover two potential functions (Shading, Daylight) in the improvement process with its related issues as major determining factors. While, the other two potential functions (Ventilation, energy generation) considered as potential for future studies. But, the adoption of the wind profile and global radiation in the research process as another determination factors related to both of the (Ventilation, energy generation) potential functions, give the possibility for an estimation vision to evaluate.

Another fact, the integrated (energy/daylight) simulation with (opaque/ translucent) material method, offer an estimated view of the materials impact on daylight efficiency but not as energy calculation. In addition, the final energy model (with shading system), defined the shading system always takes an unfolding position (transform shape) of the movement steps due to the ability level of the computational tools to respond to the shading system based on the sun path. Therefore, all the simulations process will be with the minimum level of efficiency which means, the performance of the building could be more efficient in reality.

1.4. Methodology of the Research

Skin in the natural perspective is a highly sophisticated and developed membrane that performs various functions including protection, sensation, energy, temperature regulation, and ventilation. While the façade is the first line of defense that protects the inside from the external environment. From the perspective of building and construction, technology can perform the role of the natural organisms to control and regulate different factors and conditions which is called building physics. This research proposed a comprehensive design approach by combines some of the design strategies that have the potential to manage the research aim and goals such as high-performance design based on energy efficiency improvement. The main strategies that have been adopted for the design process are (Biomimicry and Environmental Computational Tools). The comprehensive design approach which presented as an advanced design strategy for high rise building facade offers a promising design method to achieve energy efficacy improvement. The advanced design strategy used for the design process produced an integrative façade system as (shading units with a glazing system) and four potential functions as main purposes. The (Shading, Daylight) functions with its related issues are considered as major determining factors in the improvement and research processes. While, the other two potential functions (Ventilation, energy generation) considered as a potential for future studies with the reliance on the wind profile and global horizontal radiation analysis in the research process as another determination factors related to both of the (Ventilation, energy generation) potential functions which give an estimation vision to evaluate.

In general, an improvement process methodology which conducted on one large floor of as an office in high rise building includes three case studies as potential hot cities which are (Dubai, Baghdad, Doha). The design process methodology comprises a number of bio-inspiration and a number of computational analysis steps to get a number of determining factors that make the design-decisions more accurate based on specific workflows prepared to manage the design problems. The analysis operations include 8 steps: (Temperature Analysis, Humidity Analysis, Radiation Analysis, Wind profile, Integrated Energy-Daylight improvement process, Select the effective hot discomfort period: Adaptive comfort analysis, Adaptive comfort analysis (Comparison), Daylight Autonomy (comparison)).

CHAPTER 2

LITERATURE REVIEW

To create a comprehensive platform of knowledge related to the problem definition as a high-performance design based energy efficiency, a number of approaches need to be covered. The review process shows that the high-performance design, in general, may include many approaches, concepts, and strategies that concerned with the same research area of study and research aims or goals.

2.1. Literature Table

A classification process has been conducted as in (see Table 2.1.) below to restrict the concepts and classify them based on a specific area of a study aiming to produce a comprehensive design approach as **an advanced design strategy** to manage the research problems and examining the potential to achieve the goals.

Table 2.1. Literature reviews & groups classification table.

year	Author (s)	Paper name	Concept Group	Tool / Process	Achievement(s)	Building type	Location Or Climate details	Study type
2017	Olusegun Aanuoluwapo Oguntona, Clinton Ohis Aigbavboa	Biomimetic materials and technologies for carbon neutral cities in South Africa	**Biomimicry & Energy efficiency**	materials and technologies /general	reducing the carbon footprint.	city	South Africa	Paper: Theoretical
----	The Editors of Encyclopedia Britannica	Encyclopedia Britannica	**Energy Resources**	---------	general	-----	--------	Article: Theoretical
----	The Editors of Boundless Physics	Boundless Physics	**Energy Resources**	---------	general	-----	--------	Article: Theoretical
2016	Bora Novakovic, Adel Nasiri	Electric Renewable Energy Systems	**Energy Resources**	---------	general	-----	--------	Article: Theoretical
2014	Michael J. Maglic	Biomimicry: Using Nature as a Model for Design	**Biomimicry & computation**	Organisms mimicking / Wind Flow Analysis for Optimized Form and structure	unity between the building, the users, and the environment.	Rehabilitation building	Boston /USA a humid continental climate	Thesis: Theoretical
2011	Salma Ashraf Saad El Ahmar	BIOMIMICRY AS A TOOL FOR SUSTAINABLE ARCHITECTURAL DESIGN TOWARDS MORPHOGENETIC ARCHITECTURE	**Biomimicry & computation**	Morphogenetic/digital Analysis tool	Developing design method in sustainable way	general	general	Thesis: Theoretical
2016	2030 palette	Section 1 : Overhang	**Energy Efficiency**	Shading system /overhanging shading devices analysis	Control direct sunlight	general	general	Paper: Theoretical
----	Efficient Windows Collaborative	-----------	**Energy Efficiency**	Windows construction/ Widows material improvement	General energy efficiency	general	general	Web
2019	Wind turbine systems	Wind turbine systems provide a source of renewable energy.	**Energy Resources**	Renewable energy/ Wind turbines	Energy generation	general	general	Web-article
----	Climate Technology Centre and Network	Building-integrated wind turbines	**Energy Resources**	Renewable energy/ Wind turbines	Energy generation	general	general	Web-article
2018	climatelaunchpad	ENLIL-Vertical Axis Wind Turbine ENLİL is a smart wind turbine project that transforms highways into renewable energy sources	**Energy Resources**	Wind turbines / converts the wind created by rapid transit bus line	Renewable energy generation	Highways	Istanbul/ Turkey	Web-article
2012	Christoph Maurera, Thibault Pfluga, Paolo Di Lauroa, Joze Hafnerb, Friderik, Knezb, Sabina Jordanb, Michael Hermanna, Tilmann E. Kuhna	Solar heating and cooling with transparent façade collectors’ in a demonstration building	**Energy Efficiency**	Transparent façade/ laboratory measurements To evaluate the heating and cooling	Energy saving validation by TSTC laboratory model	general	general	Paper: Experiment al.

2019	Festus Victor Bekun , Andrew Adewale Alola , Samuel Asumadu Sarkodie	Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries	**Energy Resources**	Renewable energy/ increasing the share of renewable	carbon reduction	general	general	Paper: Theoretical
----	J. H. Klems	Solar Heat Gain through a Skylight in a Light Well	**Energy Efficiency**	Skylight / heat flow measurements	Improvement process	general	general	Paper: Theoretical , Experiment al.
2010	Amir Hossein Ghorashi , Abdulrahim Rahimi	Renewable and non-renewable energy status in Iran: Art of know-how and technology-gaps	**Energy Resources**	Renewable energy / The environmentally friendly scaled energy balance	optimal energy prospects	general	Iran	Paper: Theoretical
2011	J. Alstan Jakubiec and Christoph F. Reinhart	DIVA 2.0: INTEGRATING DAYLIGHT AND THERMAL SIMULATIONS USING RHINOCEROS 3D, DAYSIM AND ENERGYPLUS	**Energy efficiency & Environmental computation tools**	Diva Integrated energy-daylight simulation / highly optimized design workflow	The impact on lighting, heating and cooling loads for a building.	office model	general	Paper: simulation
2009	Svetlana Olbina and Yvan Beliveau	Developing a transparent shading device as a daylighting system	**Energy efficiency & Environmental computation tools**	Autodesk VIZ 4 software/ Transparent shading devices	improved daylighting performance	office building	Roanoke, Virginia, US.	Paper: simulation
2017	Yuan Fang	Optimization of Daylighting and Energy Performance Using Parametric Design, Simulation Modeling, and Genetic Algorithms	**Energy efficiency & Environmental computation tools**	Honeybee-Ladybug simulation and Galapagos, octopus' optimization/ Integrated energy-daylight simulation	optimal energy and daylighting performance	Simple building	USA.	PhD Thesis: simulation
2016	Glenn A.Jones , KevinJ.Warnr	The 21st century population-energy-climate nexus	**Energy Resources**	Renewable energy / reduction in fossil fuel usage	address population and climate change	general	general	Paper: Theoretical
2016	www.energi.no	Examples of Energy Efficient buildings in Norway	**Energy Efficiency**	standers and strategies/ Improve energy performance in buildings	Energy efficiency	general	Norway	Web-article
2017	C. Koulamas, A.P. Kalogeras, R. Pacheco-Torres J. Casillas, L. Ferrarini	Suitability analysis of modeling and assessment approaches in energy efficiency in buildings	**Energy Efficiency**	comprehensive analysis / literature review and assessment methodology to facilitate the comparison of different approaches	measurement-based methods as qualitative comparison frame-works	general	general	Paper: Theoretical
2014	Rudai Shan	Optimization for heating, cooling and lighting load in building façade design	**Energy efficiency & Environmental computation tools**	TRNSYS / Triple objectives of heating, cooling and lighting load	optimizing building facade	Single office room	Michigan	Paper: simulation

2015	Javier González and Francesco Fiorito	Daylight Design of Office Buildings: Optimization of External Solar Shadings by Using Combined Simulation Methods	**Energy efficiency & Environmental computation tools**	DIVA and Galapagos/ Integrating daylight - energy simulation and optimization	Improve comfort levels and energy efficiency	Office building	Michigan	Paper: simulation
2012	Chen Y., Fazio P., Athienitis A. K., & Rao J.	Sustainable Building Design in Cold Regions: High Performance Envelope and Façade-Integrated Photovoltaic/Solar Thermal Systems at High Latitudes	**Energy efficiency & Environmental computation tools**	novel envelope prototype developing for Northern climate/ incorporating suitable solar collectors onto a structural insulated panel (SIP) wall.	investigate the potential of energy generation and conservation by a full-scale solar-harnessing envelope system in cold climate	housing	Canada's North	Paper: experiment al and simulation
2014	Eugene Mohareb , Jesse Row	Improving Energy Efficiency in Alberta's Buildings	**Energy Efficiency**	advancing energy efficiency/ energy efficiency improvements.	Decrease costs, lower energy demands, reduce GHG emissions, decrease maintenance requirements, and lead to a more sustainable building sector.	general	Alberta	Paper: Theoretical
2014	Nayera Abdelhafez	Energy Conservation in Existing Office Building: Case study Petrojet Company Head Office Buildings in Cairo, Egypt	**Energy efficiency & Environmental computation tools**	ENERGY STAR/ Energy evolution	energy conservation	Office building	Cairo, Egypt	Paper: Theoretical
2009	Matthias Haase , Igor Sartori, Natasa Djuric, and Rasmus Høseggen	SIMULATION OF ENERGY-EFFICIENT OFFICE BUILDINGS IN NORWAY	**Energy efficiency & Environmental computation tools**	(TRNSYS, esp-r, energyplus, Simien)/Improve energy performance in buildings in terms of thermal comfort and energy consumption	to make building regulations more effective	Office building	Norway	Paper: simulation
2010	Matthias Haase, Karin Buvik, Tor Helge Dokka and Inger Andresen	Guidelines for energy efficiency concepts in office buildings in Norway	**Energy efficiency & Environmental computation tools**	use different computer simulation tools / The accuracy in predicting the performance in terms of thermal comfort and energy consumption of various cases	improve energy efficiency	Office building	Norway	Paper: Theoretical report and simulation
----	Greg C. Foliente	Developments in Performance-Based Building Codes and Standards	**Energy Efficiency**	performance-based code / improvement	future of building codes and standards points toward a performance-based approach	general	general	Paper: Theoretical
2008	Nurdil Eskin , Hamdi Turkmen	Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey	**Energy efficiency & Environmental computation tools**	building energy simulation using EnergyPlus/ performance of office buildings in different climates	Energy evaluation	Office building	turkey	Paper: simulation

2013	Mostapha Sadeghipour Roudsari, Michelle Pak Adrian Smith + Gordon Gill Architecture	LADYBUG: A PARAMETRIC ENVIRONMENTAL PLUGIN FOR GRASSHOPPER TO HELP DESIGNERS CREATE AN ENVIRONMENTALLY-CONSCIOUS DESIGN	**Energy efficiency & Environmental computation tools**	Ladybug-honeybee plugins / environmental analysis tools	high performance design	general	general	Paper: Simulation
2016	Ayca KIRIMTAT	DESIGN AND COMPUTATIONAL OPTIMIZATION OF AN INTEGRATED SHADING DEVICE INTO A BUILDING	**Energy efficiency & Environmental computation tools**	optimization methods, and simulation techniques / daylight and total energy consumption	develop a shading device in a building	Office building	Izmir/turkey	Thesis: simulation
2019	Yavuzarslan, Gizem	USING COMPUTER ANALYSIS FOR CALCULATING ENERGY EFFICIENCY AND IMPLEMENTING SHADING DEVICE FOR GLASS FACADE OF A HIGH RISE BUILDING IN IZMIR	**Energy efficiency & Environmental computation tools**	Grasshopper LADYBUG HONEYBEE / analyze energy efficiency of a high-rise building with glass façade	represented the importance of the shading device considering the overall energy performance	High rise office building	Izmir/turkey	Thesis: simulation
2019	KARAMAN, Selim	THE ENERGY PERFORMANCE EVALUATION OF ETFE (ETHYLENE TETRAFLUOROETHYLENE) CUSION SYSTEMS INTEGRATED ON THE SOUTH FAÇADE OF A HYPOTHETICAL TEST ROOM AND COMPARISON OF IT WITH GLASS FAÇADE SYSTEMS	**Energy efficiency & Environmental computation tools**	LADYBUG, HONEYBEE / The performances of different types of glass currently used in ETFE	energy efficient façade applications such as ETFE that works as a filter	A HYPOTHETICAL TEST ROOM	Turkey	Thesis: simulation
2019	Görgün, Ayşegül Öykü	SHADING DEVICE DESIGN AND OPTIMIZATION VIA GENETIC ALGORITHM BY USING SURFACE TEMPERATURE METRIC AND ELECTRICITY LOAD	**Energy efficiency & Environmental computation tools**	Simulation Ladybug-Honeybee, and optimization-octopus / Shading devices optimization	improve energy efficiency	Office building	Izmir/turkey	Thesis: simulation
2017	Katherine M. DuMez	Analysis of Energy Efficient Curtain Wall Design Considerations in High-rise Buildings	**Energy efficiency & Environmental computation tools**	Curtain Wall Design Considerations /Analysis of Energy Efficient	Improved glazing and energy efficient in curtain wall assemblies	High rise building	USA	Thesis: simulation
2015	Paola Iacomussi, Michela Radis, Giuseppe Rossi, Laura Rossi	Visual Comfort with LED Lighting	**Energy Efficiency**	LED lighting /evaluation of visual discomfort parameters	suggestions for visual comfort	general	general	Paper: Theoretical
2014	Pimonmart Wankanapon, and Richard G. Mistrick	Roller Shades and Automatic Lighting Control with Solar Radiation Control Strategies	**Energy efficiency & Environmental computation tools**	EnergyPlus energy simulation / roller shades	energy saving	commercial buildings	USA	Paper: Theoretical

2015	Paul W. Stackhouse, Jr., NASA Langley Research Center David Westberg, James M. Hoell, William S. Chandler, and Taiping Zhang,	An Assessment of Actual and Potential Building Climate Zone Change and Variability From the Last 30 Years Through 2100 Using NASA's MERRA and CMIP5 Simulations	**Energy Efficiency**	Climate zones / Climate simulation analysis	Climate zones definition	general	general	Paper: Theoretical, simulation
1987	Giovanni S. Barozzi	Shading effect of eggcrate devices on vertical windows of arbitrary orientation	**Energy efficiency & Environmental computation tools**	Egg-crate shading devices / Computational analysis	Climate zones definition	Simple building	Italy/ Venice	Paper: simulation
2015	2015 INTERNATIONAL ENERGY CONSERVATION CODE	Chapter 3 [CE]: General Requirements	**Energy Efficiency**	Climate map/Climate zones analysis	Development of Climate Zones Map	general	general	Paper: Theoretical report
2014	Laura Bellia, Concetta Marino, Francesco Minichiello, Alessia Pedace	An overview on solar shading systems for buildings	**Energy Efficiency**	Shading devices / Analysis of some studies	Development of analysis process	general	general	Paper: Theoretical
2017	Shady Attia	Evaluation of adaptive facades: The case study of Al Bahr Towers in the UAE	**Energy Efficiency**	Bahr Towers adaptive facades / analysis	derive maps of the underlying decisions on how it was designed, operated, maintained, and assessed	general	general	Paper: Theoretical
2014	Stefano Schiavon, Tyler Hoyt, Alberto Piccioli	Web application for thermal comfort visualization and calculation according to ASHRAE Standard 55	**Energy Efficiency**	Climate Consultant, Autodesk Ecotect Weather tool, and the ASHRAE Thermal Comfort Tool / thermal comfort visualization and calculation analysis	assess different thermal control strategies	general	general	Paper: Theoretical
2015	Nicolò Zuccherini Martello , Patrizio Fausti , Andrea Santoni, and Simone Secchi	The Use of Sound Absorbing Shading Systems for the Attenuation of Noise on Building Façades. An Experimental Investigation	**Energy Efficiency**	Façade sound insulation materials / analysis by microphone positions placed on the external side of the windows	the evaluation of the possibility to improve facade performances, in terms of Sound Pressure Level by testing different sound insulation materials	Office building	Italy	Paper: Experiment al
2009	N.D. Dahlan, P.J. Jones, D.K. Alexander, E. Salleh and J. Alias	Daylight Ratio, Luminance, and Visual Comfort Assessments in Typical Malaysian Hostels	**Energy Efficiency**	exploitation of daylighting / lighting analysis by sensors	improve lighting ambiance and occupants' visual comfort through the exploitation of daylighting	hostels	Malaysian	Paper: Experiment al
2002	Dr. Olu Ola Ogunsote and Dr. (Mrs.) Bogda Prucnal-Ogunsote	Defining Climatic Zones for Architectural Design in Nigeria: A Systematic Delineation	**Energy Efficiency**	Climate zones / analysis	definitions of climatic design zones for architecture	general	Nigeria	Paper: Theoretical
2015	Jeongsu Park , Hyung-Jo Jung , Seung-Woo Lee, and Jiyoung Park	A New Building-Integrated Wind Turbine System Utilizing the Building	**Energy Resources**	CFD simulation / evaluates wind pressure on a building skin and rotors	innovative building-integrated wind turbine system	general	general	Paper: Simulation, Experiment al

2012	ShadyAttia, ElisabethGratia, AndréDe Herde, Jan L.M.Hensen	Simulation-based decision support tool for early stages of zero-energy building design	**Energy efficiency & Environmental computation tools**	Energyplus / integrate energy simulation into early of design	zero energy buildings in the architectural practice	Hypothetical design	Egypt	Paper: Simulation
2015	Ghaith Tibia, Ahmed Mokhtar	Glass Selection for High-Rise Buildings in the United Arab Emirates Considering Orientation and Window-to-Wall Ratio	**Energy Efficiency**	Glass types/analysis	Life Cycle Cost	residential	High-rise residential and commercial	Paper: Theoretical
2018	Yu Ting Kwok, Kevin Ka-Lun Lau, Edward Yan Yung Ng	The influence of building envelope design on the thermal comfort of high-rise residential buildings in Hong Kong	**Energy efficiency & Environmental computation tools**	EnergyPlus on the DesignBuilder software platform /climate-adaptive building envelope design	minimize building energy consumption without compromising the comfort of occupants	High rise building	subtropical Hong Kong	Paper: Simulation
2014	Pooya Lotfabadi	High-rise buildings and environmental factors	**Energy Efficiency**	using renew- able energies and new ideas in designing/ The excessive energy saving potential of high-rise buildings	reducing energy consumption	High rise building	Iran	Paper: Theoretical
2011	Evelise Leite Didoné, and Fernando Oscar Ruttkay Pereira	INTEGRATED COMPUTER SIMULATION FOR CONSIDERING DAYLIGHT WHEN ASSESSING ENERGY EFFICIENCY IN BUILDINGS	**Energy efficiency & Environmental computation tools**	EnergyPlus / evaluate energy efficiency, considering the use of daylight,	improves the assessment of the impact of using daylight in reducing energy consumption in non-residential buildings	Office building	(Test Reference Year)	Paper: Simulation
2012	Yalcin Yasar , Sibel Macka Kalfa	The effects of window alternatives on energy efficiency and building economy in high-rise residential buildings in moderate to humid climates	**Energy efficiency & Environmental computation tools**	using Design- Builder v.1.8 energy simulation software / double-glazed window units' analysis	efficient alternatives with regard to building energy consumption and economy	High rise building	Trabzon, Turkey	Paper: Simulation
2004	Agustinus Djoko Istiadji	Effect of external shading devices on daylighting penetration in residential building	**Energy efficiency & nvironmental computation tools**	LIGHTSCAPE simulations / shading devices and daylight	Examining the daylighting design in a residential building with the effect of seven different types of external shading device	residential buildings	Singapore	Paper: Simulation
2004	G.F. Menzies, J.R. Wherrett	Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows	**Energy Efficiency**	multi-glazed windows / analysis	increase the thermal efficiency and therefore life-cycle energy consumption of windows.	Office building	Edinburgh	Paper: qualitative
2007	AbuBakr S. Bahaj, Patrick A.B. James , Mark F. Jentsch	Potential of emerging glazing technologies for highly glazed buildings in hot arid climates	**Energy efficiency & Environmental computation tools**	TRNSYS / improved facade design can contribute to a reduction of operational costs	Fixed glazing, reflection HOE are predicted to reduce the air conditioning loads of comparable buildings	Different building	Middle Eastern climates	Paper: Simulation

----	Professor Bjarne W. Olesen,	INTERNATIONAL STANDARDS FOR THE INDOOR ENVIRONMENT	**Energy Efficiency**	Comfort conditions/ display	Comfort standers	general	general	Seminar
----	Gauri Agrawal	BIOMIMICRY Nature as design tool	**Biomimicry & computation group**	Applying selected biomimetic principles / in morphogenetic computational design processes	Develop design method for sustainable architectural design and construction	general	general	Seminar
2017	A. Karam M. Al-Obaidia, A.Muhammad Azzam Ismaila, B. Hazreena Husseinb, C. Abdul Malik, Abdul Rahmanc	Biomimetic building skins: An adaptive approach	**Biomimicry & Energy efficiency group**	responsive skins based on functional aspects/ A review of biomimetic building skins was presented	Adaptive biomimetic building skins	general	general	Paper: Theoretical, Quantitativ e
2018	Duygunur Koç Aslan and Semra Arslan Selçuk	A Biomimetic Approach to Rainwater Harvesting Strategies Through the Use of Buildings	**Biomimicry & Energy efficiency group**	Water collecting / Engineering Technologies	Water efficiency	general	Humid climate	Paper: Theoretical
2018	Matthew Webb , Lu Aye „ Ray Green	Simulation of a biomimetic façade using TRNSYS	**Biomimicry, Energy efficiency &Environmental computation tools group**	Biomimetic façade with/ determine heat transfer in summer design conditions /Simulation (TRNSYS) software tool	Reduce energy consumption	Office building	Melbourne	Paper: Simulation
2016	Dr.Gehan .N.Radwana & Arch. Nouran Osamab	BIOMIMICRY AN APPROACH, FOR ENERGY EFFECIENT BUILDING SKIN DESIGN.	**Biomimicry & Energy efficiency group**	Building skin / Design Matrix	determine the main building skin design requirements	general	general	Paper: Theoretical
2018	C. Vailati, E. Bachtiar , P. Hass, I.Burgert, M.Rüggeberg	An autonomous shading system based on coupled wood bilayer elements	**Biomimicry & Energy efficiency group**	Climate Adaptive Building Shells / humidity-driven wood bilayers	Responsive skin	general	moderate	Paper: Experiment al
2014	Steffen Reichert , Achim Menges, David Correa	materially embedded and hygroscopicaly enabled responsiveness	**Biomimicry & Energy efficiency group**	Responsive skin / humidity-driven wood	autonomously responsive architectural systems	General But more suitable for stadium	Continental climate	Paper: Experiment al
2019	Hasan Gokberk Bayhan, Ece Karaca	SWOT Analysis of Biomimicry for Sustainable Buildings–A Literature Review of the Importance of Kinetic Architecture applications in Sustainable Construction Projects	**Biomimicry Group**	Kinetic Architecture / SWOT analysis as the research method	pathway of sustainable buildings. References	general	general	Paper: Theoretical
2017	Gülcan MİNSOLMAZ YELER, Soner YELER	MODELS FROM NATURE FOR INNOVATIVE BUILDING SKINS	**Biomimicry group**	innovative building skins / analysis study	transform the knowledge of biological systems (natural solutions) into architectural design of innovative	general	general	Paper: Theoretical
2008	J Scott Turnerand. Rupert C Soar	Beyond biomimicry: What termites can tell us about realizing the living building.	**Biomimicry & Energy efficiency group**	termite- lung inspiration / analysis study, Design process (behavior level)	termite-inspired building designs	High rise building	general	Paper: Theoretical, design

2011	JOHN YOWELL Norman, Oklahoma	BIOMIMETIC BUILDING SKIN: A PHENOMENOLOGICAL APPROACH USING TREE BARK AS MODEL	**Biomimicry & Energy efficiency group**	Tree Skin; Bark Inspiration/ Building skin Design process (behavior level)	tree bark as a model because it is efficient with resources and is adapted to its local climate	general	general	Thesis: Theoretical
2005	https://www.sciencefocus.com/future-technology/biomimetic-design-10-examples-of-nature-inspiring-technology/	Box fish and the Bionic car	**Biomimicry & Energy efficiency group**	Emulating the Box fish/ Design process (organism level), Structural optimizations	reduce drag by emulating the Box fish	car	-----	Web-Article
2005	Stephen Webb	ENVIRONMENT DESIGN GUIDE THE INTEGRATED DE S I G N PROCESS O F CH2	**Biomimicry & Energy efficiency group**	Emulating tree parts systems/ Design process (behavior level)	Energy efficiency	Office building	Melbourne	Paper: Theoretical
2005	Hayter, Jason Alexander	The Lloyd Crossing Sustainable Urban Design Plan	**Biomimicry & Energy efficiency group**	Emulating all The ecosystem of the Site (small forest)/ Design process (Eco system level)	Energy efficiency	Residential buildings	Portland Oregon United State **zone** 8b or 9a	Web-Article
1997	Janine Benyus	Biomimicry: Innovation Inspired by Nature.	**Biomimicry group**	Innovation/ Nature Inspiration methods	Biomimicry concept	general	general	book
2007	Maibritt Pedersen Zari	BIOMIMETIC APPROACHES TO ARCHITECTURAL DESIGN FOR INCREASED SUSTAINABILITY	**Biomimicry group**	Innovation/ Nature Inspiration methods	Development of Biomimicry concept	general	general	Paper: Theoretical
2016	V. Vermesan1 & U. P. Flueckiger2	Intelligent, parametrically sustainable architectural design	**Energy efficiency & Environmental computation tools**	Ladybug-Honeybee/ generative and parametric design (grasshopper)	optimum solution of parametric modelling, assisting architects in the decision-making process.	Suburban	Amarillo, West Texas	Paper: Simulation
2014	Press, W I T	ECO-ARCHITECTUE V Harmonization between Architecture and Nature	**Energy efficiency group**	Innovation/ General knowledge	Energy efficiency	general	general	book
2016	Tony Marcel Nisha1, P.Jayasudha2	Sustainable and Energy Efficient Design Principles in Vernacular Architecture	**Energy efficiency group**	Vernacular Architecture/ Energy Efficient Design Principles analysis	Sustainability	general	general	Paper: Theoretical
2006	M. Yılmaz	SUSTAINABLE DESIGN IN ARCHITECTURE	**Energy efficiency group**	environmental preservation/ General knowledge	Energy cost improvement	general	general	Paper: Theoretical
2010	Abdi, Mahamed Y Virányi, Zoltán	Aesthetics in sustainability or sustainability in aesthetics	**Energy efficiency group**	Green architecture / General knowledge	Economics and aesthetic design	general	general	Paper: Theoretical
2014	Jenna Carr	An Introduction to Genetic Algorithms	**Computation group**	Genetic algorithms/ To optimize	Improve optimization process	-----	-----	Paper: Theoretical
1995	Melanie Mitchell	Genetic Algorithms: An Overview	**Biomimicry& computation group**	Genetic algorithms/ mimic the processes of biological evolution	natural adaptation imported into computer systems	-----	-----	Paper: Theoretical

2011	Jason Brownlee	Clever Algorithms - Nature-Inspired Programming Recipes	**Biomimicry& computation group**	Clever Algorithms/ Biologically Inspired Computation	Computational problem solving techniques	-----	-----	book
2013	Rudolf Kruse, Christian Borgelt, Frank Klawonn, Christian Moewes, Matthias Steinbrecher and Pascal Held	Computational Intelligence A Methodological Introduction	**Computation group**	Computational intelligence/ Exhibit intelligent behavior in complex environments.	Solutions-finding	-----	-----	book
2008	Philippe Marin, Jean-Claude Bignon, Hervé Lequay	A Genetic Algorithm for use in Creative Design Processes	**Computation group**	Genetic algorithms/ Fitness function	Digital tool to be used in the creative design process	-----	-----	Paper: Theoretical
1999	Peter Bentley	An Introduction to Evolutionary Design by Computers	**Computation group**	evolutionary techniques/ using computer	evolutionary design by computers	-----	-----	book
2010	Schwehr, Peter	EVOLUTIONARY ALGORITHMS IN ARCHITECTURE	**Biomimicry& computation group**	EVOLUTIONARY ALGORITHMS/ basis of Darwin's principle of natural selection	buildings which successfully resist selection pressure as long as possible	-----	-----	Paper: Theoretical
2013	PEDRO DE AZAMBUJA VARELA	Genetic algorithms in architecture HISTORY AND RELEVANCE	**Computation group**	geometric solutions/ apply in design process	using computational power in the form of genetic algorithms to find geometric solutions	-----	-----	Paper: Theoretical
2016	Mohammad Latifi, Mohammad Javad Mahdavinezhad, Darab Diba.	UNDERSTANDING GENETIC ALGORITHMS IN ARCHITECTURE	**Computation group**	Genetic algorithms / apply in design process	emergence of concepts and solving the problems of structural, mechanical, thermal, lighting and more efficient.	-----	-----	Paper: Theoretical
2007	Eleftheria Fasoulaki	Genetic Algorithms in Architecture: a Necessity or a Trend?	**Computation group**	Genetic algorithms / apply in design process	address problems of complexity in the function and the form of architectural projects	-----	-----	Paper: Theoretical
2018	Saransh Mehta	The Architect of Artificial intelligence—Deep Learning	**Computation group**	Artificial intelligence/ General knowledge	Software developing	-----	-----	Article
2016	Emil RACEC and Stefania BUDULAN and Alfredo VELLIDO	Computational Intelligence in architectural and interior design: a state-of-the-art and outlook on the field	**Computation group**	Computational Intelligence/ apply in architecture design	automatic solution arrangement, given	-----	-----	Paper: Theoretical
2016	Fathi, Saleh, & Hegazy	Computational design as an approach to sustainable Regional architecture in the Arab world	**Computation group**	Computation tools / Design process	Digital design	-----	-----	Paper: Theoretical
2018	Berk Ekici , Cemre Cubukcuoglu , Michela Turrin , I. Sevil Sariyildiz	Performative computational architecture using swarm and evolutionary optimization: A review	**Computation group**	computational architecture/ using swarm and evolutionary optimization	performative computational architecture using	-----	-----	Paper: Theoretical

2010	Toni Kotnik	Digital Architectural Design as Exploration of Computable Functions	**Computation group**	concept of computable functions / Exploit the computer as a design tool	digital design methods	-----	-----	Paper: Theoretical
2017	Danil Nagy	Design optimization	**Computation group**	optimization algorithm/ design process	optimization algorithm and Generative Design	-----	-----	Paper: Theoretical
2007	ACHIM MENGES	Computational Morphogenesis: Integral Form Generation and Materialization Processes	**Biomimicry& computation group**	Natural morphogenesis/ employ computational techniques and digital fabrication technologies	develop a design approach that allows for a much higher level of integration of form generation, materialization and construction	-----	-----	Paper: Theoretical
2006	Michael Hensel, Achim Menges, Michael Weinstock	Towards Self-Organizational and Multiple-Performance Capacity in Architecture	**Computation group**	Morphogenetic Design Strategies/ Self –organization	the concepts of emergence and self-organization in relation to the discipline of architecture	-----	-----	Paper: Theoretical
2018	Thomas Wortmann	Genetic evolution vs. function approximation: Benchmarking algorithms for architectural design optimization	**Computation group**	architectural design optimization/ simulation-based problems	Growing applications of parametric design and performance simulations in architecture, engineering, and construction allow the harnessing of simulation-based, or black- box, optimization	-----	-----	Paper: Simulation
2015	Michelle Douglass	http://www.bbc.com/earth/story/20150913-nine-incredible-buildings-inspired-by-nature	**Biomimicry group**	Mimicking natural configuration / interior is inspired by the idea of a forest	Construction system: Tree-like columns branch off near the roof for support	Sagrada Familia cathedral	Barcelona, Spain	Web-article

2.2. Background: Classification groups

From the previous table, we can conclude that the high-performance design as a general field of study could be involved within four terms: Energy efficiency, Biomimicry, Computational tools, Energy resources (renewable energy). The researchers have been adopted one or two terms to conduct their research. There is just one paper that adopted three terms for the research. In general, the table shows that any one or more than one term could be adopted to conduct a high performance-based design as a general research area. But also, if we specified the high-performance design based on energy efficiency, an exception will be made which is (Biomimicry, Computation tools without energy efficiency goal). In general, the literature review process (table) presented eight groups:

2.2.1. Biomimicry & Energy efficiency group

Biologists have provided a lot of information about nature and its philosophy. And the way organisms deal with nature system and how to impact the environment. Therefore, biomimicry offers solutions by emulating the processes, and strategies found in organisms to be able to confront the dilemmas facing humanity. Nature has effective and efficient methods to address many of the tasks we have faced today based on its more than 3.8 billion years of evolution and experience. Through the application of the adaptive methods that distinguish organisms used to address the problems within the built environment in a way that not only solve human problems but the natural environment as well. Therefore, biomimicry is a comprehensive concept of design that can provide effective solutions. A deep analysis of the way nature solves the problems it faces, we can find suitable and guaranteed success solutions and new directions can be explored in addressing the problems of the built environment (JOHN YOWELL Norman, 2011). Nature designs are truly marvelous, as they exceed human designs in terms of efficiency, performance, and complexity. Every organism must have a well-organization process to conduct its biological operations based on energy efficiency concept to survive, whether if it is flora or fauna; in humid, dry, hot, cold or above ground, or underwater. Due to its operations, the organisms can't afford to waste resources. Architects must learn the way organisms do so. Interdisciplinary studies between architectural and biological sciences reveal tremendous possibilities for solving problems by innovation. the most principles of inspiration from nature have evolved remarkably, as biomimicry are applied using taxonomic steps. In 1971, architect Frei_Otto has further claimed that biology is crucial for the architecture and the architecture is crucial for biology. Biomimicry is an expression for describing the use of the nature genius. It aims to make the most beneficial use of resources, while properly fulfilling human needs (Benyus, 1997) & (Bayhan & Karaca, 2019).

2.2.2. Biomimicry group

Biomimicry in architecture is taken several paths over the ages, which have perpetuated various architectural movements and trends. The beginnings were abstract metaphors directly or indirectly applied in architectural forms. There are many samples of Biomimicry in architecture (Ashraf Saad El Ahmar, 2011). An example in 1851, by observing the giant lily water, Paxton inspired the structural system for the crystal palace and other projects. Also, with a view of imitating the biological structural model drawn by Hegel, a German biologist in the nineteenth century, Robert Le Ricolais, a French professor at the University of Pennsylvania, has developed new structural models within the middle of the 20th century. In the same century, several architects, like Le Corbusier and Frank Lloyd Wright, inspired nature. Frank Lloyd Wright combined organic architecture into his designs, but he didn't use nature as an overwhelming element. His philosophy was the communication and complementarity between nature and architecture. As Le Corbusier stated that biology would be "the great new word in architecture and planning" (Radwan & Osama, 2016).

2.2.3. Computation group

Computation could be a multi-specialty field of study, mainly aimed at creating, exploring, and discovering intellectual workflows. In other meaning, considering rationally laws of logic and organized thought as rationale formal (Brownlee, 2011). Performing logically offers the ability to do judicious things such as anticipated utility maximization. "Computational Intelligence contains paradigms, concepts, algorithms, and systems frameworks that are designed to demonstrate cognitive processes in a dynamic environment (Kruse et al., 2016). Recently, some of attempts have been made to address different computation fields in a machine-learning manner with the aim of offering partial automation of human tasks, personal support for field specialists, and professional direction for amateurs (Emil Racec, Stefania Budulan, 2016). The use of computer-based technologies for both engineers and designers has fundamentally changed modern architecture (Saransh Mehta, 2018). In recent years, architecture has witnessed an evolution in the field of automation and technology. Many practical aspects have changed, including performance, evaluation, manufacturing, project delivery, and billing. Digital design has the greatest effect on architectural items worldwide. The digital design began as a tool for making accurate and complex drawings (computer-aided design (CAD)). Later, the concept expanded to wider applications of great importance tools that generate information 3D model (building information modeling (BIM) for the complete building including all drawings, plans, and workshop details. At another advanced stage, computation design entered the process of form-finding. The computational design uses the power of computer algorithms through coding to explore limitless iterations of forms, problem-solving, very complex geometric calculations, and rationalization. The computational design penetrates many fields, including industrial design, animation, simulation, and others. Nevertheless, the application of computational design is very promising. It is considered as a new addition to the architectural thinking method in design and manufacturing (Saransh Mehta, 2018) & (Fry et al., 1985) & (Jacob, 2013).

2.2.4. Biomimicry& computation group

Natural morphogenesis "is the method of evolutionary development and growth, derives polymorphic systems that obtain their complex form, organization, and flexibility from the interaction of external environmental influences and system intrinsic material capacities and forces". during this system, the method of formation and materialization are inextricably linked and contribute together within the process of natural morphogenesis (Achim, 2007). The promising potential of the technology can provide a new approach to design through which the process of form generation and materialization processes are integrated together for the best ability to form. The complexity, the differentiation, and homogeneity cannot be obtained without customizing current software by scriptural computer programming (Wortmann & Tunçer, 2017). Morphogenesis is a complex biological process that includes growth, rehabilitation, adaptation, and aging according to environmental and genetic influences to reach the most appropriate procedure. This concept may be adopted in architecture and applied in terms of composition and architectural formation, especially structures and dynamic architecture (Ashraf Saad El Ahmar, 2011). In architecture, morphogenic (digital morphogenesis or computational morphogenesis) is referred to as a multi-method procedure using digital media not as visualization tools but as generative. It is related to various concepts such as emergence, self-organization, and form seeking. Amongst the benefits of bio-inspired forms, their potential for structural profits resulting from redundancy and differentiation and therefore the ability to act multiple simultaneous functions (Roudavski, 2014).

Computational processes for the form finding and generation of genetics algorithms are based on the mathematical synonym of the Darwinian model of evolution and the biological developments. Evolutionary computing provides the potential to link special and cultural parameters, with design patterns, process, form, and behavior. Evolutionary computational morphogenesis strategies are likely to be combined with advanced structural and material simulations to examine the performance under gravity and load stress (Ashraf Saad El Ahmar, 2011).

2.2.5. Energy efficiency group

The energy efficiency concept has been a phenomenon since the 1970s, and in the last decade has expanded considerably. The growing interest in climate change and greenhouse have caused engineers, architects, and researchers to concentrate on energy consumption using different passive and active strategies for heating, cooling, and ventilation strategies, daylight utilization, and explored a few approaches of the integrated energy generation. A great part of the global energy usage links to the built environment and buildings demand (Oguntona & Aigbavboa, 2017). The main goal of buildings is to deliver a comfortable interior atmosphere for the inhabitants, whatever the external environment conditions are. This requires a series of practical and technological procedures to make buildings suitable for occupants. Therefore, the efficiency of the building determined by the provision of the required comfortable level of the indoor environment with the least energy usage, which means mitigate the emission levels. So, to attain an appropriate balance between the level of energy usage and the provision of the required comfortable level of the indoor environment, many approaches have emerged to achieve this goal. The link between facade design and energy usage attracts much more consideration than ever before. The design of the façade controls the level of comfort, heating and cooling, artificial light, and even natural ventilation for the inhabitant. In general, the façade of the building is the most responsible part of energy consumption in buildings due to the ability to “determine indoor physical environment related to thermal comfort, visual comfort, and even occupancy working efficiency, thus affecting energy usages in buildings". And the methods of the manufacture used today are very dangerous because many of the consumer construction materials are harmful to the environment. Therefore, more sustainable construction mechanisms must be created includes recyclable and harmless materials (Minsolmaz Yeler & Yeler, 2017). So, the performance within energy consumption will identify the efficiency of the building. Building industry energy demands must be reduced by improved building efficiency in compliance with various aspects, for example, glazing, walls, roofs, lighting systems, transformable façades, comfort and standing, and several other aspects without sacrificing occupants comfort (*Sustainable and Energy Efficient Design Principles in Vernacular Architecture*, 2017).

2.2.6. Energy efficiency & Environmental computation tools group

Performance-based environmental computation tools design has become a vital approach to achieve many objective goals. It is a guiding designer to manages the design process into logical directions based on information related to the final output of the design. The Performance-based environmental computation process aims to change the traditional design approach to a more logical and efficient way including all three phases of Principal component analysis (form generation, performance evaluation, and optimization) by relying on computational abilities. In other meaning, the performance concept is a method of thinking and focusing on goals rather than means. It is concerned with what a building or building product is required to achieve, and not with prescribing how it's to be constructed. So, the concerns with what a building or construction products are required to have and not how it is designed (Ekici et al., 2019). Generally, performance means the qualitative or quantitative features that are objectively identifiable of the building, and that contributes to the determination of its ability to fulfill its various functions for which it was designed (Shi & Yang, 2013).

Therefore, many supporting tools used to help architects with early decision making based on performance, especially by environmental analysis tools. Rhino-Grasshopper is one of the most commonly used platforms that are exploited by architects. Also, there are already lots of environmental plugins developed for Rhino-Grasshopper. However, Ladybug and Honeybee plugins offer a number of advantages that existing

Rhino-Grasshopper unable to do so. In these plugins, energy plus weather files (EPW) are imported giving the ability to provide a different interactive 2D and 3D graphics visualization to assist decision making in the first design stages. It also facilitates the process of analysis, automation, and calculation and provides simple graphs and charts. Allowing the architects and engineers to evaluate energy and daylight engines like EnergyPlus, Radiance, and Daysim. With the ability to control the parametric tools of grasshopper gives extra flexibility to modify the design based on instantaneous feedback. The interactive of design stimuli within the information and analysis of the environment. In this way of the design process, many different outcomes of design performance can be produced. The designer chooses the best solutions that make the building more suitable for its environment (Roudsari & Pak, 2013).

2.2.7. Energy resources group

Energy is present in nature; it cannot be destroyed, it cannot be produced from anything and existing energy cannot be destroyed. However, it can be transformed from one form to another. This is the principle of conservation of energy. “It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms” (Britannica, 2018). Energy is a central issue for every challenge or opportunity facing humanity. Development, security, food production, and increased income all depend on energy as a basic issue. Energy is a major contributor to climate change (United Nations Development Programme, 2000). Coal and other fossil fuels, mineral oil, and natural gas propellants are the most used resources. Consumption has become more sophisticated. And energy sources have become a necessity for the national security of nations (Maggio & Cacciola, 2012). The tremendous technological development has produced many alternative methods for us that have less negative effects on the environment. Traditional methods of energy production have their environmental problems, which confiscate the right of future generations to live in an environment that is sustainable and prosperous (Karaman, 2019). In general, energy sources can be classified into three categories: renewable, fossil, and nuclear. In more specifically, the classification could be divide into renewable and non-renewable. Non-renewable Energy Resources are the sources that can be depleted over time and not compensated. It is often accompanied by a negative impact on the environment due to its conversion to other forms of compounds when used to produce energy. These resources include nuclear energy, coal, oil, and natural gas, etc. Nonrenewable energy accounts for 85%

of all energy sources and oil makes up the largest proportion (Novakovic & Nasiri, 2016). It is expected that non-renewable energy sources will continue to lead the energy sources in the coming years (Boundless Physics, n.d.). While Renewable energy, energy that can be naturally replenished at the same rate as it is used in our planet such as hydropower and biomass. In general, it is an inaccessible source found in nature and restores itself whenever it is used. After the 2000s, the issue of alternative energy and its sources became more serious. Studies and research have begun to be carried out in various fields of sustainable energy. Its renewable and eco-friendly properties have made it one of the most effective solutions to combat climate change and global warming. There are different types of renewable energies. Renewable and sustainable energy sources are grouped as sunlight based, wind, geothermal, hydraulic, biomass, and wave, and hydrogen energies prosperous (Karaman, 2019).

2.2.8. Biomimicry, Energy efficiency & Environmental computation tools group

This is a sort of rare grope based on literature reviews and researches have conducted. "Biomimicry is the term to describe the use of genius in nature. It basically aims to use resources in the most effective method while sufficient human needs". Biomimicry strategy as a novel design approach offers a potential link with the concept of energy efficiency and high-performance buildings. The experience of nature-based on finding the best solutions and improving environmental performance through the continuous adaptation to the surrounding changes could be inspired. For instance, the adaptation of the organism, its fitness, and its homogeneity with its surrounding environment (Benyus, 1997). The process of applying bio-inspiration in buildings requires advanced technologies and costs. For this reason, analysis, simulations, and tests operation carried out at the early stages of design to ensure the results. Computation tools and software simulate technologies and applied principles to extract the estimated results in the built environment. However, environmental computation tools are the major tools that contribute to performance-based designs to improve building efficiency and reduce energy usage.

From the previous classification groups, there are four main terms that have a major contribution in high-performance design based on energy efficiency as a field of study.

The terms are; Energy efficiency, Biomimicry, Computational tools, Clean energy resources. Generally, researchers conduct a lot of studies related to high-performance design based energy efficiency by adopting one or two or more terms to conduct the research. Just one researcher has adopted three terms to do the research.

Therefore, in this research a comprehensive approach by adopting all the four terms (combined) to examine the potential of this comprehensive approach as an advanced design strategy to achieve the research goals. The advanced design strategy will restrict the four terms and make them fallen in the same area of study as a high-performance design based on energy efficiency.

CHAPTER 3

DESIGN STRATEGIES

There are a number of design strategies have been emerged recently that show a great potential to serve the research aims and goals such as high-performance design. These strategies presented a promising design method to achieve energy efficacy improvement. Therefore, create a general knowledge of the most efficient concepts towards a high performance- design, increase the opportunity to develop a comprehensive approach that can make the design process more accurate, more logic, and more capable to solve the problems.

3.1. Biomimicry: Historical Background

“From my designer’s perception, I wonder: if i can design a building like a tree? A building that can produce oxygen, fixes nitrogen, seizes carbon, purifies water, uses solar wave as fuel, able to produce sources, creates microclimates, adaptive with the seasons and self-replicates. It’s a charming vision (McDonough and Braungart, 1998)”.

Biomimicry is the term to describe the use of genius in nature. It basically aims to use resources in the most efficient way while satisfy human needs. Biomimicry originally is a Greek word that contains two terms, bio (life) and mimicry (imitation). The harmony and ratio between all the organisms’ parts produce perfect models. Since ancient civilizations, philosophers and critics considered nature as a synonymous model of the idyllic beauty throw the strength of the wholeness, integrity, unity. Each part has its influence to affect the whole, and no part may remove without some harm to the whole. Aristotle defined many basic elements of aesthetics based on these concepts. There are common properties based on the Aristotelian opinion in both living creatures and the best works of art (Ashraf Saad El Ahmar, 2011).

Leonardo da Vinci is one of the pioneers' men of the Renaissance, inspired a lot of his works from nature. For instance, in 1482, Leonardo Da Vinci mimicked birds fly as an early case for bio-inspiration to create a flying machine. This example helped to develop the first prototype of an aircraft in 1948 built by wright's brother. Leonardo da Vinci said, "Those inspired by a model other than nature are working uselessly". Additionally, another pioneer as an architect in the 19th century, Antonio Gaudi, has a great influence on nature and its vital composition. Gaudi has a distinctive design direction by inspiring the structure systems found in nature and employing them in its buildings (see Figure 3.1.) The natural world was also a key influence for Art Nouveau as an inspiration source, which was illustrated in a number of ways. Art_Nouveau designers have used forms of organisms to express nature into modern life (see Figure 3.2.). Through Art Nouveau glassware, the interior, ceramics, and illustrated books a large number of flora and fauna, orchids and irises, poppies and tulips, used (JOHN YOWELL Norman, 2011).

Figure 3.1. example of Antonio Gaudi design

Figure 3.2. example of Art nouveau

In 1950 "Biomimicry" term is coined by Otto Schmitt. Also in1958, Jack E. Steele introduced a term (Bionics) and he defined it as a science of natural systems or their analogs. The term biomimicry appeared as early as 1982. Janine Benyus the scientist, published in 1997 (Biomimicry: Innovation Inspired by Nature). Benyus defined Biomimicry as a "new science that studies nature's models and so imitates or takes inspiration from these designs and processes to resolve human problems". Benyus suggests to absorb Nature as a "Model, Measure, and Mentor" and emphasizes sustain-ability as an objective of biomimicry (Okuyucu C., 2015). Yet, Schwan Bryony and Janine Benyus initiate the Biomimicry institute in 2005. While in 2007 "AskNature" a major digital library that in the world for bio-inspiration issues has founded by Chris

Allen, Beynus, and Schwan, containing a list of natural potential solutions for designers to scan the natural systems set organized as a source for inspiration toward design (Radwan & Osama, 2016).

3.1.1. Biomimicry: Why biomimicry?

Why do we imitate nature? Do engineers have to look at nature for inspiration? The answer is linked to what nature can offer. Imitating something means having it in a different form. It's a vital matter to know if it's worth what you imitate. Imitation should be done when and where something is highly valued when the concept goes beyond and reaches the purpose. The huge admiration for the work of Van Koch and look at it a certain distance or think about the enormity of the China Great Wall or the pyramids, or of the hanging gardens due to the result of great thought and a vague or known purpose. They give us a glimpse of the thoughts of the designer and their order and elegance exceed all unintentional incidents. Ancient civilizations have paid great attention to nature; they absorbed, analyzed it, and used many of it in their activities. Babylonians, Egyptians, and indigenous people sanctified nature and considered it a source of inspiration. They were aware nature is not an absurd product. Historical and modern studies have shown that architects, philosophers, writers, artists, and scientists have viewed nature with great appreciation. The interpretation of Heidegger concerning the "mysteriousness" of the natural world has developed an environmental ethic for nature conservation. There are strong proofs that something is happening behind everything (JOHN YOWELL Norman, 2011).

The Biomimetic term mainly appeared in England and due to Webster's dictionary (2010), it's defined as "The study of formation, structure, or function of biologically produced substances, material and biological mechanisms and processes. Especially for the purpose of synthesizing similar products by artificial mechanisms that mimic natural ones (Julian Vincent is a professor of Biomimetic at the University of Bath in the U.K. and is a world-renowned expert in the field)". In Germany the term Bionik (or Bionic) used for a simple definition, "The interdisciplinary field of bionics is about scrutinizing and transferring 'natural inventions' into technical applications". It is derived from the word 'Bionics' from the Greek's bios (life) and ikos (unit). Those who work in these fields do not attempts to trace or copy but should provide ideas for new designs that can improve the current design way (JOHN YOWELL Norman, 2011). Nature provides scientists and engineers from different fields of interest with an endless source of inspiration. Each organism has its own environment and is fully adapted. By responding to their needs and finding practical solutions, nature evolves (El-Zeiny, 2012).

The aware imitation of life's genius, innovation inspired by nature in a culture used to be dominating everything is a totally new approach, a revolution really. The Biomimicry expansion could present an age-based "on what" can absorb from nature and "not on what" can cutting, as the Industrial Revolution did. "nature's way" has the possibility to manage the way of produce materials, growing food, use energy, healing, collect information, and manage a business. In a biomimicry world, the industrial could be done in the way that animals and plants do, using sun and simple ingredients to produce totally biodegradable fibers, ceramics, plastics, and chemicals. We would absorb animals and insects that have used plants for millions of years to keep themselves fit and fed. The farms, would be self-fertilizing and pest-resistant the same on prairies. Even computation would take its hint from nature, with software that "evolves" solutions, and hardware that uses the lock-and-key model to compute by touch (Benyus, 1997).

In addition, Janine Benyus presented different biomimicry definitions to lead society to understand the term in a comprehensive way. Benyus suggests observing nature as a "Model, Measure, and Mentor" and making the objectivity of the biomimicry is for sustainability (see Figure 3.3.).

* Nature as model: "studies nature's strategies, process, designs and inspire them to solve human problems, e.g., a solar cell inspired by a leaf".

* Nature as measure: "Biomimicry uses an ecological scale to decide the (rightness) of our innovations. 3.8 billion years of evolution, nature has learned: What works. What is fitting, and What sustain".

* Nature as mentor: "Biomimicry is a new way of viewing and valuing nature. It produces an era based not on what we can extract from the natural world, but on what we can learn from it" (Benyus, 1997).

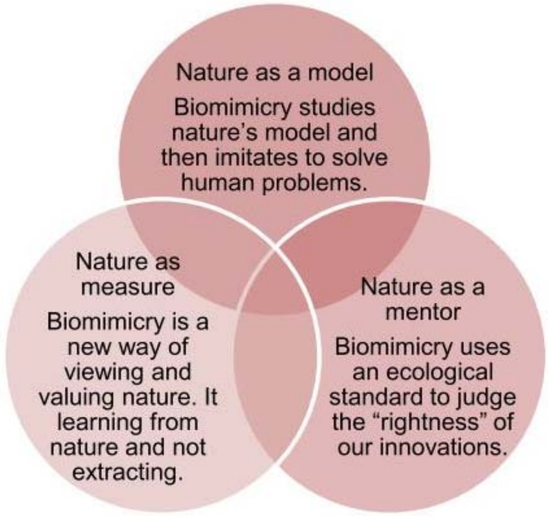


Figure 3.3. Benyus suggestions (Agrawal, n.d.)

The concept of biomimicry aims to design by imitating nature's genius. These designs, inspired by nature, aim to solve the problems that arise in current designs. From early humans, humankind has been imitating from nature consciously or subconsciously. Furthermore, Janine Benyus in her 1997 book Biomimicry mentioned that there are various strategies that can be utilized for inspiration as three stages of biomimicry:

Organism level (natural form): "Simple characteristic or feature of the creature to be transferred from the nature appearance. explored and transferred. (Example: bird's feather shapes' visual transfer) (Bayhan & Karaca, 2019)".

Baumeister notes that 'the exploration and development have been done'. Living organisms are regularly developed over millions of years. Living organisms that still exist on earth have already survived and adapted to continuous changes over time. Therefore, it is very reasonable to search these creatures for appropriate solutions to the problems we face, these organisms may have special mechanisms to solve their problems. Especially with climate change and reduction of resources, nature may have its say in how to correct the consumer human path and develop viable solutions to sustainability (Pedersen Zari, 2007).

Behavioral level (natural production): "Behavior and specific features of creatures to be transferred from nature are researched and transmitted. (For example: imitate the bird's feathers to keep its body temperature constant) (Bayhan & Karaca, 2019)".

The organisms are affected by the surrounding environment, face their problems, and seek solutions to these problems as a human does. The coping strategy of these organisms depends primarily on the environment of the place and the availability of resources and energy. It works within the capacity of the environment and ensures that it is not depleted and sustainable. These problems are also created a new generation with more power and ability to cope with these problems through the laws of evolutionary and natural selection on which the survival is for the strongest. Humans are undoubtedly effective architects of the ecosystem, especially as they acquire the environmental knowledge of other organisms. It is important to mention that not all organisms show behaviors suitable for human inspiration. These principles may also be used for harmful practices under the excuse of the behavioral inspiration of other organisms. Overall, the level of behavior requires ethical decisions and extensive studies on the appropriateness of human inspiration. For example, the behavior of the building (and the results of it) of termites may be suitable to produce thermally comfortable, passively controlled buildings but poorly organized buildings. It may be more appropriate to inspire certain behaviors of organisms and apply them to the environment built. It is necessary to develop the built environment and make it able to renew and adapt along with the conservation of energy and resources based on the durability of this environment to ensure continuity and renewal (Pedersen Zari, 2007).

Ecosystem level: The site, position, advantage, and disadvantage aspects of the organism to be transferred from nature and investigated into the ecosystem (Bayhan & Karaca, 2019).

Benyus, Vincent states that ecosystems imitation is a vital level of biomimicry. The ecosystem level is advocating a shift to regenerate design process by adopting a new form of sustainability in which the goal is the well-being of the environment and people, instead of profits. This level could be used with other levels (organism and behavior) which is one of the features added to this level. Also, this level can be combined with the human methods and concepts used and make it more effective and mutually beneficial with the environment. In general, the Ecosystem will develop a broader and comprehensive concept that seeks mutual benefit between the part and all through the systems of participatory and complex including all. A simple example, John and Nancy Todd's Living or Eco Machines in which mimicking and integrated the operation of the Sewage treatment with plants (Pedersen Zari, 2007).

These three main levels of biomimicry can be used to tackle any design problem by bringing solutions from nature by observing the organism or ecosystem and determining which aspect of biology, to be imitated, is important (Radwan & Osama, 2016).

Within these biomimicry inspiration levels, there are further five sub-classifications of imitation. "Designers may mimic for example in terms of what it looks like (form), how it works (process), how it is made (construction), what it is made out of (material), or what it is able to do (function)". The variances of biomimicry are described in (see Figure 3.4.) as the biomimicry levels and are exemplified by considering how different features of the organism could be imitated (Pedersen Zari, 2007).

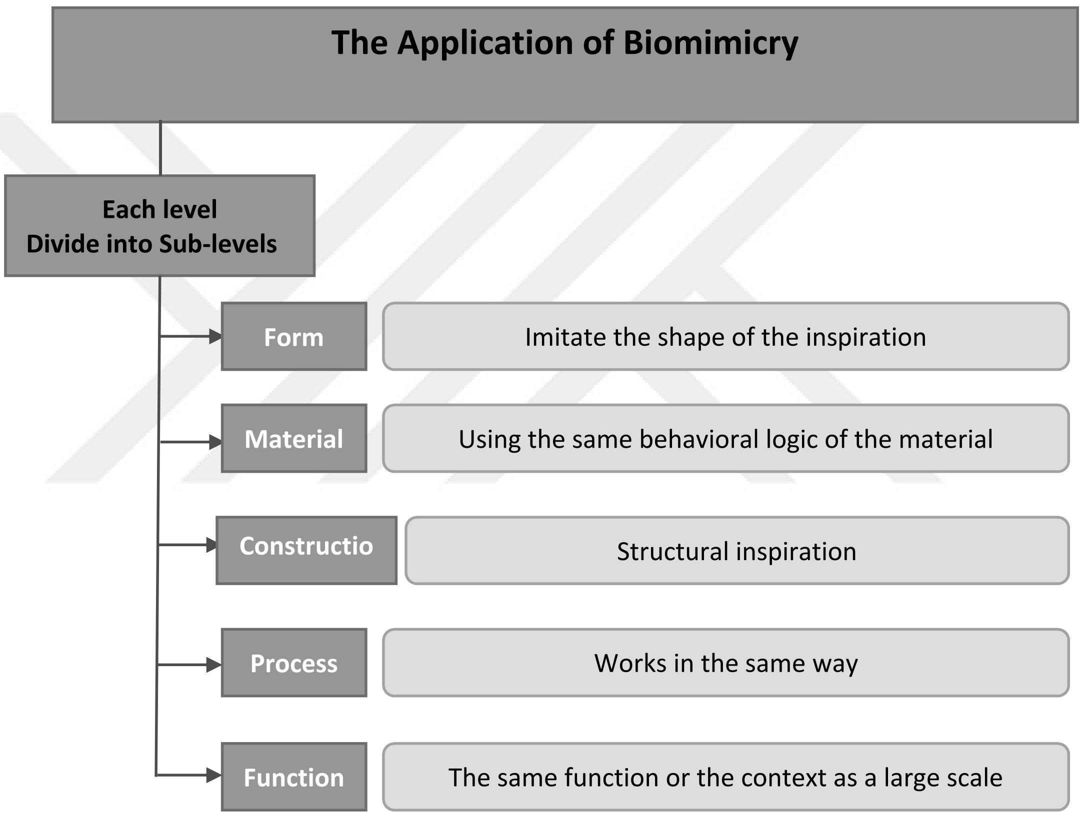


Figure 3.4. Zari's classification for Biomimicry levels as a framework (adapted from Pedersen Zari, 2007).

We recognize that all our inventions have already appeared in nature in a more efficient way and much lower environmental costs. The central heating and air-conditioning we use appeared in nature by termite tower's fixed 86 F. Our growing architectural bars and beams are already found in bamboo and lily pads. Our most development radar inspired from the bat's multi-frequency transmission. Also, the smart material recently used and developed, appeared in nature by dolphin's skin or the butterfly's proboscis (Benyus, 1997).

“Biomimicry is an applied science that derives inspiration for solutions to human problems through the study of natural designs, systems, and processes”. A deep analysis of the way nature solves the problems it faces can find suitable and guaranteed success solutions and new directions can be explored in addressing the problems of the built environment (Panchuk, 2006). Nature designs are truly marvelous, as they exceed human designs in terms of efficiency, performance, and complexity. From the streamlined shape of fishes and the molecular structure of microorganisms, everything is an example of relative perfection (Bentley, 1999). At some point, we must draw our standards from nature.

Biomimicry is a constantly evolving approach, both applied and theoretically, aimed at supporting engineering and architecture concepts by adopting nature as a basis in design. The practical application of biomimicry in the built environment is still limited. (Ahmar et al., 2010). Biomimicry offers a very promising solution to these issues. This is because of the possibilities it provides by adopting nature as a platform for innovative design and inspiration. And create a built environment that is recoverable and sustainable. Nature has constantly enhanced the nature systems for us and this feature offers the root for a novel design approach. Biomimicry may also seek to know how nature has learned its adaptive processes and extract its characteristics and advantages that helped it to such an integrated performance. And the possibility of application in design processes (Agrawal, n.d.). Flora, fauna, or whole ecosystems could be used for inspiration. Through the possibilities it provides in the design process, solutions, or even what it can provide to create a sustainable environment (Pedersen Zari, 2007). Biomimicry is a novel concept in architecture, confronts several matters that restrict its progress. as an example, the biomimicry has some limitation to transfer biology mechanism to design on a certain scale. Nature has many alternative strategies that could be applied in biomimetic design. Several varieties of biomimetic designs are a selection of suitable algorithmic growth processes (Al-Obaidi et al., 2017).

Natural skins, whether on flora or fauna, in wet, dry, hot or cold climates or above ground or underwater, all must be efficient in terms of energy to survive. The organism cannot afford to waste energy due to its skin. Architects must learn the way organisms do so. Interdisciplinary studies between architectural and biological sciences reveal tremendous possibilities for solving problems by innovation. the most principles of inspiration from nature have evolved remarkably, as biomimicry are applied using taxonomic steps. Furthermore, architect Frei Otto (1971) declared, biology becomes crucial for building and the building becomes crucial for biology.

"If architecture is to please through imitation, it must imitate nature (Durand et al., 2000)".

3.1.2. Biomimicry in architecture

Biomimicry in Architecture is taken several paths over the ages, which have perpetuated various architectural movements and trends. The beginnings were abstract metaphors directly or indirectly applied in architectural forms. There are many samples of Biomimicry in architecture. An example in 1851, by observing the giant lily water, Paxton inspired the structural system for the crystal palace and other projects. Also, with a view of imitating the biological structural model drawn by Hegel, a German biologist in the nineteenth century, Robert Le Ricolais, a French professor at the University of Pennsylvania, has developed new structural models within the middle of the 20th century. In the same century, several architects, like Le Corbusier and Frank LloydWright, inspired nature. Frank Lloyd Wright combined organic architecture into his designs, but he didn't use nature as an overwhelming element. His philosophy was the communication and complementarity between nature and architecture. As Le_Corbusier stated that biology would be "the great new word in architecture and planning" (Radwan & Osama, 2016).

Recently, Technological progress and also the development of the latest concepts that can control the process of decision-making have led to the adoption of new principles in design. The nature look today has been highlighted by the priority accorded to terms such as energy efficiency and sustainability. Benyus states that biomimicry as a novel science can observe, emulate, and inspiring features of nature so as to search out solutions to the issues facing humanity. The interesting characteristics of all organisms in nature, the use of energy conducted only as much as required, making the finest form based on its function, recycling of everything, profiting from local ingredients and avoiding wastes may well be related to the efficient use of resources and energy to be capable for adaptive to the climate. Furthermore, Taylor Buck 2015 interrogated with biomimicry experts mentioned, most consumers are motivated by profitability and they have seen biomimicry as a way to create specific products that lead to distinguish the market and increasing profits. Biomimicritical strategies can help minimize the maintenance costs of services by reducing environmental fines and taxes (Bayhan & Karaca, 2019).

On the opposite side, the essential feature of the biomimicry field is that it's an idea supported by mixing and sharing different science. However, it is also difficult to merge various professions with architectural design and technology.

The transfer of knowledge between design and execution stakeholders is effective if stakeholders have the same project aims. Therefore, the matter lies in the way to create a common science platform for this scientific field that may produce experts who are conversant in the relevant scientific fields and are able to innovate (Bayhan & Karaca, 2019). In addition, the entry of biomimicry in architecture has contributed greatly to the event of building technology to produce them more efficiently. We are now within the stage of innovation and development and this stage could be a great concern for investors because it's fraught with correctable experiences. The challenges in the complex design are particularly significant for the investors as construction projects, in line with the specific production requests of materials, implementation, and operation of these materials. Aimed to end it in a very desired budget and time. Biomimicry has the potential for sustainability at different levels by contributing to the development of materials technologies, and the emergence of recent technologies like adaptive and responsive buildings to the environment and making them more efficient (Bayhan & Karaca, 2019). To develop our existing design methods, architects must look in nature for ideas. Benyus says "When I look at where biomimicry could make the most impact, the built world is it. Benyus believes that architecture and design on the critical, cutting edge of environmental sustainability (Benyus, 1997)". Albert Einstein's words suggest, "You can never solve a problem at the level at which it was created". The solution to the problems of inefficiency requires radical innovations and a review of the current construction methods. As dependence on the existing construction technology, a new, sustainable structure will not be built. The building industry must look past itself and look closely at nature. And designers must delve into nature and its strategy to inspire solutions because nature already has solved many of existing problems. For instance, every tree leaves better than a solar panel ever produced convert sunlight into energy. And without damaging the earth, it grows in. In the region, nature works best and uses the appropriate survival systems. Using advanced technologies allows us more than ever to understand the natural world. Scientists from different fields learn how nature works using computers and microscopes. And what they see in nature, can be used to overcome human difficulties. In fact, the Biomimicry Institute puts an online database of biological. information to aid designers in this endeavor called AskNature. It is described as 'a free, open-source project, built by the community and for the community. The goal is to link innovative minds with nature's best ideas, and in the process, inspire technologies that create circumstances favorable to life' (Biomimicry Institute). The amazing taxonomy created here provides a valuable resource for the construction industry to utilize" (Bayhan & Karaca,2019).

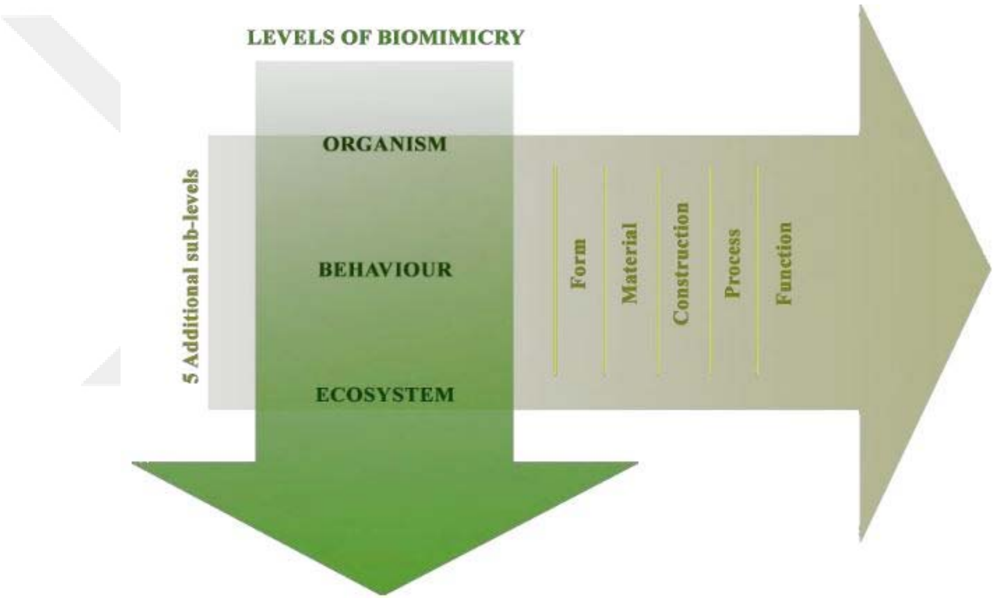


Figure 3.5. Levels and sub-levels of Biomimicry (Pedersen Zari, 2007)

3.1.3. Biomimicry design approaches

Biomimicry becomes a growing research area in architecture and technology, it provides new and inspired solutions and provides an opportunity to improve sustainability in a built environment (Radwan & Osama, 2016). Biomimicry design approaches, as Zari classified, typically fall into two categories: Problem-based approach (design to biology) and Solution-based approach (biology to design) (Perdersen Zari, 2007) (see Figure 3.6.).

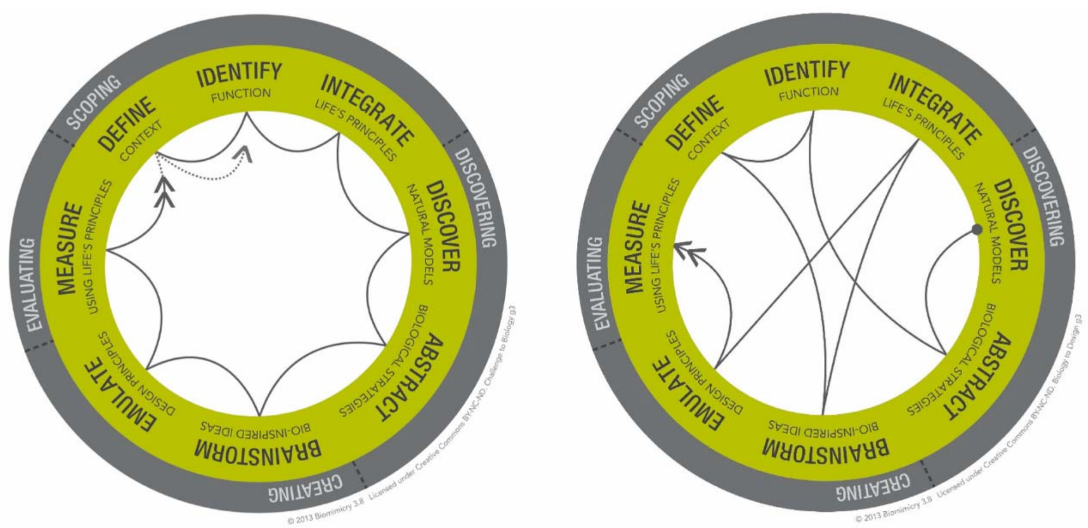


Figure 3.6. Biomimicry design approaches, as proposed in showing the "design to biology" method on the left and the "biology to design" method on the right. Attribution: Biomimicry 3.8, creative commons BY-NC-ND.

3.1.3.1. Problem-Based Approach (design to biology)

In this approach designers need to recognize problems and biologists to compare these problems with organisms that have overcome similar issues as they understand the nature strategies to find solutions (Pedersen Zari, 2007). In other meaning, designers analyze the problem and objectives by providing accurate initial information for the design that needs to be done. Biologists compare the information and the problem with living organisms that provide effective solutions to the same problem. A problem-based approach is based on setting goals and design constraints. Thus find the best inspirational solutions to apply in the design (see Figure 3.7.) (Radwan & Osama, 2016).

To assess the potential of biomimicry solutions, designers don't need deep scientific knowledge in biology or ecology. Designers can collaboration with a biologist or ecologist or even getting some knowledge to be able to access available biological researches for more understanding and absorption of nature solutions. But, the adaptation of such biological information to the human design context with very limited scientific understanding is likely to remain at a low level. As an example, it's maybe easy to emulate forms and specific mechanical features of organisms but it's hard to emulate some aspects such as chemical processes without scientific association (Pedersen Zari, 2007). However, the concept of biomimicry may generally transfer the built environment to an efficient sustainable environment. it's therefore the basis of fundamental rethinking of how architectural design approaches

Figure 3.7. The steps of problem- based approach (Hosny & Anous, 2015)

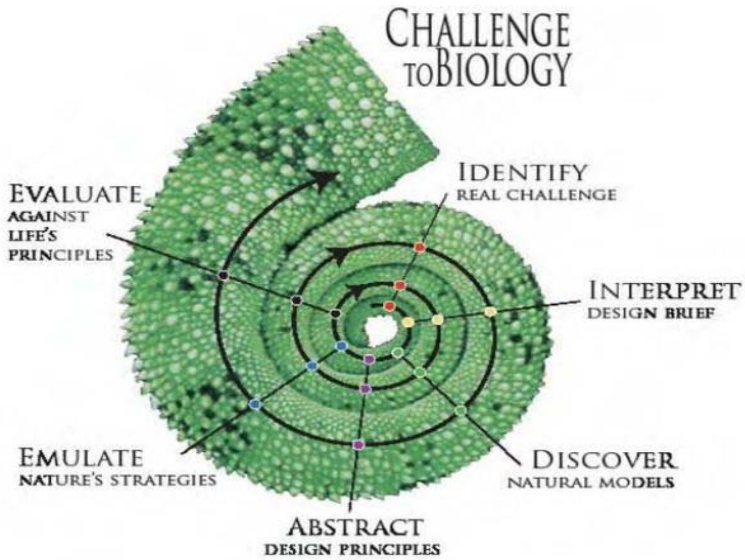


Figure 3.8. Design Spiral by the Biomimicry Institute (challenge to biology)

An example of design to biology Approach (up - bottom): Boxfish and the Bionic car which is a low flux resistance system and an impressive 0.06 drag coefficient considering the bulky appearance of the boxfish. In comparison, the coefficient is 0.19 for penguins swimming by water. In the year 2005, boxfish designed with highly rigid, weight-low, and fuel use are significantly lower than conventional cars due to Mercedes Benz 's inspiration for creating the Bionic Car which stated decreasing the drag (Sharfman, 2006). (see Figure 3.7.)

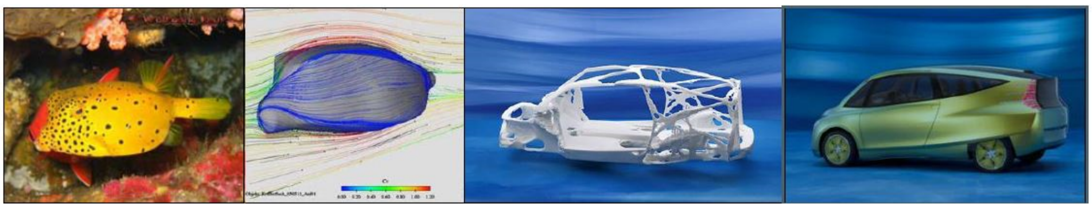


Figure 3.9. DaimlerCrysler bionic car. (Pedersen Zari, 2007)

It is clear that the Bionic Car is more efficient through decreasing fuel consumption by applying a streamlined fish box shape and making the body more dynamic. As well as the use of minimal physical body design needs based on growth patterns found in trees that take the most efficient ways to perform the purpose. (Pedersen Zari, 2007).

3.1.3.2. Solution-Based Approach (biology to design)

Sometimes the designer has access to biological research projects or has joint collaboration with biologists capable of providing biological discoveries that are applicable in design areas. The designer can draw inspiration from these discoveries and explore their applicability. within the simplest sense, an answer found before the problem itself. This approach has multiple names related to, as the biology influence design, bottom-up approach, and also the solution has driven biologically inspired design. Through the design process, it can be noticed that this design approach originally relied on the information derived from biologists and scientists more than human design problems (Pedersen Zari, 2007) & (Radwan & Osama, 2016). (see Figure 3.10.)

Figure 3.10. The steps of solution- based approach (Hosny & Anous, 2015)

An example of biology to design Approach (bottom - up): the scientific analysis of the lotus flower process to clean itself from swampy waters, which led to many design innovations as detailed by (Baumeister, 2007) including Sto's Lotusan paint that makes buildings to be self cleaning (Pedersen Zari, 2007). Lotus plants grow in muddy and dirty ponds. However, biologists questioned the reason for the constant cleanliness of the surface and studied it. Through analysis and research, there are many distinguishing features that make the lotus able to clean the surface. When the dirt atoms settle on their surface, waves the leaf, directing the dust particles to one particular spot. Drops of rain and dew are sent to this spot and then the dirt falls due to the form of microscopic fringes make the water granules drop at certain angles, causing the sliding and put dirt with it (Merhan & Mohammed, 2018). (see Figure 3.11.)

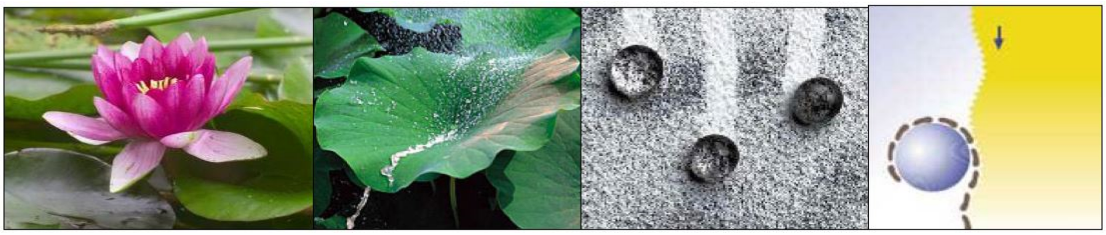


Figure 3.11. Lotus Inspired Lotusan Paint.(Pedersen Zari, 2007)

In spite of this approach relies on biological research projects first, in this approach biology may provide humans with innovations outside the preparation problem or not identified yet. Thus, inspire designers to new ideas, systems, and techniques not previously studied or maybe new design methods. Therefore, biologists and ecologists must be prepared in the creation of new applications to recognize the potential of their research.

3.1.4. Examples of the biomimicry design levels

According to the biomimicry levels of inspiration, there are many examples especially in the building sector that implemented a specific characteristic found in nature. The three main levels of biomimicry can be used to tackle any design problem by examining the potential and determining which aspect of biology deserve to be imitated (Radwan & Osama, 2016).

3.1.4.1. Example of biomimicry organism level (Water cube, Beijing)

The Beijing National Center was inbuilt 2007 to host the 2008 Beijing Olympics. the building consists of 4 floors. Bubble shape was inspired in design for functional and formal purposes. Designed by ChrissBoss, TristamCarfrae, PTW Architects, CSCEC-CCDL, and Arup. The concept was for decreasing the surface area of the building's skin. further, as absorption of a sufficient amount of solar radiation to scale back energy consumption. Tristam Carfrae, the water cube designer, found that the former scientist, Lord Kelvin, revealed during the 19th century, that the tetrakaidecahedron (polyhedron with 14 faces) enables spaces to be divided to equivalent sizes of cells within the minimum area of surfaces (see Figure 3.12.).

The Belgian scientist Plateau has been investigating soap bubbles and thus how they form lines within the three faces. Soap bubbles and its rules have explored how they joined together. Soap films have the power to cut back surface area and surface energy. This has answered out of Kelvin's blue question since the surface area of the bubbles decreases with the physical phenomenon (surface tension) of the parts. Thus, the best way to subdivide a volume is the geometry of the bubble. Therefore, the embodiment of the foam structure through a duplicate unit was paved during a three-dimensional space. they're rotated and cut across specific axes to achieve the required shape. Although the structure of the building is kind of regular, it gives a touch of randomness, irregularity, and almost organic. These bubbles are transparent enough to permit light and sunlight into the inside. it's also a physical separation system between indoors and outdoors with the chance of visual communication (Radwan & Osama, 2016). (see Table 3.1.)

Figure 3.12. Water cube, Beijing

Table 3.1. Preview of the Water Cube project (Radwan & Osama, 2016).

Example	Biomimicry level	Biomimicry approach	The application of biomimicry	Aim	Inspiration	Process	Achievement
The Water Cube, Beijing	Organism	Design to biology (Problem – based)	Form, Construction, Process, Function	Energy Efficiency	Bubbles Structure	Divided space into cells of equal sizes with the least surface area.	1- Energy reduce by 30% 2-Artificial lighting reduced by 55% 3- 20% of solar energy is trapped and used for heating

3.1.4.2. Examples of biomimicry behavior level (The Council House 2, Melbourne CH2)

(CH2) Is a sustainable building in Melbourne Australia consists of ten stories built-in 2006. The building Green rating is six. Due to the innovation approach applied in the design. The biomimicry approach was Design to biology. Technology has played a major role in this building and made a connection between architecture and science to reach the goals and connect it to the surrounding environment as a highly interactive building. As a result, the building adapted to its environment. The building involved of many overlapping systems. The bio-inspiration appeared through the whole building parts and systems (Radwan & Osama, 2016).

The west façade is, to demonstrate, the tree's epidermis. The way the façade moderated the external climate was completely inspired from it. The East core and hence the façade, comprising the toilet and the service core, imitated the skin of the tree (bark). The skin acts as a barrier layer that filters light and air behind the ventilated wet area. Therefore, the facade overlapping layers made with polycarbonate-walling perforated metal to place the loops louvers.

During the northern and southern façade, tree bronchi were inspired. These have been installed as windpipes, which allow air to reach the CH2 from outside (Webb, 2005). (see Figure 3.13.)

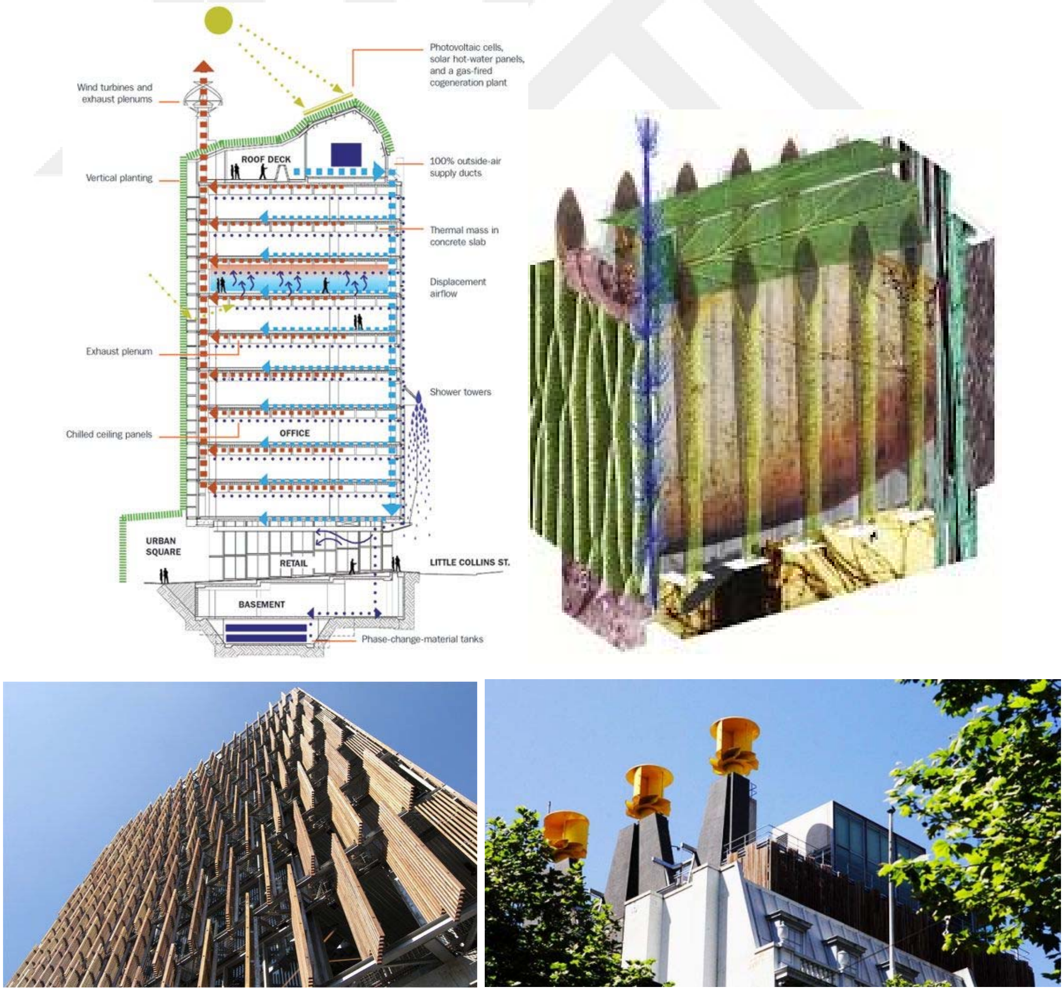


Figure 3.13. The Council House (Melbourne)

Table 3.2. Preview of the Council House project (Radwan & Osama, 2016).

Example	Biomimicry level	Biomimicry approach	The application Of biomimicry	Aim	Inspiration	Process	Achievement
The Council House 2, Melbourne CH2).	Behavior	Design to biology (Problem – based)	Form, construction, material, process, function	Energy Efficiency	Tree	Comprised many overlapping systems found in tree, on the west façade – an epidermis (the outer living layer of an animal or plant) inspired the way the western façade moderated external climate and on the north and south, bronchi (wind pipes) came to symbolize expressed air ducts on the outside of the building.	1-Air is 100% filtered 2-Natural lighting and ventilation saved by 65% 3-Maximizes natural

3.1.4.3. Examples of biomimicry Ecosystem levels (The Lloyd Crossing Sustainable Urban Design Plan)

The Lloyd Crossing Sustenable Urban Design Plan is a revolutionary idea for a 35-block, inner-city commercial area of Portland focused on the radical strategic, planning, and economic agenda to add up to 8 million square feet of construction over 45 years. The concept of design mixes various sustainable concepts based on water, energy, and habitat strategies to refurbish the area in order to significantly improve the environmental performance of the area (see Figure 3.14.).

This project is based on pre-development site metrics as an integrated environment. The theoretical basis of the concept to be adopted is to preserve the environmental character of the site before human existence. Through this, the idea can be used to re-develop intensive urban development to reverse the current environmental impacts. And restore many of the characteristic environmental characteristics to the site as a hybrid pine forest. The three factors in which this project sets output goals include wildlife habitat, water, and usage quality and energy use. The pre-development vegetation-covered 90% of the land. The proposed plan is to keep up 30% and preserve the current plant diversity. Furthermore, the concept involving natural green streets, rooftop gardens, and habitat corridors. The idea includes original “forest patches”, green roads, rooftop gardens, and habitat corridors. A suggestion proposed for off-site habitat renewal. The site has 64 million gallons of precipitation per year. The plan proposes to take advantage of this runoff and recycle wastewater to scale back water consumption by 62% of external sources. In terms of energy, studies indicate that the site receives 161 million kilowatts of solar energy annually. Other sources of renewable energy will be exploited, such as daylight, wind power, photovoltaic systems, and biogas. A "thermal loop" balance the requirements for heating for various applications. The idea is to take advantage of this typical forest capacity. Another objective is to reduce emissions from CO_2 because 40 percent of the raw materials are consumed by the building industry. And they are specialized in the recycling and use of local and organic materials. Which have low incarnated energy and helpful life cycle. Therefore, by 29,000 tons a year, the carbon average mitigates to 2,000 tons per year, despite the 8 million ft^2 of the modern buildings. Nearly 90% of the facilities are made from renewable sources (Architects & Planners, 2005) & (The American institute of architecture, n.d.) (see Table 3.3.).

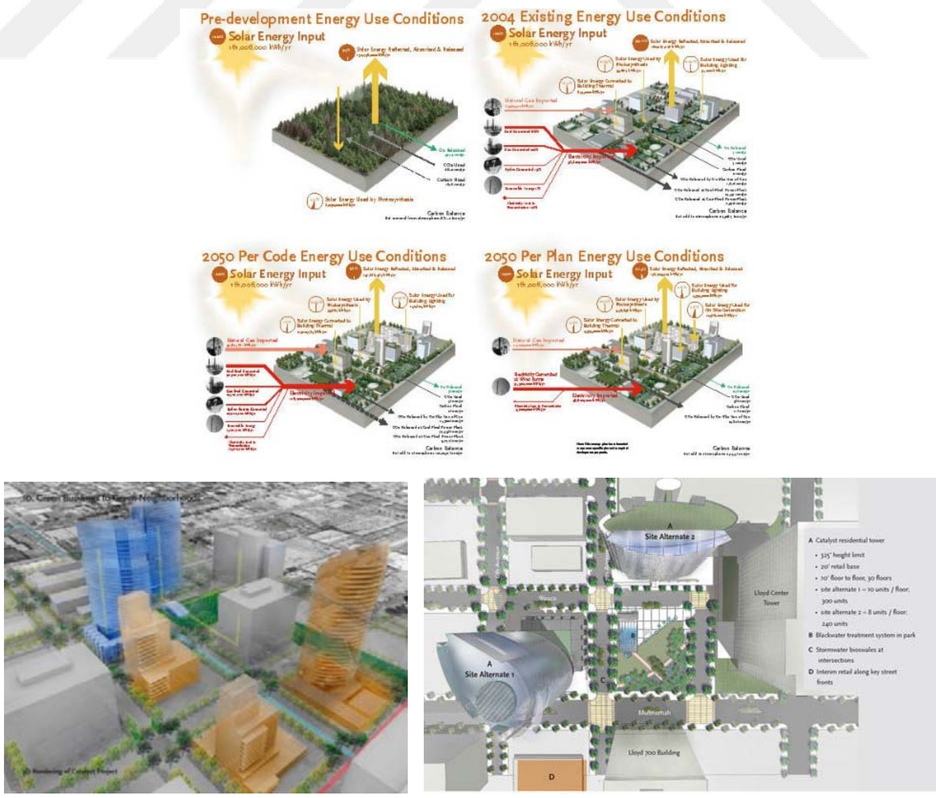


Figure 3.14. TheLloydCrossing Sustainable Urban Design Plan (The American institute Of Architecture).

Table 3.3. Preview of The Lloyd Crossing Sustainable Urban Design Plan (The American institute Of Architecture).

Example	Biomimicry level	Biomimicry approach	The application Of biomimicry	Aim	Inspiration	Process	Achievement
The Lloyd Crossing Sustainable Urban Design Plan	Ecosystem	Design to biology (Problem – based)	Form, Construction, Material, Process, Function	Energy Efficiency	The ecosystem of the Site	Benefit modeling included detailed analysis of the input and output flows of the district. Included carbon, water, solar energy, tree cover, etc.	1-90% of the power will come from renewable sources 2-Potable water use will be reduced by 62% and annual fees will be reduced by 89% 3- the carbon balance will be reduced from 29,000 tons per year to 2,000

3.2. Computation: Computation and Architecture

Computation is a multi-specialty field of study, mainly aimed at creating, exploring, and discovering intellectual workflows. In other meaning, considering rationally laws of logic and organized thought as rationale formal. Performing logically offers the ability to do judicious things such as anticipated utility maximization (Brownlee, 2011). "Computational Intelligence contains paradigms, concepts, algorithms, and systems frameworks that are designed to demonstrate cognitive processes in a dynamic environment". Recently, some attempts have been made to address different computation fields in a machine-learning manner with the aim of offering partial automation of human tasks, personal support for field specialists, and professional direction for amateurs (Kruse et al., 2016). Recently, some efforts have been made to address different computation fields in a machine_learning manner with the aim of offering partial automation of human tasks, personal support for field specialists, and professional direction for amateurs (Emil Racec, Stefania Budulan, 2016).

The use of computer-based technologies for both engineers and designers has fundamentally changed modern architecture. Individuals are moving from using explicit programs based on designers order to build computational based models where the computer has a large contribution to make decisions and orders. The workflow presently is depending on driven information to make decisions rather than somebody physically characterizing rules (Saransh Mehta, 2018). In recent years, architecture has witnessed an evolution in the field of automation and technology. Many practical aspects have changed, including performance, evaluation, manufacturing, project delivery, and billing. The inevitable emergence of modern strategies of computer-aided design (CAD), substituted primary math, due to the formal complexity of CAD systems, from its central position in the architectural profession, which involves using a parsimonious information model (Emil Racec, Stefania Budulan, 2016). Paradoxically, mathematics is the core component of computer-aided systems.

Digital design always has the greatest effect on architectural items worldwide. The digital design began as a tool for making accurate and complex drawings (computer-aided design (CAD)). Later, the concept expanded to wider applications of great importance tools that generate information 3D model (building information modeling (BIM) for the complete building including all drawings, plans and workshop details. At another advanced stage, computation design entered the process of form-finding. Generative, Bio morphogenetic, Parametric, and algorithmic design are all synonyms and sub-disciplines for computational design, aiming to use "Artificial Intelligence" and advanced mathematics to generate and processing complex design with no need to the manual old- fashioned way of a process. Moreover, digital fabrication techniques allow us to easily build complex designs at astonishing accuracy and time management. It is worth mentioning, that CAD is almost used as a digital drawing tool to automate routine design processes and digitize drawings. In other words, CAD is not involved in the process of logical thinking and decision-making. In contrast, the computational design uses the power of computer algorithms through coding to explore limitless iterations of forms, problem-solving, very complex geometric calculations, and rationalization. The computational design penetrates many fields, including industrial design, animation, simulation, and others. Nevertheless, the application of computational design is very promising. It is considered as a new addition to the architectural thinking method in design and manufacturing. In this case, computational design tools can be used in all phases of building, including design (shape grammars, building information modeling (BIM)), construction (Digital fabrication, construction phases simulation), and management (smart building control, environmental responsive utilities). The use of computational design techniques helps to increase the speed of processing in the design of buildings. It also provides the designer with the possibility to imagine more broadly through the introduction of complex organic configurations that cannot be designed in the usual way. It also combines all the design operations together in one comprehensive model, which are often fabricated with minimal need for human contributing. Computation is about the exploration of the uncertain, blurred, hazy, and frequently ill-defined procedures. computation facts are for extending the human judgment skills and decision making; since of its exploratory nature. it's around rationalization, optimization, performance, thinking, simulation, logic, calculation, deduction, acceptance, extrapolation, investigation, and valuation. In its complex insinuations, it includes issue tackling, mental structures, cognition, simulation, and rule-based intelligence, to title some (Terzidis, 2006). Computational design can manage different levels of design practices. These practices combinations called computational processes. Computational processes are explicit patterns of rules that may manipulate data (Fry et al., 1985). In such a case, the designer must write codes, which may require some specialized experience in computing. More specifically, computational design is represented as a better way of applying procedural thinking to a design task. Rather than creating specific design representations, the designer creates a collection of rules that characterize a framework capable of making many outcomes. Designs are presented in abstract terms, resulting within the potential to make numerous varieties that share a collection of constraints (Jacob, 2013). In a more sophisticated step, The emergence of concepts of parametric and algorithmic architecture. Where architecture has become defined through advanced equations and mathematical formulas and not through the geometric shape. Furthermore, in computational design, there are many important categories that play an essential role in the architectural design such as optimization and performance-based design (Kotnik, 2010). Computation techniques are not limited to the stage of creating the form, but it is involved in many applications that contribute to making architecture more efficient including restoration, fabrication, simulations, and building management systems (Fathi et al., 2016).

We live today in the era of globalization, which has played a major role in changing the face of architecture towards an international abstract architecture that reflects the values of capitalism and the culture of consumption and technology. Thus, many revolutionary concepts have been introduced, influenced by the concept of globalization and its logical solutions. Including energy, sustainability, environment, and regional identity. Since the 1990s. Many technologies and concepts derived from globalization have been used in the field of design to enhance complexity, accelerate and improve environmental performance, energy efficiency, and the use of renewable resources. In addition, computational design, utilizing artificial intelligence and algorithms to promote building for more efficiency. The idea of computational design itself is not new; it was used even before the invention of reliable computer systems. However, it is innovative applications in architecture that have only started since the use of computer-aided design (CAD), then was developed into a smarter form of building information modeling (BIM) (Fathi et al., 2016).

3.2.1. Biomimicry in computation processes

Natural Computing is an inter-disciplinary field regards with the connection of computation and biology, which consists of three sub-disciplines: "Biologically Inspired Computing, comprised of Computationally Motivated Biology, and Computing with Biology" (Brownlee, 2011). Jason Brownlee 2011's book (Clever Algorithms - Nature-Inspired Programming Recipes) states the definition of the three fields of natural computing as follows:

Biologically Inspired Computation: The aim of this field is to presume mathematical and engineering tools for problem-solving. Involves the use of procedures for finding solutions derived from nature to address computationally defined problems.

While **Computationally Motivated Biology:** involves exploring biology via computers. The intention of this field is to use sciences data and simulation to model biological systems digitally in computers aiming to copy and better recognizing behaviors in natural systems. this area simplifies the system to higher understanding life as it is and investigates life as it could be. it's focused on simulating natural phenomena. An example of this field of computation, Fractal Geometry as (Iterative Function Systems, L-systems, Particle Systems, Brownian motion), and Cellular Automata.

In addition, **Computation with Biology:** is that the examination of facts apart from silicon during which to implement computation. Common examples include molecular or DNA Computing and Quantum Computing.

(Brownlee, 2011).

3.2.2. Genetic algorithms

“Genetic algorithms (GAs) are computer programs that imitate the procedures of biological evolution so as to solve problems and to model evolutionary systems (Mitchell, 1995). While Jenna Carr defined genetic algorithms as a “sort of optimization algorithm, meaning they're able to find the maximum or minimum of a function (Carr, 2014)”.

According to the evolution theory of Darwin, the vast array of potential genetics possibilities and also the ability to spot desired solutions that are the result of high fitness and adaptable organisms, evolutionary biology has become a strategy for solving complex problems that carry many numbers of outputs. “The repetitive application of the evolution procedures alter, initial species from other species. Nevertheless, only the stronger prevail”. In another meaning, Genetic Algorithms operate similar processes on the population of potential targets, but only those that can fit the solution better can survive. In fact, the strategy based on finding solutions in natural evolution has influenced many research fields. As a parallel processing search method, evolution exams, and shifts whole species populations at once instead of working on one particular species at a time (Fasoulaki, 2007). Genetic algorithms become even more desirable due to the parallel computing process that can minimize their disadvantage like speed lack. This allows more repetitions and more complete runs, which also improves the possibilities of better alternatives and increases the likelihood that ideal options are picked up

(Carr, 2014). “Parallel computing is a type of computation in which many calculations or the executions of processes are carried out simultaneously. Large problems can often be divided into smaller ones, which can then be solved at the same time” (see Figure 3.15.).

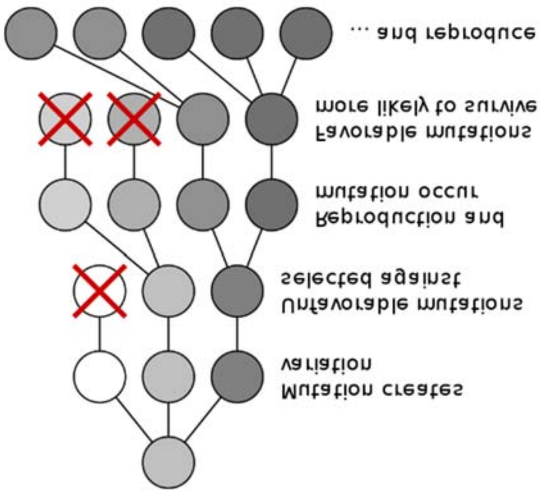


Figure 3.15. Mutation & Selection diagram (Source: www.wikipedia.org)

The main objective goal that led to the emergence of the genetic algorithm is the attempt to understand and absorb the concept of natural adaptation in the 1960s, by John Holland who worked on a population of potential solutions as processes to solve optimization and search problems. Biological evolution is an effective reference of inspiration to tackle the problems. The mechanism of evolution in nature is one of the most important processes that have been absorbed and used to find solutions to the most complex problems computationally in various disciplines. Which weighs many possible probabilities and limits the best options. Genetic algorithm is a process inspired by nature. Therefore, many of its properties and terms have been imported from nature, for instance, a fitness, population, Selection, Crossover, and Random mutation , etc. (Mitchell, 1995).

As with natural evolution, one of the most important principles of a genetic algorithm is randomization. However, the level of randomization and the control level can be regulated. These algorithms are stronger and more accurate than random checks and comprehensive searches and do not need further data about the particular problem. This feature allows them to resolve problems that cannot be resolved through the lack of continuity, variants, linearities, or other aspects of other optimization techniques (Carr, 2014).

Phylogenies are the species development: this evolution is governed by mutation, crossover, and selection. These principles direct the development of digital and artificial systems. Design and evolutionary biology combined to make design concepts more efficient. Design and evolutionary biology, a combination towards more efficient design concepts. Evolutionary design is rooted in computer science. It is an evolutionary computing subdivision, covering and combining CAD and software for analysis. It has no hesitation in deriving ideas from natural development (Marin et al., 2008). The evolutionary design relies on software tools by taking part in the design process. It enables designers to automatically enhance the efficiency of their designs by using analysis software to. By generating such potential options, the designer can find numerous innovative solutions to problems (fixation of design, overcoming, or limiting of conventional knowledge). additionally, Evaluation involves the utilization of fitness functions to assign optimal solutions. These fitness functions can have single or multiple objectives; they will be unimodal or multimodal, continuous or discontinuous, smooth or noisy, static or continuously changing. the most important aspects of evolutionary design divided into four main categories: evolutionary design optimization, creative evolutionary design, evolutionary art and evolutionary artificial life (Bentley, 1999).

In general, as a computational technique the genetic algorithm endorsed evolutionary principles, was recently implemented in architecture to deal with sophisticated problems of the function and hence the form of the architectural projects. Genetic algorithm used in the initial design step for solving problems, like structural and facility structure, it's used due to the possibility of random solutions to optimize problems and research issues (Latifi et al., 2016). Genetic algorithms as a part of digital tools applied in the creative design process. In fact, the vast amount of information and hence the level of sophistication involved in most building projects are among the major problems in architecture. This problem can't be resolved by conventional design methods. Genetic algorithms deliver an efficient solution to the existing problematic by optimization and pursuit problems, which work on a spread of possible solutions. In architecture, "GAs works in two ways: as optimization tools and as innovation form generating tools (Fasoulaki, 2007)".

Furthermore, there are real attempts to apply the principle of morphology to architecture design through the inspiration of evolutionary systems and apply it through digital tools with a logical mechanism to help the architect in the process of creative configuration and optimization through the early phases of design (Marin et al., 2008). Genetic algorithms are used to generate an optimal option in the form-finding processes and to set up new structures with several complexities (Latifi et al., 2016).

The counterpart to the mutation in architecture is innovation. Although the innovation is generally "purposefully developed". It is often characterized by strong inherent dynamism, which is controlled only to a limited degree (Schwehr, 2011). In fact, architecture and biology are connected, both operationally and on a material basis, as they are both morphological and structural (Fasoulaki, 2007).

3.2.3. Morphogenesis in computation design

Natural morphogenesis, "is the method of evolutionary development and growth, derives polymorphic systems that obtain their complex form, organization, and flexibility from the interaction of external environmental influences and system intrinsic material capacities and forces". during this system, the method of formation and materialization are inextricably linked and contribute together within the process of natural morphogenesis (see Figure 3.16.). The promising potential of the technology can provide a new approach to design through which the process of form generation and materialization processes are integrated together for the best ability to form (Achim, 2007).

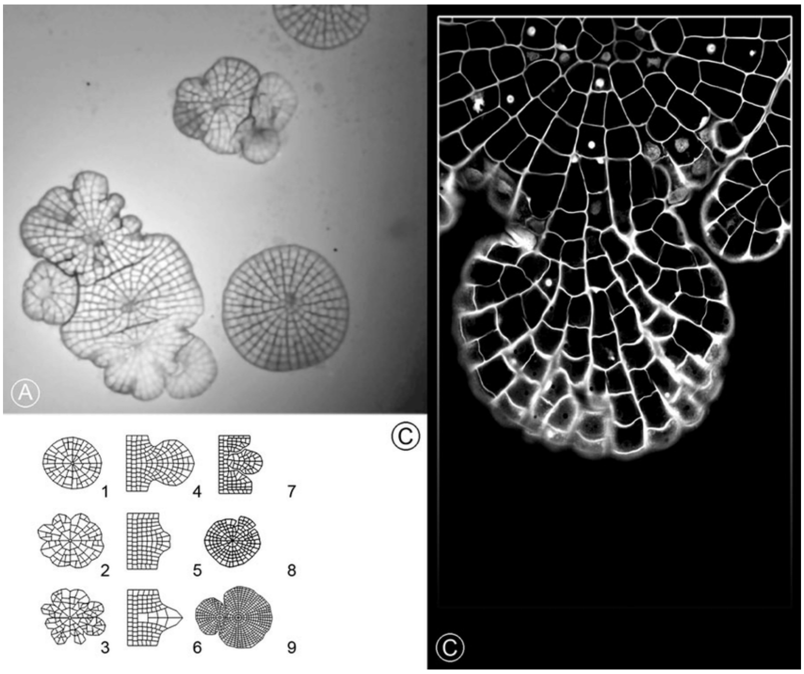


Figure 3.16. The development of Coleochaete orbicularis (Roudavski, 2009)

With conventional building information modeling, the complexity, the differentiation, and the homogeneity cannot be obtained without customizing current software by scriptural computer programming (Wortmann & Tunçer, 2017). Morphogenesis is a complex biological process that includes growth, rehabilitation, adaptation, and aging according to environmental and genetic influences to reach the most appropriate procedure. This concept may be adopted in architecture and applied in terms of composition and architectural formation, especially structures and dynamic architecture (Ashraf Saad El Ahmar, 2011).

In architecture, morphogenic (digital morphogenesis or computational morphogenesis) is referred to as a multi method procedure using digital media not as visualization tools but as generative. It is related to various concepts such as emergence, self organization, and form seeking. Amongst the benefits of bio-inspired forms, their potential for structural profits resulting from redundancy and differentiation and therefore the ability to act multiple simultaneous functions (Roudavski, 2014).

Computational processes for the form finding and generation of genetics algorithms are based on the mathematical synonym of the Darwinian model of evolution and the biological developments. Evolutionary computing provides the potential to link special and cultural parameters, with design patterns, process, form, and behavior. Evolutionary computational morphogenesis strategies are likely to be combined with advanced structural and material simulations to examine the performance under gravity and load stress (Ashraf Saad El Ahmar, 2011).

In addition, computational morphogenesis is often defined as a process of continuous differentiation. The difference of elements in morphological and functional aspects, enabling the system's performative capacity developed in different levels based on the divergent effect of a heterogeneous environment and multiple functional criteria (Ashraf Saad El Ahmar, 2011). In biology the differentiation includes changing cells or tissues to a more specialized type or function, which progressively focuses on precise responsibilities, to achieve a particular capacity of performance (Hensel, 2006).

When the reliance "connection" of components and the variety "distinction" increase, complexity is increased. The process of increasing the quantity or the strength of connections is called integration and the differentiation is the process of increasing diversity. Evolution produces differentiation and integration in many 'scales' that interact with each other, from the formation and structure of an individual organism to species and ecosystems (Ashraf Saad El Ahmar, 2011). Furthermore, the Self organization term is described as “a dynamic and adaptive process through which systems achieve and maintain structure without external control. Self organizing systems display capacity for adaptation within the presence of change, a capability to respond is stimulated from the dynamic environment”. The stimulation makes it easier for devices to respond to changes. Adapting geometry to a dynamic environment during the design process is time-consuming and costly effects. On the other hand, design tools offer the chance of serious changes right up to the industrial stage, present the flexibility in the design process at different levels (Hensel, 2006).

3.2.4. Optimization

Genetic Algorithm, one between the eldest and preferred metaheuristic algorithms (“a metaheuristic is a higher level procedure or heuristic designed to find, generate, or select a heuristic that may provide a sufficiently good solution to an optimization problem, especially with incomplete or imperfect information or limited computation capacity”) for design optimization. This algorithm inspires its procedures and functions in the evolution from nature, which allows us to exploit certain natural design possibilities (Danil Nagy, 2017). Biological evolution has generated complex forms and solved adaptation difficulties, it can be reasonably assumed that the same optimization strategies, can find good solutions for complex optimization problems (Rudolf Kruse, Christian Borgelt, Frank Klawonn, Christian Moewes, 2013).

The major use of genetic algorithms is employed as a tool of optimization. Optimization is quite an evolutionary computational process that deals with design at an early stage in a good way to reach the design to the optimal situation as close to the global optimal, logical as possible (Bentley, 1999). In many cases, a set of (close-fitting) parameters should be initiate and specified as a given real-valued function as a set of variables that could manage the problem. To resolve these problems, multiple methods of mathematics and computer science have established a number of methods called optimization algorithms. Optimization term is a processing mechanism that works once the problem is defined then displayed on the input instructions and therefore the limits set to seek out the most efficient solutions that fit this problem.

Generally, optimization algorithms work by being directed by three platforms that control the decision-making process.

* Input parameters

The problem of optimization is restricted by combining all input parameters that can define various solutions to the problem (Danil Nagy, 2017).

* Objective functions

The objective purposes define the objectives of the advance problem. Determining the problem and selecting the solutions is conducted by determining the specified desire goal whether to minimize or maximize the value of every objective task. When processing, the optimization algorithm will try and direct the resulting value to the lowest or highest possible value based on the input instructions and therefore the desired goals. Any optimization problem must comprise one objective task at least to lead the optimization process (Danil Nagy, 2017).

* Constraint functions

Constraint functions assess the range of options, however large, and identify the viability of different design solutions offered in the design. Therefore, based on the input instructions and also the objective function, the functions of the constraint describe the supposed performance of every option of the design and exclude options that are incompatible with the goals. However, they determine whether a design should even be assumed as a choice instead of evaluating the relative viability of a design (Danil Nagy, 2017).

In general, Genetic algorithms play a part in the design, creation, and optimization of new forms and performance-based design. Algorithms can help generate highly complex forms based on the concept of optimization to choose the best solutions, which influenced by a range of inputs. The optimization concept also leads to the resolving of structural, mechanical, thermal, lighting, and energy efficiency issues. Design optimization was introduced as a method for the building industry to achieve optimum efficiency level and best performance at the least cost. Structure, acoustics, lighting, electricity in a building are parts of the building's performance (Latifi et al., 2016). generally, the optimization is to find ideal approaches of how to act in the dilemma.

3.2.5. The contemporary overlap between biomimicry and computation

Biomimicry is an applied concept based on the philosophy of inspiration that needs a lot of supporting tools to make the inspiration process very successful. Computation as a developed discipline has many principles in common with nature both deal with influential parameters in logic language to achieve the best response. The complexity, configuration, differentiation, integration, homogeneity, and heterogeneity, are very complex application principles require high qualification of logical and practical operation (Ashraf Saad El Ahmar, 2011). Biological processes and adaptation to dynamic loads and environmental pressures are complex. Therefore, the interactions between multiple processes, are not linear (Ashraf Saad El Ahmar, 2011).

Biological evolution has been targeted at highly complex systems. Nevertheless, the question of how we can actually calculate the complexity of life forms is an open issue in evolutionary biology. The concept of evolution is investigated by the use of evolutionary algorithms in computer design processes. Form customization and automated production processes, parametric, and generation-based computer technologies allow the holistic silicon systems for manipulation and thus the subsequent production of increasingly complex architectural arrangements. The automation of parts of the design processes facilitates the development of designs (through versioning and gradual adjustment). These design approaches are described as morphogenesis in recent architectural discourses (Roudavski, 2014).

Since the 90s, leading architects have modified their approach to invest in, or represent contemporary architectural complexities through the use of evolutionary biology technologies (Latifi et al., 2016). Existing computer software and technology innovations provide an opportunity to fully explore the possibilities and advantages of biological concepts revealed in nature and their application in the architectural design process in order to improve or even recreate sustainability in the built environment (Agrawal, n.d.).The influence of ideas derived from nature has always been pervasive throughout the history of architecture. Differentiation in biological structure, components, shape, and material properties offer significant benefits over the constant area usually taken up in conventionally engineered structures. The different fibers and bundles, cell spread, according to various parameters, offers a very interesting model for design systems (Hensel, 2006). Modern architects and researchers are seeking similar analogies of design with formation and growth. In some cases, they experiment with computer systems, the growth design to develop. They explore new design approaches derived from the evolution of living organisms, their adaptive responses to environmental changes, their material properties, and their metabolisms (Ashraf Saad El Ahmar, 2011).

Generally, Understanding the strategies found in nature has helped bring up new influenced by nature in many disciplines. Morphogenesis in nature involves many principles including self-organization, differentiation, integration, and optimization that generate complexity. There are many attempts to adopt these evolutionary and genetic principles to be applied to architecture but the high levels of complexity of these principles require tools that exceed the level of human absorption and it has the ability to process logic based on influential parameters. Therefore, the concept of computational design appeared which contributed to the emergence of the principles of form generation and the ability to create complexity in a way that traditional methods cannot accomplish. Many techniques imported from nature have been applied in computational designs to optimize the expected performance of buildings and reach the state as close as possible to the ideal. The evolutionary principles and the genetic concept in nature have inspired many researchers, designers, and scientists to adopt newly applied methods that revolutionize the technical development of various disciplines including architecture and high performance. Every day we are fascinated by Nature's ability to adapt, perform, and efficient in different circumstances. We can compare today buildings to organisms. Both are under conditions and circumstances that the building or organism must demonstrate the ability to absorb and find optimal solutions for adaptation. All this would not have been possible without the adoption of nature principles and their formulation by computational concepts in a way that architecture could be applied for the purpose of reaching novel and effective ways in design, especially with regard to issues of energy efficiency.

3.2.6. Performance-based design (PBD) using Environmental analysis tools as a computational method

Performance based design (PBD) has become a vital approach to achieving many objective goals. It is guiding designers to manage the design process into logical directions based on information related to the final output of the design. The Performance-based design (PBD) process aims at changing the traditional design approach to a more logical and efficient way including all three phases of (PCA) Principal component analysis (form generation, performance evaluation, and optimization) by relying on computational abilities (Ekici et al., 2019). In other meaning, the performance concept is a method of thinking and focusing on goals rather than means. It is concerned with what a building or building product is required to achieve, and not with prescribing how it's to be constructed. So, the concerns with what a building or construction products are required to have and not how it is designed (Foliente, 2000). Generally, performance means the qualitative or quantitative features that are objectively identifiable of the building, and that contributes to the determination of its ability to fulfill its various functions for which it was designed.

The architectural design guided by the energy efficiency issue promotes an integrated and systematic optimization process of several quantifiable building performances. In directing and implementing performance-based design architects play a crucial role. In addition, PBD as an ineffective technique in design, it has become necessary to develop these techniques and facilitate the process of conduction so that the architect can make early design decisions to enhance the design process and optimization from the viewpoint of architects. The PBD platform appropriate for architects to improve the technology. In addition to its Graphic Algorithm Editor, Rhinoceros, the Architectural Modeling Program Grasshopper, is used to improve this process with the inclusion of three performance simulation programs: Ecotect, radiance, and energyplus (Shi & Yang, 2013).

Therefore, many supporting tools used to help architects with early decision making based on performance, especially by environmental analysis tools. Rhino-Grasshopper is one of the most commonly used platforms that are exploited by architects. Also, there are already lots of environmental plugins developed for Rhino-Grasshopper. However, Ladybug and Honeybee plugins offer a number of advantages that existing Rhino-Grasshopper unable to do so. In these plugins, energy plus weather files (EPW) are imported giving the ability to provide a different interactive 2D and 3D graphics visualization to assist decision-making in the first design stages. It also facilitates the process of analysis, automation, and calculation and provides simple graphs and charts. Allowing the architects and engineers to evaluate energy and daylight engines like EnergyPlus, Radiance, and Daysim. With the ability to control the parametric tools of grasshopper gives extra flexibility to modify the design based on instantaneous feedback. The interactive of design stimuli within the information and analysis of the environment (Roudsari & Pak, 2013).

In this way of the design process, many different outcomes of design performance can be produced. The designer chooses the best solutions that make the building more suitable for its environment. The first step in the high-performance design based on parametric environmental plugins is to determine the important environmental factors that affect building design in order to increase the likelihood of making design decisions that are environmentally friendly during early design stages. At this point, designers assess their decisions based on any analysis and personal judgment acquired through experience and environmental data understanding (Roudsari & Pak, 2013).

At present, Rhino-Grasshopper has several analytical tools that designers can use (see Table 3.4.). These tools simplified environmental analysis through the relation of weather information and analysis in the simulation process. This relation can control the performance based on the parametric settings in different stages of the design. The environmental analytical tools thus help Grasshopper's parametric platform to absorb a strong relationship between environmental data and design generation based on various graphic data outputs related to the construction form (Roudsari & Pak, 2013).

Table 3.4. Compare the current Rhino_Grasshopper environmental analysis tools (Roudsari & Pak, 2013).

PROCESSES		ANALYSIS TOOLS				
		Ladybug	Heliotrope	Geco	Gerilla	Diva-for-Rhino
Climate Analysis	Analysis	✓				
	Visualization	✓	✓**			
Massing/Orientation Study		✓		✓		✓
Daylighting Study		✓		✓		✓
Energy Modeling		✓			✓	✓*

* Limited to one thermal zone
** Only daily sun path diagram

Energy building standards and codes in many countries have been established and implemented to control buildings' design and to raise awareness about and innovate energy-conscious building design. After the UN climate conference, many governments are taking serious measures to promote a culture of consumption, especially in the construction industry, the energy use is usually between 30% and

50% of main energy and half of total electricity usage. In recent years, institutions or organizations related to energy and consumption issues have begun to legislation working methods relied on the development or revision of energy codes to develop an approach based on the principle of performance, with a view to improving flexibility, clarity and effectiveness in organizational documents.

The minimum conditions in terms of code satisfaction, such as the minimum equipment efficiency and isolation standards, are conventionally strict building development due to the fact that the codes are defined for every building parts. Prescriptive needs to facilitate using and following without intention to limit the development of new technologies and techniques. But, rigid codes are not designed to take into account the combination between building systems and standers. Which need to be optimized based on the performance of the holistic cooperation systems. This could be seen as a creative barrier and making the framework very accurate. Alternative codes implementation, therefore, needs to be promoted a more systematic approach based on energy-efficient buildings for designers. There is a growing trend around the world in recent years to create and adopt performance-based building standards such as building protection and structural design, by taking into consideration the mutual relationship among building systems and parts to be optimized. The propensity to performance based design is motivated by the increasing rate of changes in building technology, the availability of improved urban planning, design techniques, and the increased capacity of buildings' indoor environment (Foliente, 2000). Building codes based on performance produce what needs to be done instead of suggesting the method of achievement of the desired result. In general, the term of performance describes the situation in which instructions are written with regard to the desired result, so it is obviously very broad and multi-functional. Using this approach opens up the possibility of innovative construction technologies. It provides an obvious definition of a certain country 's degree of health, safety, and other social issues as a minimum for its own society in the meantime. The energy standards within the performance-oriented building determine the allowed consumption levels without detailing the means, processes, and materials for doing so.

Therefore, the predictive study of the consumption of the building will be the responsibility of the architect based on various predictive methods. Dependence on the performance principle in buildings gives preliminary data on potential energy usage levels based on the predictable integrated performance of the components related to energy consumption, such as building envelope. After the architect has applied the innovation ideas based on the concept of performance-based design, the annual energy consumption results of the proposed building are evaluated by comparing the annual energy consumption data for another existing building called the Reference Building. The annual energy demand outcomes are assessed by comparing annual energy consumption data with the reference. The reference and also the proposed building must have the similarity within energy resources, floor area, geometry, exterior design conditions, occupancy, thermal data, etc. The energy budget, expressed in kWh or MJ per square meter of conditioned floor area each year. The performance based codes provide more design flexibility and can take into account innovative aspects like daylighting, passive solar heating, heat recovery, better zonal temperature control, thermal storage, off-peak power, etc. (Hui, 2002). Generally, the adoption of the principle of performance based on the criteria of calculating the energy consumption in buildings requires accurate analysis of the building to ensure that the building is demonstrating code compliance, by ensuring that the level of energy usage does not surpass the bound. In other words, achieve the desired goal. This concept permits flexibility in the building design and separate systems to open the space of innovation given to the engineer to reach new ideas in more efficient ways (Hui, 2002).

3.3. Envelope Design: The concept of energy efficiency through envelope design

There are many definitions of the building envelope. On one hand, "the boundaries at which the building interacts with its environment, consist of multiple layers and filters that interact with light, air, humidity, sound, and heat". The most common aspect is the ability to maintain ideal conditions to the indoor environment, in response to the functions it carry. The building envelope consists of the façade and the roof, which include the exterior walls, floors, roofs, ceilings, windows, and doors (Radwan & Osama, 2016). Building envelope can control the energy consumption and maintains internal the comfort level thermally and visually. In the previous definitions, the building envelope is "a thermal barrier to prevent loss of heat in the cold atmosphere" and provide shade to prevent thermal gain in hot weather. In fact, most of the building envelopes are traditionally designed that lake the ability to meet the contextual requirements and adaptive with it. Recently, serious attempts have been made to create a technical and mechanical adaptation that simulates natural systems to improve energy consumption. But the lack of general knowledge in technology may remain an obstacle, researchers found that a number of occupants of buildings with smart technologies are not very interested in these technologies and suffer from technical pressure. Although for future adaptive envelope, a new system has been developed. Many buildings have used biomimicry to provide adaptive systems for contextual needs. Many mechanical and latent responses have inspired from plants and other organisms (Al-Obaidi et al., 2017).

In general, the facade of the building is the most responsible part of energy consumption in buildings due to the ability to “determine indoor physical environment related to thermal comfort, visual comfort, and even occupancy working efficiency, thus affecting energy usages in buildings”. And the methods of the manufacture used today are very dangerous because many of the consumer construction materials are harmful to the environment. Therefore, more sustainable construction mechanisms must be created includes recyclable and harmless materials (Minsolmaz Yeler & Yeler, 2017). In terms of reducing the impact of buildings on their environment and trying to adapt to it, the architectural profession is at a crucial stage in history. Architects should make the facades of our buildings more appropriate. And a breakthrough to correct the global design and construction approach, which has become a significant threat to our planet. The behavior of nature's approach to mutual benefit with its environment may be the starting point of a new concept. Where effective and renewable materials and efficient systems for adaptation and construction as needed (JOHN YOWELL Norman, 2011).

3.3.1. Problems with current envelope design

At the moment, most envelopes don't interact and don't react to different factors with their surrounding environment. Given how natural skin protects the interior from the external environment, architectural skin looks dim compared to that. The desired development of the building envelope goes beyond the concept of the insulating membrane only but aspires to reach the approach of interaction and response to the external environment. As well as reducing the number of materials used to the least amount possible while ensuring the use of recyclable materials and ensure ease of manufacturing that requires least energy consumption and Keep away from using substances that have toxic effects. Imagine a building envelope better suited to its surrounding environment and also being able to produce electricity for the building.

The envelope also composed of many different components. It causes a lot of material failure possibilities and produces condensation, thermal bridges, and plenty of waste. In addition to damage caused to the environment by the installation, maintenance, and manufacture. Consuming a lot of energy in manufacturing. In traditional types of envelopes, the skin is made as a closed system that makes the envelope act as a front barrier, unlike the skins in nature, which act as adaptive and responsive filters (JOHN YOWELL Norman, 2011). Therefore, improving the overall performance of building envelope is essential towards a sustainable concept in its industry and construction. These sustainable envelopes are expected to protect the entire building from surrounding conditions, environmentally friendly manufacturing, recyclability, contain multiple adaptive and responsive systems, ability to maintain water, thermal, aerodynamic and lighting balance efficiently, consistent with its local environment and use of local materials in manufacturing, it has aesthetic properties that reflect the identity of the place. In order to meet these sustainable aspirations, we must go deep into the technology and modern techniques in the construction of envelopes and integrating the concepts of biomimicry and environmentally computation analysis tools into envelopes industry as an intellectual concept that creates innovation and efficiency. Therefore, the skin of the buildings must conduct multiple functions.

Designers work on addressing these challenges. Kieran Timberlake is focusing on, for example, solutions to answer the question: “Can a façade system provide not only thermal resistance but also a high degree of transparency?”. Additionally, innovative facades are advancing technology projects. At present, there is no explicit tendency to meet the requirements of envelopes for efficiency and sustainability. (JOHN YOWELL Norman, 2011). Almost all envelopes are deaf and just a barrier membrane between inside and outside. However, natural skin fulfills all aspirations. Therefore, it should be the standard measure for creating more efficient envelope designs. To reach an effective platform that corrects deaf concepts in design towards more vibrant innovations.

3.3.2. The connection between building envelope and natural skin

In order to get a promising concept within the biomimicry approach design for the building envelopes, it's important to develop the design process and investigate the common properties between the envelope of the building and also the skin of the organisms. This involves determining the most resemblances and the complex forces influencing nature as well as the phase of architectural design. The building envelope (skeleton in live organisms), controls the mechanical, plumbing, and electrical, and determines the interior spaces, which is a very thin membrane. The envelope of the building equals natural skin as it consists of different layers and filters that respond to various circumstances. Natural skin's desire to keep optimal internal conditions and by reacting appropriately or consciously to the dynamic environments (Radwan & Osama, 2016). In general, building envelopes are complex systems that require controlling many aspects, including heat, light, moisture, and ventilation. To use adaptive building envelope, different systems and elements such as sensors, actuators, command wires, materials, structure, and technologies to meet the natural skin abilities to do different operations like metabolism and morphology (Al-Obaidi et al., 2017).

Efficient in energy usage to survive, natural skins must be efficient, whether in the flora or infauna, in hot and cold environments, warm, dry, above, or underwater. The organism does not waste resources by its skin. Dr. Petra Gruber (2008) is an architect and professor at the Vienna University of Technology and has developed these ideas in the field of availability of materials, energy sources, co-operation and so on (JOHN YOWELL Norman, 2011).

JOHN YOWELL, during his analytical study, classified four elements representing the basic functions of the skin. Were identified based on literary reviews of relevant studies to confirm that “natural skins deal with the same four functions. Which are clockwise: Regulate Transfer of Air, Regulate Transfer of Moisture, Regulate Transfer of Heat, and Regulate Exchange of Light” (see Figure 3.17.). Nevertheless, JOHN YOWELL didn’t insert the role of the envelope to improve the acoustic insulation, which has become an important factor in many buildings!

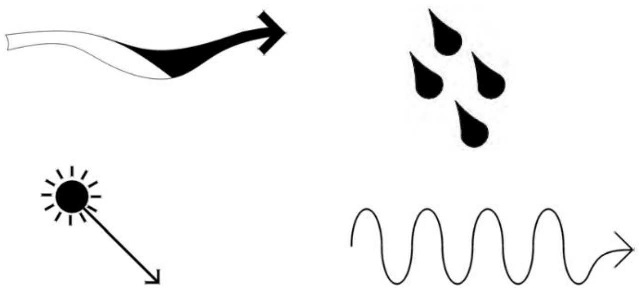


Figure 3.17. Show the main four functions of the envelope (JOHN YOWELL Norman, 2011).

Nature emulation provides multiple ways to incorporate nature-strategies and concepts to deliver sustainability to building design. However, it is difficult to transmit information from biodiversity to architecture or technology without some knowledge of biology. Superficial information and an approach that is non-imaginable or incomprehensible may result in failure. Despite this, natural approaches can be multifunctional, dynamic, and flexible. The idea of traditional building envelopes can, therefore, be replaced as static, in order to improve energy outputs, in a new adaptive model. This approach will improve the response and adaptation, of the potential envelope systems, to external and internal environments and meet comfort standards (Al-Obaidi et al., 2017).

The initiation of protracted and complex bio-inspiration researches may face many challenges in producing innovative and effective designs in the built environment. One of the most reliable researches to develop the traditional structure of the envelope of the building is the concept of (Bioskin). This concept is intended to create building envelopes that mimic living skins found in living organisms. Mazzoleni also discussed the ways to adopt animal skins for buildings performance. Moreover, Myers demonstrated a dramatic technique in which living materials are used in elements and structures. The solution introduces the principle of imitation to incorporate biology into buildings directly in order to produce new forms. Biomimicry seeks to deal with mistakes and create a more functional and efficient framework to develop the traditional ways of design (Al-Obaidi et al., 2017).

In order to have a good and effective look in the design of building envelopes. The focus on biological solutions is important, it gives a more holistic view towards a sustainable approach. These solutions are produced according to natural organisms and the information derived from them produces a relationship between man-made products and problem-solving according to this new design approach. Researches in the field of natural simulation have motivated architects, scientists, and designers to dig deeper into nature up to microscopic levels in an attempt to look for answers and solutions to proposed design problems and to achieve absolute sustainable innovation. Mazzoleni says, that just as living organisms have effective systems such as skeletons, circulatory systems, immune systems, metastases, and sensory connections, the structures have a structural system, a circulation system, energy conservation, balance systems, heat, water, communication, etc. Many physiological analyzes of plants and animals have been put forward but their practical translation into architecture is still limited. Deep studies may offer good concepts for example, some habitats offer a valuable lesson in long-term design (Minsolmaz Yeler & Yeler, 2017). "Skin in the perspective of nature is a highly sophisticated and developed member that performs various functions including protection, sensation, temperature regulation and water". It is the first line of defense that protects the interior from the external environment. At the same time, they are permeable when needed and have the advantage of self-repair and adaptation as well as aesthetic properties. It also does all this with ecologically sustainable processing at a local scale, which at the end of its life cycle is not damaging the environment (Minsolmaz Yeler & Yeler, 2017).

The use of the expression skin is not only a metaphor but a membrane that organizes resources, materials, and details. When applied in buildings, the envelope of building serves multiple roles and make a link between the residents of the building and their environment. Today, however, envelopes are seen as a barrier to the outer environment rather than as a filter and balancing system such as natural skins. Therefore, imitating nature 's creative design strategies for the building envelope may be an efficient and productive opportunity to apply inspiration from nature to the building envelopes. It is interesting to look at their strategies and seek to move them from biology to architecture in different ways. Strategies that can be borrowed in direct and indirect ways where abstraction is the basis to transfer concepts from one field of study to another towards friendly-environment with functions, systems, and solutions.

In his study, Yeler mentions that organisms live in balance with their environment by presenting latent characteristics that make it incapable of confrontation. The natural concept of adaptation assures the building behavior is dynamic, adjustable, and adaptive. It makes the building structure multi-functional and includes robust structural envelope systems. He also discussed the properties of the nature skin systems and their impact on the architectural medium. And presents a table (see Table 3.5.) showing the skin structures of the species and the characteristics of today's and future buildings envelopes (Minsolmaz Yeler & Yeler, 2017).

Table 3.5. Natural skin systems and Building skins, properties of today and future (Minsolmaz Yeler & Yeler, 2017).

PROPERTIES OF SKIN SYSTEMS			
NATURE	ARCHITECTURE		
	TODAY		FUTURE
	CONVANTIONAL	INNOVATIVELY	CONCEPT/EXPERIMENTAL
• Adaptable	• Non adaptable	• Adaptable	• Adaptable
• Growing	• Non growing	• Modular growing	• Growing
• Changable	• Unchangable	• Changable	• Changable
• Responsive	• Unresponsive	• Smart and interactive	• Responsive
• Multi-functional	• Multi-functional	• Multi-functional	• Multi-functional
• Dynamic	• Static	• Dynamic	• Dynamic
• Flexible	• Rigid	• Flexible	• Flexible
• Self-repair	• Non self-repair	• Non self-repair	• Self-repair
• Self-renewable	• Non self-renewable	• Non self-renewable	• Self-renewable
• Sustainable	• Ephemeral	• Sustainable	• Sustainable
• Minimum material	• Maximum material	• Minimum material	• Minimum material
• High-performance	• Low-performance	• High- performance	• Maximum performance
• Energi generating	• Energy comsumption	• Energy generating	• Energy generating
• Complex integrated systems	• Simple relationship	• Complex integrated systems	• Complex integrated systems

3.3.3. Adaptive systems in design

Architecture has introduced an interactive engineering field with a dynamic environment through which the building can adapt itself to undesired conditions. Technological development has contributed to this trend through the application of many innovations that were once like a dream. Recently, trends of adaptive systems in the building designs have evolved. The façade design has had a significant share of this development by adopting a layered façade system; their combinations (layers) represent a complex system and each layer operates on the basis of a particular function. Such systems have various kinds, such as automatically operated shutters, adaptive skin, climate adaptive building, robotic and kinetic interactive architecture, acclimatized kinetic_façade, adaptive building skins and architectural responsive systems. All of these systems usually aim to increase energy efficiency and allow occupants to feel comfortable mostly (Al-Obaidi et al., 2017).

Biomimicry is a term that describes the use of brilliance in nature. Aimed primarily at using resources more effectively while meeting human needs. Similarly, applications of adaptive architecture and biomimicry tend to mimic the excellent response of nature to unusual conditions, and applications of effective systems are examined in one way or another in biomimicry studies. Thus, the concept of Biomimicry with architecture intertwines and integrates over time as a result of studies and researches on this matter, which helps to develop a sustainable design process. Nevertheless, flexible, responsive design and natural mimicking activities are still missing in the building industry as these principles are seen as challenging by industry stakeholders. Architects have benefited from the natural systems and forms for eras. It is likely to profit from this imitation through the analysis of active substances, effective reaction behavior, energy systems, and external configuration. However, the rapid development of technology has been another vital improvement in the diversity of design in the building industry (Bayhan & Karaca, 2019).

There are many types of adaptation systems have mentioned in studies. kinetic systems, as a common system it is effectively found in many plants, for example, many studies presented "how plants transfer force, torque and motion to structural elements, and how these subsequently become associated with biologically compliant mechanisms and form". in addition, another concept of effective systems is like a Mechanism system that includes many activities at different levels to maintain the desired conditions. For instance, "organisms have special features that can respond to changing environments, such as darkness, light, humidity, rainwater, fire, temperature, freezing, air movement or air quality", Through the use of latent activities (materials, interactions, combinations, physical bases).

3.3.4. Innovative inspiration for façade technology

The concept of biochemistry is a link between architecture, bioscience, chemistry, and physics. However, in applied architecture is based largely on technical science. Through inspiration from the mentioned sciences that continue to provide us with new and innovative visions to solve engineering problems. The inspiration of biomimicry from insects, reptiles, mammals, and other species has progressed and inspired over 30 years. Biomimicry acts as a tool for engineering to solve specific problems at the design stage. Biomimicry is an emerging field known as a capable approach for a more sustainable environment (Al-Obaidi et al., 2017).

Biomimicry innovations could be classified into four clusters:

* Smart materials that can change and respond to external stimuli.

* Surface modifications with innovative surface structures and improved functions.
* nature-inspired architecture material that are offered innovative forms and structural preparations.
* Technologies that improve existing systems by arranging specific adaptive parameters.

One of the most important types of innovation derived from nature is material science and its applications in architecture. Bio-inspired materials offer the most relevant research of their important applications in sustainable architecture. According to the previous classification, the first and second groups of the material types found in nature are divided into two classifications in terms of effectiveness and responsiveness: first, Materials with chemical stimulants and materials with physical stimuli. For chemical stimuli, the receptor of a material perceives and stimulates a highly particular internal response. The mechanisms of smart materials as biomimicry applications are form pH changes and metal ion. Meanwhile, physical stimuli can range anywhere from heat to light and water content. The second group of materials with physical properties with specific surface modifications (e.g., repellent, drag-reductive and anti-reflective properties) typical of novel designs. Based on the concept of the repellent surfaces, some materials have very harsh properties of water-repellent properties. Which possess highly hydrophobic surfaces that allow water to easily run off over the leave epidermis through a waxy cuticle. Moreover, the ability of gecko's feet to stick to different surfaces and break free easily also gives insights into innovation material properties. A gecko footpad has nanoscale, microscale, and filamentous structures that can interact with any given substrate. The third group of materials relates to the internal and external structures of the materials. These structures are inspired from nature by the initial stages of design. Through this process, many innovative and new materials are produced and exploited in many applications. There are many good examples of structural adjustment in nature. Thus, it can be applied to the manufacture of materials that provide solutions to some of the problems such as the production of lightweight structures including "the two-layer Beetle elytra that maintain their integrity through a series of interconnecting attachments. Imitating natural photonic structures and developing new nanoscale structures can enhance the development of new structures and material properties in the field of architecture". Fourthly, the last group of nature-based innovation goes beyond the material mutation to a simulation-based on mechanisms, behaviors, and forms that are inspired from nature as a solution to certain problems. These processes are involved in many architectural applications and always synonymous with efficiency (Al-Obaidi et al., 2017). Also, we can reliance on Lurie Luke classification of biomimicry applications that goes with the fourth group, which contains three parts:

* Improvements based on movement kinetics.
* improvement-based release mechanisms.
* Improvements based on structural configuration (e.g., energy-efficient shapes).

Generally, these classifications can help improve design approaches and innovate building envelopes (Kell & Lurie-Luke, 2015) .

3.4. Building's Physics Factors through High-Rise Building Façade

The mutual effects of climate change and population growth influence the built environment and building type. High rise building becomes a necessity to face rapid urbanization, especially in the high-density cities. The high rise building has usually been a sign of power, manufacturing, and accomplishment. High rise buildings emerged as a result of the development of two technologies: steel frame structure and elevator. The windows in first-generation high rise buildings made up of 20-40% of the façade, comparing to the modern high rise building within a 50-75% glazing Making energy demand a critical issue linked to climate change and greenhouse façade (Dumez, 2017). High rise buildings exposed directly to climate factors more than other types of buildings. In the summer which is near-extreme conditions, the building consumed a large amount of energy to keep the building as comfortable as possible. So, the performance within energy consumption will identify the efficiency of the building. Building energy usage must be reduced by implementing a climate adaptive building envelope without sacrificing comfort conditions. The envelope design divided into many parts, each of them affect the whole building performance. For instance, glazing optimization, walls, roofs, and shading systems (Kwok et al., 2018).

The internal thermal comfort of the high rise buildings, however, requires real overheating treatments, especially during the hot times, due to the extreme solar radiation, inadequate air ventilation, and the slow heating release from building materials. Climate Adaptive building design strategies are adopted to optimize building performance by minimizing energy consumption without compromising the comforts. There are real attempts to improve the performance and energy efficiency of the high rise building by researchers and engineers to modify and optimize the glazing, walls, and shading systems. But, one of the most important factors impacting the building performance due to solar heat gain and heat transfer is the ration of the area of the total windows to the whole building façade (Kwok et al., 2018). The term energy efficient facades have expanded significantly in the last decade since the 1970s. Climate change and greenhouse issues have guided engineers, architects, and researchers to concentrate on energy use by applying various passive and active methods for heating and cooling, daylight use, and developing multiple solutions for more efficient facade production. The link between facade design and energy use attracts architects for much more consideration than ever before. The design of the façade determines occupant comfort, heating and cooling loads, artificial lighting, and even natural ventilation requirements (Dumez, 2017). Therefore, in this research, the study will be focused on the façade as a shading combined with glazing to create an integrated design approach for comforts and energy efficiency.

3.4.1 Glazing

Glass defined as a liquid with high viscosity even at high temperatures. Which solidifies without crystallization at normal temperature. It has the properties of a liquid object as well as mechanical properties. The main ingredient of the glass is silicon dioxide (SiO2) which is melted and dispersed in the amorphous structure which provides transparency. The first glass materials produced by the humankind were found in “Egypt and Eastern Mesopotamia in 3500 (B.C). Glasses are resistant to mechanical, lateral effects, atmospheric effects and heat changes, transparent refractory materials which have the ability to refract light and pass through to solar radiation. Glass has higher transparency than most transparent plastic. It can respond to environmental demands such as light transmittance, reflection, color, solar heat, heating energy, and noise control and security through secondary processes such as tinting, tempering, lamination, insulating glass units, solar and heat control coatings (Karaman, 2019).

The lightweight structure of Curtain wall offers the flexibility to get the building more height producing impressive highly glazed façade towers. Glazing façade is an attempt to connect occupants with the environment and providing physical and psychological benefits to the occupants, also improving the output of staff in the space. Also, the gazing system should make a balance between human comfort and energy. Therefore, the glazing system has a large number of researches and development processes. Which produced lots of glass types with different physical properties and produced many forms as well. In the mid-20th century, tinted and reflective glazing to achieve a certain aesthetic.

Nevertheless, the selection process of the glazing choices available was more closely taken into account during the energy crisis of 1970, and a range of options of glass started entering the market. The common options have been double glazed panels, low ecoatings and different gas filled cavity glazing (Dumez, 2017).

Current high rise buildings show the advance of glazing technologies in the diverse glass coatings, tinting, reflectivity, and fillings utilized during the last century. Furthermore, the current glazing systems applied in façade design aim to make a balance between daylight efficiency and thermal gains and losses. While most of the tower's façades now have single-skinned façade with varying glazing, the energy saving potential in double_skinned façades is also increasing. In the double skin façade, the cavity between the interior and exterior layer of the façade utilized to provide natural ventilation. Making the envelope able to regulate the comfort level. The glass type and properties are thus a critical problem for the performance of the curtain wall. The glazing takes up a great proportion of the high rise façade. Windows account, for example, 30% of building heat and cooling requirements in the United States (Dumez, 2017).

In most glazing, one or two of the following objectives are being pursued: solar gain control during cooling conditions, heat loss reduction under heating conditions, and visible transmission increase and/or redirect in daylighted conditions. Most new vitreous components balance the spectral properties of the glass, control the amount of transmitted light, or fully redirect the light. Nowadays, thermal and transmittance is more understood within many properties of the different glazing systems. Characterizing the different performance properties of various glazing systems helps architects to choose the building design more effectively (Dumez, 2017).

“Physically, the thermal behavior in a window conducts in three different ways: conduction, convection, and radiation” (see Figure 3.18.). Conduction is the transmission of heat through contact. Heat travels from a warmer body toward a colder one. Convection is a heat transfer by mixing fluid. Convection occurs within liquids and gases. Radiation is the transmission of energy by electromagnetic radiation. Radiation does not need a medium in which the energy needs to transfer through (Wikipedia).

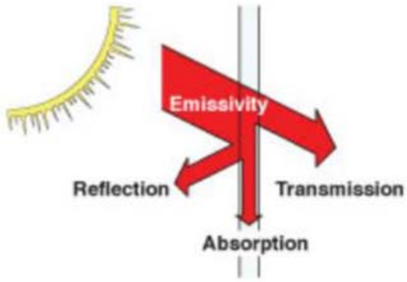


Figure 3.18. Glass Energy Transfer (Efficient Windows Collaborative, n.d.).

The glass material has different properties that defined its thermal behavior and efficiency. U-value is one important factor affecting the glass behavior when the temperature between inside and outside is different, the heat transmits based on conduction, convection, and radiation will be influenced by the U value of glass which presents the general thermal exchange rate or value of insulation (see Figure 3.19.). The low u-value reduces the temperature transmits into the interior. The U-value has important effects on heat properties.

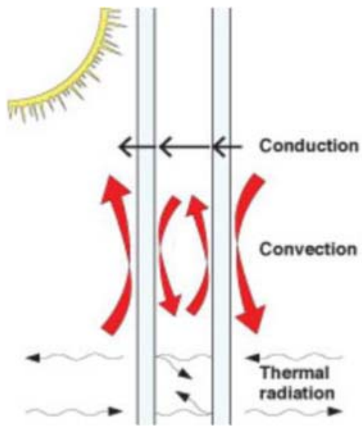


Figure 3.19. U-value (Efficient Windows Collaborative, n.d.).

Another important factor is the Solar Heat Gain Coefficient (SHGC) calculated as the ratio between the transmitted and the total incoming solar radiation on the windows (see Figure 3.20.). Low SHGC values have a great impact to reduce cooling demand. Therefore, in a hot climate the choice of the windows has to be focused on SHGC.

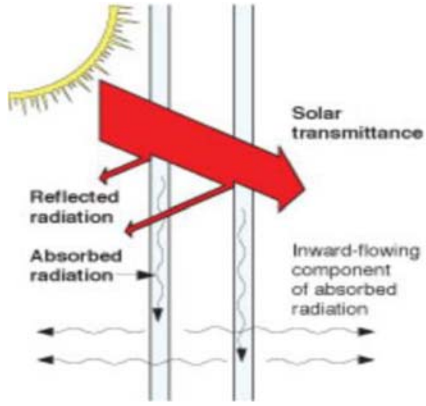


Figure 3.20. Solar heat gain coefficient (Efficient Windows Collaborative, n.d.).

While the third important factor is the Visible Transmittance (VT) which can be described as visible light transmittance of the glass. “Visible transmittance is the amount of light in the visible portion of the spectrum that passes through a glazing material”.

A greater VT means that there is more daylight in a zone that can decrease artificial lights and raise cooling demand (see Figure 3.21.). The type of glazing, the glass coatings and the number of panes affect the visible transmission (Efficient Windows Collaborative, n.d.).

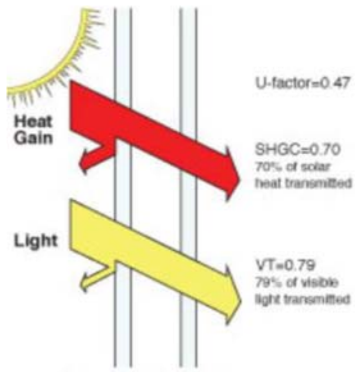


Figure 3.21. VT Rate in Double Glaze Glass (Efficient Windows Collaborative, n.d.).

Previously, heat gain reduction windows (with tints and coatings) have decreased the visible transmission. Nonetheless, new lowE solar high performance coatings and Tinted Glass have made it feasible to decrease the solar heat gain with the little visible transmission. The SHGC / VT ratio has a significant impact on the need for cooling. Therefore, depending on this ratio, the need for cooling decreases while the heating and lighting requirement increases or vice versa. Furthermore, because of the concept of splitting solar gain control and light control is so important, measures have been developed to reflect this. “The ratio between visible transmittance (VT) and solar heat gain coefficient (SHGC) defined as a LSG ratio” (Efficient Windows Collaborative, n.d.).

3.4.2. Shading systems

Shading devices are the barrier elements that prevent solar radiation from falling on the building structure. It is a significant process to control the comfort levels and keep the structure away from direct sun especially in the hot period. So, shading devisess directly affect the performance of the building. “There are many types of shading systems such as overhangs, side fins, light shelves, blinds, louvers, and screens. Shading devices can be fixed or moveable, translucent, or opaque; they can be internal, external, or even between panes of glass”. But, the external shading system is the best due to the ability to prevent solar radiation before passing the internal spaces. External shading systems used widely in architecture to regulate the radiation and daylight amounts passing into the building.

The efficiency of shading systems influenced by many factors, which affected by the shading design such as sun path and the daylight level on the site. So, the shading system controls the light performance. Therefore, shading systems should design in an optimum way to exploit the daylight and prevent solar radiation. Currently, computer-based design and simulation become vital processes that optimize the design at early stage of design (Wong et al., 2004). In high-rise buildings, there is a large percentage of glazing in the façade. Therefore, external shading devices have been utilized even with some additional costs for construction. But its ability for large energy-saving impacts more important relatively. Applying shading devices affected HVAC systems directly. Besides, the external shading system act as a shading device as well, moderating the intensity of daylight coming from outside the building and balanced it with indirect reflected light passing deeper into space in a deep plan. Hence, the effect of a light reflected by an exterior shading device is increasing the daylight zone (Yavuzarslan, 2019).

3.4.2.1. The shading systems types

The shading system is a complex possess influenced by design, façade orientation, and glazing type. Some buildings have already their way for self-shading designed within environment analysis tools (Dumez, 2017). However, there are many types of shading devices that we can classify them based on many aspects (see Figure 3.22.).

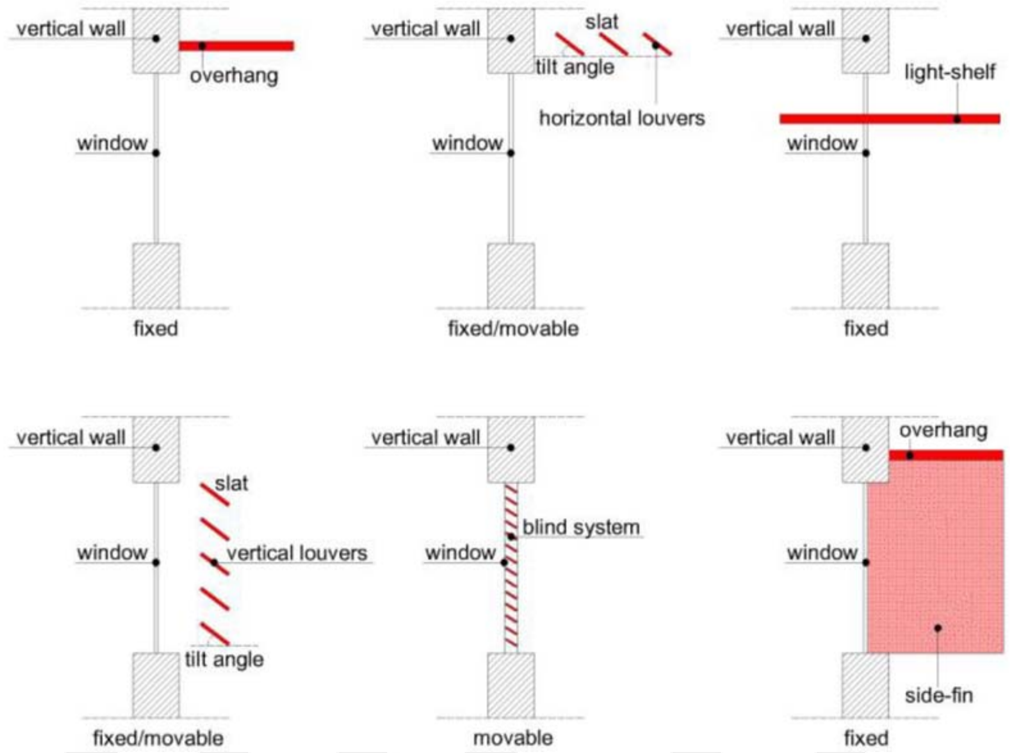


Figure 3.22. Main shading types (Factor, n.d.).

3.4.2.1.1. Fixed shading devices

Fixed shading devices have long served as solar control elements in different building types. Although fixed shading devices offer significant protection from heat gain, they should be adjustable as possible to adapt to different outdoor conditions.

▶ **Overhang**

Overhang shading are the horizontal elements that fixed at the top of the exterior face of glazing or windows. Designed accurately in a way that prevents the summer sun from fallen directly on the glazing parts and allows winter sun passing the window into the interior. Also, protect the building against harmful sunlight and rainy weather and thus, increasing visual comfort and thermal comfort. The overhang shading could be designed as one flat panel but this way affected by snow load, wind, and captures hot air. Therefore, it's better to divide the panel into a horizontal overhang louver (Factor, n.d.) & (Yavuzarslan, 2019).

▶ **Horizontal louvers**

Horizontal louvers designed accurately to shade glazed parts during hot summer and allows sun passing in the winter period. But, in both seasons it helps to maximize daylight efficiency. Horizontal louvers take many forms such as canopy, long partitions, moving horizontal louver blades. The top surface is usually covered with a prismatic aluminum film or painted with a light color to increase reflectivity. Horizontal louvers as an external shading system have the ability to reflect the indirect sunlight into deeper space and increasing daylight efficiency. In general horizontal shading type preferred in the south facade (Yavuzarslan, 2019).

▶ **Vertical**

Vertical shading system mainly used on the western and eastern façade of the building. Also, it is useful for shading the north facade from summer sunlight early and late hours of the day. There are many types of this shading device such as louver blades, projecting side fins in 45 degrees a vertical position. These devices provide a perfect shading within one direction allowed sun which is when the sun is parallel to the shading devices. Vertical louvers as an external shading system have the ability to reflect the indirect sunlight into deeper space and increasing daylight efficiency (Yavuzarslan, 2019).

▶ **Egg-Crate**

Egg crate is a mixed system that combines horizontal and vertical shading elements. Often used in architecture design. Egg crate performance determined horizontally and vertically. It might need less depth of elements but also could have some problems with limited views. Egg crate as an external shading system has the ability to reflect the indirect sunlight into deeper space and increasing daylight efficiency. It is preferred in hot climate regions (Yavuzarslan, 2019) & (Barozzi & Grossa, 1987).

3.4.2.1.2. Moveable shading devices

Installation of external movable sun shading devices is highly recommended in glazed openings that are exposed to the summer sun. Well-designed sun shading devices will help keep the building comfortable and limit the space conditioning needs. The design of effective moveable shading devices will depend on the interactive or the adaptive with the solar direction on a particular building facade.

- **Venetian Blinds**

Venetian blinds are commonly used for shading inside, outside, or even between the glazing system of the building. Offers a good ability to control the amount of direct sun radiation and passing daylight through the glazing to the interior. Venetian blinds contain a number of horizontal and vertical blades made from different materials such as wood, plastic, or metal which are connected together by cables that run through the blind blades. It can be controlled manually or by remote control to take the most efficient form that provides privacy, visual and thermal comfort. Also, it can be optimized through the simulation process (Yavuzarslan, 2019).

- **Vertical Blinds**

Vertical blinds are different than Venetian blinds due to their vertical shading elements (blades). Which, makes the shading blades less possibility to collect dust. They move easier through the horizontal operation. They made from several materials such as PVC, fabric, faux wood materials, wood. Vertical blinds more suitable the other shading devices for doors especially the doorways that generally open most of the time (Yavuzarslan, 2019).

- **Roller Shades**

Roller shading device offers the ability to control the daylight and reduce the heat gain as well as providing the occupants visual and thermal comforts. It can be adjusted manually or automatically. Automated controlled types have great performance effect on energy savings (Wankanapon & Mistrick, 2011).

3.4.2.1.3. Other shading systems

Include other methods of shading or other types of devices. In general, we can classify them into two types.

- **Awnings and Canopies**

An awning is a lightweight structure from aluminum, iron, or steel as a secondary shading device covering the exterior wall of the building. The shading elements made from vinyl-laminated polyester fabric from cotton, acrylic, or polyester yarn or firmly stretched on the lightweight structure. The formation of this structure is something of a truss, planar frame, or space frame. In snowy regions, aluminum awnings are preferred due to snow load. An awning becomes a canopy with additional columns that used frequently at the entrance of hotels or restaurants (Yavuzarslan, 2019).

- **Deciduous Plants**

High deciduous trees can offer perfect shading solutions for the south façade with its ability to grow up leaves and branches at the summer period offering perfect shading and cool air near the ground and good temperature near the tree. But, in the winter the leaves are fallen and spreading offering a good chance for heat gaining. Windows and roofs can increase the absorbance of solar heat and cause an increase in cooling costs. But, landscaping elements can help reduce this solar heat gain. Lower trees are more proper at the west side because daylight angle decreases afternoon (Yavuzarslan, 2019).

3.4.3. Comfort conditions

comfort is achieved by the integration of several factors that contribute to the thermal and visual comforts of the building occupant. These factors are closely interrelated to achieve the objective and cannot be separated from each other (i.e. lighting, microclimate, acoustics, and indoor air quality). It should also be taken into consideration that thermal comfort directly affects the overall performance of the building. This has been demonstrated by extensive analytical studies. Access to occupant comfort in summer and winter may require countermeasures, for example, the sun with its light and radiation may be allowed to enter in the cold winter, in contrast, the direct sun is prevented and the natural light is controlled in the summer. All of this can be done through the new technologies that have been adopted to achieve a comprehensive approach that can balance the thermal and visual comfort levels (D’Ambrosio Alfano et al., 2006).

Comfort conditions in indoor environments are related to objective and subjective aspects. The objective ones typically concern visual, thermal and finally indoor air quality facets, whereas the subjective ones are strictly related to the subject perception of the environment in which it is exposed (D’Ambrosio Alfano et al., 2006).

The draft documents about a whole thermal comfort treatment although inspired by different philosophies:

- ▶ prEN 15251 is strictly devoted to the European Directive observance, therefore it deals with energy consumption problems related to the air conditioning design and operating.
- ▶ ASHRAE Guidelines, on the contrary hand, is based on a typical ergonomic approach taking into account the human response to the thermal environment (D'Ambrosio Alfano et al., 2006) .

In fact, ASHRAE worked about indoor environment assessment criteria up to the formulation of new Standard projects. "The environmental factors addressed in these standards are temperature, thermal radiation, humidity, and airspeed; the personal factors are those of activity and clothing".

Briefly, Thermal comfort is the condition of mind, which states satisfaction with the thermal environment. Because there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in space. There are six primary factors that must be addressed when defining conditions for thermal comfort (ASHRAE, 1992).

* Metabolic rate
* Clothing insulation
* Air temperature
* Radiant temperature
* Air speed
* Humidity

All six factors may change from one time to another. This model, however, only addresses thermal comfort in a constant state (with some restricted temperature variations with time). Thus, if you enter a building that meets the requirements of this standard, you may be not comfortable directly because you have experienced different environmental conditions before you enter this building. Previous exposure or activity may affect comfort perceptions for about an hour (ASHRAE, 1992). In addition, "(prEN 15251:2006) defines the optimal operative temperature as the operative temperature where a maximum number of the occupants can be expected to feel the indoor temperature acceptable". Thermal comfort criteria (in winter minimum room temperature, summer maximum room temperature) are used as input for heat demand

(EN 12831) and for cool demand (prEN 15255) calculations in the design process of the building and dimensioning of room conditioning systems.

However, the adaptive comfort analysis is a calculation process based on certain weather data to measure the level of comfort times that occupants can adapt themselves to. Therefore, the adaptive comfort process built on the work of hundreds of field studies in which people in ventilated buildings were asked about how comfortable they were. Results showed that users can adapt themselves to the monthly mean temperature remained above 10 ˚C and below 33.5 ˚C (mostapharoudsari). ASHRAE 55-2013 Thermal environment stander for occupancy comfort which is one of the major comfort standers to evaluate the quality of the indoor environment presented, a number of concepts and factors to improve the thermal comfort within the indoor environment. Human heat balance which determines the indoor adaptive comfort level, defined by the equation (**M-W-Eres-Cres-E = (tsk - tcl)/ Icl = R+C)**

– tsk =Mean skin temperature
– tcl =Mean clothing surface temperature
– M =Metabolic heat production
– W =Mechanical work
– R =Radiant heat exchange
– C =Convective heat exchange
– E =Evaporative heat exchange from skin
– Eres =Evaporative heat exchange from respiration
– Cres =Convective heat exchange from respiration.

So, the main factors of local thermal discomfort are: (Radiant temperature asymmetry, Draught, Vertical air temperature difference, Floor surface temperature). While, general thermal comfort determines based on Personal factors (Clothing, Activity) and Environmental Factors (Air temperature, Mean radiant temperature, Air velocity, Humidity). Therefore, the adaption in natural ventilated building requires Behavioral aspects (clothing, activity, posture) and Psychological aspects (expectations) (Olesen, 2004).

While visual comfort, it is difficult to give a clear definition. But, there are two different approaches are considered:

the most commonly accepted approach is the “NON-annoyance approach” based on the supposition that “comfort is not discomfort”. So, visual comfort doesn’t have a unique definition. However, Visual discomfort gives a lot of indications that can be clearly identified, understood and evaluated with subjective: difficulty in doing a visual task, annoyance, glare, stress, and physical symptoms like headaches, pains, sore, itchy, watering eyes… (Iacomussi et al., 2015).

The second approach is the “well-being approach” based on the estimation of the positive factors proved by well-being and satisfaction. The parameters in this approach that determine comfort and discomfort are connected to “NON-annoyance approach” (Iacomussi et al., 2015).

International Commission on Illumination (CIE) documents, standards on lighting environments and available research results specify/recognize the following parameters as relevant for visual comfort in indoor lighting:

* Glare (from luminaires, daylight, bright surfaces like windows, …);
*Veiling reflections;
* Illuminance levels (work plane, surrounding, ...);
* Luminance ratios and uniformities;
*Color rendering index – CRI;
* Correlated Color Temperature – CCT;
*Flicker
For the visual comfort evaluation some researches also consider:
* Space and room appearance;
* Surfaces brightness and color;
* Light distribution;
* Appearance of light and luminaires
(Iacomussi et al., 2015).

3.4.4. HVAC System

In buildings, the operations costs are much bigger than the initial cost. “The technical journal from the Council of Tall Buildings and Urban Habitat sates, for a building with a 50-year lifespan, the initial costs are 12%, maintenance counts for 4%, and operation costs account for 85% of the lifetime costs of the building”. HVAC is one of the major operation factors connect to climate conditions in the building area. Also, the design and the environmental treatment affect the energy consumption. Recently, annual energy saving is a critical issue for the built environment by taking into consideration the peak load conditions which affect largely cost saving as well. The HVAC system should be sized for the most extreme heating and cooling demands. Thus, it is important to reduce energy demand for peak time by applied different treatments on building design. Furthermore, the reduction in the peak load contributes to annual cost-saving and smaller central heating and cooling plant, as well as smaller ducts, pipes, and other system equipment. Therefore, accurate building energy modeling and equipment sizing are critical issues for energy efficiency in the building (Dumez, 2017).

There are many types of research trying to develop the HVAC systems in term of energy efficiency. However, a lot of systems in recent history have been used for heating and cooling in high rise buildings. The most commonly one used in high rise buildings is the Variable-Air-Volume (VAV). In some buildings, low-temperature VAV systems utilized, in which the supply air is colder than normal (32-48 degrees Fahrenheit) to allow for lower supply air volumes. Also, duct size can affect the system, yet, some operations must be taken to insulate vents and prevent condensation due to the fact that there are some times that the perimeter zones demand heating while the interior zones need cooling. In this situation, The VAV systems are enhanced by hot-water or electric baseboards, or by a reheat system. Another AVA method to provide heating and cooling to the perimeter zones by fan-coil units, while implementing VAV units in the interior zones. This offers a reduction of the mechanical systems that support the VAV system but does require additional mechanical pumps and heat exchangers for the fan coil units (Dumez, 2017).

Another example of HVAC system used for the high rise buildings which offer an ability for heating and cooling at the same time. In the potential of energy saving displacement ventilation has grown as a concept encouraging the stratification of the space. Yet, the concept of displacement ventilation applied at the under-floor air distribution system (UFAD). In this system only occupied space will condition. Due to the concept of stratification with the "displacement ventilation, the space is only conditioned to about 1.8m above the floor height, which is much a little over half the typical floor-to-ceiling height, reducing the overall volume of space that requires more energy for HVAC system". UFAD relatively is new technology and also currently not widely implemented.

Need fewer ducts, which can limit system expenses but the control of perimeter zones separately from the interior zones is difficult for UFAD systems. Room air stratification within UFAD systems also have benefits due to the fact that the hot air and contaminants concentrated at the ceiling with the potential of possible health and thermal conductivity issues (Dumez, 2017).

Some high rise buildings designed with a central atrium based on the stack effect to provide natural ventilation to the building spaces (see Figure 3.23.). The stack effect happens when the outside temperature is lower than the interior temperature. So the cool air flows in the lower floors and rises within the building's thermal operation to the top. The effectiveness of the central atrium and airflow appears more clearly due to the height of the building.

Therefore, the stacking effect in a high_rise building can cause pressure issues and makes it difficult to keep the building heated and cooled uniformly. During the winter, the mixed-mode operating system moves to a mechanically ventilated system to decrease heat losses. An isolation and heat arrangement can be provided with a double skin facade via a mixed Trombe wall system (Dumez, 2017).

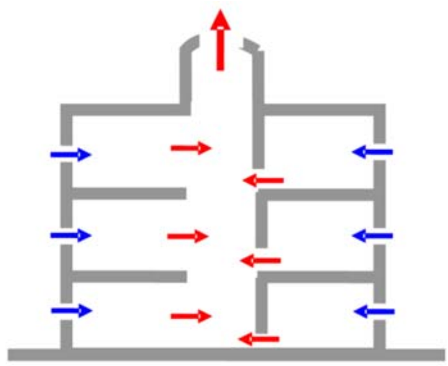


Figure 3.23. Natural ventilation through an atrium (Dumez, 2017)

3.4.5. Natural Ventilation

In the past, the buildings have been ventilated by windows in general. As the design of the facades has changed, however, natural airflow controlled mechanically which is increasingly depends on. However, Mixed-mode offers potential concepts due to the abilities that the mechanical system can offer for energy-saving and increase the attention for passive concepts to the building ventilation system. Natural ventilation in high rise buildings has the potential of buoyancy and the stack effect to remove heat from the building envelope.

Generally, the natural ventilation systems influenced by several factors in the design process such as orientation, thermal mass, and façade design. Climate also has a large effect on the design and the success of natural ventilation systems. The building orientation, surface to volume ratio, and other factors must all be designed to maximize natural ventilation from the early stage of the design process to guarantee success. Natural ventilation can be integrated into the daily HVAC system, or it can be used separately in a "night-flush" strategy. The natural ventilation strategy depends on climate conditions. For instance, a daytime natural ventilation strategy could be used within suitable climate conditions to improve the occupant comforts and satisfy the code ventilation demands for fresh air. While nighttime ventilation exploits the cooler night temperature to imitate heat gains that have been captivated in the space. Therefore, if nighttime ventilation within the right situations will decrease the peak and total cooling load, and some time helps to eliminate the air condition system. Natural ventilation system can be taken different concepts of design such as isolated floors with cross-flow ventilation or in individual rooms with single-sided ventilation. Nevertheless, individual spaces are usually simple to model and predict performance (Dumez, 2017) (see Figure 3.24.).

Natural ventilation strategies could be applied in the façade building with different design concepts. For example, natural ventilation system has applied in double-skin façade so the second layer offers protection from different factors such as thermal issues, noise, and wind while the gap between layers could provide the natural ventilation with or without mechanical system (Dumez, 2017).

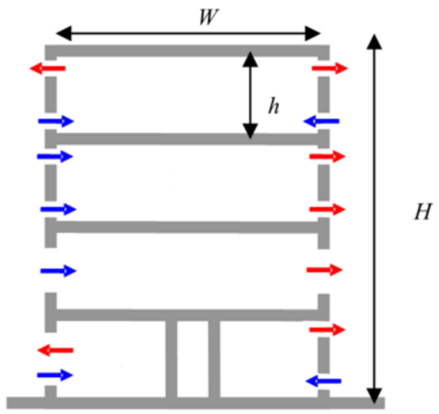


Figure 3.24. Natural ventilation in isolated spaces (Dumez, 2017)

3.4.6. Daylight

To achieve a comprehensive design concept that can make a balance between energy and comfort, the building design should consider the visual comfort within natural daylight which significantly improves the health and efficiency of occupants, and enhance the energy efficiency of buildings. Furthermore, natural daylight influences the occupants positively based on some facts such as the higher productivity, lower absence, better mood, reduce exhaustion, and decrease eyestrain also solar radiation on is essential for human skin to produce vitamin D. In general, daylight can improve the physiological and psychological behavior for the human body. Researchers found the space within sunlight effect positively related to job satisfaction. Daylighting considered as an alternative to artificial lighting which offers the simplest method for energy efficiency. But, daylight needs some control strategies that can lead to cost and energy saving by analyze the daylight efficiency in building and switch off the artificial lighting whenever the sunlight is sufficient (Yuan et al., 2017).

In addition, reducing artificial lighting demands and using daylighting instead can also reduce the building's cooling load by reducing the heat released by the artificial lighting (Yuan et al., 2017). However, with a large ratio of glazing, the building problems become more complicated within the high potential of heat gain and heat loss and that can affect energy costs significantly. So the design concept and strategies must consider the climate condition firstly and make the balance between HVAC energy demand and daylight efficiency (Jakubiec & Reinhart, 2011). One of the strategies that have been used to control the direct sun radiation and make the balance to achieve the comfort is shading system which influenced by the glazing type or façade design (Wong et al., 2004).

To understand daylight concept, there are some factors defined by researchers to evaluate the daylight efficiency:

- Illuminance

Illuminance counts the amount of light on a surface per unit area, and it measures by lux unit. Also illuminance usually used to evaluate the brightness of inside space. The Illuminating Engineering Society (IES) defined the recommended levels of illuminance according to the space type, visual works, the age of occupants, etc. (Yuan et al., 2017).

- Daylight factor (DF)

"Daylight factor (DF) is the ratio of the interior illuminance to the exterior illuminance within overcast sky". This factor offers an evaluation of daylight condition of a building. DF is easy to calculate and it's a static value, which means there is no change in DF by changing building location, orientation, and some daylight problems cannot be noticed by DF (Yuan et al., 2017).

- Daylight Autonomy (DA)

Daylight autonomy (DA) is the proportion of the number of hours in the year when the daylight provide illuminance above the minimum illuminance demand, to the total hours in a year of occupation (Yuan et al., 2017).

- Useful Daylight Illuminance (UDI)

Useful Daylight Illuminance (UDI) is the proportion of the number of hours in a year that daylight provide an illuminance within useful range, to the total hours in the year of occupation. Usually the useful range of daylight presented by three ranges: UDI <100 lux, UDI 100-200 lux, and UDI >2000 lux. But, the useful illuminance range is between 100 lux to 2000 lux. Therefore, the illuminance under 100 lux consider as dark, and illuminance above 2000 lux is considered as very bright (Yuan et al., 2017).

- Continuous Daylight Illuminance (cDA)

Continuous Daylight Autonomy (cDA) is the same as DA but, when the illuminance below the minimum demand, the cDA gives a partial credit to the times. To illustrate, the minimum illuminance demand of the space is 300lux, but at a certain time step the illuminance is just 150lux. So, DA gives 0 credit, while (cDA) would give 0.5 credit (Yuan et al., 2017).

- Spatial Daylight Illuminance (sDA)

Spatial Daylight Autonomy (sDA) which considers both the spatial and temporal characteristics of daylighting performance, is the percentage of area that meets the minimum daylight illuminance for a specified percentage of hours in a year (Yuan et al., 2017).

- Annual Sunlight Exposure (ASE)

sDA and ASE are generally used together to evaluate the daylighting condition of the space. Annual Sunlight Exposure (ASE) is the percentage of area that surpasses specified illuminance for more than a specified percentage of hours in a year (Yuan et al., 2017).

3.4.7. Renewable energy generating technology

Recently, renewable sources of energy become more and more reliable especially within the tremendous progress in technology and engineering innovation. Renewable energy technologies provide marketable energy by changing natural phenomena into useful shapes of energy (Kalogirou, 2014). The building sector has a large share of global energy consumption. Therefore, a new trend of integrated building design towards energy reducing or even nearly zero energy building has appeared recently. For these purposes, there are some renewable energy generating technologies that have been applied in a different building so they can generate power that can contribute to providing buildings energy they need.

The building sector is a large sector, which could offer an opportunity to exploit it in a different way. For instance, high rise building provides a good chance to use the different conditions surrounding the building. For example, exploit the height of the towers which have more exposure to exterior conditions for using a solar panel or wind turbine to generate power. However, photovoltaic systems as renewable energy technology is a common system that can be integrated into different parts of the building such as the facade, roofs, or separately. PV systems playing an essential part in improving the building energy performance and decreasing the environmental effects (Chen et al., 2018). A solar panels system converts sun waves into energy and building facades can be used for solar panels applying. Renewable energy systems can be installed into the façade (Solar Constructions Company, n.d.). Engineers have developed a new photovoltaic system called Ruukki, which has been fully integrated into a facade. The new system can produce power even in spaces without direct sunlight since the technology can also use sun rays in cloudy weather. In snowy places and near water, the system increases production from reflected rays. The Ruukki PV units as a thin-film technology are aesthetically pleasing. The Ruukk PV system used in the facade of an average-sized office building in Finland, Ruukki's solar panel facade can provide 18,000 kWh of electricity a year (buildings smarter facility management, 2011) (see Figure 3.25.).

Figure 3.25. The Ruukki's solar panel facade in the facade of office building in Finland (buildings smarter facility management, 2011).

Another commonly renewable energy generating technology is wind turbines which can take different forms and sizes to exploit the wind speed and convert it to electrical power. In high rise buildings, there is an ability to take advantage of the height of towers where the wind speed is in the higher range. Research about wind turbine technology in high rise building has been done in Brussels to explore the potential of Brussels'skyscrapers to harvest wind speed (see Figure 3.26.). Researchers found there is a potential to develop renewable energy technology through small wind turbines in the city as a major conclusion of the study. The study confirmed that the high rise building can get a proper wind speed to make wind turbines generate electric energy especially on the roof of towers which can provide the same wind velocity as coast wind. Further information, the researchers estimate that small wind turbines just on the top of towers would be earned back through energy generation in about seven years (flanderstoday, 2014).

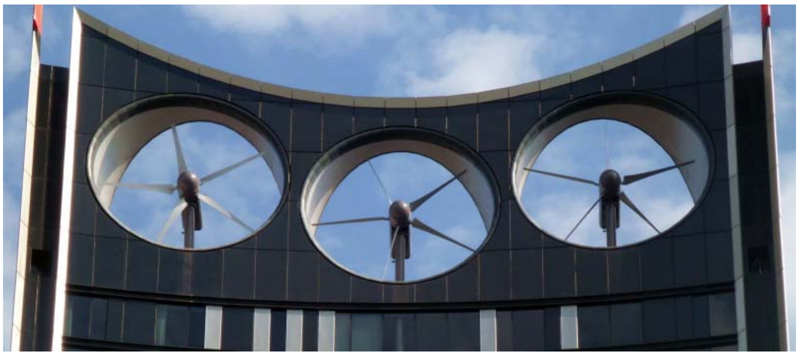


Figure 3.26. Integrating wind turbines to the high-rise buildings (flanderstoday, 2014)

Wind speed has an influence on wind turbine ability and operating features. In general, wind speeds are as follows:

- ▶ 2 (m/s) required as a minimum wind speed to start rotating most small wind turbines.
- ▶ 3.5 (m/s) is the usual cut-in speed, when a small turbine starts generating power.
- ▶ 10–15 (m/s) wind speed produces the maximum generation power.
- ▶ 25 (m/s) maximum, the turbine is stopped or braked (cut-out speed).

However, the efficiency of turbine increases with height above the ground, with a minimum of 10 meters recommended (Level, 2019).

Significant advancement in building integrated wind turbine technologies included improving dependability, increasing efficiency within low wind speeds, and decreasing the cost. Wind turbine blades are now designed with lightweight materials and aerodynamic principles so that they are a response to slight air movements. Moreover, "the use of permanent magnet generators, based on earth permanent magnets, produced lightweight and compact systems that allow low cut-in wind speeds. In this way, electricity can be generated with wind speeds as low as a few meters per second".

In addition, micro wind turbines as a small type of wind turbines used to generate energy with different heights of buildings. Without negotiating performance level, the micro wind turbines can be visually more attractive. Another goal is the elimination of noise from the rotation of blades and generators. This can be done by using low noise blade designs, vibration insulators to reduce the absorption of sound around the gearbox system and the generator (Climate Technology Centre and Network, n.d.) (see Figure 3.27.).

Figure 3.27. Integration of micro-wind turbines into urban area as a built environment (Climate Technology Centre and Network, n.d.)

Yey, in various applications several types of wind turbines have been used for power generation. The wind tree of the Aeroleaf is, for example, designed for lower wind speed and requires an electromagnetic breaker and microprocessor for safety purposes. The Wind Tree, according to the data presented, is a steel structure with a height of 9,8 m and 7,2 m (23,6 ft). It's about 3 feet high for every Aeroleaf. The nominal power per Aeroleaf is 5400 Watt, or 163 Watt, with 36 leaves (Forbes, 2018) (see Figure 3.28.).

Figure 3.28. The Wind Tree (Forbes, 2018)

Another example is Istanbul Traffic Wind Turbine which is hybrid system includes vertical axis wind turbine and a solar panel on top of it, placing on highways, ''Metrobus-lines'' and other transportation lines (see Figure 3.29.). This system will exploit the winds created by the vehicles as well as the natural winds and solar radiation to generate energy (climatelaunchpad, 2018).

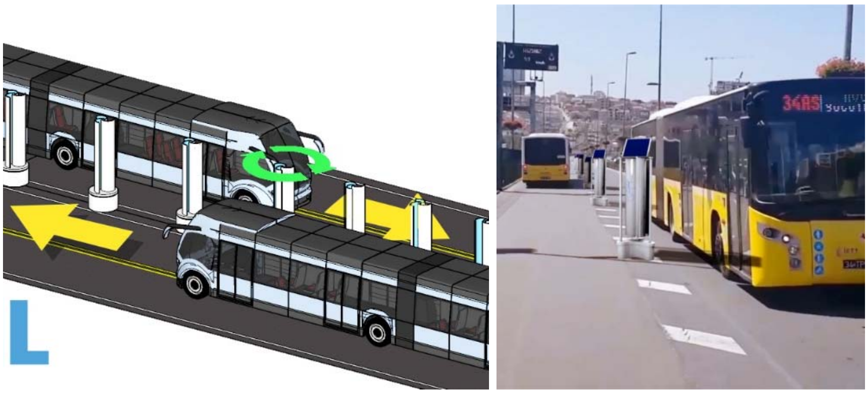


Figure 3.29. Istanbul hybrid system: Traffic Wind Turbine and solar panel (climatelaunchpad, 2018).

3.4.8. Sound Absorbing Shading Systems

Sometimes, the high percentage of the glazed façade could affect the acoustic level inside the building as same as the comfort levels thermally and visually. Mostly, the noise comes from outside the building especially when the building located in a traffic place or near the airport. Recently, a number of researches have done to develop acoustic technology and improve the level of noise passing into indoor spaces. "Façade sound isolation can be improved either by using high-performance building elements or, with self-protection from noise, with smart design, achieved by the building form itself". Yet, shading devices widely used for buildings with a high ratio of glazed façade and located in discomfort climate conditions. Researchers showed an interesting to develop shading devices technology to absorb the acoustic effects at the same time.

To illustrate, a four-story office building within a high percentage of glazed façade shaded by lightweight metal louvers manually adjusted has selected to evaluate acoustic performance. An insulating material called polyurethane within 7 mm thick-film added to modify the sound absorption properties of metal louvers. façade sound insulation is slightly improved when absorbing louvers are used (see Figure 3.30.). The sound-absorbing material applied on louvers improve the noise shield of the system in terms of the sound pressure level decrease, over glass surfaces, eliminate the negative effect that standard shading devices cannot control (Martello et al., 2015).

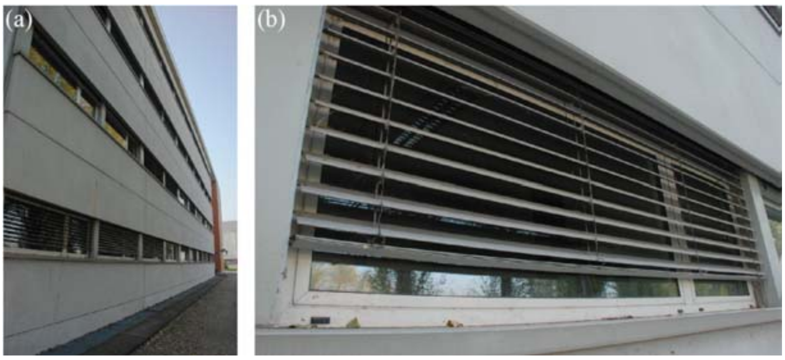


Figure 3.30. (A)The Building; (B) Shading fins placed over the glazing area.

3.4.9. Climate Zones

The building sector growing significantly and the energy demand and carbon emissions increasing with it. Therefore, scientists and climate organizations started to analyze the world and classify its region based on climatic zones characteristic. The Koppen system of climate classification is widely used for the global evaluation of climatic zones. This system was projected in 1900, but it has been modified by several authors since. The Koppen classification defined five main zones and several sub-zones. The main five climate types used in the classification are (A, B, C, D, E) (see Figure 3.31.). The Koppen classification influenced by some factors which give the characteristic for each climatic region (Ogunsote & Prucnal-Ogunsote, 2002). These factors include:

* Latitude and solar radiation received.
* Air mass.
* High and low pressure zones.
* Heat exchange from ocean.
* Mountain barriers.
* Pattern of winds.
* Distribution of land and sea.
* Altitude. (World, n.d.) .

So far, based on the determining factors, the koppen classified the world regions into:

* Humid tropical (A): The average temperature all year is 18 ° C. Tmin ≥ + 18 ° C, therefore, there is no clear winter.

* Dry (B): Evaporation is more than rainfall and there is a lack of water Yearly.

* Moist Subtropical Mid-Latitude Climates (C): This climate generally has warm and humid summers with mild winters. The average temperature of the coldest month is below 18 ° C and below 0 ° C. above, the average temperature of the hottest month is above 10 ° C. Tmax> 10 ° C and 0 ° C <Tmin <+ 18 ° C.

* Moist Continental Mid-Latitude Climates (D): The average temperature of the coldest month is equal to or below 0 ° C and the maximum The average temperature of the hot month is above 10 ° C. Tmax> 10 ° C and Tmin ≤ 0 ° C.

* Polar Climates (E): There is no summer and the average temperature of the hottest month is 10 ° C. Below. Tmax <+10 ° C. (World, n.d.) & (Karaman, 2019).

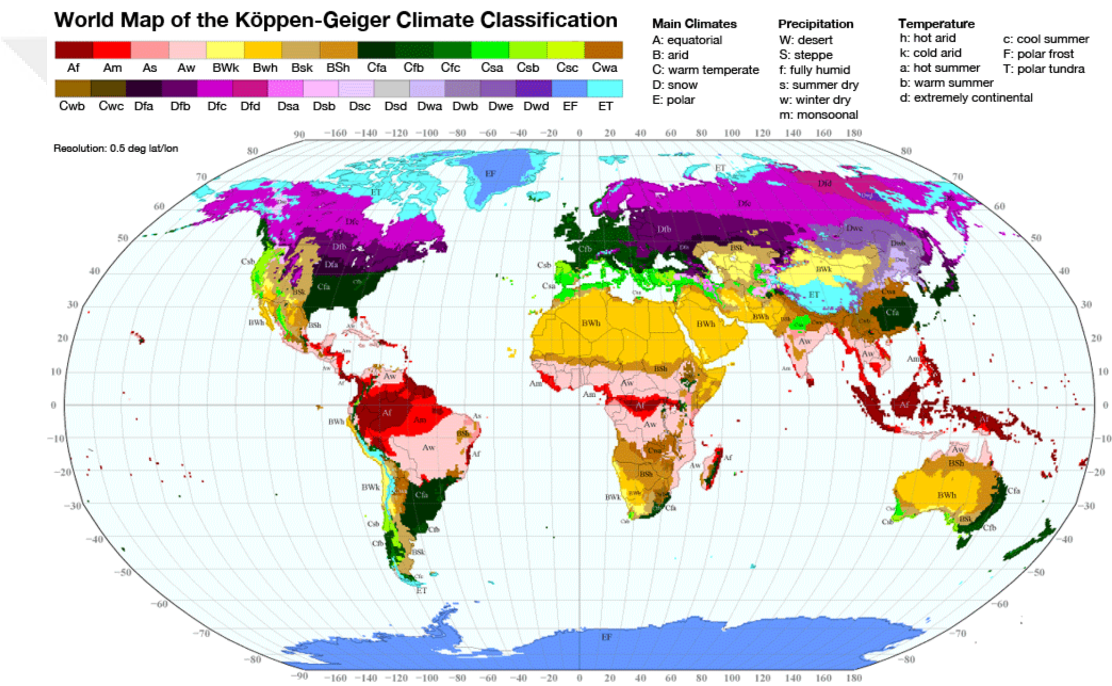


Figure 3.31. Köppen Climatic Classification

CHAPTER 4

METHDOLOGY

The research proposed a comprehensive design approach by combines a number of design strategies that have the potential to serve the research aims and goals such as high-performance based energy efficiency design. The main strategies that have been adopted for the design process are (Biomimicry and Environmental Computational Tools). The comprehensive design approach presented a promising design method to achieve energy efficacy improvement.

The first concept of design strategies is Biomimicry, which offers a great opportunity of using nature methods found in organisms for more efficient solutions. The nature inspiration produces sustainable solutions based on the adaptive ability of nature to manage the problems it faces without damages its environment. “Biomimicry is a term to describe the use of genius in nature. It basically aims to use resources in the most effective method while fulfills human needs”. For instance, mimic the brilliant systems in nature such as forms, materials, processes, constructions, and functions, which are invested in the research design. While, the second concept which is the environmental computation tools, offers the ability to evaluate the behavior of the inspired design in the built environment by conducting series of analytical operations and simulations to exam the potential of the design performance at the early stage of decision making. It is guiding architects to manage the design process into more logical directions based on information related to the final output of the design. The environmental computation tools give a great chance to optimize, improve, and prove the design and make the right decisions that can help architects to think and conduct more accurately based on simulating the built environment virtually.

Generally, the environmental computation tools conducting through the adoption of the principle of performance-based design on the criteria of calculating the energy consumption in buildings which requires accurate analysis of the building to ensure the level of energy consumption. In other words, achieve the desired goal. This approach enables flexibility in the building design and individual components based on the open space of innovation given to the engineer to reach new ideas. In general, façade design has a great impact on building performance. The façade design has the potential to control the level of comfort and energy efficiency in building. Generally, building façade is a complex system that needs to control of many aspects, like heat, light, humidity, and ventilation, among others. Yet, designing an adaptive system through building facade requires various elements like sensors, actuators, command wires, materials, structure, and technologies to be efficiently meet the high performance-based design requirements. The high-performance design based energy efficiency requires a general knowledge of building physics, which define the properties of the building performance. Building physics influenced by multiple factors. But, generally, it can be analyzed through the environmental computation tools. The building physics factors combined to make the general definition of the building performance.

4.1. Biomimicry-Based Design as a First Design Strategy

In previous chapters, a number of approaches and concepts as design strategies for multiple purposes, have mentioned in detail. In this research, the main goals are to achieve energy efficiency and high-performance by using some new approaches which have been ensured its ability to achieve the desired goals based on different literature reviews. Biomimicry is one of the design strategies which has been adopted for the design process at the first stage. Biomimicry has the potential to serve the goals and the research problem. However, biomimicry as a novel approach has been tested, analyzed, and improved through researches operations. The most influential steps to develop the concept of biomimicry, done by some of the leading scientists in this field such as Benyus and Zari. They put the foundation stone of the biomimicry theoretically. Zari as mentioned in the previous (Chapter-Biomimicry part) presented other biomimicry approaches as an application process which are typically fallen into two categories: Problem based approach **(design to biology)** and Solution based approach **(biology to design)**. Which means, that the architect or designer can apply bio-inspiration based on the problem and ask nature for a solution. Or the architect influenced by some biological researches and found a couple of interesting characters and looked for a chance to apply these natural features as a problem definition even if it is still not existing. While Janine Benyus, divided inspiration into three types: **Organism level** (natural form), **Behavioral level** (natural production), and **Ecosystem level**. Zari invested Benyus classification to introduce more sub-divisions and make more accurate methods for design. Zari divides each of the three types of Benyus classification into five sub-divisions **(Form, Material, Construction, Process, Function)**. The foundation knowledge of the Biomimicry field, which introduced by Zari and Benyus, produced a potential method for design concepts based on sustainability and efficiency. In this research, the classifications and foundation knowledge of biomimicry combined together and invested to create a new way for design. The combination produces an accurate method for design that can meet environmental needs and multiple design purposes and goals. The combination offers a clear way to design within sustainability, energy efficiency, and high-performance terms. The new integrated biomimicry approach could be stepped as the flowchart below (see Figure 4.1.). creating a method or a strategy for architects, engineers, and designers for innovations.

sometimes the problem needs to search for a solution and other times the solution searches for a problem to fit with. The last approach is called a solution-based approach, where the workflow starts from a potential inspiration with exact characteristics or features that can be adapted to support the design with extra solutions without advance planning for this specific problem. While the other concept is called a problem-based approach where the workflow of the integrated biomimicry design strategy as a design to biology approach, starts with problems and problem definition with a mutual connection due to the fact that some problem definitions related to others. The next steps are to search deeply in the problem definition and find potential strategies in nature to inspire which goes more accurate every step forward according to the levels and sub-levels of biomimicry that have been used. The final step is producing the concept that fits the problem definition. However, the final concept will be based on the available technological capacity which offers the potential to imitate nature characteristics using available technologies to produce some new innovations. For that purpose, the integrated biomimicry design strategy with its workflow will be used in this research to solve/support the problems definition and achieve the goals as a first strategy.

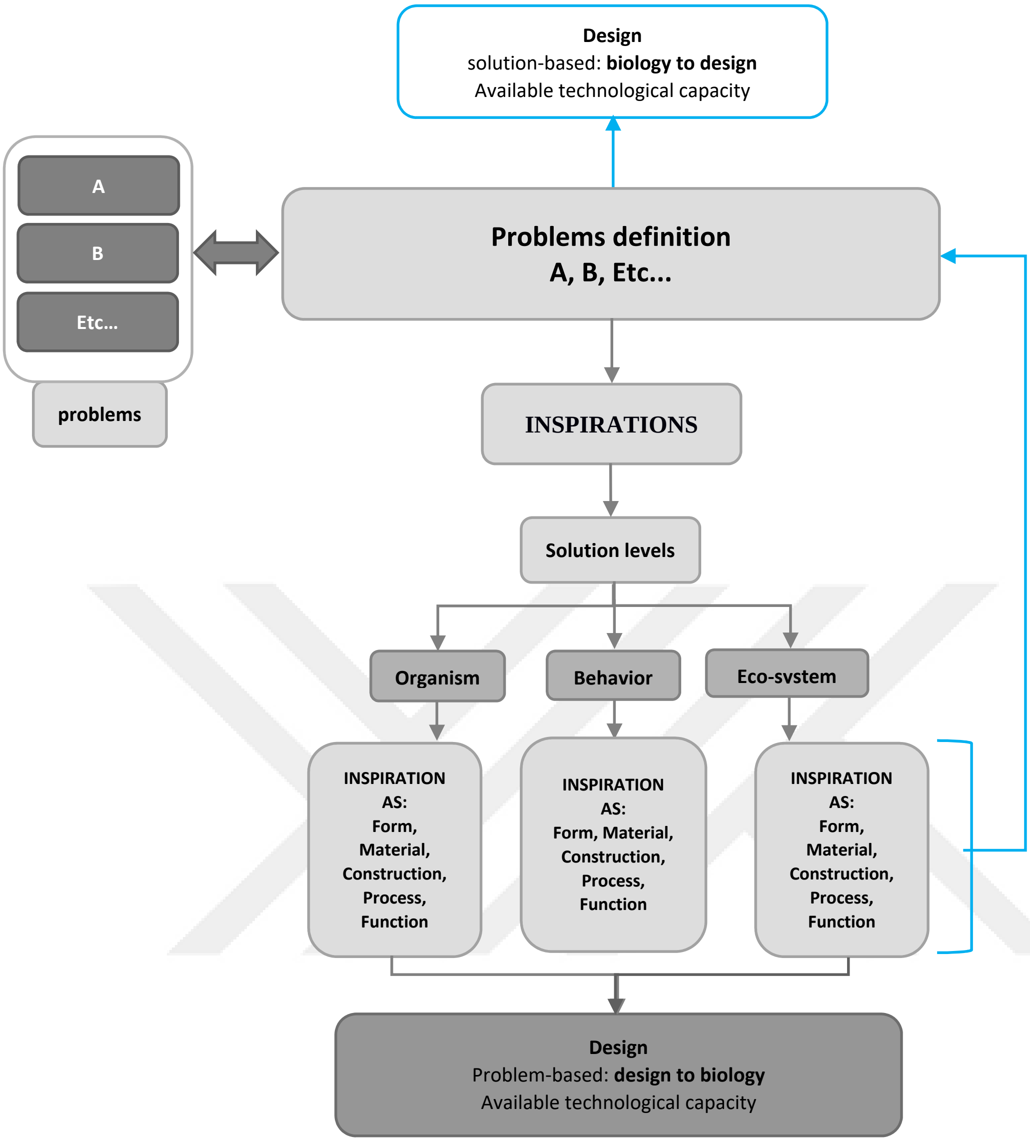


Figure 4.1. Flowchart of the integrated biomimicry design strategy

4.2. Environmental computation tools as a second design strategy.

Computation as mentioned before in detail is a multi-specialty field that is mostly related with creating and exploring frameworks that work or act intellectually. Acting logically offers the ability to do judicious things such as anticipated utility maximization. Computation offers a lot of concepts that can contribute to any design process. “Computation comprises concepts, paradigms, algorithms, and implementations of systems that are purported to exhibit intelligent behavior in complex environments. It depends strongly on sub-symbolic, nature-analog, or at slightest nature-inspired strategies”. These days, digital improvement and connected fields depend intensely on computer applications. These applications largely support choice making, to control forms, to acknowledge and translate designs, or to control robots autonomously in obscure situations. In architecture, computation has been one of the most-distinguished advancements of the decade. Architects are moving from using explicit programs based on designers' orders to computational based models where the computer has a large contribution to make decisions and orders. Many practical aspects have changed, including performance, evaluation, manufacturing, project delivery, and billing. Performance based design has become an essential method for achieving many objective goals. It is a guiding designer to manages the design process into logical directions based on information related to the final output of the design. The Performance based design process aims at changing the traditional design approach to a more logical and efficient way.

Yet, a number of supporting tools used in this research to help with early decision making based on performance especially by environmental analysis tools. Rhino-Grasshopper is one of the most commonly used platforms that are used by architects. Also, there are already lots of environmental plugins made for Rhino-Grasshopper. Ladybug and Honeybee plugins offer a number of benefits that existing Rhino-Grasshopper unable to do so. In these plugins, energy plus weather files (EPW) are imported giving the ability to provide a variety of 2D and 3D graphics of interactive and analytical data to support the decision making process during the initial stages of design. It is also making the process of analysis, automates, and calculations much easier and providing simple graphical visualizations. Allowing to evaluate energy and daylight engines like EnergyPlus, Radiance, and Daysim to control the parametric tools of grasshopper which gives extra flexibility to modify the design based on instantaneous feedback. But, in some situations, there are a lot of parameters and a lot of probabilities that traditional ways cannot handle it in a reasonable time. Therefore, optimization algorithms may use to manage parameters and data information to come with a reasonable number of decisions. In this way of design process different outcomes of design performance produced. The designer chooses the best solutions that make the building more suitable for its environment. The first step in the high-performance design based on parametric environmental plugins is to recognize the major environmental factors that affect building design aiming to rises the opportunity of creating environmentally adaptive design decisions at the initial stages of design. In this stage, designers assess their options, based on the results of analysis and personal judgment that results from experience and the understanding of environmental data.

However, environmental analysis tools have been used in this research in different levels with some support of optimization tools at the early process of design. Which, offers the ability to evaluate the efficiency of any design concept and manage it responsively. In general, the computational workflow of this research could be stepped as below (see Figure 4.2.) to manage the parameters and data information in a suitable way.

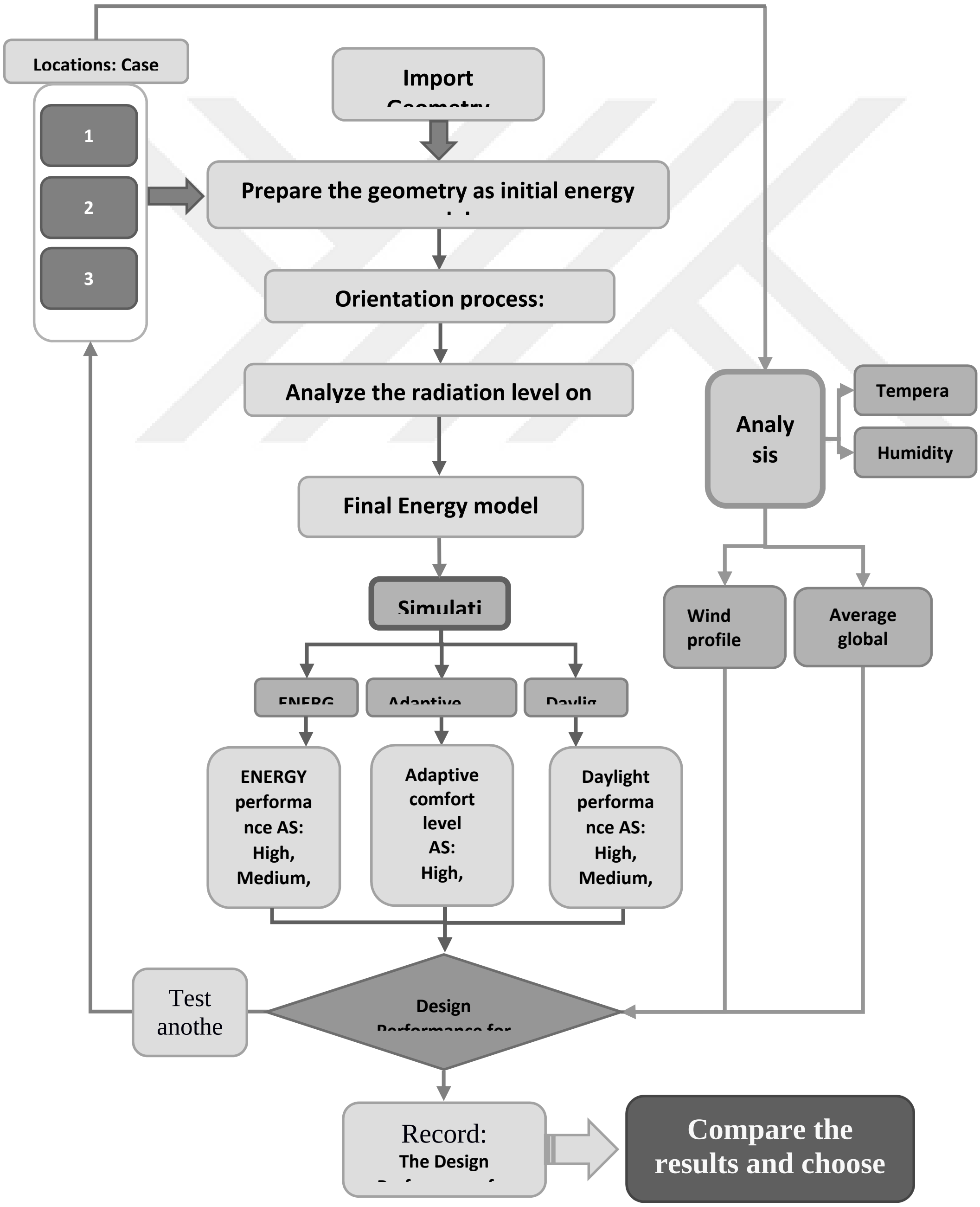


Figure 4.2. Flowchart of the computational strategy used for the design approach.

4.3. Geometry design

Through the growth of populations and the development in constructions technology, high-rise building becomes more and more the dominant type of buildings which considers as an indication of the strength and power especially when high-tech been used in building. High technology can take different forms to apply and many levels to achieve.

In this research, the proposed building is a high rise building located in a hot area. High-rise buildings exposed to the environmental conditions and climate factors such as density and air pressure, wind speed, and other similar factors in high-rise buildings, and huge amounts of energy use, more than other types of buildings (Lotfabadi, 2014). Therefore, the technology must apply in different treatment levels to balance the conditions and make the indoor spaces more comfortable for the occupants.

Yet, the proposed building designed to take a triangle plan and form. In the hot areas, where the radiation level is very high, triangle form can offer a chance to reduce the number of facades exposed to radiation thus reduce the opening ratio and glazed percentage which considered as a major contributor in the thermal exchange between indoor and outdoor spaces. Furthermore, the triangular shape and engineering for high rise buildings can decrease the sway level during an earthquake more than a rectangular building because triangular shape increases the resistance to twisting which regularly cause major damage during a severe earthquake (WOLFE, 1988).

The proposed building defined as a large office building which occupies whole the area of one floor of the proposed tower which is 1155.3 m^2 (without cantilevers and balconies). The proposed floor placed on 24 meters'height to be tested within an average height of the tower floors. The office plane divided into 7 spaces with 5 functions as follow (see Figure 4.3.):

* Lobby (104.1 m^2)

* Breaking room (104.1 m^2)

* Office: open office (818.1 m^2)

* Storages (88.9 m^2)

*Core (40 m^2)

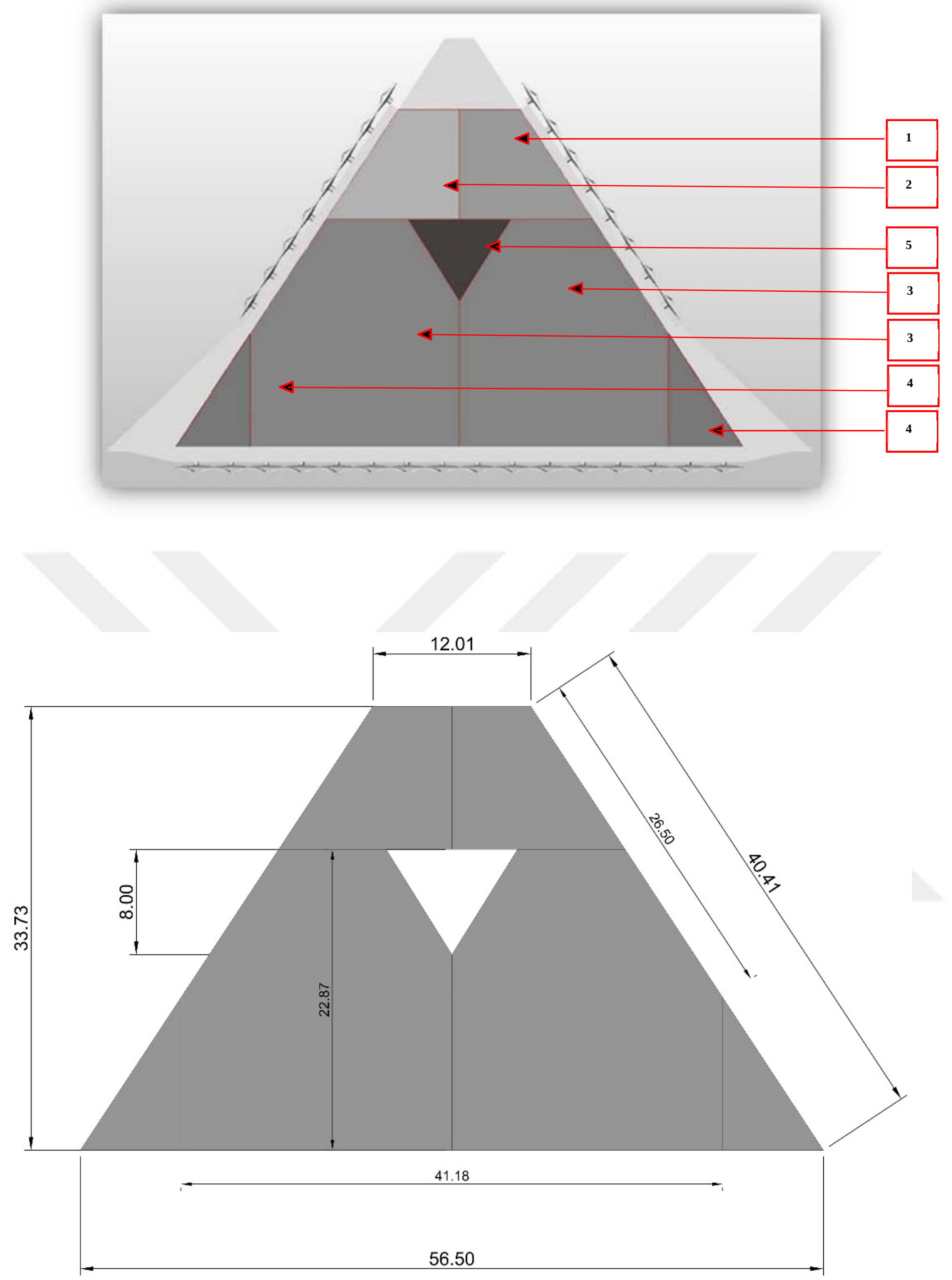


Figure 4.3. Zones definition of one floor plan of the proposed tower.

The division of the plan has been done according to Honeybee plugin limitations. To calculate energy consumption with honeybee and energy plus, the divisions must be as simple shapes as possible (closed Breb in honeybee definition) to create zones. These zones arrange next to each other making one plane with different functional zones.

Moreover, the test points system for Daylight Autonomy simulation defined with (1meter distance system) to divide the plan and (0.75m height) as the height level of work and activity. While, for the integrated energy-daylight simulation, (6 daylight sensors) have distributed on the plan to evaluate the daylight threshold on zones that can influence the lighting load. Illumination values for working spaces are recommended between 200 and 500 lux. And according to some studies, 300 lux is the minimum lighting value for the working area (*Master Thesis Shading Device Design and Optimization Via Genetic Algorithm By Using Surface*, 2019).

The height of each floor is 4 meters and each side of the wall designed and defined within 85% glazed façade (see Figure 4.4.).

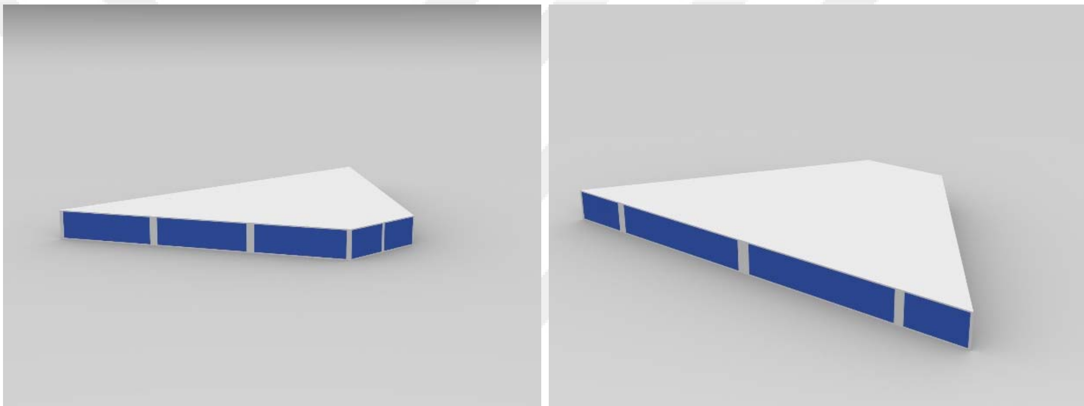


Figure 4.4. One floor of the proposed tower

The site of the proposed office building will be located in hot cities which are selected for its potential to fit the façade design. The three suggested cities are:

* Dubai (hot humid)

* Baghdad (hot dry)

* Doha (hot humid)

The three cities and their climate characteristic will be detailed next steps in this chapter. Each city has the potential to exploit the façade design and achieve maximum adaption to the climate and environmental conditions. In these cities, the harsh climate can increase the energy demand to the highest level. So, it is important to apply façade technology in an adaptive way to make reasonable balance.

The floor as a large office building defined within an open office system which means the main working zones are linked together without full separating. Each zone should have enough glazed ratio for natural lighting but also thermal load must consider as a major factor. For this purpose, the façade has the greatest role.

The office building tested in each one of the three cities to select the best orientation that reduces the energy demand and minimize the radiation levels. For this purpose, a definition has been done for grasshopper with multiple plugins to conduct the optimization process using the Galapagos algorithm. The floor defined as follows (see Figure 4.5.).

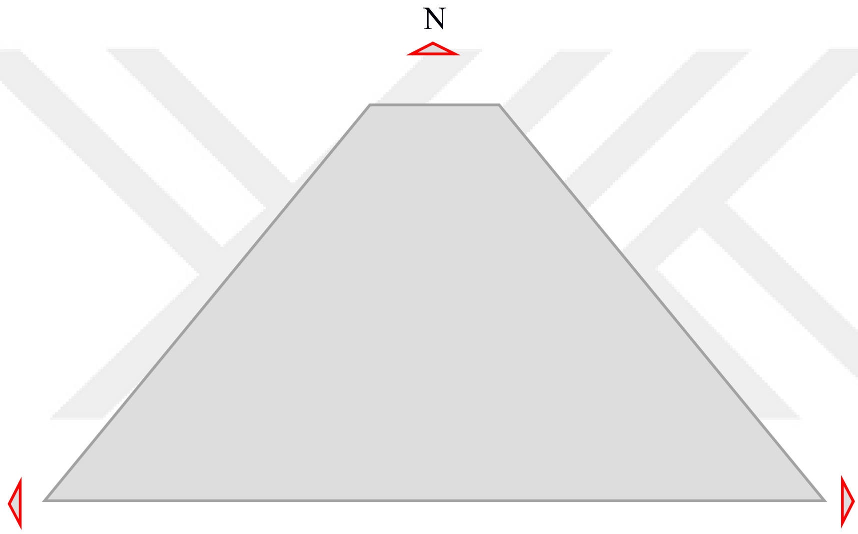


Figure 4.5. Orientation optimization process

The building position shown in (see Figure 4.5.) represents the 0 degree in the optimization process. So, the optimization algorithm will change the north angle in the range from 0 to 360 degrees in 24 steps each step with 15 degrees to determine the best orientation that achieves the minimum level of energy demand due to different affected factors (see Table 4.1.). However, the optimization process in each of the three cities has shown that the orientation with 0 degree is the best for energy efficiency (see Figure 4.6.).

Table 4.1. Orientation optimization process

Parameters	Range Of angles	Steps	Optimized values
North direction	0 - 360 Degrees	15 degrees	0 degree

Figure 4.6. Orientation optimization process by Galapagos algorithm

Also for honeybee plugin purposes, the energy model which is a large office must place between two floors (up and down). These duplicated floors defined as plenum zones with no conditioning load (see Figure 4.7.). purposing of such zone definition is to make the simulations and analysis operations more accurate by making the main energy model has a ceiling and floor instead of roof and ground.

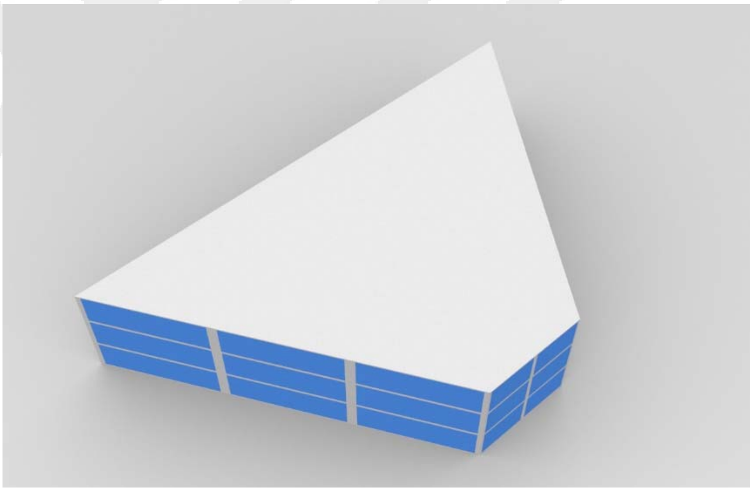


Figure 4.7. initiate the energy model with main zones and two plenum zones

After the optimization process to choose the best potential orientation, another computational operation has been used to test the radiation level on the glazing system (without shading) of each side of the facade. This computational process will help to determine the need for each side of the building facade for shading and design considerations. The computational tool for this process is ladybug plugin for grasshopper. In this process, the glazing surfaces defined as the geometry that receives the radiation and the rest of the building as a context that affects the radiation fallen on the glazing system. The simulation has been done for the three selected cities (see Figure 4.8.).

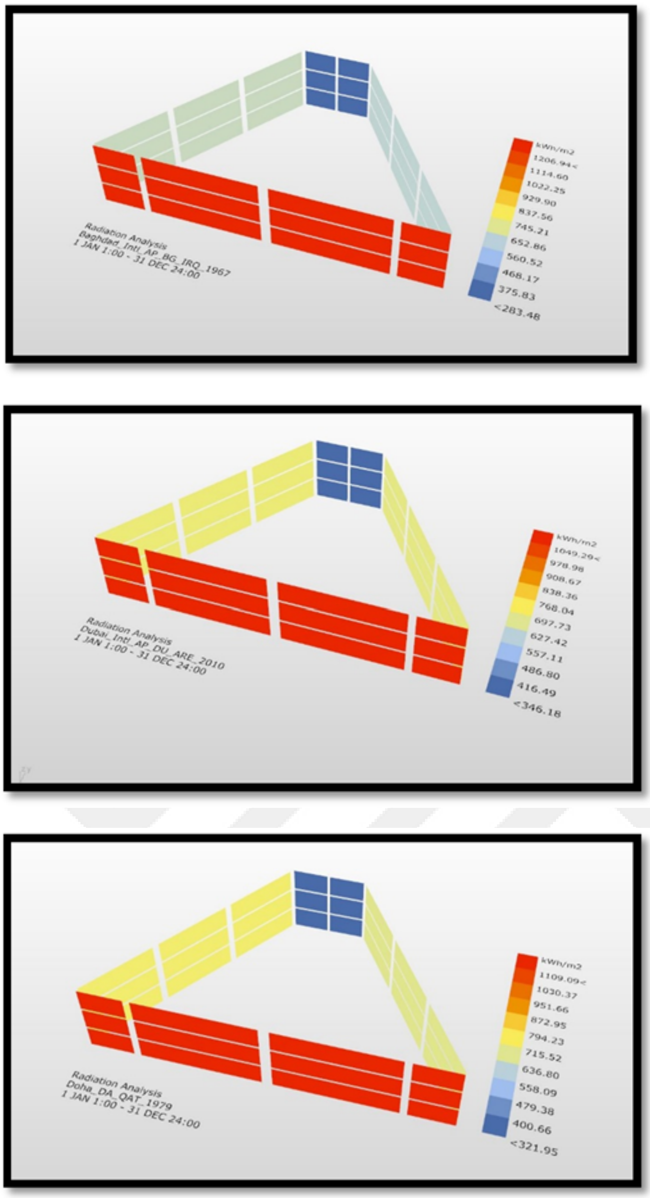


Figure 4.8. Radiation analysis on the glazing system without shading-by Ladybug.

The radiation analysis on the glazing system without shading system has shown that the south façade in each of the three cities has the greatest amount of radiation levels and the north is the least. While the east and west vary between cities within medium level of radiations in general.

Based on previous information, the north façade within the small glazed ratio and small area, in general, does not need for strict shading systems according to the sun path and radiation analysis. Yet, in the proposed design a small balcony applied in the north façade for different purposes as a design decision. While the south façade in the three case studies need for shading system and treatments to block the sun radiation. This level of radiation on the south façade can even influence the walls as well as the glazing system. Therefore, the research will suppose that the south façade should be fully shaded to protect the glazing system and walls from the direct high level of solar radiation during the day hours. On the other hand, the east and west façades have a medium level of radiation but it is still effective relatively for energy consumption so the east and west façade need for shading. But, in the previous (see Figure 4.3.) zones definition of a one-floor plan, shows that the storage zones have located in the corner and have a two-sided opening as a glazed façade with small ratio on the south and large ratio relatively on the other side (east or west). In such a harsh climate reduce the unneeded opening is better for building performance. Generally, storage zones don't need that much of daylight. Therefore, as mentioned before the south façade will be fully shaded to reduce the effective radiation on the glazing system and walls. So, keeping the south full shading and the storage's window on it, is more reasonable. Especially that the reducing of the glazed area in east and west will reduce the number of shading units and costs double what south façade does if the elimination of one glazed façade of the storages has done on the south façade. Therefore, the design decision made to decrease the glazing system of the storage zones from the east and west façade. And the building geometry will be defined as below (see Figure 4.9.).

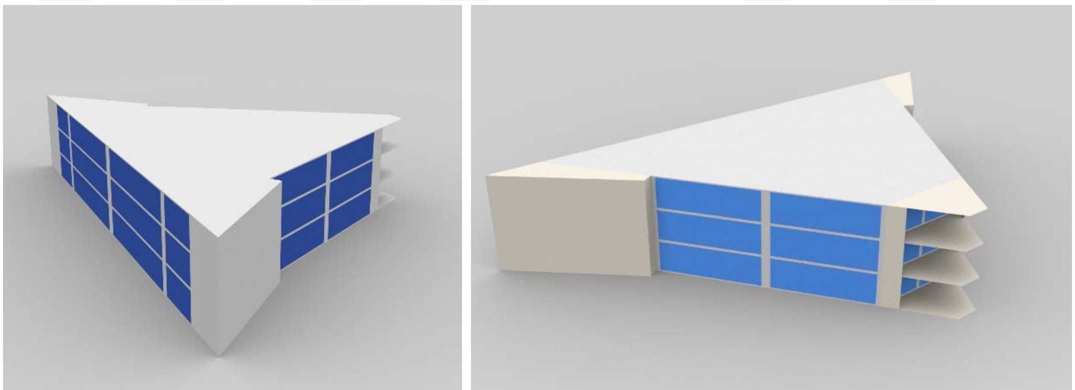


Figure 4.9. Developing energy model form without shading system

So, the building geometry has developed based on multi-reasonable decisions and defined in the honeybee/ladybug by visual codes to make an energy model. But as mentioned before, the energy model will be covered by a shading system on the south, east, and west façade. Thus, to design the façade system, two design strategies have been used to create an integrative façade. Biomimicry strategy and Environmental computational tools used to evaluate the comprehensive shading system with its ability for shading, ventilating, power generating, and daylight using.

4.3.1. Shading units' design strategy based on biomimicry

The comprehensive shading system designed within the biomimicry integrative flowchart (see Figure 4.1.) which, defined the design steps accurately. All of the design inspirations have exploited the available technologies that exist today to imitate the nature behavior and strategies for more innovative approaches. However, the workflow of shading units based on the flowchart (Figure 4.1.) will process the design operation as follow:

4.3.1.1. Shading function

For shading function, there are four features for inspiration related to the form, material, function, and construction of the shading units to make building performance more efficient when the units cover the façade.

4.3.1.1.1. Design to biology approach /Organism level/Form & Construction

In this step a Monestera fruit and Cactus thorns have been inspired.

▶ Hexagon system is essential in nature and it is the best system ever found to occupy area or space effectively (see Figure 4.10.).

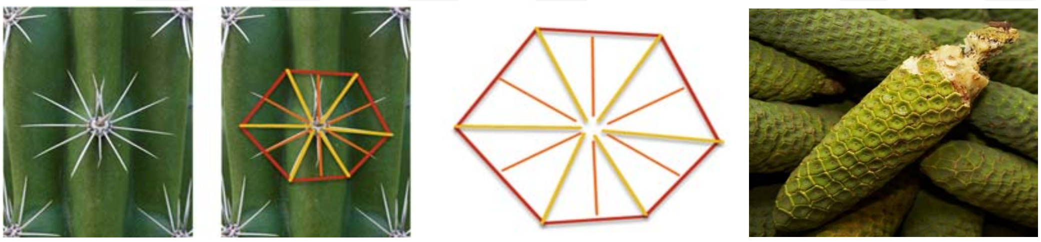


Figure 4.10. Cactus thorns system & Monestera fruit form.

▶ The cactus thorns system can divide the hexagonal shape into 12 parts.

▶ The thorns system division can be applied efficiently on the hexagonal unit system as the main construction system (see Figure 4.10.).

4.3.1.1.2. Biology to design approach / Organism level / construction

In this step dragonfly wings (voronoi system) have been inspired (see Figure 4.11.).

Figure 4.11. The voronoi system found in dragonfly wings.

- Using the voronoi system as the support construction for the 12 parts of each unit to support the construction system and material resistance.
- Voronoi system is one of the systems that are abundant in nature and characterized by great homogeneity

4.3.1.1.3. Design to biology approach / Organism level / Function & Form

In this step Butterfly wings have been inspired (movement axis & wings shape).

- inspire the movement axis of the butterfly wings to connect each two symmetrical parts of the 12 divided parts with each other to create 6 symmetrical sub-units.
- Each part of the 12 will be shaped as the butterfly wings.
- inspire the axial motion system in the butterfly to make the sub-units able for movement (see Figure 4.12.).

Figure 4.12. The wings axis and form of the butterfly wings.

4.3.1.1.4. Design to biology approach / Behavioral level / Material & Function

In this step Cactus skin have been inspired in many levels.

- The cactus skin has translucent waxy material represents the main line of resistance to hot climate by isolating the plant core from external heat and prevents it from affecting the plant. The wax layer is also lightly colored and reflects some of the direct sunlight.

Figure 4.13. Cactus Skin

- The cactus skin has a number of stomata, but the number of stomata per square area, however, is less than the number for normal plants. So, it is another water-saving characteristic (see Figure 4.13.).
- The cactus skin and its waxy layer provides mechanical support for the plant to prevent the water vaporization.

4.3.1.2. Ventilation function

For ventilation function, there are one feature for inspiration related to the form which is the hexagon concave form to make the natural ventilation process more efficient when the units cover the façade.

4.3.1.2.1. Biology to design approach / Organism level / Form

In this step Monestera fruit (concave hexagon) have been inspired.

- Monestera fruits contain a unique hexagonal concave system that can be invested in the process of natural ventilation through its auxiliary form as a concave (see Figure 4.14.).

Figure 4.14. The monestera fruit concavely hexagon system

4.3.1.3. Daylight function

For daylight function, there are two choices for inspiration related to the material and process that can increase the percentage of daylight passing through the building to make the daylight performance more efficient when the shading units cover the façade.

4.3.1.3.1. Design to biology approach / Behavioral level / Material

In this choice The Windowpane oyster (translucent shell feature) might be inspired.

- Windowpane oyster shells are characterized by a certain percentage of transparency (see Figure 4.14.).
- This feature can be utilized in shading material, allowing to a useful percentage of daylight to enter.

Figure 4.15. The Windowpane oyster translucent shell

4.3.1.3.2. Design to biology approach / Behavioral level / Process

In this choice The heliotropism behavior in sunflowers might be inspired.

- The heliotropism behavior in sunflowers is the movement of the sunflower's buds and young blossoms following the sun as the earth moves during the day (see Figure 4.16.).

Figure 4.16. The heliotropism behavior in sunflowers.

▶ The heliotropism behavior can be applied in shading system units by investing the sun response logic of the sunflowers to control the opening and closing of the shading units based on sun paths during the day using some sensor technology. Which, is used already in a number of building shading systems to increase the daylight efficiency.

4.3.1.4. Energy generation

For energy generating function, there are two features for inspiration related to the process and form to make the building able to provide energy for itself and make the building performance more efficient when the shading units cover the façade.

4.3.1.4.1. Biology to design approach / Behavioral level / Process

In this step the photosynthesis process in the plants have been inspired.

▶ Photosynthesis is the process that green plants and some other organisms convert sunlight energy into chemical energy (see Figure 4.17.).

▶ Makes the plant able to provide the resources it need by itself.

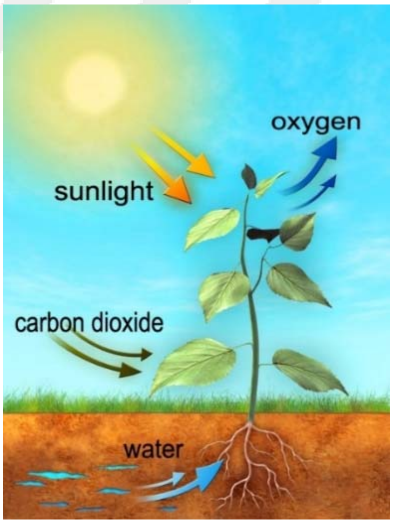


Figure 4.17. The photosynthesis process in plants.

4.3.1.4.2. Biology to Design approach / Behavioral level / Process & Form

In this step Foliar Nyctinasty process have been inspired.

▶ Nyctinasty behavior in plants, is the movement such as the closing of leaves, petals or flowers, that occurs in response to the alternation of day and night. For instance, Foliar Nyctinasty During the day, the leaves assume a horizontal position that optimizes their ability to carry out its functions. While at night, the positions that the leaves assume is a vertical (see Figure 4.18.).

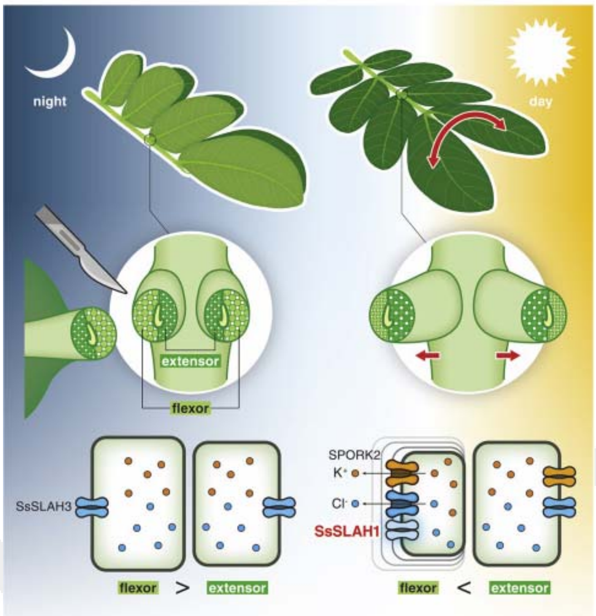


Figure 4.18. The Foliar Nyctinasty behavior in plants

- Foliar Nyctinasty behavior offers two concepts which can be invested to control the opening and closing of the shading system.
- The first concept is investing the folding form and process of blade leaves in the 6 sub-units of each shading unit to increase the air pressure on one side of the 6 sub-units which create a type of wind turbine to generate the electric energy.
- The second concept is investing the response to the alternation of day and night, to solve the wind turbine noise issues based on the fact that the night period is not for working and the building is not occupied. So, the folding form as a wind turbine can be used during the night.
- While, the unfolding position within the hexagonal concave form inspired, offer the ability to concentrate the air velocity at the center of the units which can create efficient micro wind turbines system to generate power at the daytimes.

4.3.2. Shading units' construction process

The biomimicry integrative design process based on the flowchart (see Figure 4.1.), invested the potential of nature organisms to deal with problems facing the design process and offering better solutions within available technologies. The workflow of the biomimicry integrative concept makes the complex design processes more clear. So, the designer can solve many problems based on nature solutions on many levels. The final concept within all inspired solutions can produce a comprehensive design concept which is could be a hard task for designers and engineers using the traditional methods. However, all the inspiration levels to solve the design problem in this research have been made. Therefore, the next step after the inspiration is to convert the natural concepts that inspired, into construction processes using available technologies. The construction processes of the façade design will be stepped as follow:

▶ Based on Monestera Fruit and Cactus thorns system inspirations, regular hexagon shape has been used in the construction of shading units and in the structural system of the glazing layer (see Figure 4.19.) due to its efficiency of dividing areas as it exists in nature.

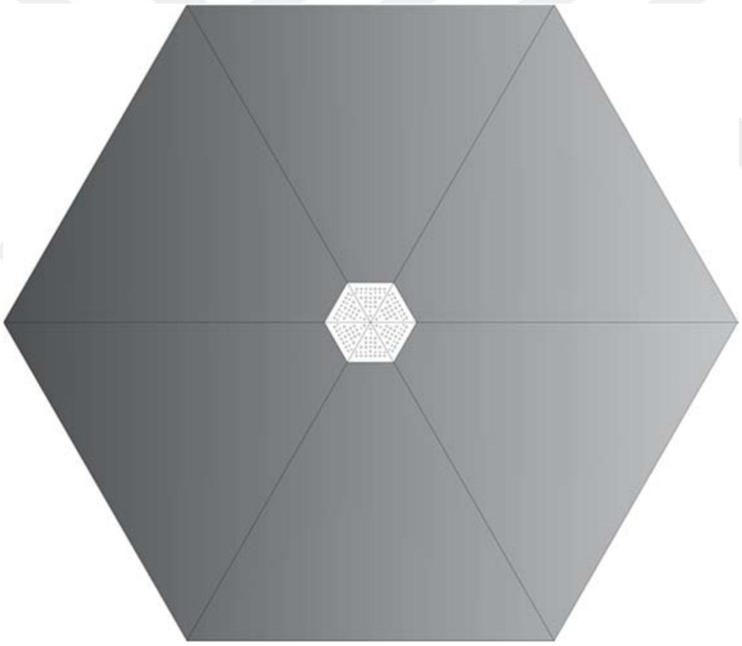


Figure 4.19. The use of regular hexagon shape in the construction of shading units and in the structural system of the glazing layer.

▶ Based on concave form found in Monestera Fruit, increase the depth of the unit from the central region making a concave hexagon as follow (see Figure 4.20.).

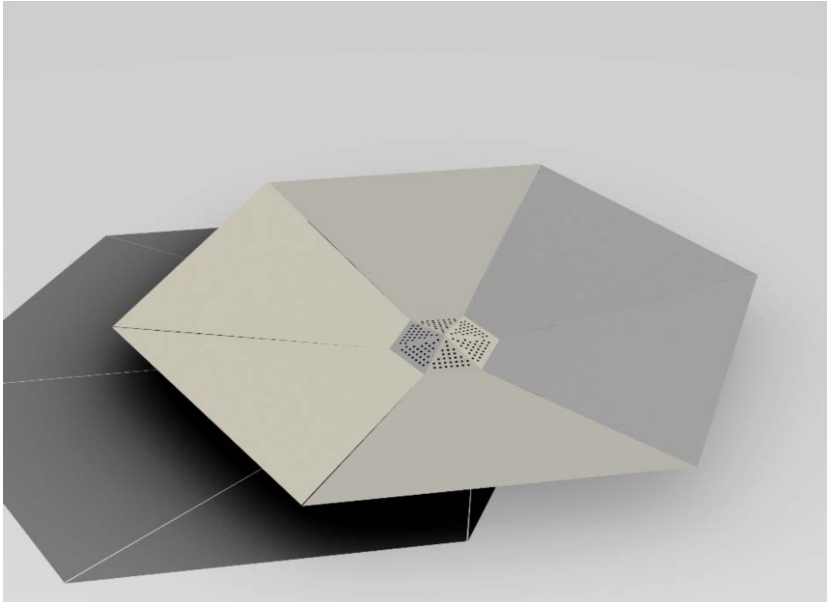


Figure 4.20. increase the depth of the unit from the central region making a concave hexagon.

▶ Based on the cactus thorns system inspiration, the axes system of the cactus thorns will be used to divide the unit into 12 parts and using the same division to apply the main structure system for shading part (see Figure 4.21.).

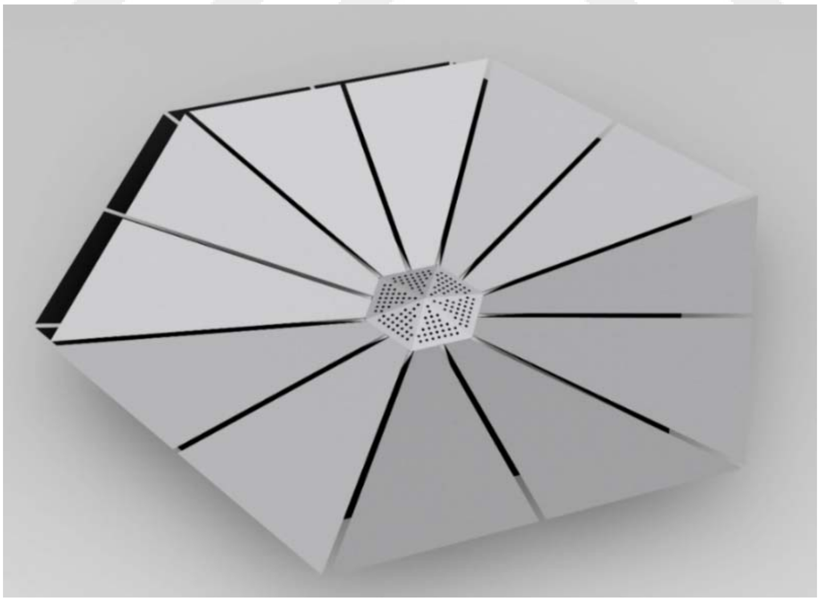


Figure 4.21. The division of the unit into 12 parts.

▶ Based on the cactus thorns system inspiration, the thorns will be inspired as a support structure for frames to enhance the system and mitigate the vibrations (see Figure 4.22.).

Figure 4.22. The support structure for frames.

▶ Based on the movement axis of the butterfly wings inspiration, each two symmetrical parts of the 12 parts (placed on main axes) will join to be one symmetrical sub-unit. Also, inspire the butterfly wings form for more Streamlined (see Figure 4.23.).

Figure 4.23. The two symmetrical parts joined to be one symmetrical sub-unit.

▶ Based on dragonfly wings inspiration, the voronoi system will be used as a support structure for the shading material (see Figure 4.24.).

Figure 4.24. The supportive voronoi structure for shading material.

▶ In the building construction process, the glazing layer represents the same function as the waxy layer to protect the inside, to disperse some amount of the direct sunlight, to prevent the loss of comfortable indoor conditions, as the main line of resistance. Also, reducing the direct opening per area may offer a reasonable solution in a hot climate. So, the direct opening system will be designed as small windows that can manually and automatically control (see Figure 4.25.). In addition, the glazing layer needs to be considered not just as a random choice but to be fitted the multifunction layers (shading units and other construction) of the system as much as possible. The glazing layer should absorb the dynamic parameters of the system as multifunction layers with mutual impact among them, to be optimized.

Figure 4.25. The glazing layer.

▶ Based on the Photosynthesis behavior inspiration, a photovoltaic system can be applied in shading units to make the building more dependence and efficient by convert sunlight into electric energy (see Figure 4.26.).

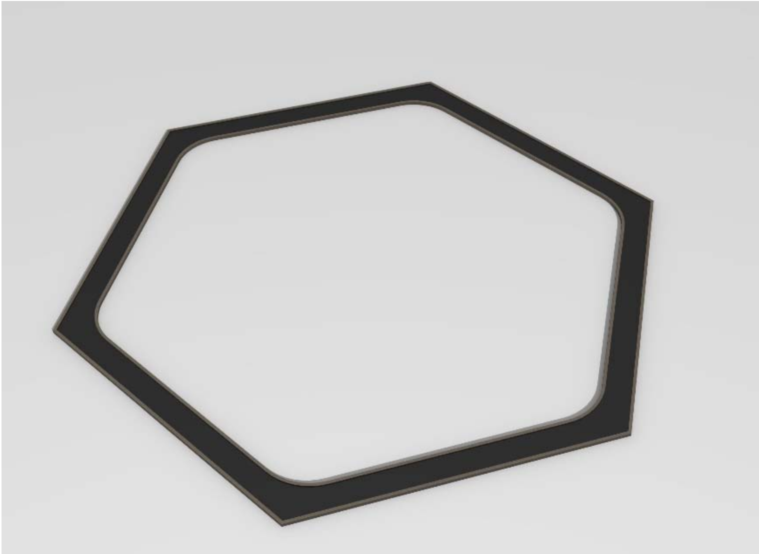


Figure 4.26. The photovoltaic system in shading unit.

▶ At night time, Foliar Nyctinasty behavior inspiration can be invested to fold the form of each one of the 6 sub-units to increase the air pressure on one side of the 6 sub-units which create a type of wind turbine to generate the electric energy (see Figure 4.27.).

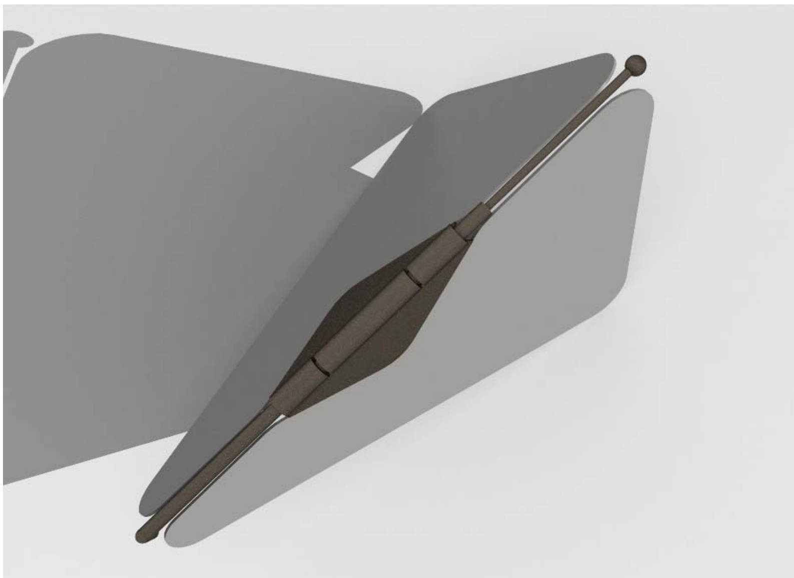


Figure 4.27. The folding form of the 6 sub-units of the shading unit.

▶ At day time, Foliar Nyctinasty behavior inspiration, which takes the unfolding position within the hexagonal concave form inspired, offer the ability to concentrate the air velocity at the center of the units to make the micro wind turbines possible which can generate electricity (see Figure 4.28.). Also, the unfolding position can increase the efficiency of noise improvement.

Figure 4.28. The unfolding form of the 6 sub-units of the shading unit

The bio-inspiration produced a comprehensive concept for the shading system design with all the four potential functions (shading, daylight, ventilation, energy generating) as integrative approach toward high performance based energy efficiency design. Yet, the construction process for the shading units to make the whole façade system, continues as follow.

▶ Supportive column (see Figure 4.29.).

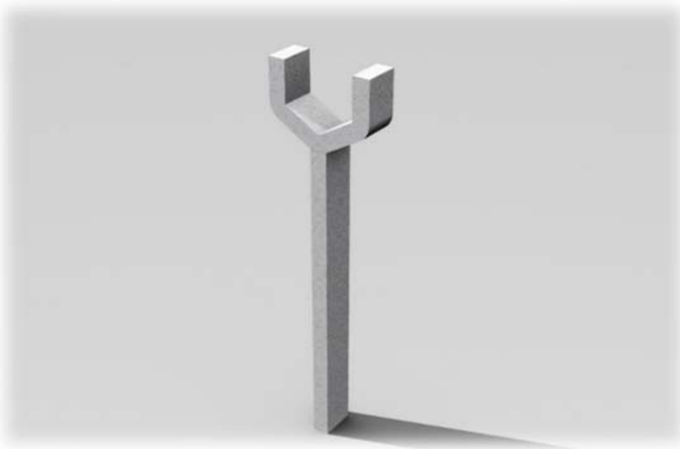


Figure 4.29. Supportive column.

▶ The hollow base for air intake and purification and noise mutation from air velocity and wind turbine (see Figure 4.30.).

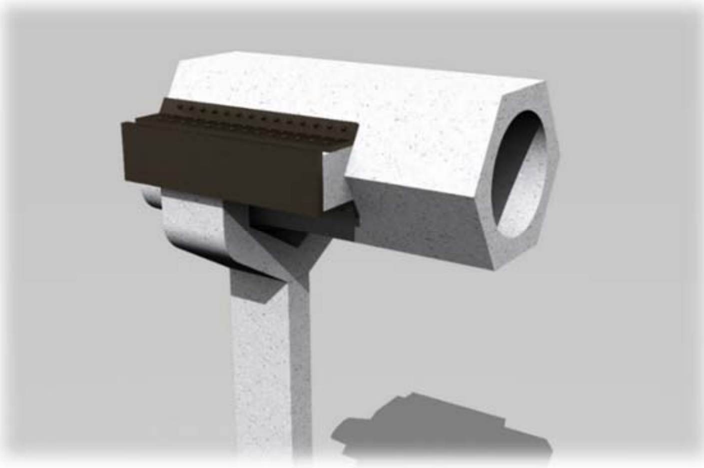


Figure 4.30. The hollow base for air intake.

▶ The hexagonal structure shape for glazing system.

▶ the general motor as a small wind turbine with 6 arms as a movement axes for the 6 shade wings (sub-units). (see Figure 4.31.)

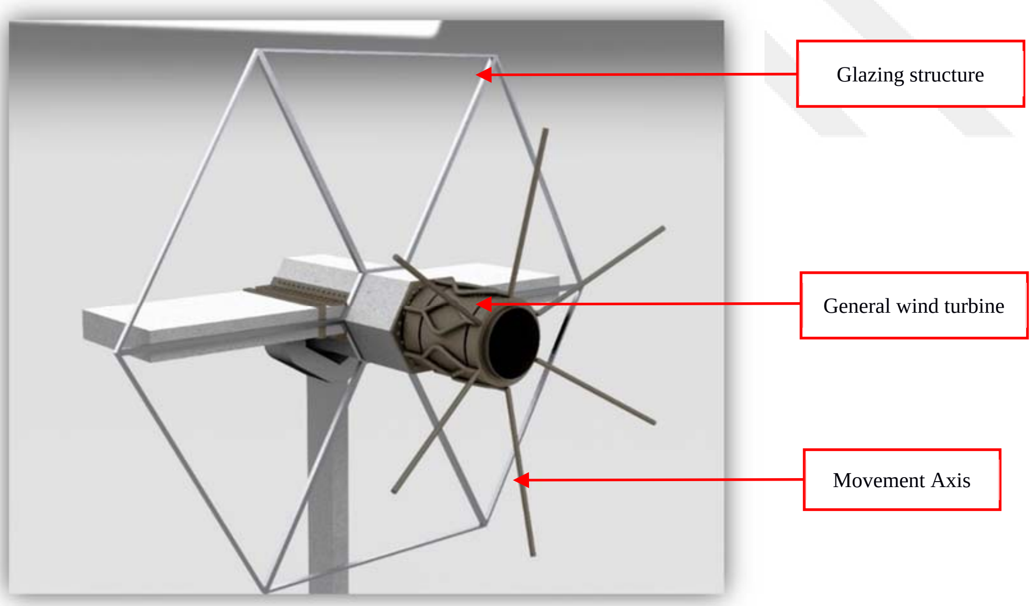


Figure 4.31. The hexagonal structure shape for glazing system and general motor with 6 arms as axes for the 6 shade wings (sub-units) actuators.

▶ Air ducts system for natural ventilation intake : noise mutation from air velocity and wind turbine (see Figure 4.32.).

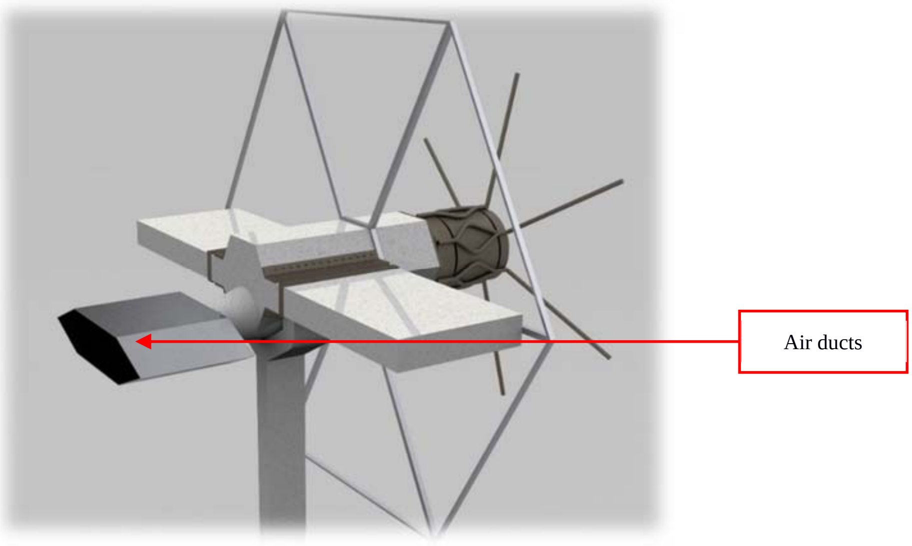


Figure 4.32. The Air flow silencer system.

- glazing system.
- shading wings and its motors, shading material and voronoi structure.
- Air intake hole. (see Figure 4.33.)

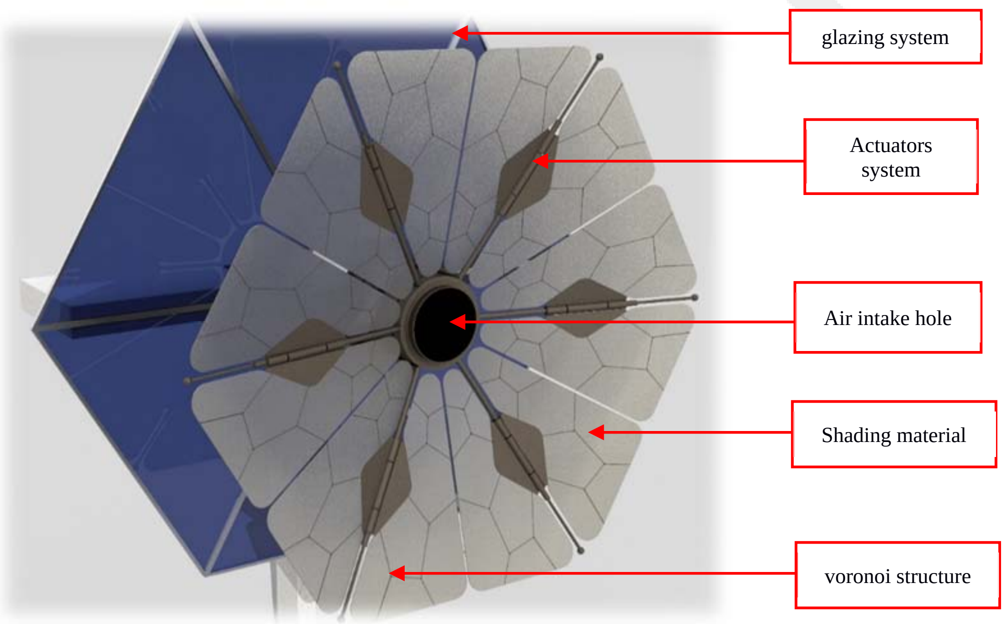


Figure 4.33. shading unit under construction.

- Air intake hole cover.
- Solar panel part.
- Solar panel supportive structures.

▶ Main structure to support whole units as a Carrier and portable. (see Figure 4.34.)

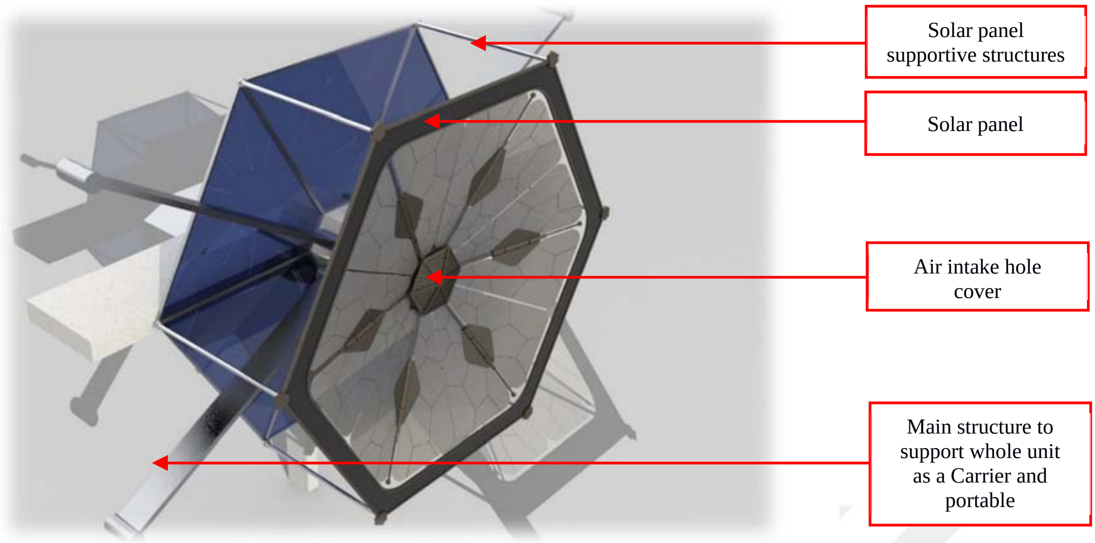


Figure 4.34. The development process of shading unit under construction.

▶ The supportive thorns system as a support structure for frames to enhance the system and mitigate the vibrations (see Figure 4.35.).

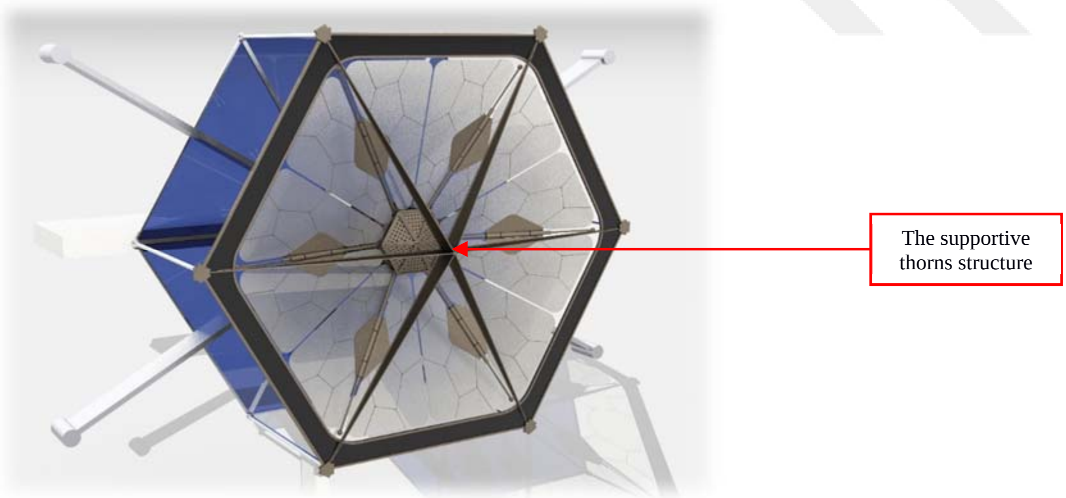


Figure 4.35. The final shading unit (type A) as a portable.

▶ Type A shading unit is a portable type in the shading system, which has the central intake hole placed in the middle of each space (on 2 meters'height from each floor). Therefore, the central hole in this unit used mainly for manually and automatically ventilation systems. The cover on the hole and the hollow base used to control the airspeed. Generally, it is used as a window for spaces. And because the type A unit placed in the middle of the glazed system of each space (without supportive ceiling or floor) it will be carried by the other units which are placed on the ceiling or the floor (see Figure 4.35.).

▶ Type B shading unit is a carrier type in the shading system, which has the central intake hole placed on the ceiling or the floor (on 4 meters'height from each floor). Therefore, the central hole in this unit used mainly for an automatic ventilation system. In this type (type B) there is no cover for air intake hole but, there is instead the micro wind turbine. This type designed to automatically natural ventilate the system all the time. The automatically natural ventilation system will always take the air to the system which is designed to be placed above the secondary ceilings as central ducts system. Generally, it is used as a micro wind turbine all the time. And as an air intake. The type B unit placed within a supportive structure of the ceiling or floor. So, this type B will carry the other units type A which are placed on the glazing system (see Figure 4.36.).

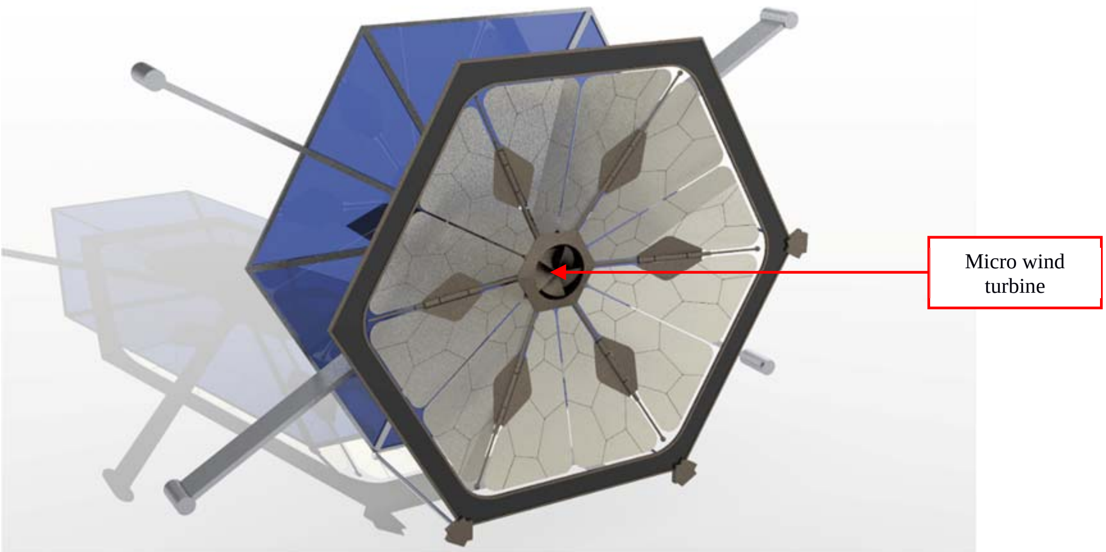


Figure 4.36. The final shading unit (Type B) as a carrier.

▶ İn general, the shading system consist of two units as a carriar and portable with two types A and B (see Figure 4.37.).

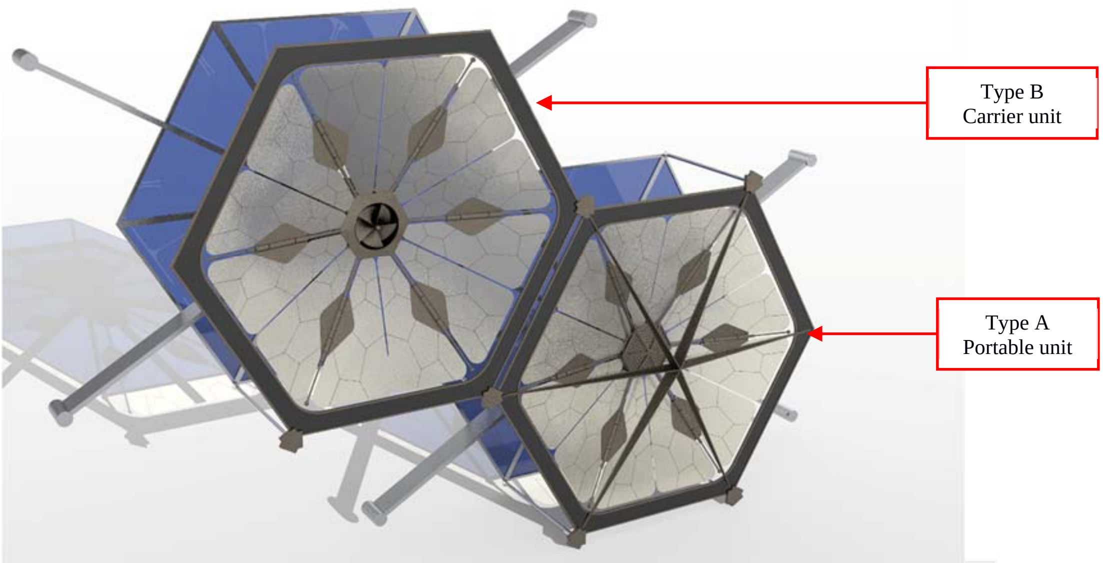


Figure 4.37. The two of the shading units (Type A and B) as a carrier and portable.

▶ Type B units, are mainly used for heights with a below average wind profile that requires for the main wind turbines. So, the micro wind turbines applied in type B can work with local wind speed and in different height which are relatively on low heights.

▶ While, the main wind turbines can work with a specific wind speeds averages (3.5 m/s) as mentioned before (Level, 2019). Which in general could be achieved on sufficient heights. The main wind turbines could be applied in the Type A or B units (see Figure 4.38.).

Figure 4.38. The main wind turbine.

▶ So, the integrative facade with its all systems designed presented as below (see Figure 4.39.) & (see Figure 4.40.).

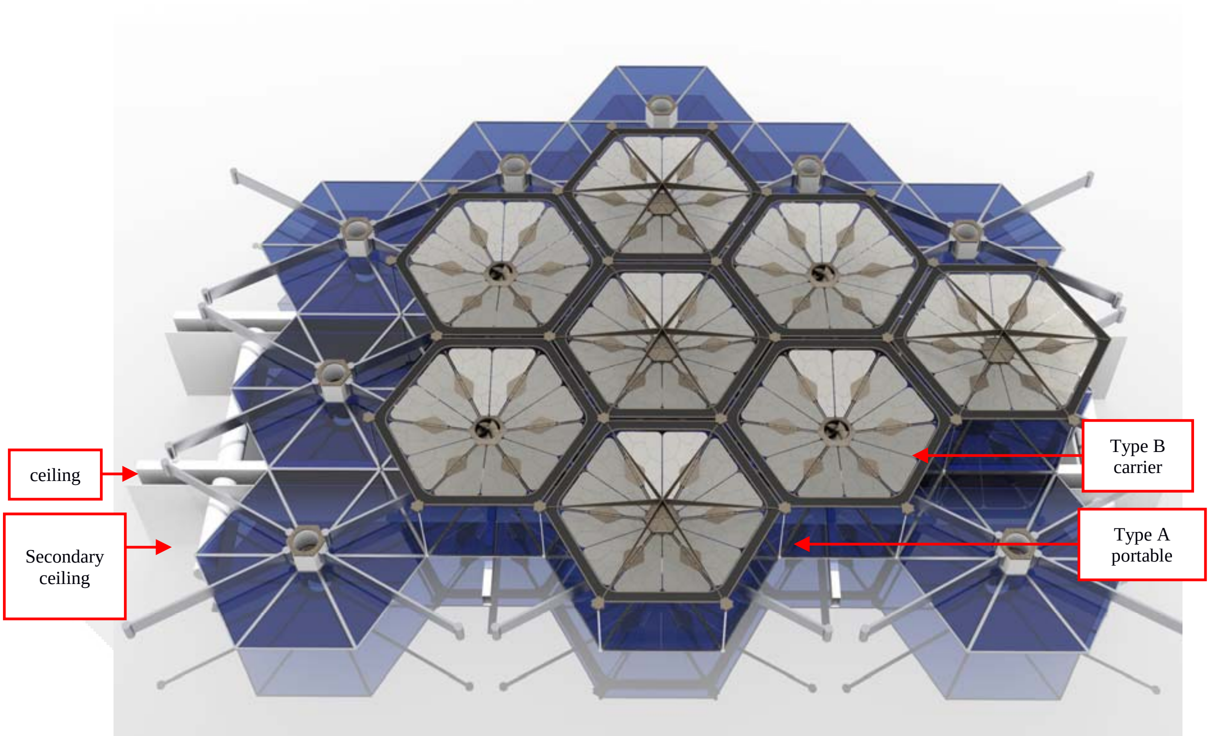


Figure 4.39. The exterior facade design.

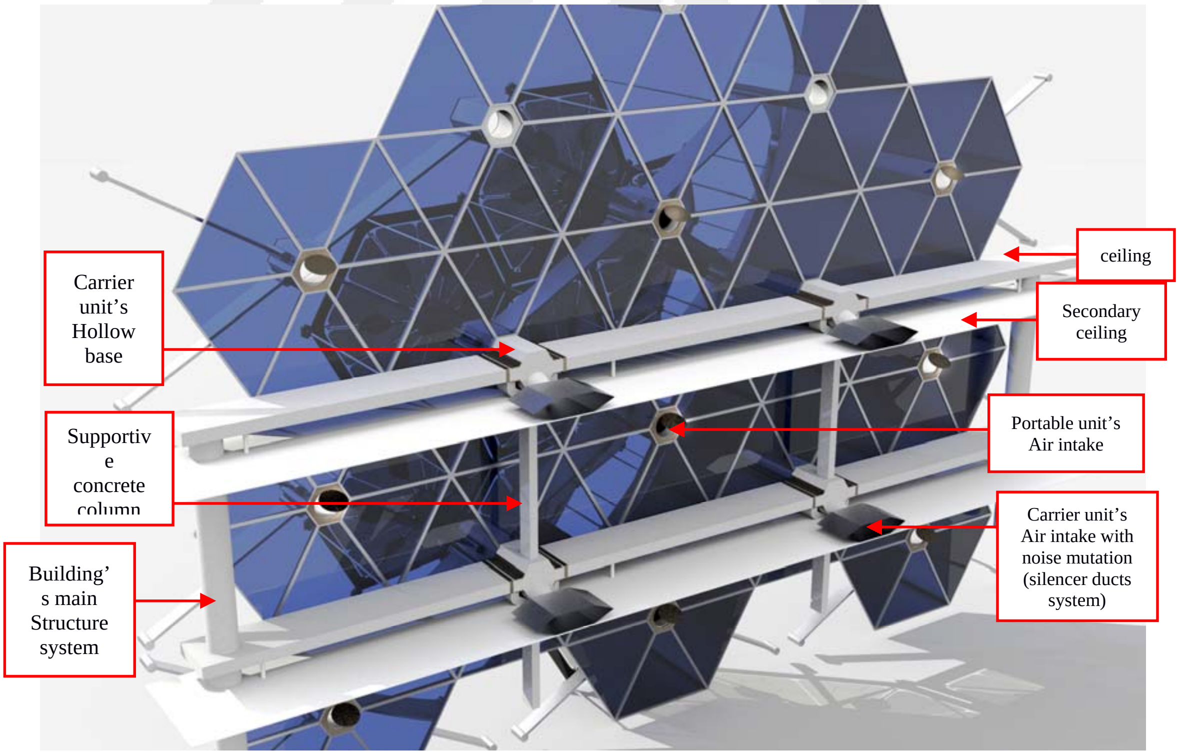


Figure 4.40. Facade design interior view.

In general, the façade structure system can be classified into four main layers, which combine together by multiple supportive structure elements to make one integrative system that can carry shading units and bear different loads.

▶ glazing structure layer (see Figure 4.41.)

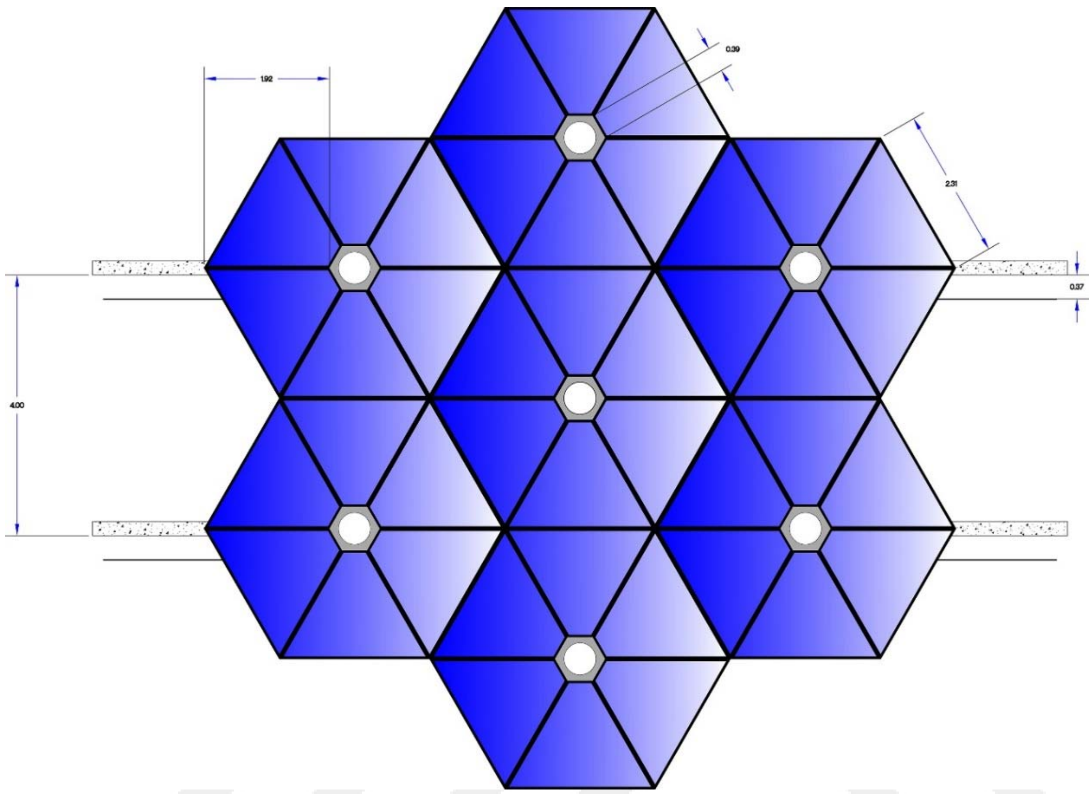


Figure 4.41. Facade - glazing structure layer.

▶ Supportive steel structure layer (see Figure 4.42.).

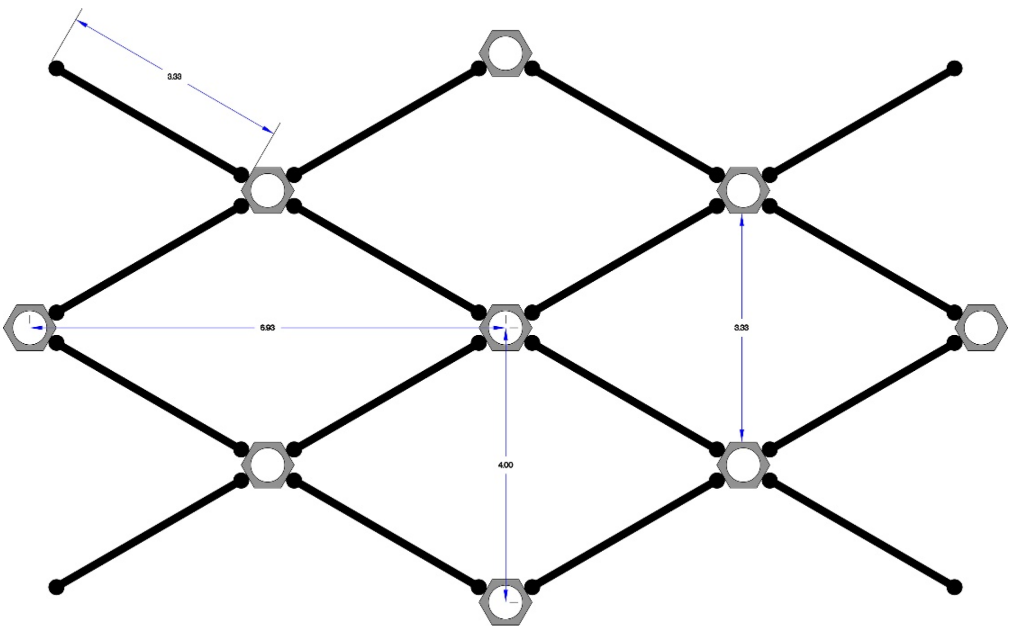


Figure 4.42. Facade - supportive steel structure layer.

▶ shading units' layer (see Figure 4.43.).

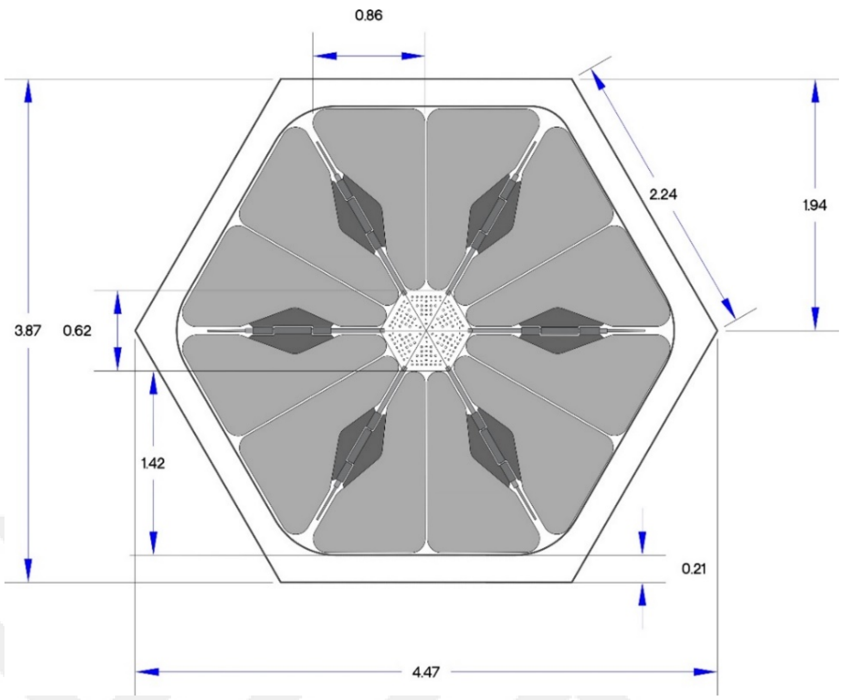


Figure 4.43. One-unit front view.

▶ solar panels structure system (see Figure 4.44.).

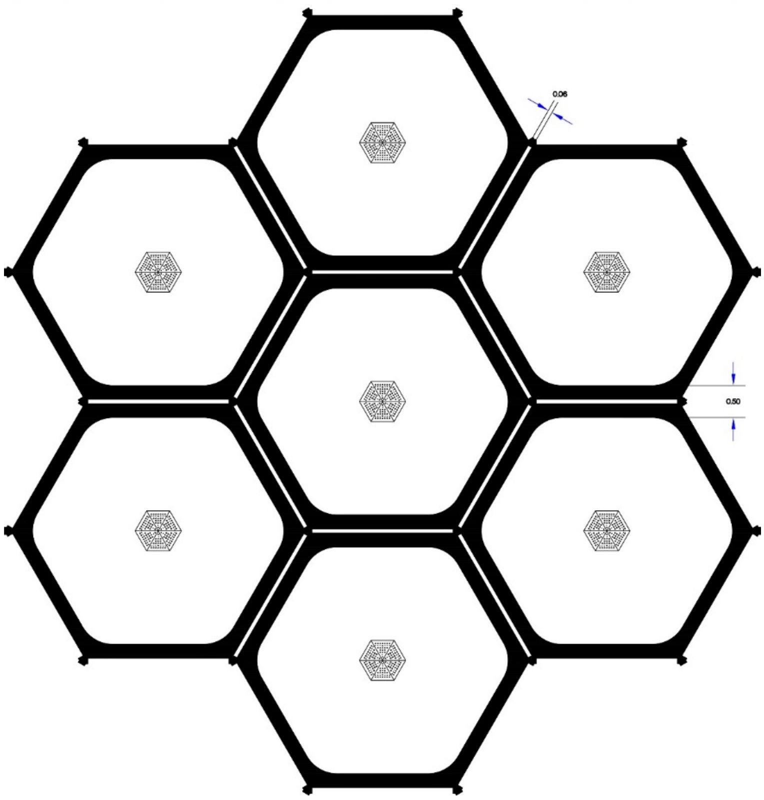


Figure 4.44. Facade - solar panels layer.

For more details, sections can illustrate the main four layers with the different supportive elements and structures that combine all layers together to make the façade (see Figure 4.45.).

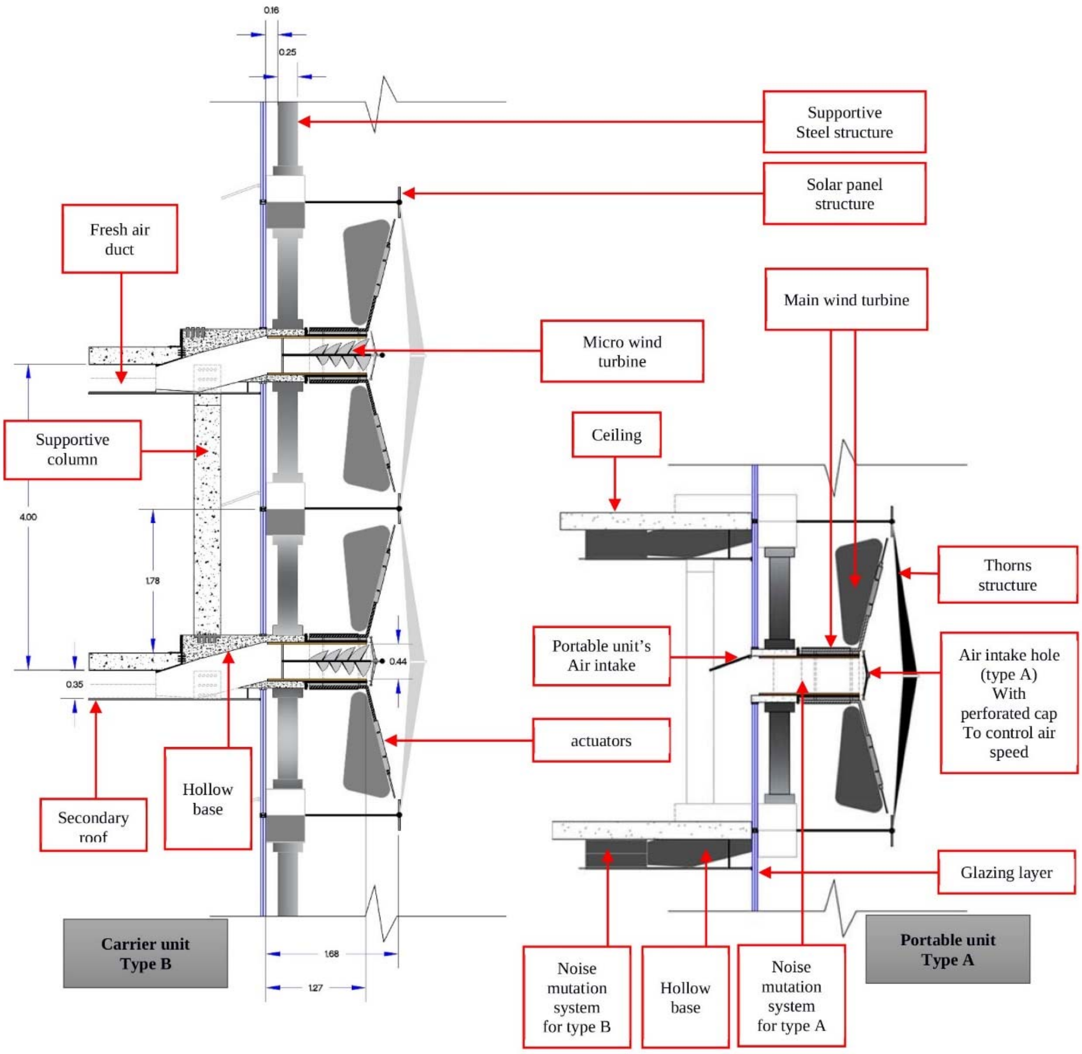


Figure 4.45. Facade – Sections.

4.3.3. Shading units' material-movement concepts

In this design, there are two choices for shading material. Which in general, can be defined physically as 1- Translucent material, 2- Opaque material. These two physically properties can be achieved by Fiberglass material which is widely used recently in different purposes. Fiberglass reinforced materials are manufactured with specific properties.

Generally, fiberglass materials (everychina, n.d.):

- Lightweight

- Good resistance
- Serve the potential aim of wind turbine generators
- Easy balance
- Mitigate the noise as a turbine blades
- Manufacture to serve any concept

Fiberglass reinforced material can serve the design purposes and goals in this research. Thus, **fiberglass reinforced material adopted in the design concept as a**:

▶ **Translucent material:** has the ability to reduce solar glare without blocking daylight completely by allowing a certain percent of sunlight to pass and defuse. But, the fact that the suggestion sites for this design are hot locations could be a problem for energy efficiency especially that based on the Energy consumption example for buildings in tropical regions have the lighting energy demand less than air condition demand with great disparity (Katili, A. Boukhanouf, R. Wilson, n.d.). However, in a number of translucent material manufacturing companies, the range of visible light transmittance is almost between (5% min- 30% max) and the 30% VLT is not recommended (kalwall). Therefore, in this research, 5% of VLT will be used as a minimum range that can give an approximate perception. Another fact should be taken into consideration, the Honeybee plugin with energy plus engine for integrated simulation (HVAC and Daylight) has limits for custom shading system material calculation. Therefore, honeybee plugin will calculate the integrated energy consumption based on the facts, that will not calculate the sun radiation pass through the translucent material. But, the plugin will calculate the daylight pass through the same material. So, it is better to calculate the integrated energy consumption with the minimum range 5 % VLT with an efficient translucent material that has the ability for thermal improvement. Also, the air gap between glazing system and shading material is relatively large (1.6m) so the ventilated air gap can really reduce the impact of using translucent material especially that the material transparency is at the minimum ranges (5%).

▶ **Opaque material:** has the ability to block the direct solar radiation and direct daylight completely. Opaque material with high reflectivity can mitigate daylight loss at some levels.

▶ **The movement ability of the shading units (translucent or opaque)** with sensors system to trace sun path and prevent direct solar glare and radiation can offer a solution for daylight loss. But still, the limitation of the plugins (Ladybug, Honeybee, and Energyplus) prevents the calculations process of such a potential system. So, the proposed system as a definition for honeybee will consider the façade system always with a full shading position. This process gives the minimum efficiency as a measure for the proposed system (material with movement).

Previously, the integrative façade system has been explored in details with its potential construction design, material and potential concepts that can be achieved by this design. So far, as mentioned before the shading units have potential to achieve four main purposes:

1- shading 2- daylight 3- ventilation 4- energy generation.

▶ **Shading:** the concept of shading system, designed based on the fact that the suggestion sites for the building are in hot climate areas. The shading system has a great impact on energy demand and comfort level. In such harsh hot climate regions, the radiation level fallen on the façade system is very high. Therefore, managing the affected facades by covering it with a shading system consider as a solution. The shading system used in this research is not a traditional system. The integrative shading system applied to cover the whole affected facades (south, east, west) with the ability to control the sunlight level pass using some concepts.

First concept: using translucent fiberglass (5% VLT) as a shading material to reduce solar glare without blocking daylight completely, allowing to a certain percent of sunlight to pass and defuse. Which, can increase the efficiency of daylight but also can increase air-condition demand.

Second concept: using opaque fiberglass with a high reflective material color as a shading material to block the direct sunlight (glare and light). This concept can decrease the air-condition demand but also can decrease the daylight efficiency. Also, the reflectivity can mitigate the loss of daylight efficiency.

Third concept: as a compromise, using fiberglass material (translucent or opaque) with a transformable shading system using sun path tracking sensors to block the direct solar glare when the sun is directly fallen in this area. When the sun is not at an effective position, the sensors system gives information to open this area and fold the shading system for the same area. This system used already in some buildings offers the potential to block the direct sun glare and exploit useful daylight. Thus, increasing energy efficiency by reduce air condition energy consumption and increase daylight efficiency or reduce daylight loss.

However, the shading system in this research considers as a main purpose or major goal due to the fact that the shading system is the most affected factor in the energy demand in hot climates. The shading system directly linked to HVAC energy conception and comfort level. Based on some research papers an example of the energy intensity in hot and hot humid climates as below (see Figure 4.46.) (Katili, A. Boukhanouf, R. Wilson, n.d.).

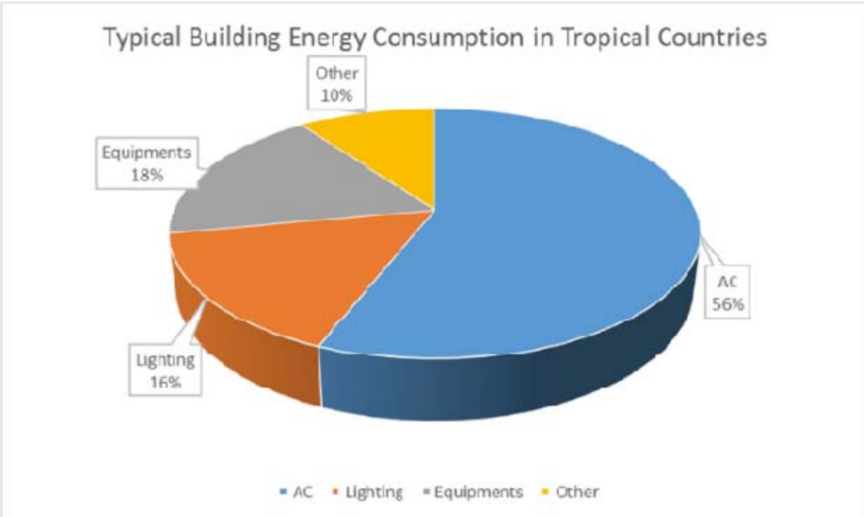


Figure 4.46. Energy consumption example for buildings in tropical regions (Katili, A. Boukhanouf, R. Wilson, n.d.).

Therefore, it is clear that the air condition system has the biggest share of energy. And the lighting system the second. In this research, the majority of the design will be based on this classification.

However, the integrative shading system designed carefully aiming to achieve the balance between shading requirements and other requirements. A transformable shading system offer a range of flexibility to achieve a certain percent of balance with the material potentials.

▶ **Daylight:** Shading systems affecting daylight autonomy significantly. However, lighting energy demand based on research paper Fig (81) in the typical building located in tropical countries, takes the second position of priority which is less than air condition energy consumption by a huge disparity (Katili, A. Boukhanouf, R. Wilson, n.d.). Therefore, the compromise should be on the daylight autonomy side in favor of air condition consumption which is influenced by the shading system. In general, the shading system reduces the number of hours that interior spaces receive an illuminance within a useful range (100 lux to 2000 lux) or even more 2000lux. This also mean, increasing the hours that interior spaces receive illuminance within under 100 lux (consider as dark), and decrease the illuminance above 2000 lux (considered as very bright).

However, the daylight autonomy based on the suggested three concepts of (material & movement) can give deferent outcomes.

First concept: using translucent fiberglass (5% VLT) as a shading material to reduce solar glare without blocking daylight completely, allowing to a certain percent of daylight to pass and defuse. Which, can increase the efficiency of daylight.

Second concept: using opaque fiberglass with a high reflective material color as a shading material to block the direct sunlight (glare and light). This concept can decrease the daylight efficiency. But also, the reflectivity can mitigate the loss of daylight efficiency.

Third concept: as a compromise, using fiberglass material (translucent or opaque) with transformable shading system based on sun path tracking sensors to block the direct solar glare when the sun is directly fallen at this area. When, the sun is not at an affective position, the sensors system gives information to open this area and fold the shading system for the same area. Thus, increasing the energy efficiency by increase the daylight efficiency (or reduce daylight loss).

▶ **Ventilation:** The integrative shading system offers the ability for a natural ventilate and reduces the energy used for this purpose as a secondary potential function. The hexagonal concave shading units facilitate the process of ventilation and air distribution. The integrative façade system provides the building of the natural air needed to make the building capable of breathing. The hexagonal concave units applied on the high rise building façade can exploit the air pressure and increase it based on the units' forms. Recently, there is a desire to make the building able to breathe always with some level of mechanical control. For instance, the Council House (Melbourne) which mentioned in the biomimicry part, has the ability to ventilate the spaces that need for fresh air always directly like wc functions, kitchens. In this research, the integrative facade designed to be able to ventilate the spaces that need fresh air always. Wc, kitchens, and the spaces with mechanical engines which produce heat and carbons. So, this system can provide fresh air directly without much energy using. At the same time the system will provide fresh air directly to the ducts used for ventilation to all spaces with some mechanical controlling to save energy and provide the fresh air to just the spaces in need and close ventilation holes to the spaces that do not need for fresh air. The control system will save energy by preventing the loss or gain heat by changing the air and allowing the spaces in need to exploit the fresh air. Yet, the fresh air enters from air intake holes found in shading units and flow to the hollow base to be purified and mute the noise. After that, the air reaches the ventilation ducts and distributed. The control system will manage the fresh air by allowing and preventing the air to enter the spaces. If the fresh, which already reached the ducts is not needed anymore, the redundant air will flow directly to the central core which is connected to the top of the building. This process occurs airflow to push the hot polluted air out of the core. Also, the outlet system connected with a hole in the north façade in each floor to increase the efficiency of airflows.

In general, the ventilation system divides into two parts (using the carrier units type B). One part for providing fresh air, which is placed on the floor of each space as a duct system with a control system. This part connects directly to the integrative units of the façade on one side and the other side connects to the second part which is the hot polluted air part allocated to the floor below. The hot polluted air system used to absorb hot polluted air for each space located under the ceiling and above the secondary roof. The second part (similar to the first part) manage by a control system to prevent energy loss and also used to get rid of unwanted fresh air from the ventilation system.

From previous, the proposed system design as a potential concept for future studies could be detailed as below (see Figure 4.47.) & (see Figure 4.48.) based on the information above:

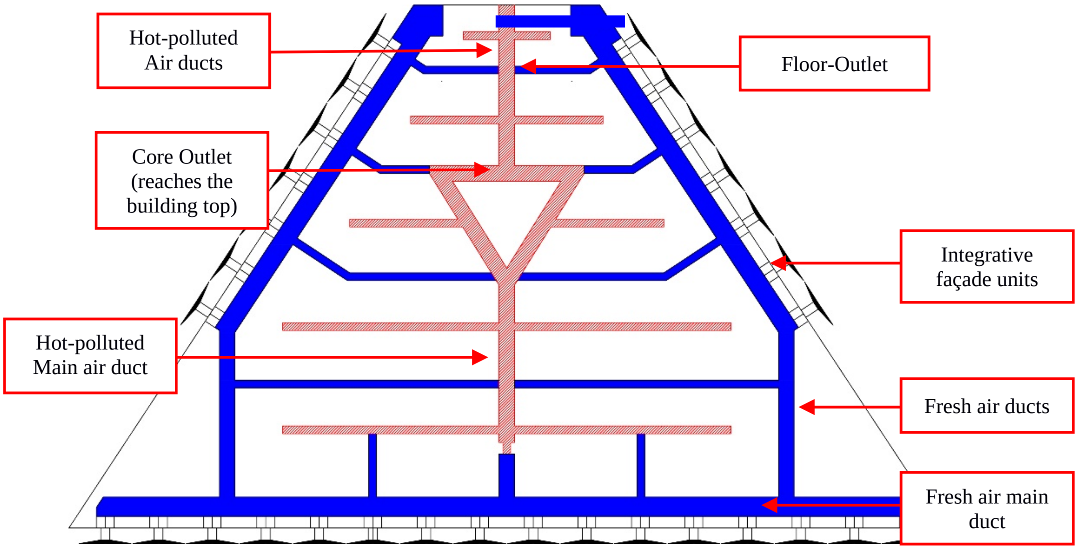


Figure 4.47. Proposal ventilation system plan.

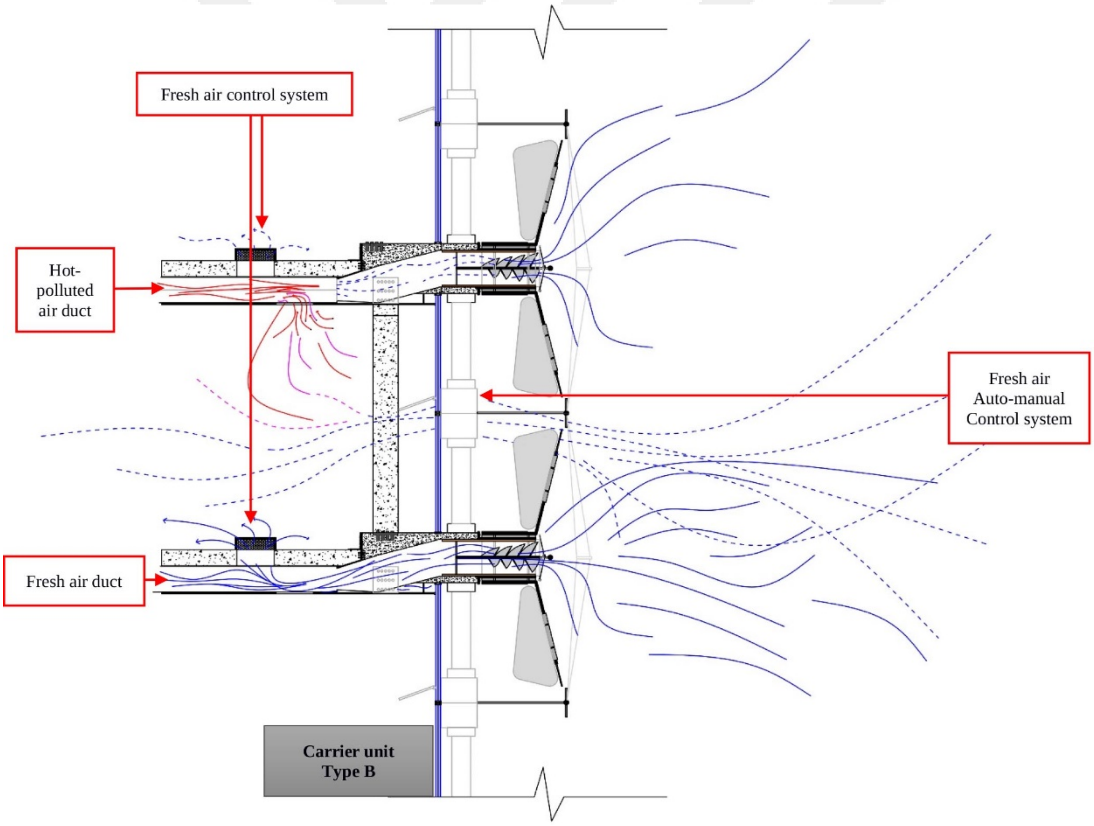


Figure 4.48. Proposal ventilation system (Carrier Unit Type B) as a potential concept for future studies.

Furthermore, the portable units type A have also a role in the ventilation system. The portable units have a mutual control system. The portable units located in the middle of each space which can control manually the same as windows (see Figure 4.49.). But when the building reaches the time that needs general ventilation operation, the air cap for portable units can open with auto control to help the other types units for ventilation process.

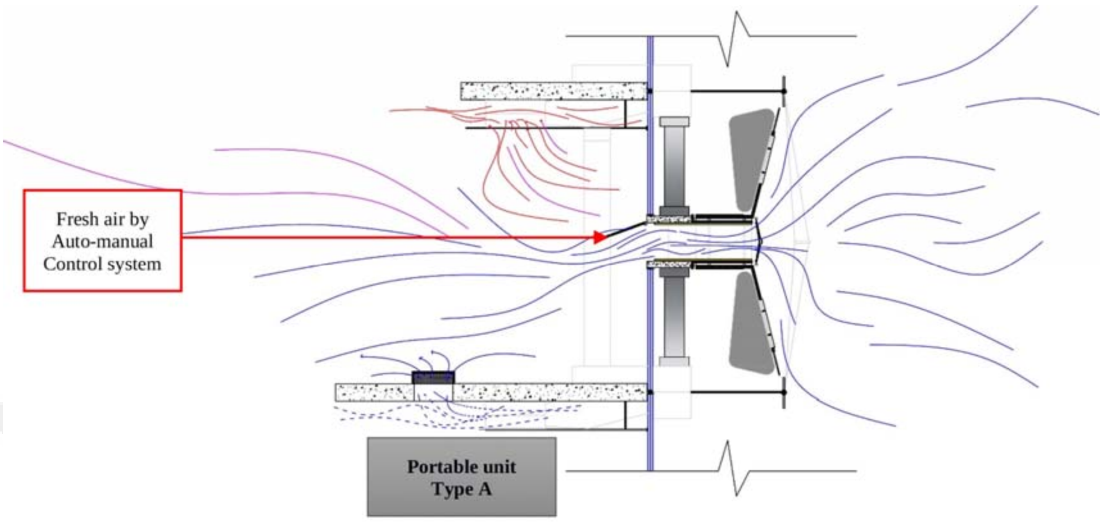


Figure 4.49. Proposal ventilation system (portable units type A) as a potential concept for future studies.

In addition, ventilation system can work with the three concepts of (material & movement) as follow:

First concept: using translucent fiberglass (5% VLT) as a shading material will be no impact on the ventilation process.

Second concept: using opaque fiberglass with a high reflective material color as a shading material will be no impact on the ventilation process.

Third concept: as a compromise, using fiberglass material (translucent or opaque) with transformable shading system based on sun path tracking sensors, in this concept the folding and unfolding unit will affect the quantity of air and the may affect a little the pressure of the air on the air intake holes. So, the ability and capacity of the unfolding unit better than folding units. But in general, when the building need for ventilation, the shading system can be informed to unfold the units.

▶ **Energy generating:** Recently, there is a desire to exploit the buildings' density with its heights to apply renewable energy concepts. There are already a lot of examples of building with the ability to provide energy for its occupants. This process can reduce non-renewable energy consumption in general and decrease the bills cost. High rise buildings have a great potential to exploit the environment conditions and generate energy.

The integrative façade system offers two concepts of renewable energy technologies. **The first technology, is the solar panels system** placed on the frame of each unit on the building façade (see Figure 4.50.). And with the height of the building as a high rise building, the solar panels can work efficiently in the daytime. Solar panels have already used in façade systems in many examples. This technology can exploit the huge vertical area of the high rise building and contributes in energy provide. As mentioned previously, engineers have developed a new photovoltaic system called Ruukki, which has been fully integrated into a facade. The new system can produce power even in spaces without direct sunlight since the technology can also use sun rays in cloudy weather. In snowy places and near water, the system increases production from reflected rays. The Ruukki PV units as a thin-film technology are aesthetically pleasing. The Ruukk PV system used in the facade of an average-sized office building in Finland, Ruukki's solar panel facade can provide 18,000 kWh of electricity a year (buildings smarter facility management, 2011).

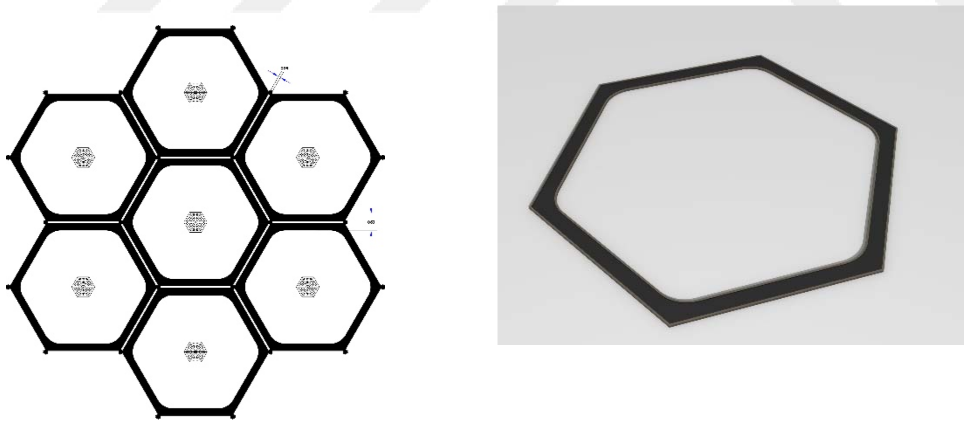


Figure 4.50. The solar panels system in the integrative facade.

While the second technology in the integrative facade is based on the transformable units' design. The integrative units designed to be able to transform into a potential form that can be influenced by air velocity as a wind turbine. In general, wind turbines can work with specific wind speeds averages (3.5 m/s) (Level, 2019). Which could be achieved on sufficient heights based on the wind profile of each city.

İn the integrative unit's design, the main wind turbines can be applied in each one of Type A and Type B units. But, the unit should be located on a sufficient height with an average wind velocity that exceeds (3.5 m/s). Therefore, the units with heights that do not reach the average (3.5 m/s) of wind speed, will not need for the main wind turbine to be installed.

Therefore, a micro wind turbines which can work below the average have used in Type B units with local wind speed. Micro wind turbines have applied already in different buildings with a small number of floors. So, the integrative units designed already with a potential shape (hexagonal concave) to absorb air as much as possible and may increase the air pressure on the air intake holes where the micro wind turbine locates in Type B units.

So far, the integrative facade system can provide building with multiple renewable technologies:

- ▶ Solar panels at daytime applied on (Type A, B).
- ▶ main wind turbines after the business times with sufficient height of units (Type A, B); because of the main turbines used for shading during the business days. Also, the main wind turbine can cause a big disturbance for occupants and workers due to the fact that the wind turbines blades when they rotate, they cause shadow-light issues which can affect the occupants' concentration. Furthermore, the main wind turbines system can cause noise also. So the better solution is to use the main wind turbines after business time.
- ▶ Micro wind turbine applied on the (B Type) units with different heights and all the time. The system for unit B type designed to absorb air and mute the noise.

From previous all, the units have the ability to achieve the four potential purposes:

1- shading 2- daylight 3- ventilation 4- energy generation. And, the three (material & movement) concepts.

First concept: using translucent fiberglass (5% VLT) as a shading material.

Second concept: using opaque fiberglass with a high reflective material color.

Third concept: using a fiberglass material (translucent or opaque) with (transformable shading system based on sun path tracking sensors).

4.3.4. Shading units' transformation steps

In addition, the units have the ability to move and transform which can be illustrated in four steps (see Figure 4.51.).

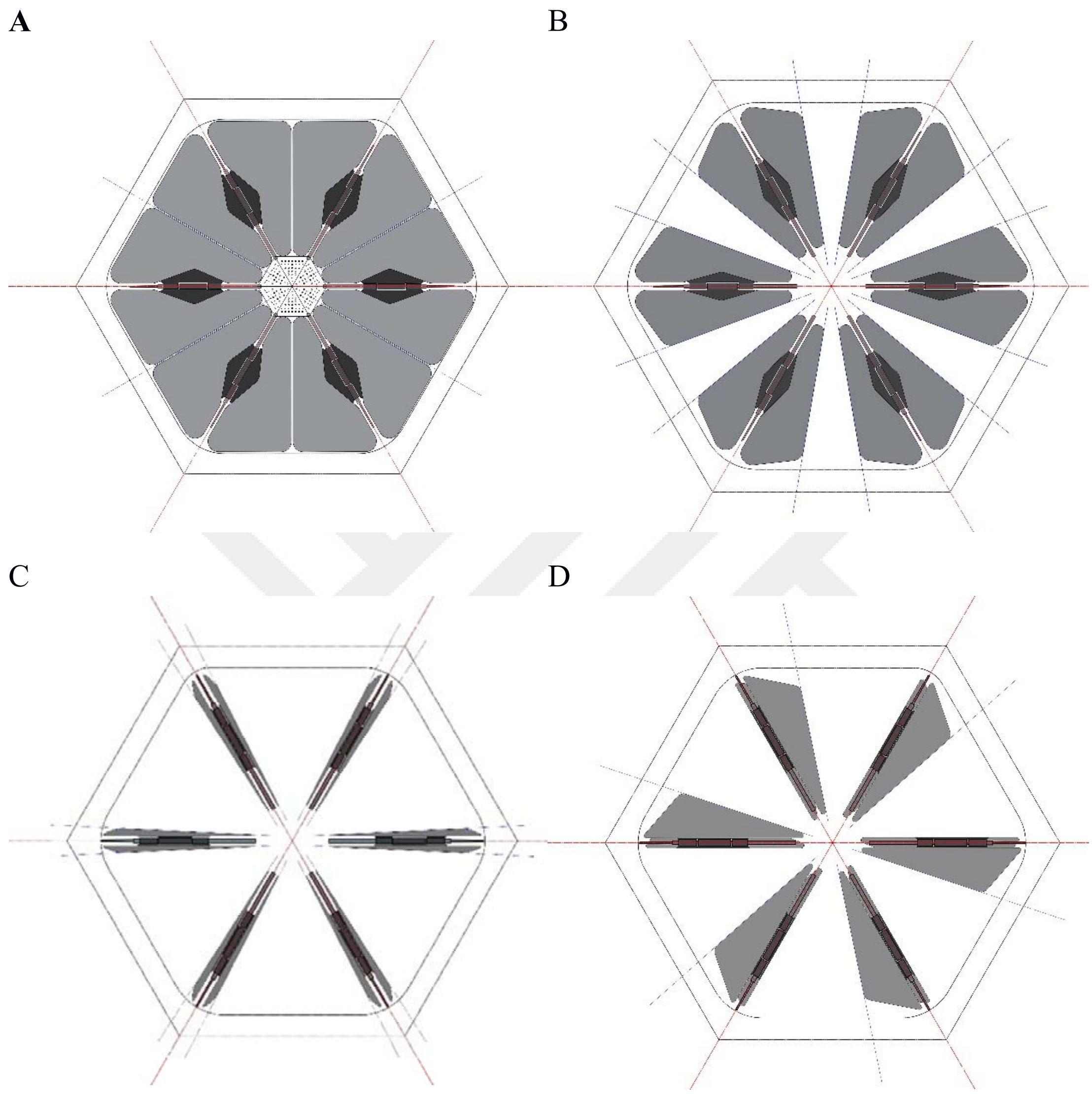


Figure 4.51. Unit movement steps

The folding positions influence each of the four purposes and three concepts as follow:

Position A: is the full shading position in the movement steps. The position A used at the business times to shade the facades with direct sun position which means (see Figure 4.52.).

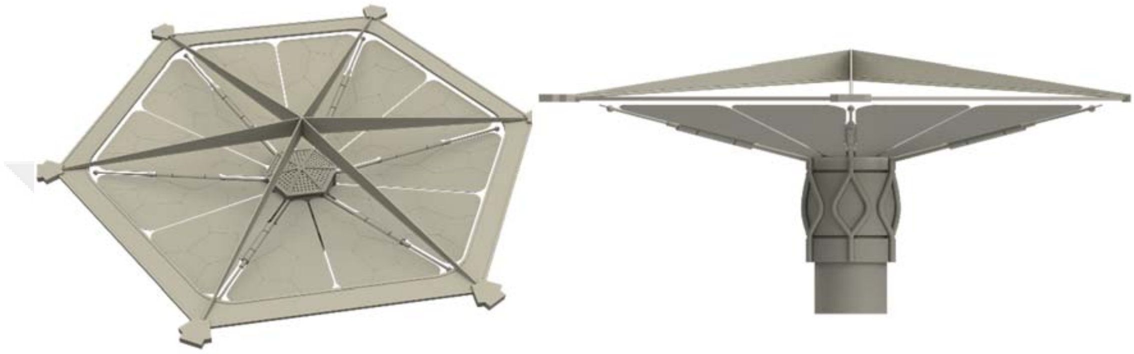
* Block the sun based on the three **(material & movement)** concepts.
* Decrease the daylight autonomy level based on the three **(material & movement)** concepts.

* Increase the ventilation efficiency by increase the air pressure on the intake holes. Thus, increase the air quantity inters.

* The energy generating process will be based on the solar panels and micro wind turbines only.

-Also, this position can mitigate the noise or sound waves.

A



perspective **Side view**

Figure 4.52. Movement steps – position A

Position B: is the 50% of the full shading position in the movement steps. The position B used mainly as a transitional step (see Figure 4.53.). Also, it could be used with sensors system to control the level of effectiveness of the four purposes. which means:

* 50% of the folding ability, decrease the sun block operation the based on the three **(material & movement)** concepts.

* 50% of the folding ability, increase the daylight autonomy level based on the three **(material & movement)** concepts.

* Decrease the efficiency of the ventilation process for building spaces but, it can be used to ventilate the gap between shading layer and glazing layer .

* The energy generating process will be based on the solar panels while, the micro wind turbines can work with lower efficiency (half folding position).

B

perspective **Side view**

Figure 4.53. Movement steps – position B

Position C: is the folding position in the movement steps. The position C used mainly as a transitional step (see Figure 4.54.). Also, it could be used with sensores system to control the level of effictivness of the four purposes. which means:

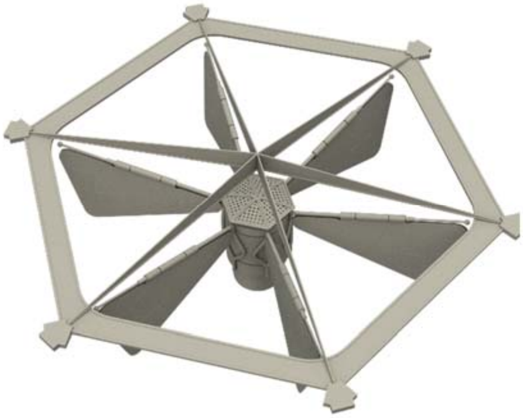
* Allows the sunlight (radiation,daylight) to pass at the heighest possible level especially for cold winter days based on the three **(material & movement)** concepts.

* Increases the daylight autonomy level by allowing the sunlight to pass with the heighest possible level especially for cold winter days based on the three **(material & movement)** concepts.

* Decrease the efficiency of the ventilation process for building spaces to the lowest but, it can be used to ventilate the gap between shading layer and glazing layer .

* The energy generating process will be based on the solar panels while, the micro wind turbines can work with lowest efficiecny (folding position).

C



perspective **Side view**

Figure 4.54. Movement steps – position C

Position D: is the folding and rotatable position (with oblique blades) in the movement steps. The position D used mainly as a final step for the main wind turbine (see Figure 4.55.). Generally, it is used after business daytimes for energy generating. This possition:

* Used after business daytimes. So, this position not related with shading positions.
* Used after business daytimes. So, this position not related with daylight autonomy.
* Decrease the efficiency of the ventilation process for building spaces to the lowest but, it can be used to ventilate the exterior facade.
* Increase the efficiency of energy generating process, which will be by the main wind turbines and the micro wind turbines which can work with lowest efficieny (folding position).

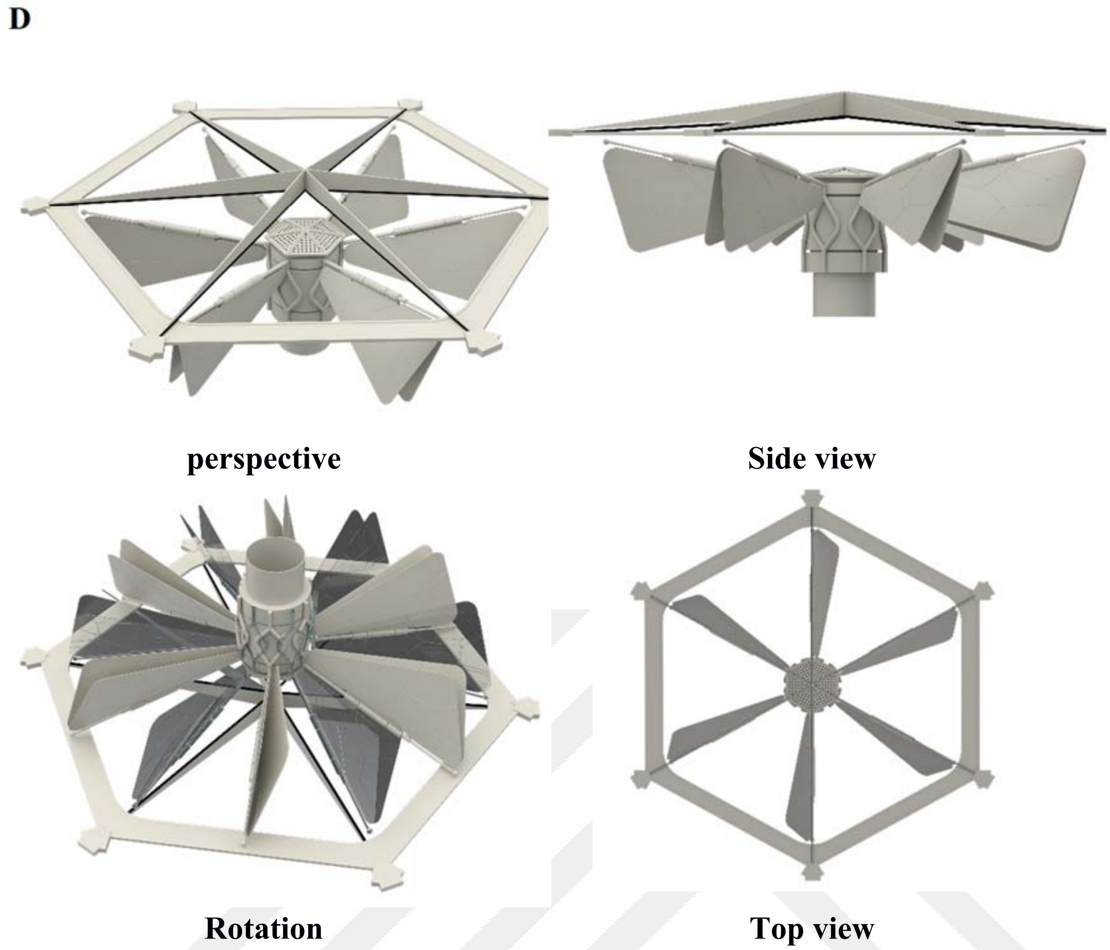


Figure 4.55. Movement steps – position D

4.3.5. Energy model

The integrative façade design with all the potential systems has been explained in detail. The integrative façade concept offers actionable methods to solve problems and serve the goals. But, the potential concepts of this research **(1- shading 2- daylight 3- ventilation 4- energy generation)**, it may intersect with the limitation of the computational (Honeybee, Ladybug, Energyplus, Galapagos) tools that have been used to prove the efficiency of integrative facade concept to achieve the high-performance building goals based on energy efficiency. Therefore, the process of energy modeling will be based on the ability of the computational tools.

So, the next steps are attempting to define the final energy model for this research and which potential concept will be covered and which are considered as a potential concept for future studies.

The building body for energy model based on Honeybee/Ladybug plugins defined as a large office building that occupies whole the area of one floor of the proposed tower which is 1155.3 m^2 (without cantilevers and balconies). The proposed floor placed on 24 meters'height to be tested within the average height of the tower. The office plane divided into 7 spaces with 5 functions as follow: Lobby (104.1 m^2), Breaking room (104.1 m^2), Office: open office (818.1 m^2), Storages (88.9 m^2), Core (40 m^2).The division of the plan has been done according to Honeybee plugin limitations. To calculate integrated energy consumption with honeybee and energy plus, the divisions must be as simple shape as possible (closed Breb in honeybee definition) to create zones. These zones arrange next to each other making one plane with different functional zones. The height of each floor is 4 meters and each side of the wall designed and defined within 85% glazed each façade.

As mentioned before, the office building has an integrative façade design with potential concepts to achieve the four main purposes (1- shading 2- daylight 3- ventilation 4- energy generation). But, with the limitation of the computational tools used in this research and the research scope, the methodology of this research will focus on the integrative energy consumption (Energy and Daylight) and adaptive comfort analysis for the (1- shading 2- daylight) purposes. And the other purposes (ventilation and energy generation), will consider as potential concepts for future studies. So, the wind profile and global horizontal radiation in each case study (cities) offer determination factors to help the process of selecting the best performance city which fits as much as possible the potential of the four main purposes (1- shading 2- daylight 3- ventilation 4- energy generation).

The average of the global horizontal radiation analysis during the daytimes can determine the potential level of each city for using solar panels. While, The wind profile determination factor, can provide a general vision for the potential each city has to serve the energy generation and ventilation specifically.Therefore, a method has been used to estimate the wind profile efficiency for each case study based on the proposed building design for this research which has three sides of the integrative façade unites applied on (south, east, west). While the north side has the redundant / hot-polluted air outlet under with balcony. Therefore, it's better than the north façade has low air pressure. Yet, the eligibility of the wind, in general, evaluated based on the (3.5 m/s) average velocity that could achieve on the lowest height possible to generate electricity. Based on these factors, the wind profile for each city can be estimated (see Table 4.2.).

Table 4.2. The general evaluation process of wind profile.

	Wind directions based on reference Building design				**The height with Average Wind speeds 3.5 m/s**	**Evaluation**
	South	**East** E- SE -NE	**West** W-SW-NW	**North**		
	High	High	High	Low	The least height possible	The best
	best case for wind direction				best case for wind velocity	

The integrative energy consumption (Energy and Daylight) involves evaluating energy consumption and artificial light performance through the simulation process using the Daysim and EnergyPlus programs. Daysim generates a report that describes the control of the artificial lighting based on daylight autonomy, which is used by EnergyPlus for calculating the final energy consumption in the analyzed environments (Didoné & Pereira, 2011).

The integrative energy method also has some limitations with the custom shading system which used for the integrative facade. The limitations are with the definition of the materials used for the shading (translucent and opaque). The honeybee and ladybug plugins, cannot simulate the custom shading system with translucent material as an integrated energy model based on (Energy and Daylight simulations). İnstead, the honeybee plugin defines the shading material based on the Radiance system which is used to affect the daylight autonomy only while, the energyplus within honeybee plugin assumes the shading material always opaque which means, the enegypluse program will neglect the amount of the solar radiation passed through the translucent material. The radiance system defines the material based on the physics of light such as reflection, transmission, and/or refraction depending on the type of material. The energy plus within honeybee plugin, cannot calculate the radiation pass through the translucent shading material which defined based on these physical properties of the radiance system (Chris Mackey, developer of the honeybee / ladybug plugins).

Therefore, in this research, opaque material will be used for the main integrated energy/ daylight simulations. Which in this case of using opaque material, the process of simulation will conduct the energy simulation based on the daylight autonomy simulation (integrated energy consumption). But in general, as mentioned before an integrated energy/daylight simulation for translucent shading material will be conducted also (besides the opaque material) in this research due to the fact that the translucent material used with just (5% VLT). And this percentage is almost the minimum percent used for translucent material in many manufacturing companies. It will give a general estimation of using translucent material for daylight efficiency and neglect the small amount of solar radiation pass through the material.

The integrated (energy/daylight) simulation with (opaque/ translucent) material method, offer an estimated view of the materials impact on (daylight efficiency) even with the limitations. In addition, the final energy model (with shading system), defined the shading system always takes position A of movement steps (see Figure 4.56.) due to the ability of the computational tools with the responsive shading system based on the sun path.

Therefore, all the simulations process will be with the minimum level of efficiency which means, the performance of the building could be more efficient in the reality.

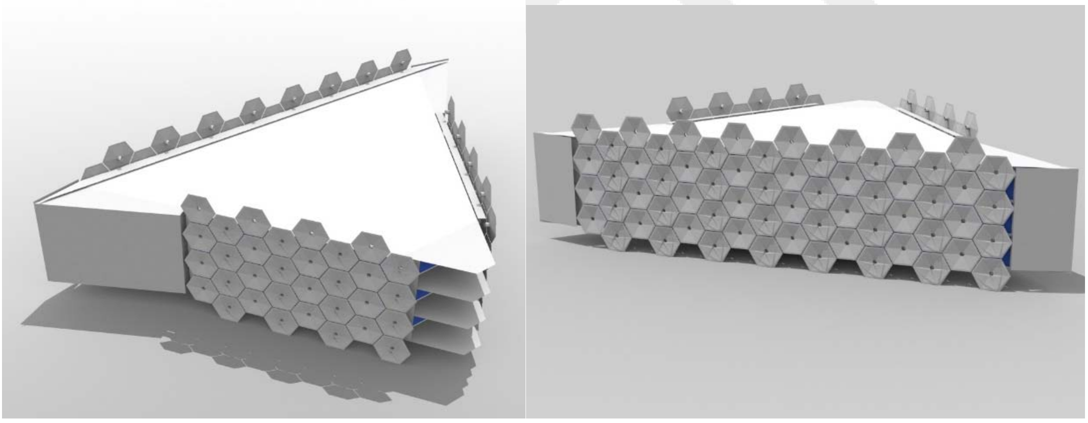


Figure 4.56. Final energy model definition (energy/daylight)

İn the final energy model for the integrated energy simulation (energy/daylight), the materials' definition process will be conducted based on the scope and limitation of this research. The limitation of this research is to exam the potential of the integrative façade design based on the application of the (glazing material and shading material) on the integrative facade. The other material of the building (wall, roof, constructions) will not be optimized. Therefore, this research focuses on the impact of the shading material on the glazing material selection. And, the impact of the combination system on the building performance using integrated energy simulation (energy/daylight) outputs as a computational tool.

Glazing material: four choices selected for this research due to its potential to serve the integrative shading system. Also, these materials have been used in many types of research and all its values are available. The best glazing choice will be determined by the optimization process to choose the best glazing material behavior after applying the shading system (see Table 4.3.).

Table 4.3. EP window Construction Materials (EnergyPlus library).

Material Classification	Material name & properties	Constructions	Simulation responsiveness
EP Window Constructions (four options)	**1. Single Clear 6mm (The reference)** U=5.894 SHGC=0.905 TSOL=0.899 TVIS=0.913	Sgl Clr 6mm, !- Name CLEAR 6MM; !- Outside Layer	Energy/Daylight
	2.Double Clear 3mm/13mmAir U=2.556 SHGC=0.764 TSOL=0.705 TVIS=0.812	DblClr 3mm/13mmAir, !- Name CLEAR 3MM, !- Outside Layer AIR 13MM, !- Layer 2 CLEAR 3MM; !- Layer 3	Energy/Daylight
	3. Double Blue 6mm/13mmAir U=2.511 SHGC=0.494 TSOL=0.373 TVIS=0.505	Dbl Blue 6mm/13mmAir, !- Name BLUE 6MM, !- Outside Layer AIR 13MM, !- Layer 2 CLEAR 6MM; !- Layer 3	Energy/Daylight
	4. TripleLowE(e5=.1)Clear3mm/13mmAir U=1.062 SHGC=0.579 TSOL=0.458 TVIS=0.698	TrpLoE(e5=.1)Clear3mm/13mmAir, !Name CLEAR 3MM, !- Outside Layer AIR 13MM, !- Layer 2 CLEAR 3MM, !- Layer 3 AIR 13MM, !- Layer 4 LoE CLEAR 3MM Rev; !- Layer 5	Energy/Daylight

Terminology used in construction names:

- Sgl Single pane
- Dbl Double pane
- Trp Triple pane
- Clr All panes are clear glass
- LoE Low-emissivity metallic coating on one or more panes
- Air Between-pane gas fill is air
- U Nominal Center-of-glass U-value (W/m^2-K) calculated
  - for winter conditions (-18ºC outside air temperature,
  - 21 ºC inside air temperature, 5.5 m/s wind speed and zero solar radiation).
- SHGC Solar heat gain coefficient of the construction calculated

- o for summer conditions (32 ºC outside air temperature,
- o 24 ºC inside air temperature, 2.8 m/s wind speed and
- o 783 W/m^2 incident beam solar radiation normal to glazing

- ➢ TSOL Solar transmittance at normal incidence of the construction
- ➢ TVIS Visible transmittance at normal incidence of the construction

Other construction materials: in the research process, walls, roof, floor, and other construction material for building will not be considered as a research priority. So, these materials will not involve in the improvement process based on research scope and limitation. Therefore, these materials selected from the ASHRAE 2005HOF Materials found in energyplus construction materials library (see Table 4.4.) as a one choice to define the building body materials based on the functions such as wall material or roof material and etc...

Table 4.4. EP Construction Materials (Energyplus library)

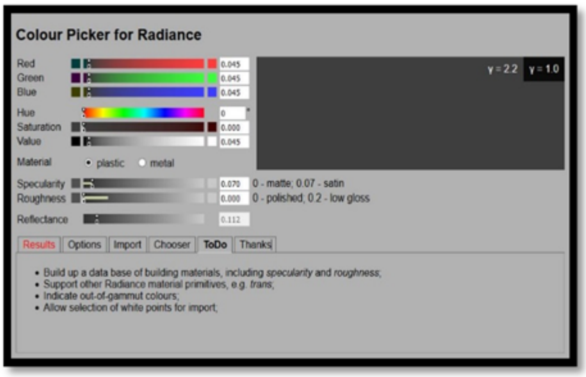
Material Classification	Material type	Material Name for Energy simulation As Ep construction	Material Name for Daylight simulation As RAD material Inside layer (Inside the building)	Simulation responsiveness
EP Construction Materials	1. Walls	ASHRAE 189.1-2009 EXTWALL STEELFRAME CLIMATEZONE 1-3	Interior_ Wall	Energy/Daylight
	2. Roofs	ASHRAE 90.1-2007 EXTROOF IEAD CLIMATEZONE 1-2 SEMIHEATED	Interior_ Ceiling	Energy/Daylight
	3. Floors	ASHRAE 90.1-2010 ATTICFLOOR CLIMATEZONE 1-2 SEMIHEATED	Interior_ Floor	Energy/Daylight

In addition, the RAD materials for Daylight simulation (outside layer) which may influence the integrated energy simulation (Energy/Daylight), defined by the radiance system using color picker program to give the physical properties of each color used (see Table 4.5.).

Table 4.5. Color picker program for construction radiance material (outside layer) used for integrated simulation (Energy/Daylight).

Shading material color

Exterior walls material color



Solar panels color

So far, the energy model with the (glazing, shading) materials for impact focus has been defined for the integrated energy simulation (Energy/Daylight).

4.4. Climate information of the three case studies as potential sites for the design

The three case studies as potential hot locations have been chosen based on:

- All of them have the hottest average range of temperature on the earth.

- Providing different examples of hot-dry climate type and hot-humid climate type.
- Most of them have not cold winter periods, which mean that the building will need the shading system all over the year.

4.4.1. Dubai

Elevation: 4 meters Latitude: 25 15N Longitude: 055 20E clear skies Köppen Classification: c.

Dubai is the most populous city of the United Arab Emirates. The climate of Dubai is subtropical desert with very mild or nicely warm winter, and extremely hot summer combines with high level of humidity. Indeed, in the summer the wind generally comes directly from the sea bringing moisture. The temperature average is 27.2 °C, ranges from 19.5 °C (67.5 °F) in January to 36.5 °C (98 °F) in August (see Figure 4.57.). The average amount of precipitation for the year in Dubai is 6.3" (160 mm) (Travel, n.d.). Based on the Köppen Climate Classification subtype for this climate is "Bwh". (Tropical and Subtropical Desert Climate) (Weatherbase, n.d.).

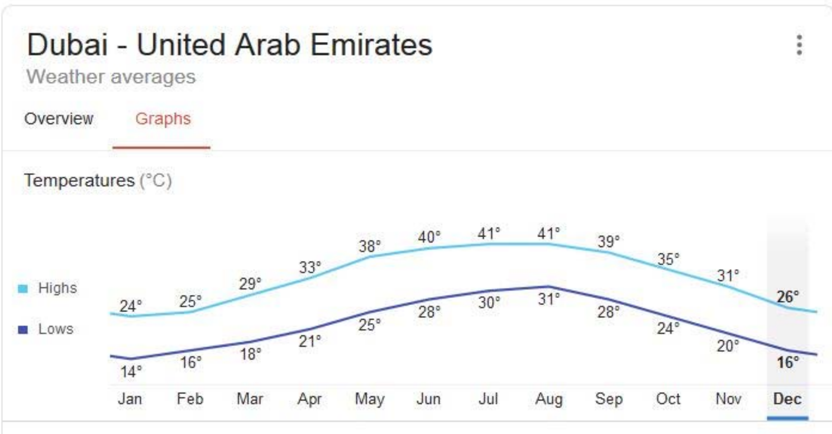


Figure 4.57. Dubai-Average temperatures (Averages, n.d.)

4.4.2. Baghdad

Elevation: 34 meters Latitude: 33 14N Longitude: 044 41E clear skies Köppen Classification: Tropical and Subtropical Desert Climate (Weatherbase, n.d.).

Baghdad is the most populous city of the Iraq. The climate of Baghdad is subtropical desert with cold winter, and extremely hot summer. The temperature average for the year is 72.0°F (22.2°C), ranges from 48.0°F (8.9°C) in January to 94.0°F (34.4°C) in August (see Figure 4.58.). The highest recorded temperature in Baghdad is 122.0°F

(50°C) in July and the coolest recorded temperature in Baghdad is 25.0°F (-3.9°C) in January. The average amount of precipitation for the year in Baghdad is 6.1" (154.9 mm) (Travel, n.d.). Based on the Köppen Climate Classification subtype for this climate is "Bwh". (Tropical and Subtropical Desert Climate) (Weatherbase, n.d.).

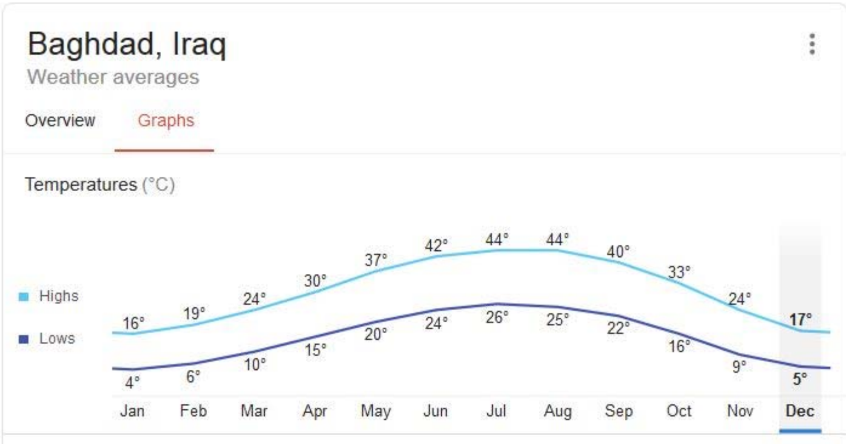


Figure 4.58. Baghdad-Average temperatures (Averages, n.d.)

4.4.3. Doha

Elevation: 10 meters Latitude: 25 15N Longitude: 051 34E clear skies Köppen Classification: Tropical and Subtropical Desert Climate (Weatherbase, n.d.).

Doha is the most populous city of Qatar. The climate of Doha is subtropical desert with very mild or nicely warm winter, and extremely hot summer combines with high level of humidity. Indeed, in the summer the wind generally comes directly from the sea bringing moisture. The temperature average is 81.0°F (27.2°C), ranges from 63.0°F (17.2°C) in January to 96.0°F (35.6°C) in August (see Figure 4.59.). The average amount of precipitation for the year in Doha is 3.2" (81.3 mm) (Travel, n.d.). Based on the Köppen Climate Classification subtype for this climate is "Bwh". (Tropical and Subtropical Desert Climate) (Weatherbase, n.d.).

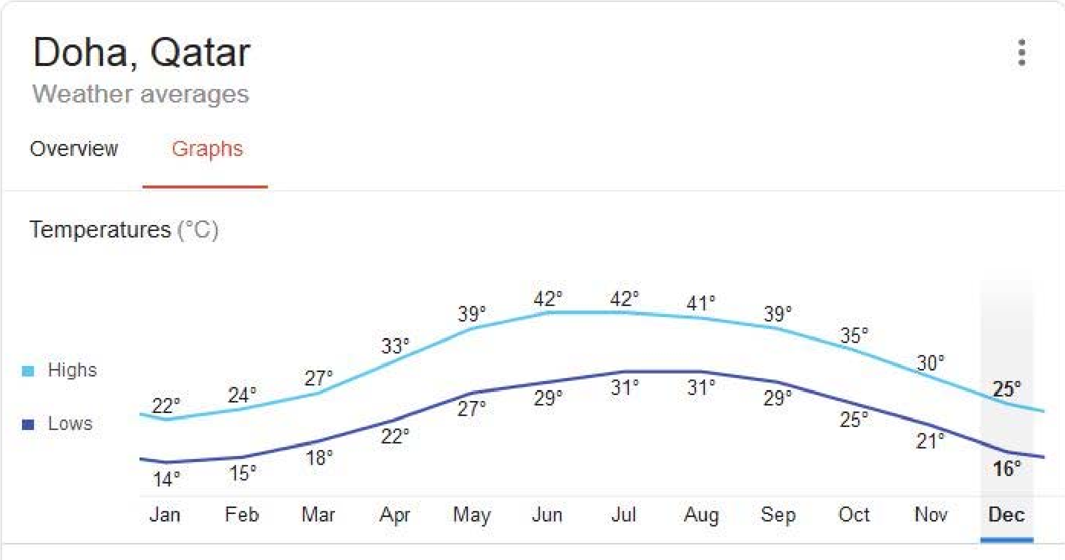


Figure 4.59. Doha-Average temperatures (Averages, n.d.)

Briefly, the geometry story went through multiple stages and concepts to reach the final design. But in general, the process can be explained briefly as follow:

- building definition as a large office occupies the whole floor of a high rise building. The high rise building designed with triangle plan for many purposes mentioned before.
- the definition of glazing/wall ratio which is 85% of glazing area.
- using Biomimicry concept as a strategy for high performance design. Biomimicry concept applied to generate the integrative shading units.
- the final integrative shading units designed to achieve four main purposes (1- shading 2- daylight 3- ventilation 4- energy generation). With the ability of shading units to transform based on sun path tracking system.
- using environmental computation tools as a strategy for high performance design. But, based on the computational tools limitations and research scope, the research will exam the shading and daylight purposes with related issues. And the shading units assumed with unfolding position (A) always (tools ability). While, ventilation and energy generation considered as potential purposes for future studies. But, the research can exam the wind profile and global horizontal radiation for each case study as another determination factors to measure the potential of each city to serve the other potential purposes.

- using Computational tools for an optimization process to achieve the best orientation of the office building to minimize energy demand by Galapagos plugin.
- based on the computational tools limitation and research scope, the final definition of the energy model with the shading system has been produced for (Honeybee/ladybug) computational plugins to simulate the integrated energy consumption based on (Energy/Daylight).
- defines the case studies as hot climate cities (Dubai, Bagdad, Doha).
- conducting the simulation processes based on five determination factors (energy consumption, adaptive comfort, daylight autonomy, wind profile, global horizontal radiation).
- based on the limitations and computational tools ability, the rustles might be at the minimum efficiency levels. Which mean, the result could be more efficient with all the potential concepts in reality.

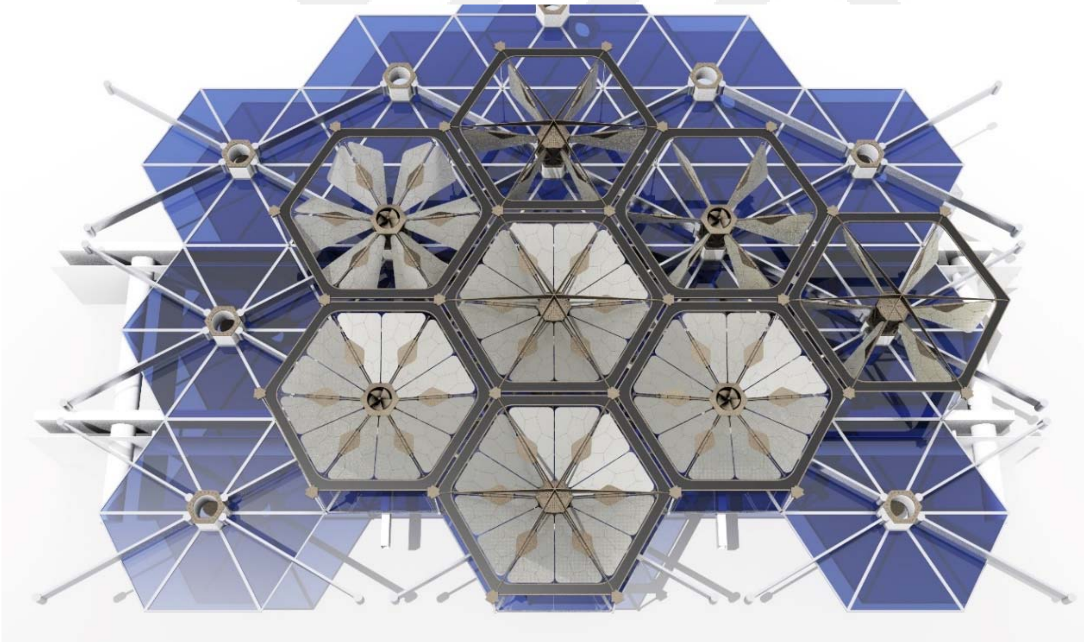


Figure 4.60. The integrative façade design with different operations possibilities

4.5. The research methodology of the simulation processes

Three potential cities that are located in hot climate areas (Tropical and Subtropical Desert Climate based on Köppen Classification (Weatherbase, n.d.)) have been selected as case studies to evaluate the proposed building with the integrative shading units. The integrative shading system designed to manage the hot climates with all the potential concepts to achieve design purposes. But, based on the limitations and research scope, the research concept focuses on the shading system and how influences Energy consumption, comfort level, and daylight autonomy. The shading system impacts the integrated energy consumption based on cooling and heating loads as well as affects the adaptive comfort level. The integrative shading units also affect daylight autonomy which influences the artificial light schedule. Furthermore, the wind profile and global horizontal radiation analysis for each case study will be considered as a determining factor by evaluating the potential level that each city has to serve the other potential purposes for future studies (ventilation and energy generation) as well as the main two purposes (shading and daylight).

So far, the methodology process conducting as improvement method to demonstrate the design effectiveness. The process in general goes through analysis and simulation processes that can estimate the adaptiveness.

- **Temperature Analysis**

Average temperature for the coldest and hottest months.

- **Humidity Analysis**

The type of the city based on the ratio Dry period: Humid period.

- **Radiation Analysis**

Global Horizontal Radiation is the total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface. This factor widely used to determine the solar potential level of any location to generate electricity by solar panels. The evaluation process conducted by taking the Average of Global Horizontal Radiation during the daytime.

- **Wind profile**

The wind profile determination factor can provide a general vision for the potential each city has to serve the energy generation and ventilation specifically. Therefore, a method has been used to estimate the wind profile efficiency for each case study based on the proposed building design for this research which has three sides of the integrative façade unites applied on (south, east, west). While the north side has the redundant / hot-polluted air outlet’. Therefore it's better than the north façade has low air pressure. Yet, the eligibility of the wind, in general, evaluated based on the (3.5

m/s) average velocity that could achieve on the lowest height possible to generate electricity. Based on these factors, the wind profile for each city can be estimated.

▶ **Integrated Energy-Daylight improvement process**

The process of the Integrated Energy-Daylight improvement aims to exam all the possible choices selected and the parameters meet the ability limitations of the computational tools used to conduct the simulation processes of this research. In general, the process:

* Starts with the four choices of glass types which are selected due to its potential properties to work efficiency with shading system and put a limited range of glass types to accelerate the improvement process. The four glass types have been simulated first without shading system.

* Excluding the least efficient choice to reduce the possible options.

* Apply the opaque shading system (position A always) with each of the three glass types left to determine the best system based on (glass type + shading system).

* Optimize the chosen system (glass type + shading system) form by changing the depth of the concave hexagonal unit with the range (0.0 - 0.4) m and choose the best form for each city.

* Comparing the optimized shading system (chosen glass+ shading material + form) with a potential concept by using a translucent shading material with almost the minimum effective percentage of transparency 5% is to establish a general estimation vision about using translucent material in future studies if the computational tools developed to process such concepts.

* Comparing the optimized custom shading system (glass+ opaque shading + form) with a conventional opaque shading system as a mixed type (south: horizontal shading devises (1M distance:1M depth)) and (west, east: vertical shading devises (1M distance:1M depth)) (see Figure 4.61.).

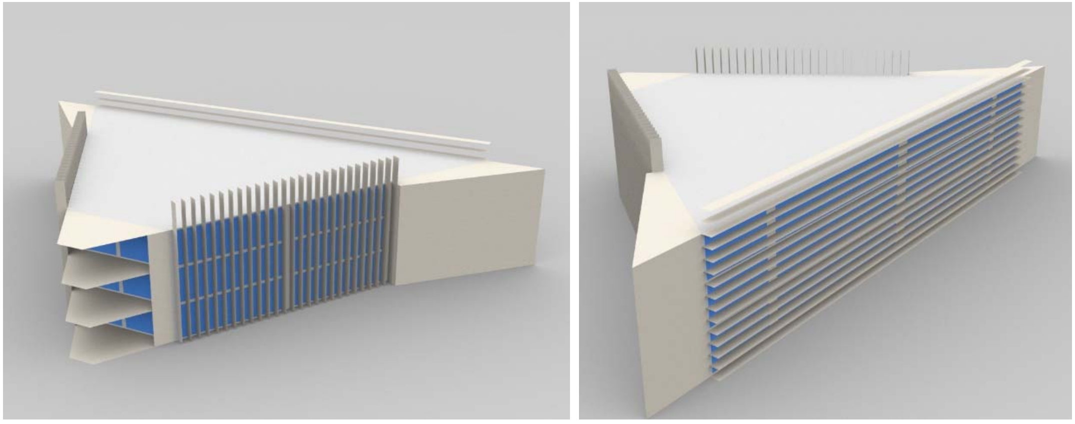


Figure 4.61. Conventional opaque shading system as a mixed type.

* The most important step, is the final comparison of the total energy conception between the building with just the glass type which worked already efficient with the shading system, and the building with the optimized custom shading system (chosen glass+ opaque shading + form).

▶ **Select the effective hot discomfort period: Adaptive comfort analysis**

ASHRAE 55-2013 Thermal environment stander for occupancy comfort which is one of the major comfort standers to evaluate the quality of the indoor environment presented, a number of concepts and factors to improve the thermal comfort within an indoor environment. So, the main factors of local thermal discomfort are: (Radiant temperature asymmetry, Draught, Vertical air temperature difference, Floor surface temperature). While, general thermal comfort determines based on Personal factors (Clothing, Activity) and Environmental Factors (Air temperature, Mean radiant temperature, Air velocity, Humidity). Therefore, the adaption in natural ventilated buildings requires Behavioral aspects (clothing, activity, posture) and Psychological aspects (expectations) (Olesen, 2004).

The adaptive comfort analysis is a calculation process based on certain weather data to measure the level of comfort times that occupants can adapt themselves to. Therefore, the adaptive comfort process built on the work of hundreds of field studies in which people in ventilated buildings were asked about how comfortable they were. Results showed that users can adapt themselves to the monthly mean temperature remained above 10 ˚C and below 33.5 ˚C (mostapharoudsari).

Selecting the effective hot discomfort period is an analytical step to measure the annual discomfort level inside the building with the chosen glass type (Trp LoE (e5=.1) Clr

3mm/13mm Air) which has the best potential of work efficiently if the shading system has applied. The analysis process of the adaptive comfort for the office building in the three selected cities presented a common, intersecting, effective hot discomfort times with a slight difference in the hot discomfort period ranges among the three cities.

The hot discomfort period spans from 09:00 until the 20:00. But, the effective hot discomfort period, which the shading can improve it positively, considered from (10:00 to 19:00) in Dubai and Baghdad. While Doha showed less hot discomfort time range which considered from (10:00 to 18:00). Therefore, the 09:00 o'clock from the morning has been neglected in each of the three cities due to the fact that it has an ineffective morning-sun position and also the annual discomfort period on this hour intersects with cold discomfort period at the wintertime. So, the shading system can affect the adaptive comfort level inside the office building negatively by adding extra heat loads (this issue has improved by extra simulations). While, the 20:00 o'clock period time (Dubai, Baghdad) has very small percentage (a couple of days) of the hot discomfort period and the sun with the set position, therefore it has been neglected. Moreover, Doha shows a different last effective hot discomfort period which is at 18:00.

Generally, adaptive comfort analysis and selecting the effective discomfort period can provide an estimation vision to initiate a concept for the HVAC systems by engineers. Also, it could prove the efficiency of the integrative shading units by increasing the comfort level significantly. Furthermore, it provides an approximate idea about the periods in which the building needs for shading.

▶ **Adaptive comfort analysis (Comparison)**

The office building model will be simulated to evaluate the adaptive comfort/discomfort percentage during the year. The adaptive comfort process conducts as follow:

* Simulate the office building firstly with only the glass type which worked already efficient with the shading system to evaluate the percentage of comfort and discomfort times.

* Simulate the office building secondly with both of (the chosen glass option and shading system). The glass is the choice which worked already efficient with the shading system. While, the shading system is the optimized custom shading system

(chosen glass+ opaque shading + form) to evaluate the percentage of comfort and discomfort times.

* The final comparison of the Percentage of time comfortable between the building with the chosen glass type only, and the building with the optimized custom shading system (chosen glass+ opaque shading + form).

▶ **Daylight Autonomy (comparison)**

The Daylight Autonomy is a calculation process conducting in a certain location (based on weather data) to measure the effectiveness level of the daylight autonomy which is defined as "a percentage of the time during the active occupancy hours that the test point receives more daylight than the illuminance threshold". Daylight analysis depends on the three main parts of the daylight autonomy which are divides usually as:

* Daylight illuminance Less_100: Percentage of time during the active occupancy hours that the test point receives less than 100 lux.

*Useful Daylight illuminance 100_2000: Percentage of time during the active occupancy hours that the test point receives between 100 and 2000 lux.

*Useful Daylight illuminance more 2000: Percentage of time during the active occupancy hours that the test point receives more than 2000 lux.

The three classification parts determine the level of daylight autonomy efficiency. Thus, determine the level of using artificial lights inside the building which affect the integrated energy consumption (mostapharoudsari).

In general, the office building as a simulation model is defined as follows:

* defined the office building and generate the test point grid which is done by (1 distance meter) size and 6 sensor points distributed through the plan.

* the test point grid generated on (0.75 meter) heights due to the fact that the activity level is on the 0.75m heights from the ground.

* the illuminance threshold for the daylight autonomy calculation considered as 300lux.

* simulate the building after applying the chosen glass type on the building (glazing system) with no shading.

* simulate the building with the optimized custom shading system (chosen glass+ opaque shading + form).

* simulate the building with the translucent shading system (chosen glass+ translucent shading + form) to establish a general estimation vision for future studies about using translucent material with almost the minimal effective percentage of transparency 5 % VLT and how influences the daylight autonomy.

* comparison process to evaluate the daylight loss after applying the shading systems.

CHAPTER 5

RESULTS

In general, the improvement process methodology includes three case studies as potential hot cities which are (Dubai, Baghdad, Doha). The improvement process methodology comprises a number of analysis steps to get many determination factors and make the decision more accurate.

5.1. First case study: Dubai

Dubai is the most populous city of the United Arab Emirates. The climate of Dubai is subtropical desert with very mild or nicely warm winter, and extremely hot summer combines with high level of humidity. Based on the Köppen Climate Classification subtype for this climate is "Bwh". (Tropical and Subtropical Desert Climate) (Weatherbase, n.d.).

Temperature analysis

In Dubai, the minimum temperature average is in January with 19c. While, the maximum temperature average is in August with 36˚C. SO, the general average temperatures during the year show that Dubai is a hot city (see Figure 5.1.).

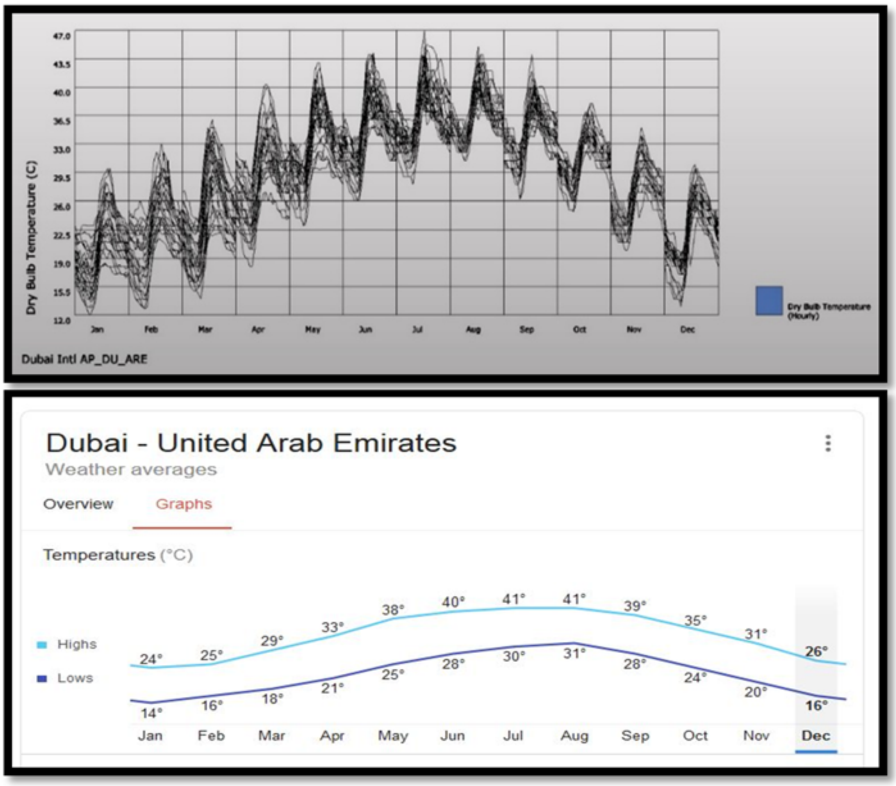


Figure 5.1. Dubai_ Temperature analysis

Humidity Analysis

Humidity analysis which conducted by Ladybug plugin, shows that Dubai has a dominant humid period during the year with a very short dry period in the mid-day hours. The blue colors symbolize the dry periods during the year. While the red and yellow (and the range between) symbolize the periods with high levels of humidity during the year. So, the general ratio (humid: dry) shows that Dubai city has very long humid periods in comparison with the dry periods. And that make Dubai a humid city (see Figure 5.2.).

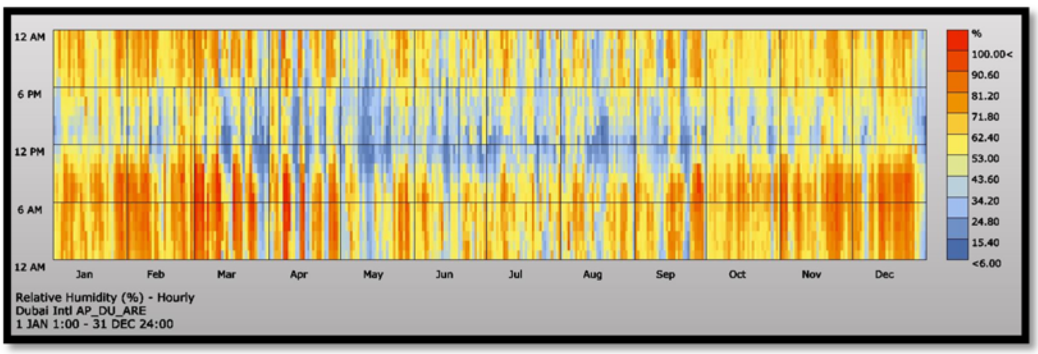


Figure 5.2. Dubai_ Humidity Analysis

Radiation Analysis

While, the radiation level in Dubai is high, which starts with the morning hours and continues until the sunset (see Figure 5.3.). The evaluation process by taking the Average of the Global Horizontal Radiation during the daytime in Dubai is **474.37 (Wh/ m^2).**

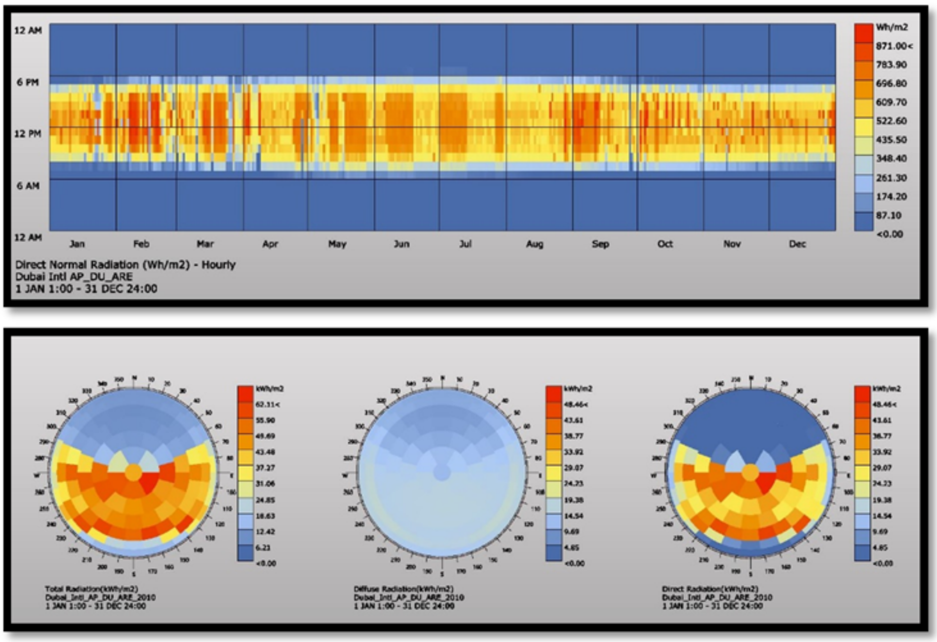


Figure 5.3. Dubai_ Radiation Analysis

Wind profile

The wind profile in Dubai has constant winds with different speed levels. There are multiple dominant directions of winds (south, west, northwest, and east with less effectivity). While, the wind velocity based on height, shows low average speeds. Yet, the wind directions of Dubai serve the potential purposes of the reference building design for this research. But, the wind velocity based on height is not sufficient for the main wind turbines which require (3.5 m/s) average at minimum to generate electricity (see Figure 5.4.). However, the Micro wind turbines system could work with relatively lower averages of wind speeds. So far, the evaluation process of the city will be conducted using (Table 5.1.) compared to the general evaluation process of wind profile (see Table 4.2.).

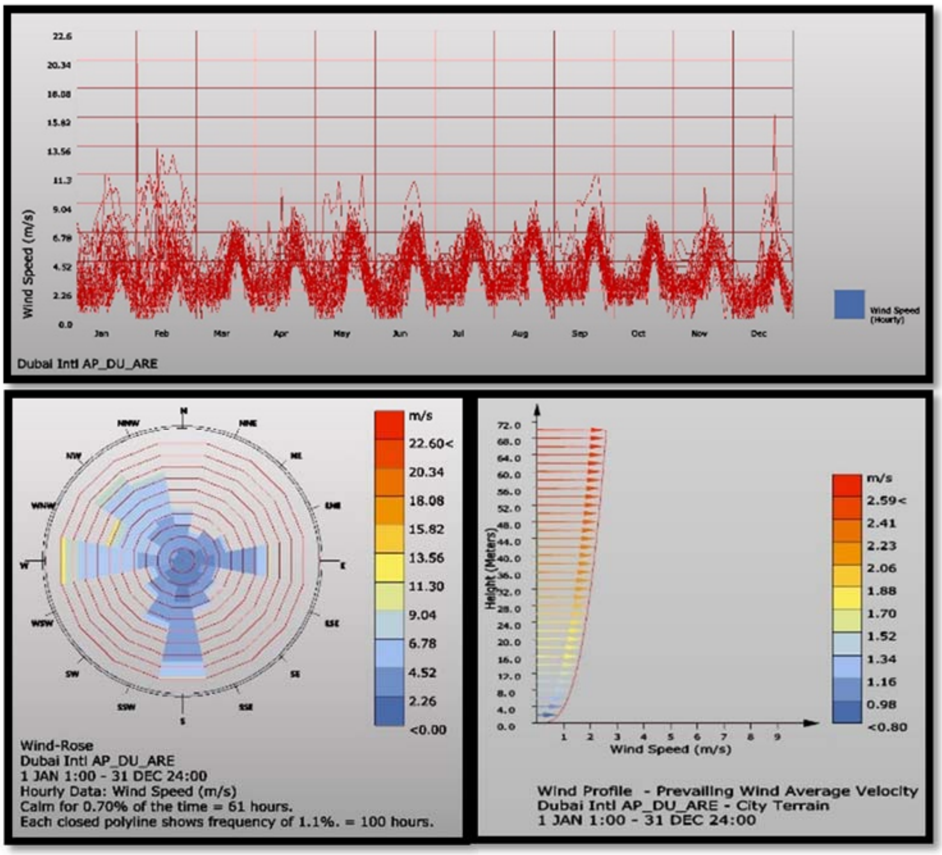


Figure 5.4. Dubai_ Wind profiles

Table 5.1. The evaluation process of wind profile_ Dubai.

1	Wind directions based on reference Building design				The height with Average Wind speeds 3.5 m/s	Evaluation
	South	**East** E- SE -NE	**West** W-SW-NW	**North**		
	High	Medium	High	Low	Unknown	The Lowest potential
	The wind directions fit the reference building design				Below the average speed required	

Integrated Energy-Daylight improvement process

The process of the Integrated Energy-Daylight improvement in Dubai shows:

* The first best glass type using for the office building with no shading system is the (Double Blue 6mm/13mm Air). While, the (TripleLowE(e5=.1) Clear3mm/13mmAir) is second. And the (Double Clear 3mm/13mm Air) comes third.

* The (TripleLowE(e5=.1) Clear3mm/13mmAir) is the best glass option could work efficient with the custom opaque shading system.

* Shading form optimized in Dubai with 0.3m depth of the concave hexagonal units' form.

* The optimized shading system (glass+ shading material + form) with a potential concept by using a translucent shading material showed some effectivity by improving lights load.

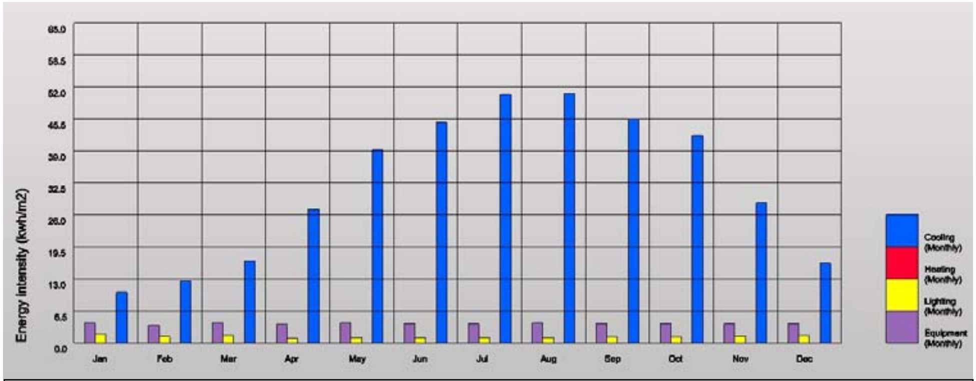
* Comparing the optimized custom shading system (glass+ opaque shading + form) with a conventional shading system showed that the custom shading system is much better than the conventional shading system.

* The final comparison which is used as a determination factor, between the building with just the glass type which worked already efficient with the shading system (TripleLowE(e5=.1) Clear3mm/13mmAir), and the building with the optimized custom shading system ((TripleLowE(e5=.1) Clear3mm/13mmAir) + opaque shading + form 0.3m), has showed (444.78 – 333.11 = 111.67 kwh /m^2) shading benefit (see Figure 5.5.) & (see Table 5.2.).

Table 5.2. Integrated Energy-Daylight improvement process _ Dubai.

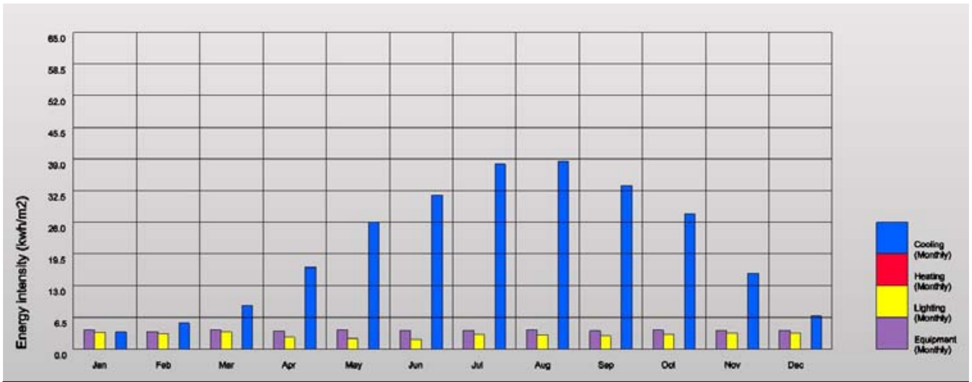
1		Glazing And Shading			analysis period	Cooling	heating	lighting	equipment	Total (KWh/m^2)
Improvement process	Glazing material	Single clear glass 6mm		No shading	Months: 1 to 12 Time: 1 to 24	451.175541	0.023172	12.949509	46.524914	510.673136 (forth best glazing result)
		Double Clear 3mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	431.686944	0.000978	13.570701	46.524914	491.783538 (third best glazing result)
		Double Blue 6mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	355.13877	0.008118	19.889331	46.524914	421.561134 (first best glazing result)
		TripleLowE(e5=.1)Clear3mm/13mmAir		No shading	Months: 1 to 12 Time: 1 to 24	383.737416	0.000000	14.523234	46.524914	444.785565 (second best glazing result)
	shading system	Full Shading --- Opaque:	Double Clear 3mm/13mm Air		Months: 1 to 12 Time: 1 to 24	264.915525	0.06789	33.460584	46.524914	344.968914
			Double Blue 6mm/13mm Air		Months: 1 to 12 Time: 1 to 24	265.618251	0.08868	40.904199	46.524914	353.136045
			TripleLowE(e5=.1)Clear3mm/13mmAir		Months: 1 to 12 Time: 1 to 24	256.143369	0.022791	38.501628	46.524914	341.192703 (Best system)
	Shading form	TripleLowE(e5=.1) Clear3mm/13mmAir	Full Shading --- Opaque:	Concave hexagon (3.28 degree) (0.1 m depth)	Months: 1 to 12 Time: 1 to 24	254.808411	0.022818	37.245117	46.524914	338.601261
				Concave hexagon (6.54 degree) (0.2 m depth)	Months: 1 to 12 Time: 1 to 24	252.207753	0.023025	34.619445	46.524914	333.375138
				Concave hexagon (9.76 degree) (0.3 m depth)	Months: 1 to 12 Time: 1 to 24	252.062967	0.023178	34.500612	46.524914	333.111672 (Best form)
				Concave hexagon (12.92 degree) (0.4 m depth)	Months: 1 to 12 Time: 1 to 24	252.126639	0.023247	34.675386	46.524914	333.350187
Notes		The next steps are for comparing with other concepts **to establish a general estimation vision about the integrative shading system with the minimal level of work efficiency. Which mean that the design can work more efficient with the potential concepts designed but cannot proved with the current ability level of computational tools.**								

Transparency	**Shading Material**	**TripleLowE(e5=.1)Clear3mm/13mmAir**	**Full Shading --- Concave hexagon (9.76 degree) (0.3 m**	**Translucent Material 5 % VLT DT,ST 0.05 Refl 0.70**	**Months: 1 to 12 Time: 1 to 24**	------------	------------	**30.435384**	---------------	----------------
		This step is to establish a general estimation vision for future studies about using translucent material with almost the minimal effective percentage of transparency 5 % VLT and how influences the artificial light load (neglects the radiation amounts pass through the translucent material due to the Energyplus limitations). (*DT is the diffuse transmission , ** ST is the specular transmission)								
Comparison	**Conventional Shading**	**TripleLowE(e5=.1)Clear3mm/13mmAir**	**Full Shading --- Opaque:**	**Mixed** South: Horizontal East: vertical west: vertical (1M distance: 1M depth).	**Months: 1 to 12 Time: 1 to 24**	**285.995601**	**0.002007**	**22.871277**	**46.524914**	**355.3938**01
The benefit from shading TripleLowE(e5=.1)Clear3mm/13mmAir (without shading-with shading)					**444.78 – 333.11 = 111.67 kwh**/m^2					



Dubai__ 1 Jan To 31 Dec : No shading _ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 444.78 (kwh/m^2)



Dubai__ 1 Jan To 31 Dec: Full shading _ Concave hexagon 0.3_Opaque_ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 333.11(kwh/m^2)

Figure 5.5. Total Energy Consumption Charts _ glazing with/without shading _ Dubai

Select the effective hot discomfort period: Adaptive comfort analysis

For Dubai;

The hot discomfort period in Dubai generally spans from 09:00 until the 20:00. But, the effective hot discomfort period, which the shading can improve it positively, considered from 10:00 to 19:00 (see Figure 5.6.).

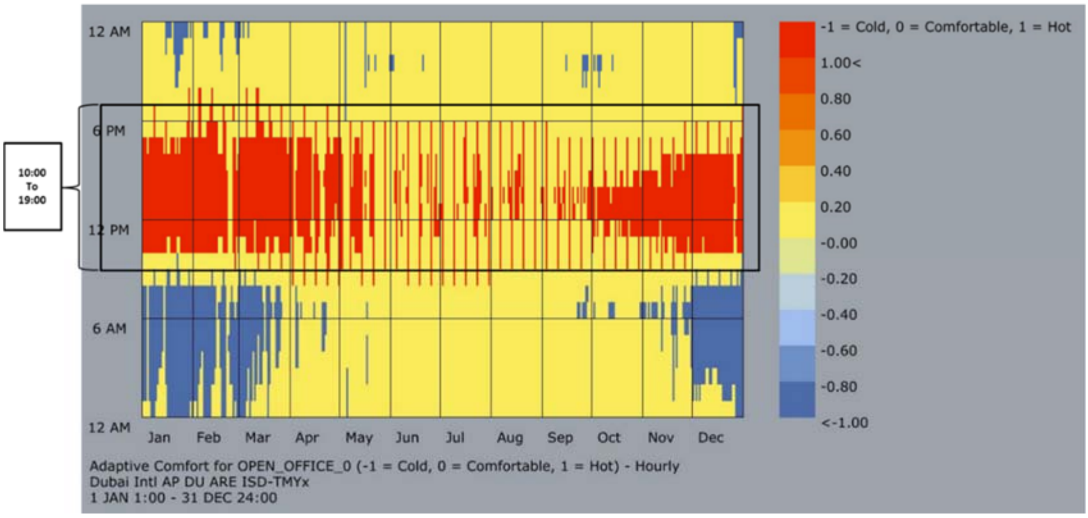


Figure 5.6. Dubai_ Discomfort period: annule analysis_Trp LoE (e5=.1) Clr 3mm/13mm Air - No shading

Adaptive comfort analysis (Comparison)

The process of the Adaptive comfort analysis during (10:00-19:00) period in Dubai shows an improvement in the time comfortable percentage which is increased significantly from 56.76% when the office building with the chosen glass type (Trp LoE (e5=.1) Clr 3mm/13mm Air), to 91.23% when the office building with the optimized custom shading system (chosen glass+ opaque shading + form) (see Figure 5.7.) and (Table 5.3.).

Table 5.3. Adaptive comfort analysis _ Dubai.

1	**Glazing and Shading**	**Analysis period**	**Percentage Of time comfortable**	**Percentage of Time too hot or too cold**
No shading	TripleLowE(e5=.1) Clear3mm/13mmAir	Annual (10:00-19:00)	56.767123%	43.232877%
TripleLowE(e5=.1) Clear3mm/13mmAir	**Full shading** **---** **Concave hexagon** **(9.76 degree)** **(0.3m depth)**	Annual (10:00-19:00)	91.232877%	8.767123%
Adaptive Comfort advantage after applying shading and glazing systems		91.23 % - 56.76% = **34.47 %** TripleLowE(e5=.1)Clear3mm/13mmAir Percentage of time comfortable (with shading-without shading)		

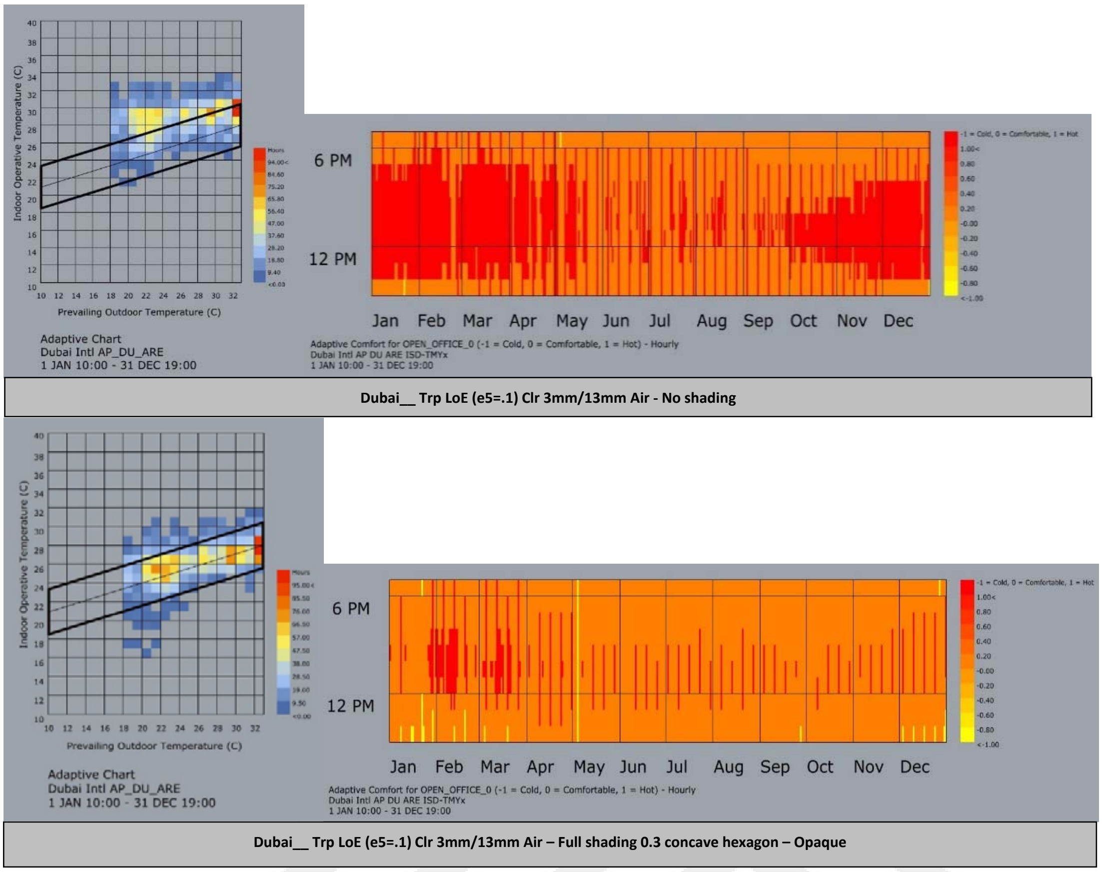


Figure 5.7. Comparison of the Adaptive Comfort Percentage Charts_glazing with/without shading_Dubai

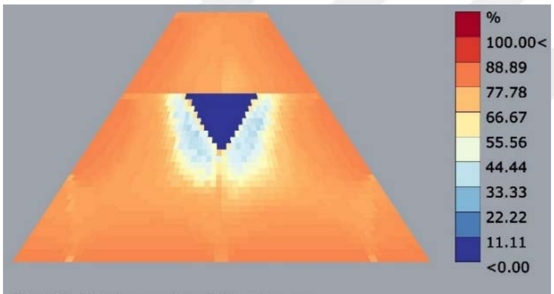
Daylight Autonomy (comparison)

For Dubai,

The results show that the daylight autonomy has decreased from 66.92% (Trp LoE (e5=.1) Clr 3mm/13mm Air) to 37.18% after applying the optimized custom shading system (chosen glass+ opaque shading + form). While, changing the opaque material to translucent material with just 5% VLT increase the daylight autonomy to 44.16% (see Figure 5.8.) and (Table 5.4.).

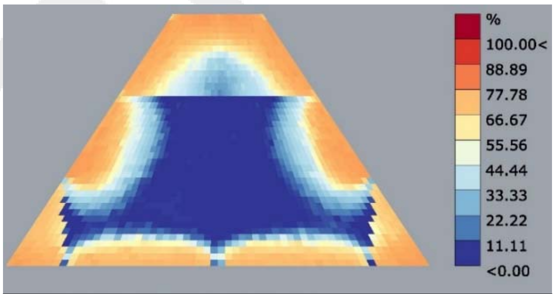
Table 5.4. Daylight Autonomy analysis _ Dubai.

1	Shading and Glazing	analysis period	Daylight percentage less 100LUX	Useful Daylight percentage between 100-2000LUX	Daylight percentage more 2000LUX	Daylight autonomy The percentage of receiving light more than the illumines threshold
No shading	TripleLowE(e5=.1) Clear3mm/13mmAir	Months: 1 to 12 Time: 1 to 24	27.96875 %	47.703571 %	24.288839 %	66.921429 %
Full shading Concave hexagon (9.76 degree) (0.3m depth) ---- Trp LoE (e5=.1) Clr 3mm/13mm Air	Opaque Material	Months: 1 to 12 Time: 1 to 24	43.1625 %	50.678571 %	6.15 %	37.183036 %
	Translucent Material 5% VLT DT,ST 0.05 Refl 0.70	Months: 1 to 12 Time: 1 to 24	37.032589 %	55.304911 %	7.653125 %	44.167857 %
Daylight Loss		Opaque shading material	37.18 % - 66.92 % = **- 29.74 % (loss)**			
		Translucent Material VLT0.05	44.16 % - 66.92 % = **- 22.76 % (loss)**			



Dubai__ Annual Daylight Autonomy:

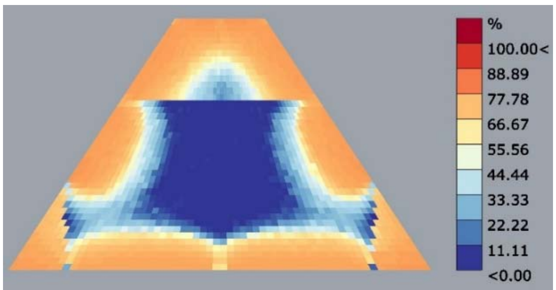
No shading _ Trp LoE (e5=.1) Clr 3mm/13mm Air



Dubai__ Annual Daylight Autonomy:

Full shading _Concave hexagon 0.3 Depth _ Opaque _

Trp LoE (e5=.1) Clr 3mm/13mm Air



Dubai__ Annual Daylight Autonomy:

Full shading _Concave hexagon 0.3 Depth _ Translucent VLT 0.05_Trp LoE (e5=.1) Clr 3mm/13mm Air

Figure 5.8. Comparison Charts of the Daylight Autonomy Analysis_Dubai

5.2. Second case study: Baghdad

Baghdad is the most populous city of the Iraq. The climate of Baghdad is subtropical desert with cold winter, and extremely hot summer. Based on Köppen Classification Baghdad is: Tropical and Subtropical Desert Climate (Weatherbase, n.d.).

Temperature Analysis

In Baghdad, the minimum temperature average is in January with 10 ˚C. While, the maximum temperature average is in July with 35˚C. SO, the general average temperatures during the year show that Baghdad is a hot summer and cold winter (see Figure 5.9.).

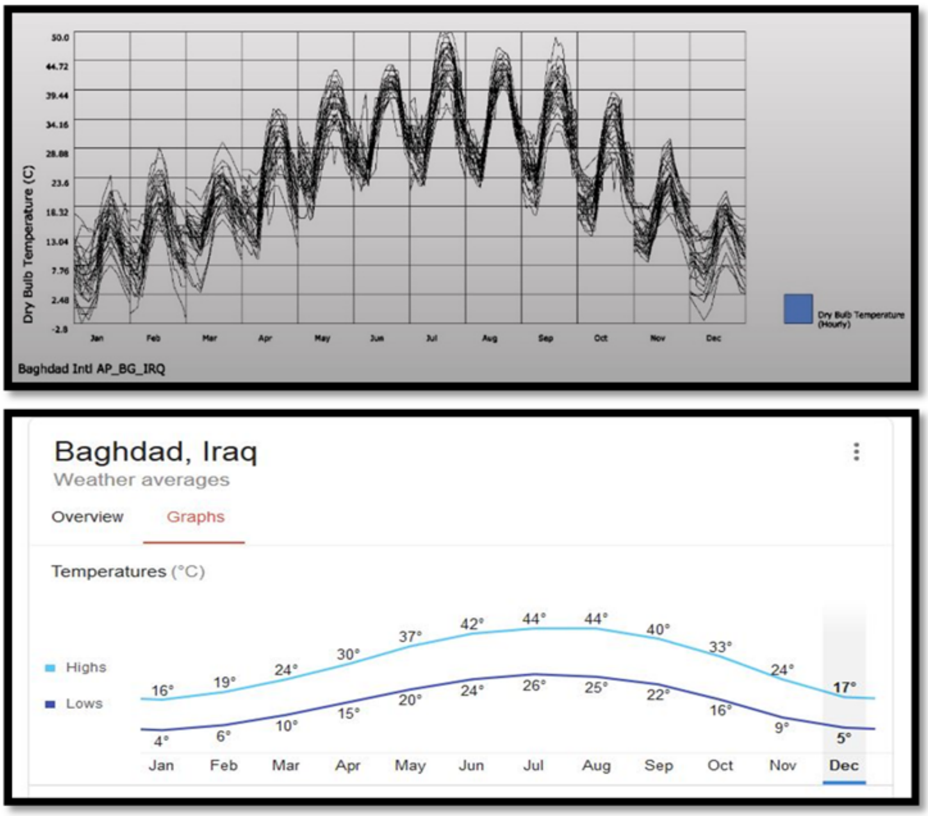


Figure 5.9. Baghdad_Temperature analysis

Humidity Analysis

Humidity analysis which conducted by Ladybug plugin, showed that Baghdad has a long dry period epically at summer with shorter humid periods in winter. The blue colors symbolize the dry periods during the year. While the red and yellow (and the range between) symbolize the periods with high levels of humidity during the year. So, the general ratio (humid: dry) shows that Baghdad city has long dry periods in comparison with the humid periods. And that make Baghdad a dry city (see Figure 5.10.).

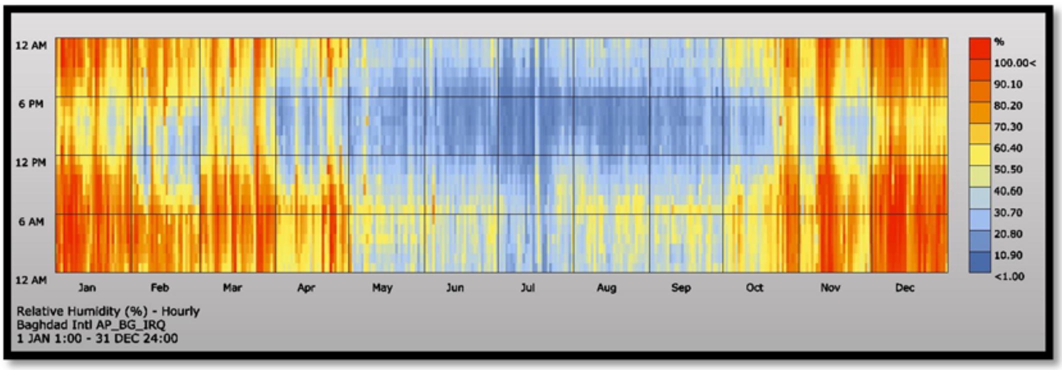


Figure 5.10. Baghdad_Humidity Analysis.

Radiation Analysis

While, the radiation level in Baghdad is high, which starts which starts with the morning hours and continues until the sunset (see Figure 5.11.). The evaluation process by taking the Average of the Global Horizontal Radiation during the daytime in Baghdad is **461.48 (Wh/ m^2).**

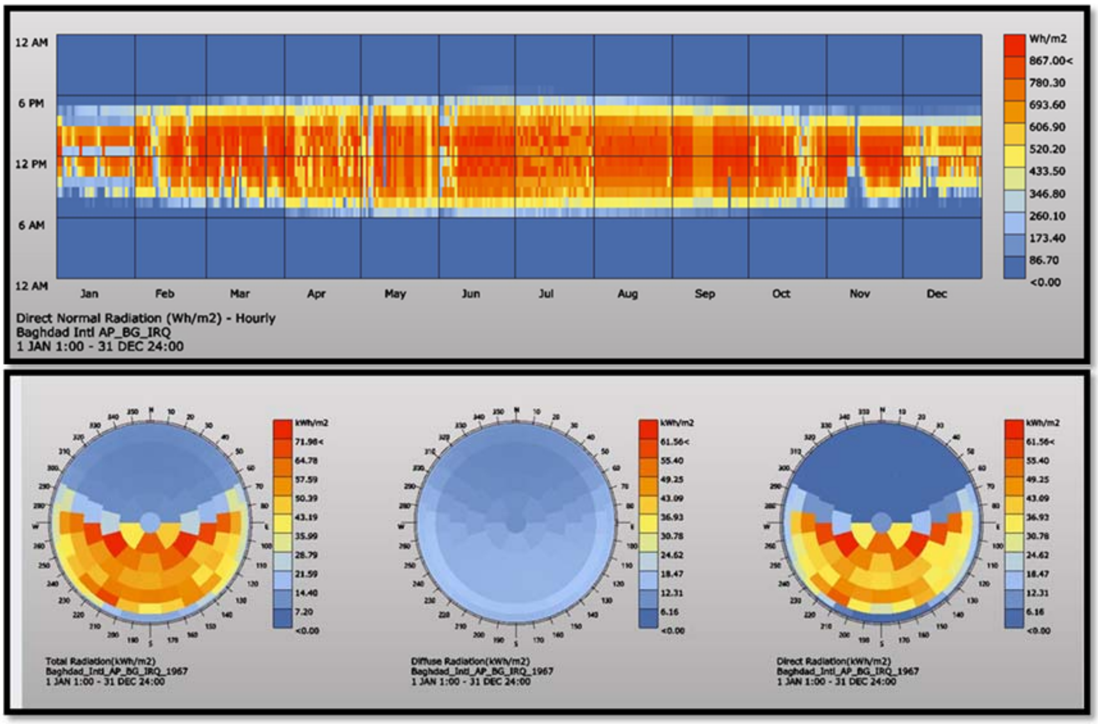


Figure 5.11. Baghdad_Radiation Analysis.

Wind profile

The wind profile in Bagdad has constant winds with different speed levels. The dominant directions of winds are (northwest, north, and west with less effectivity also south with very low percent). While, the wind velocity based on heights, shows (3.5m/s) average speed on 55m height. Yet, the wind directions of Baghdad between the (west until North) serve the potential purposes of the reference building design for this research. And, the wind velocity based on height is sufficient for the main wind turbines above the 55m height, which require (3.5 m/s) average at minimum to generate electricity (see Figure 5.12.). However, the Micro wind turbines system could work with relatively lower averages of wind speeds. So far, the evaluation process of the city will be conducted using (Table 5.5) compared to the general evaluation process of wind profile (see Table 4.2.).

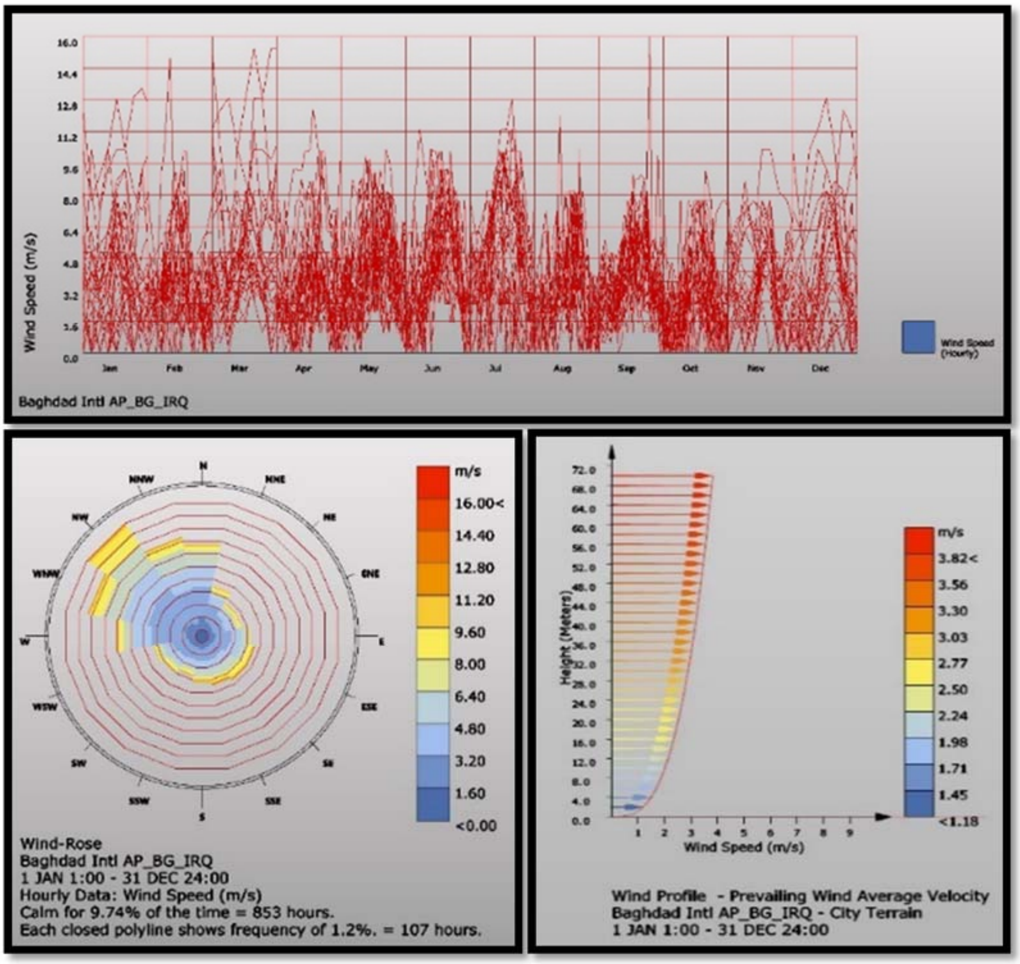


Figure 5.12. Baghdad _Wind profiles

Table 5.5. The evaluation process of wind profile_ Baghdad.

2	Wind directions based on reference Building design				The height with Average Wind speeds 3.5 m/s	Evaluation
	South	**East** E- SE -NE	**West** W-SW-NW	**North**		
	Low	Medium	High	Medium	55 meter and above	
	The west, east, wind fit the reference building design. While, the south wind is low. And the north wind is a bit higher than the optimum situation				The integrative shading units on 55m height and above can work as main wind turbines	**The medium**

Integrated Energy-Daylight improvement process

The process of the Integrated Energy-Daylight improvement in Baghdad shows:

* The first best glass type using for the office building with no shading system is the (Double Blue 6mm/13mm Air). While, the (TripleLowE(e5=.1) Clear3mm/13mmAir) is the second. And the (Double Clear 3mm/13mm Air) comes third.

* The (TripleLowE(e5=.1) Clear3mm/13mmAir) is the best glass option could work efficient with the custom opaque shading system.

* Shading form optimized in Baghdad with 0.2m depth of the concave hexagonal units' form.

* The optimized shading system (glass+ shading material + form) with a potential concept by using a translucent shading material showed some effectivity by improving lights load.

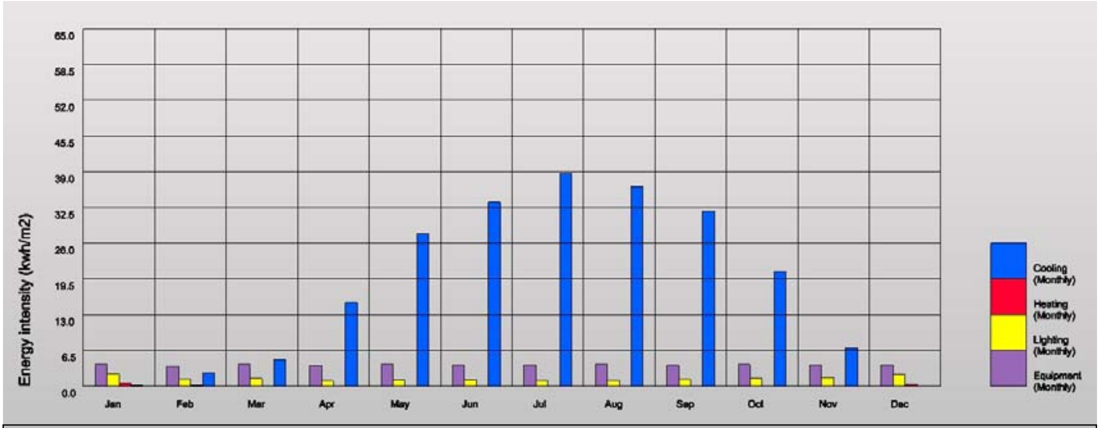
* Comparing the optimized custom shading system (glass+ opaque shading + form) with a conventional shading system showed that the custom shading system is much better than the conventional shading system.

* The final comparison which is used as a determination factor, between the building with just the glass type which worked already efficient with the shading system (TripleLowE (e5=.1) Clear3mm/13mmAir), and the building with the optimized custom shading system ((TripleLowE(e5=.1) Clear3mm/13mmAir) + opaque shading + form 0.3m), has showed (282.57 – 215.37 = 67.2 kwh /m^2) shading benefit (see Table 5.6.) and (see Figure 5.13.).

Table 5.6. Integrated Energy-Daylight improvement process _ Baghdad.

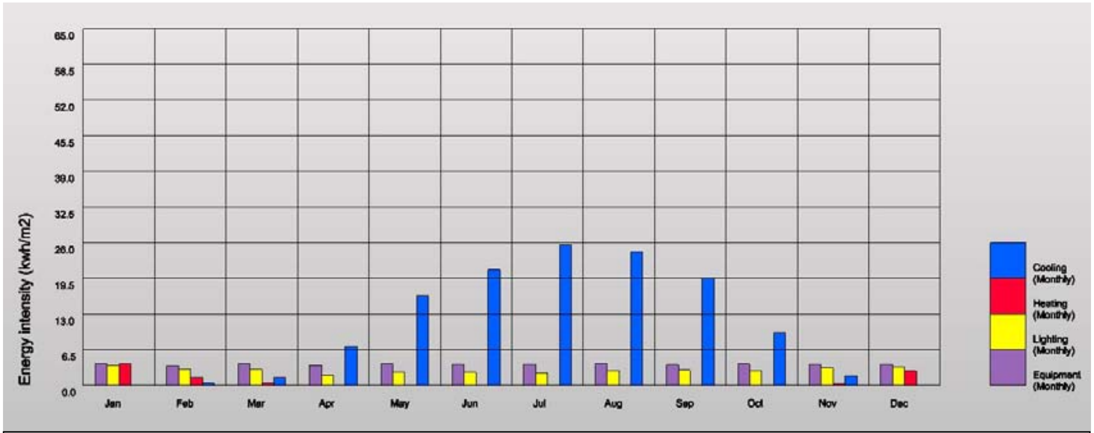
2		Glazing And Shading			analysis period	Cooling	heating	lighting	equipment	Total (KWh/m²)
Improvement process	Glazing material	Single clear glass 6mm		No shading	Months: 1 to 12 Time: 1 to 24	269.067539	5.505036	14.322092	46.524914	**335.419581** **(forth best glazing result)**
		Double Clear 3mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	253.402623	2.3187	14.867925	46.524914	**317.114163** **(third best glazing result)**
		Double Blue 6mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	195.747003	4.50966	20.938188	46.524914	**267.719766** **(first best glazing result)**
		TripleLowE(e5=.1)Clear3mm/13mmAir		No shading	Months: 1 to 12 Time: 1 to 24	218.356089	1.139571	16.553313	46.524914	**282.573887** **(second best glazing result)**
	shading system	Full Shading --- Opaque:	Double Clear 3mm/13mm Air		Months: 1 to 12 Time: 1 to 24	135.805413	12.814977	32.596761	46.524914	**227.742066**
			Double Blue 6mm/13mm Air		Months: 1 to 12 Time: 1 to 24	136.793112	13.490298	39.452838	46.524914	**236.261163**
			TripleLowE(e5=.1) Clear3mm/13mmAir		Months: 1 to 12 Time: 1 to 24	129.611265	8.53788	36.614547	46.524914	**221.288607** **(Best system)**
	Shading form	TripleLowE(e5=.1) Clear3mm/13mmAir	Full Shading --- Opaque:	Concave hexagon (3.28 degree) (0.1 m depth)	Months: 1 to 12 Time: 1 to 24	129.179103	8.507022	36.174195	46.524914	**220.385235**
				Concave hexagon (6.54 degree) (0.2 m depth)	Months: 1 to 12 Time: 1 to 24	127.040841	8.645745	33.159474	46.524914	**215.370976** **(Best form)**
				Concave hexagon (9.76 degree) (0.3 m depth)	Months: 1 to 12 Time: 1 to 24	**126.978228**	**8.69391**	**33.460584**	46.524914	**215.657637**
				Concave hexagon (12.92 degree) (0.4 m depth)	Months: 1 to 12 Time: 1 to 24	127.613754	8.644224	34.499841	46.524914	**217.282734**
Notes		The next steps are for comparing with other concepts **to establish a general estimation vision about the integrative shading system with the minimal level of work efficiency. Which mean that the design can work more efficient with the potential concepts designed but cannot proved with the current ability level of computational tools.**								

Transparency	**Shading Material**	**TripleLowE(e5=.1)Clear3mm/13mmAir**	**Full Shading --- Concave hexagon (9.76 degree) (0.3 m**	**Translucent Material 5 % VLT DT,ST 0.05 Refl 0.70**	**Months: 1 to 12 Time: 1 to 24**	------------	------------	**29.34537**	---------------	----------------
		This step is to establish a general estimation vision for future studies about using translucent material with almost the minimal effective percentage of transparency 5 % VLT and how influences the artificial light load (neglects the radiation amounts pass through the translucent material due to the Energyplus limitations). (*DT is the diffuse transmission , ** ST is the specular transmission)								
Comparison	**Conventional Shading**	**TripleLowE(e5=.1)Clear3mm/13mmAir**	**Full Shading --- Opaque:**	**Mixed** South: Horizontal East: vertical west: vertical (1M distance: 1M depth).	**Months: 1 to 12 Time: 1 to 24**	148.440675	4.331295	22.63571	46.524914	**221.932594**
The benefit from shading TripleLowE(e5=.1)Clear3mm/13mmAir (without shading-with shading)					282.57 – 215.37 = **67.2 kwh/m^2**					



Baghdad__ 1 Jan To 31 Dec: No shading _ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 282.57 (kwh/m^2)



Baghdad__ 1 Jan To 31 Dec: Full shading _ Concave hexagon 0.2_Opaque_ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 215.37 (kwh/m^2)

Figure 5.13. Total Energy Consumption Charts _ glazing with/without shading _ Baghdad.

Select the effective hot discomfort period: Adaptive comfort analysis

For Baghdad;

The hot discomfort period in Baghdad generally spans from 09:00 until the 20:00. But, the effective hot discomfort period, which the shading can improve it positively, considered from 10:00 to 19:00 (see Figure 5.14.).

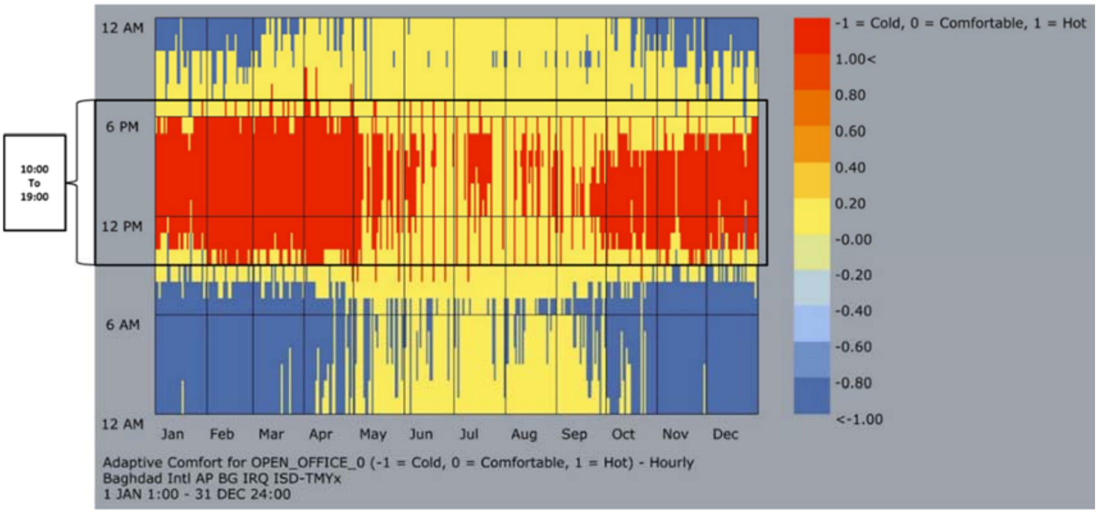


Figure 5.14. Baghdad _ Discomfort period: annule analysis_Trp LoE (e5=.1) Clr 3mm/13mm Air - No shading.

Adaptive comfort analysis (Comparison)

The process of the Adaptive comfort analysis during (10:00-19:00) period in Baghdad shows an improvement in the time comfortable percentage which is increased significantly from 43.06% when the office building with the chosen glass type (Trp LoE (e5=.1) Clr 3mm/13mm Air), to 80.30% when the office building with the optimized custom shading system (chosen glass+ opaque shading + form) (see Table 5.7.) and (see Figure 5.15.).

Table 5.7. Adaptive comfort analysis _ Baghdad.

2	**Glazing and Shading**	**Analysis period**	**Percentage Of time comfortable**	**Percentage of Time too hot or too cold**
No shading	TripleLowE(e5=.1) Clear3mm/13mmAir	Annual (10:00-19:00)	43.068493 %	56.931507 %
TripleLowE(e5=.1) Clear3mm/13mmAir	**Full shading** --- **Concave hexagon (9.76 degree) (0.2m depth)**	Annual (10:00-19:00)	80.30137 %	19.69863 %
Adaptive Comfort advantage after applying shading and glazing systems		80.30% - 43.06% = **37.42 %** TripleLowE(e5=.1)Clear3mm/13mmAir Percentage of time comfortable (with shading-without shading)		

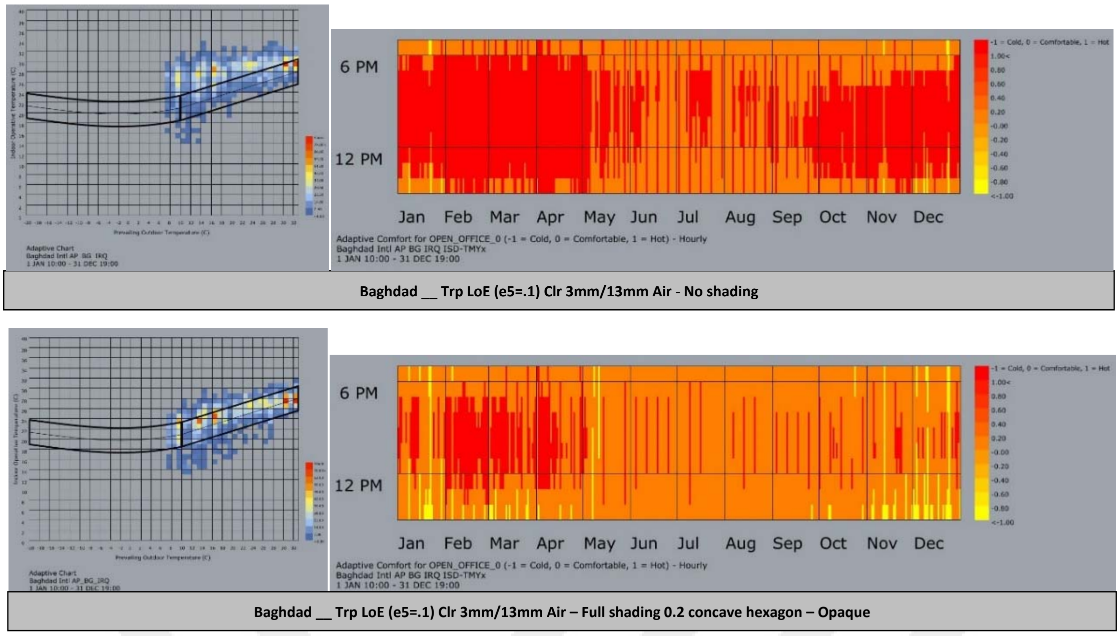


Figure 5.15. Comparison of the Adaptive Comfort Percentage Charts _ glazing with/without shading _ Baghdad.

Daylight Autonomy (comparison)

For Baghdad,

The results show that the daylight autonomy has been decreased from 65.58 % (Trp LoE (e5=.1) Clr 3mm/13mm Air) to 36.61% after applying the optimized custom shading system (chosen glass+ opaque shading + form). While, changing the opaque material to translucent material with just 5% VLT increase the daylight autonomy to 43.75% (see Table 5.8.) and (see Figure 5.16.).

Table 5.8. Daylight Autonomy analysis _ Baghdad.

2 Shading and Glazing		analysis period	Daylight percentage less 100LUX	Useful Daylight percentage between 100-2000LUX	Daylight percentage more 2000LUX	Daylight autonomy The percentage of receiving light more than the illumines threshold
No shading	TripleLowE (e5=.1) Clear3mm/ 13mmAir	Months: 1 to 12 Time: 1 to 24	29.18125%	48.348214 %	22.129018 %	65.587054 %
Full shading Concave hexagon (9.76 degree) (0.3m depth) ---- Trp LoE (e5=.1) Clr 3mm/13mm Air	Opaque Material	Months: 1 to 12 Time: 1 to 24	44.295089%	48.660714 %	7.034375 %	36.616518 %
	Translucent Material 5% VLT DT,ST 0.05 Refl 0.70	Months: 1 to 12 Time: 1 to 24	38.076786%	53.554464 %	8.367857 %	43.75625 %
Daylight Loss		Opaque shading material	36.61 % - 65.58 % = - **28.97 %** (loss)			
		Translucent Material VLT0.05	43.75 % - 65.58 % = - **21.83 %** (loss)			

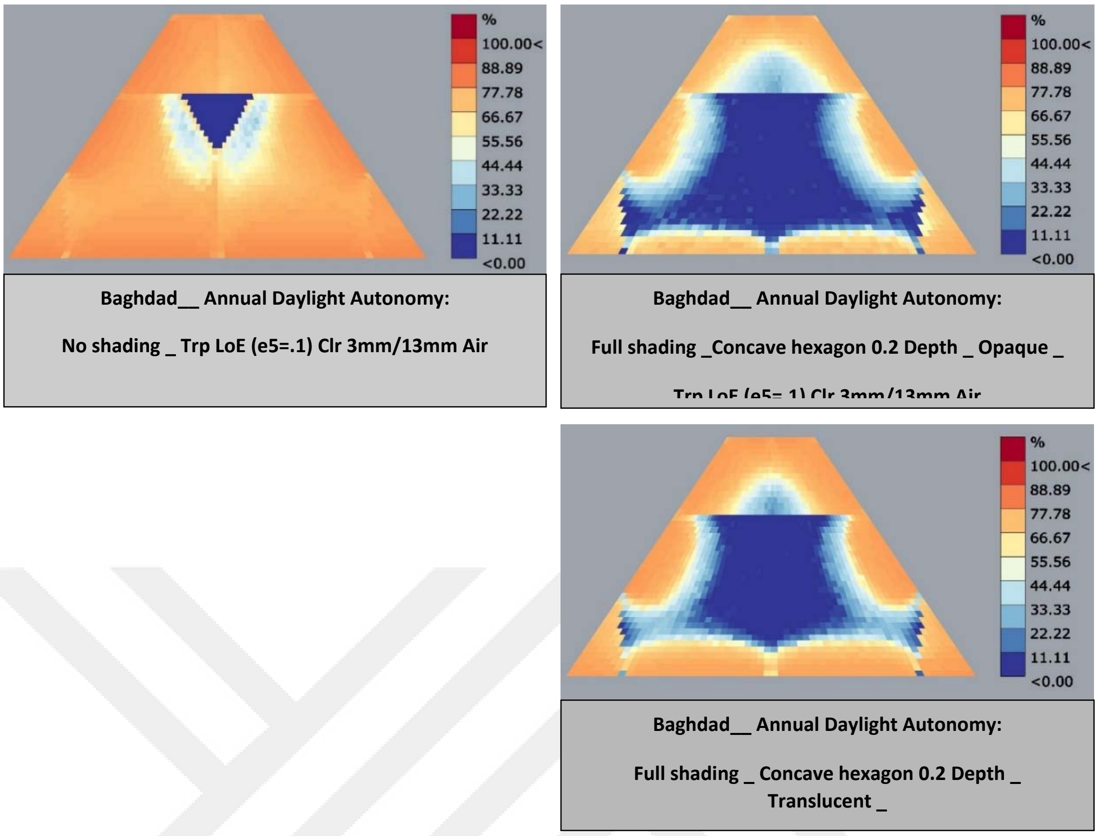


Figure 5.16. Comparison Charts of the Daylight Autonomy Analysis_ Baghdad

5.3. Third case study: Doha

Doha is the most populous city of Qatar. The climate of Doha is subtropical desert with very mild or nicely warm winter, and extremely hot summer combines with high level of humidity.

Based on Köppen Classification Doha is: Tropical and Subtropical Desert Climate (Weatherbase, n.d.).

Temperature Analysis

In Doha, the minimum temperature average is in January with 18 ˚C. While, the maximum temperature average is in July with 36.5 ˚C. SO, the general average temperatures during the year show that Doha is a hot (see Figure 5.17.).

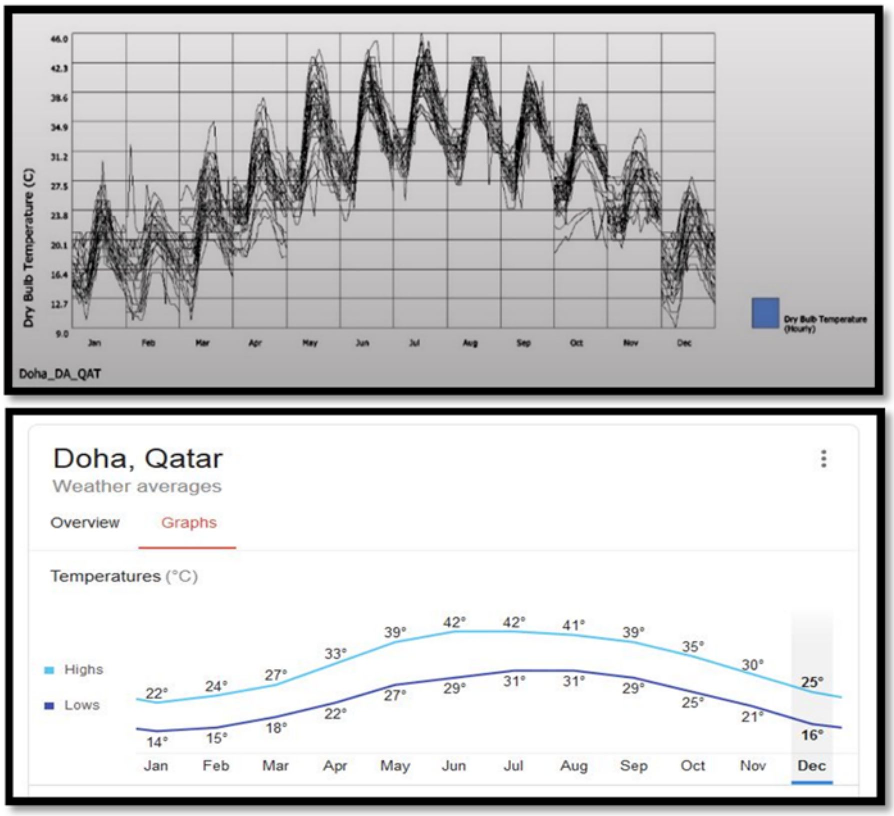


Figure 5.17. Doha_ Temperature analysis

Humidity Analysis

Humidity analysis which conducted by Ladybug plugin, showed that Doha has a dominant humid period during the year with a very short dry period in summer. The blue colors symbolize the dry periods during the year. While the red and yellow (and the range between) symbolize the periods with high levels of humidity during the year. So, the general ratio (humid: dry) shows that Doha city has long humid periods in comparison with the dry periods. And that make Doha a humid city (see Figure 5.18.).

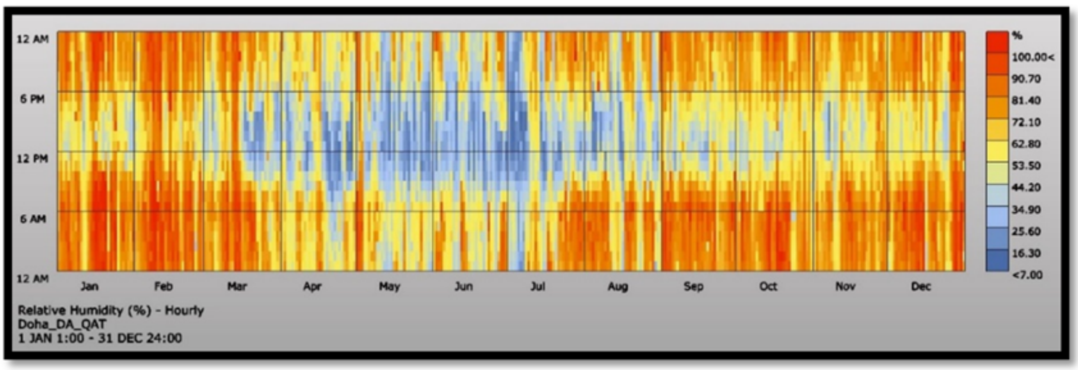


Figure 5.18. Doha_ Humidity Analysis.

Radiation Analysis While, the radiation level in Doha is high, which starts which starts with the morning hours and continues until the sunset (see Figure 5.19.). The evaluation process by taking the Average of the Global Horizontal Radiation during the daytime in Doha is **497.25 (Wh/ m²).**

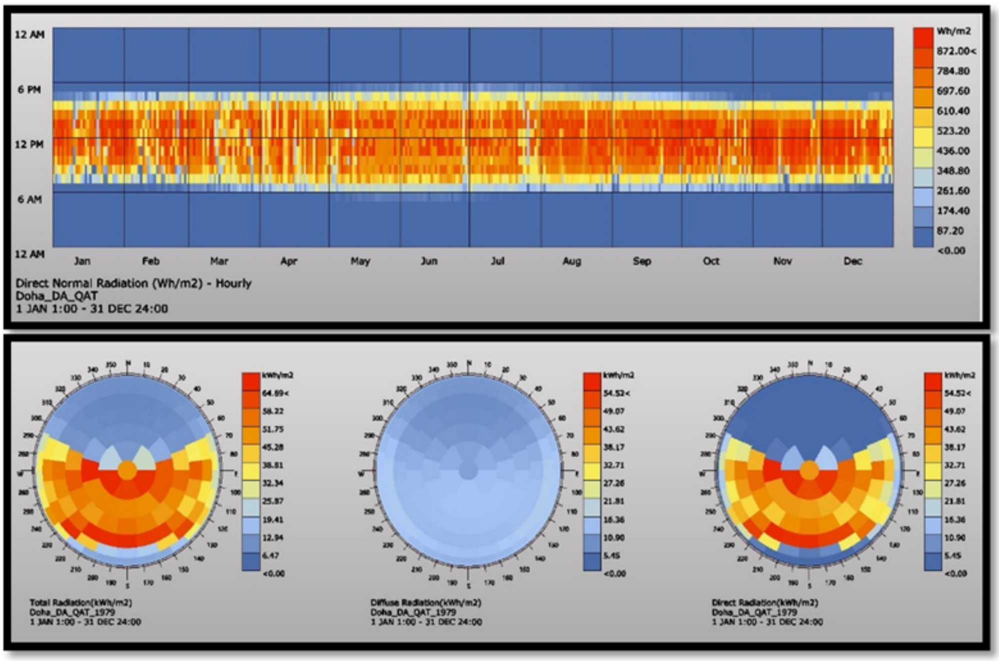


Figure 5.19. Doha_ Radiation Analysis.

Wind profile

The wind profile in Doha has constant winds with different speed levels. The dominant directions of winds are (northwest, north, and west, east with less effectivity also south with low percent). While, the wind velocity based on height, shows (3.5m/s) average speed on 26m height. Yet, the wind directions of Doha (west, east and south) serve the potential purposes of the reference building design for this research. And, the wind velocity based on heights is sufficient for the main wind turbines on above the 26m height, which require (3.5 m/s) average at minimum to generate electricity (see Figure 5.20.). However, the Micro wind turbines system could work with relatively lower averages of wind speeds. So far, the evaluation process of the city will be conducted using (Table 5.9) compared to the general evaluation process of wind profile (see Table 4.2.).

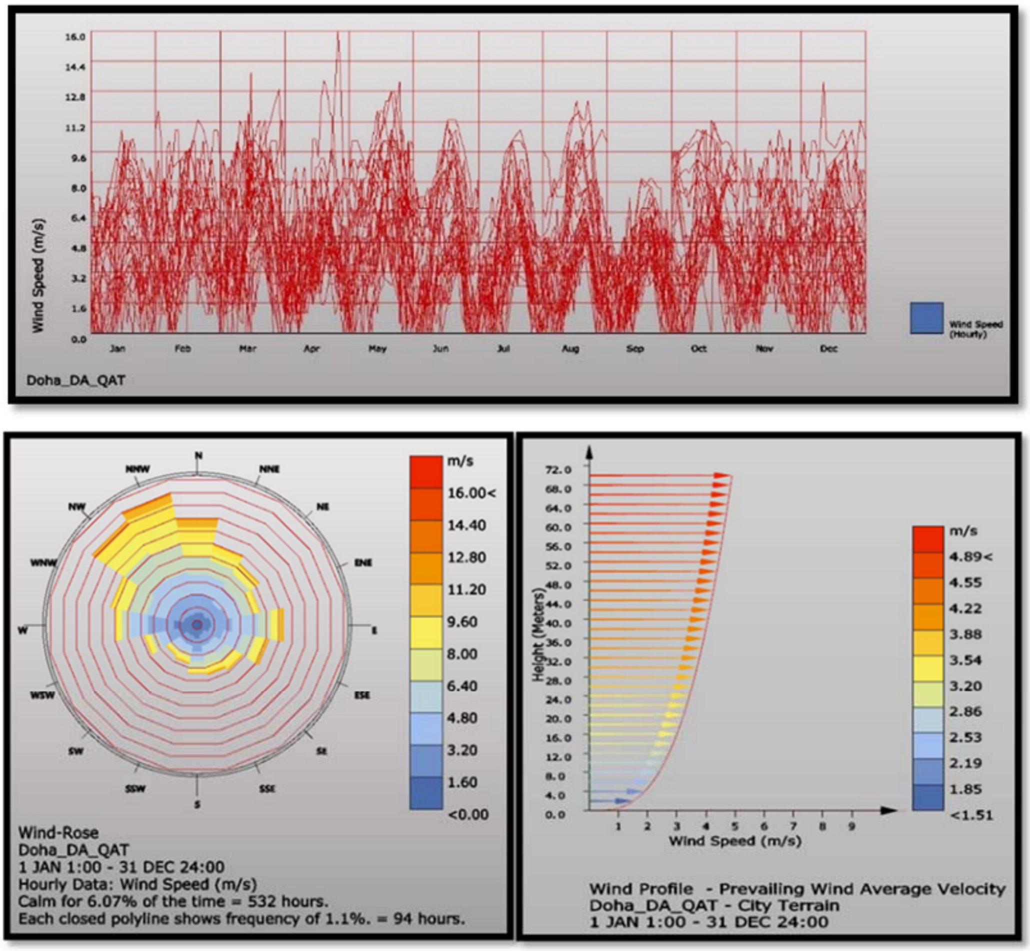


Figure 5.20. Doha_ Wind profiles

Table 5.9. The evaluation process of wind profile_ Doha.

3	Wind directions based on the reference Building design				The height with Average Wind speeds 3.5 m/s	Evaluation
	South	East E- SE -NE	West W-SW-NW	North		
	Low	Medium	High	Medium	26 meter and above	The Best potential
	The west, east, wind fit the reference building design. While, the south wind is low. And the north wind is a bit higher than the optimum situation				The integrative shading units on 55m height and above can work as main wind turbines	

Integrated Energy-Daylight improvement process

The process of the Integrated Energy-Daylight improvement in Doha shows:

* The first best glass type using for the office building with no shading system is the (Double Blue 6mm/13mm Air). While, the (TripleLowE(e5=.1) Clear3mm/13mmAir) is the second. And the (Double Clear 3mm/13mm Air) comes third.

* The (TripleLowE(e5=.1) Clear3mm/13mmAir) is the best glass option could work efficient with the custom opaque shading system.

* Shading form optimized in Doha with 0.2m depth of the concave hexagonal units' form.

* The optimized shading system (glass+ shading material + form) with a potential concept by using a translucent shading material showed some effectivity by improving lights load.

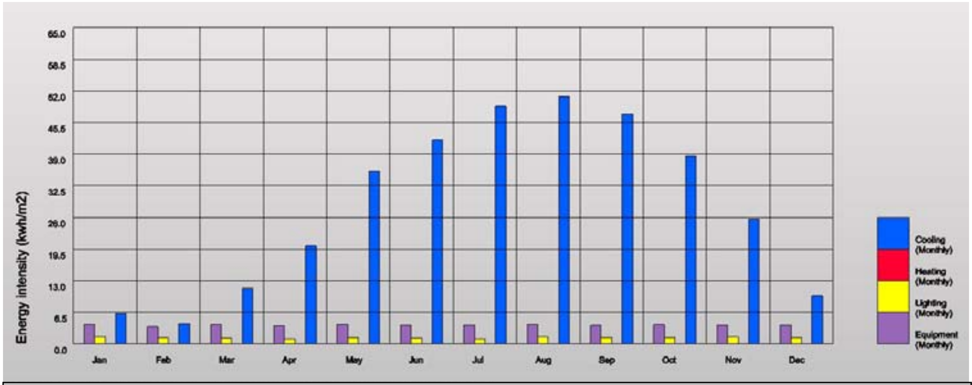
* Comparing the optimized custom shading system (glass+ opaque shading + form) with a conventional shading system showed that the custom shading system is much better than the conventional shading system.

* The final comparison which is used as a determination factor, between the building with just the glass type which worked already efficient with the shading system (TripleLowE(e5=.1) Clear3mm/13mmAir), and the building with the optimized custom shading system ((TripleLowE(e5=.1) Clear3mm/13mmAir) + opaque shading + form 0.3m), has showed (402.85 – 295.43 = **107.42** kwh / m^2) shading benefit (see Table 5.10.) and (see Figure 5.21.).

Table 5.10. Integrated Energy-Daylight improvement process _ Doha.

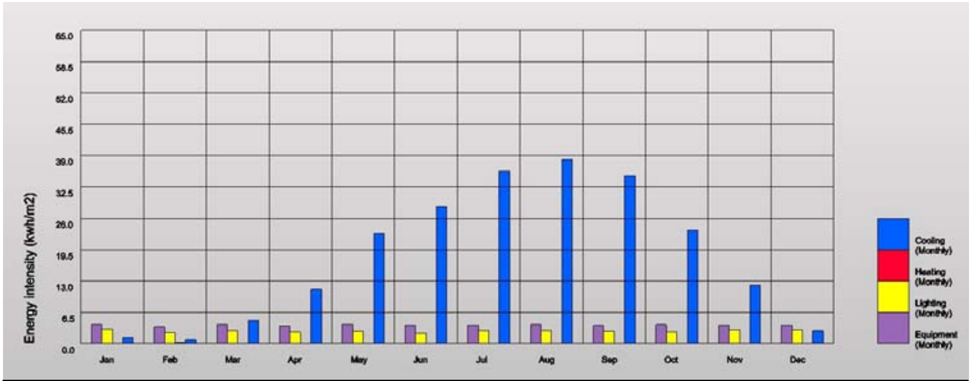
3		Glazing And Shading			analysis period	Cooling	heating	lighting	equipment	Total (KWh/m^2)
Improvement process	Glazing material	Single clear glass 6mm		No shading	Months: 1 to 12 Time: 1 to 24	395.143433	0.143724	14.139816	46.524914	**455.951887** **(Forth best glazing result)**
		Double Clear 3mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	382.128273	0.022188	14.842659	46.524914	**443.518035** **(third best glazing result)**
		Double Blue 6mm/13mm Air		No shading	Months: 1 to 12 Time: 1 to 24	307.699557	0.076143	19.395906	46.524914	**373.696521** **(first best glazing result)**
		TripleLowE(e5=.1) Clear3mm/13mmAir		No shading	Months: 1 to 12 Time: 1 to 24	340.606425	0.000963	15.727335	46.524914	**402.859638** **(second best glazing result)**
	shading system	Full Shading --- Opaque:	Double Clear 3mm/13mm Air		Months: 1 to 12 Time: 1 to 24	227.697708	0.68232	31.332969	46.524914	**306.237912**
			Double Blue 6mm/13mm Air		Months: 1 to 12 Time: 1 to 24	228.307542	0.642957	39.405501	46.524914	**314.880915**
			TripleLowE(e5=.1)Clear3mm/13mmAir		Months: 1 to 12 Time: 1 to 24	220.644285	0.315078	35.714532	46.524914	**303.19881** **(Best system)**
	Shading form	TripleLowE(e5=.1) Clear3mm/13mmAir	Full Shading --- Opaque:	Concave hexagon (3.28 degree) (0.1 m depth)	Months: 1 to 12 Time: 1 to 24	220.290261	0.105177	35.506881	46.524914	**302.637588**
				Concave hexagon (6.54 degree) (0.2 m depth)	Months: 1 to 12 Time: 1 to 24	217.0035	0.351468	31.552758	46.524914	**295.43264** **(Best form)**
				Concave hexagon (9.76 degree) (0.3 m depth)	Months: 1 to 12 Time: 1 to 24	217.937487	0.339543	32.686134	46.524914	**297.488079**
				Concave hexagon (12.92 degree) (0.4 m depth)	Months: 1 to 12 Time: 1 to 24	217.483323	0.361947	31.947432	46.524914	**296.317617**
Notes		The next steps are for comparing with other concepts **to establish a general estimation vision about the integrative shading system with the minimal level of work efficiency. Which mean that the design can work more efficient with the potential concepts designed but cannot proved with the current ability level of computational tools.**								

Transparency	**Shading Material**	**TripleLowE(e5=.1) Clear3mm/13mmAir**	**Full Shading --- Concave hexagon (9.76 degree) (0.3 m**	**Translucent Material 5 % VLT DT,ST 0.05 Refl 0.70**	**Months: 1 to 12 Time: 1 to 24**	------------	------------	**27.111612**	-------------- -	----------------
		This step is to establish a general estimation vision for future studies about using translucent material with almost the minimal effective percentage of transparency 5 % VLT and how influences the artificial light load (neglects the radiation amounts pass through the translucent material due to the Energyplus limitations). (*DT is the diffuse transmission , ** ST is the specular transmission)								
Comparison	**Conventional Shading**	**TripleLowE(e5=.1)Clear3mm/13mmAir**	**Full Shading --- Opaque:**	**Mixed** South: Horizontal East: vertical west: vertical (1M distance: 1M depth).	**Months: 1 to 12 Time: 1 to 24**	247.838736	0.103044	21.513591	46.524914	**315.980284**
The benefit from shading TripleLowE(e5=.1)Clear3mm/13mmAir (without shading-with shading)					402.85 – 295.43 = **107.42 kwh/** m^2					



Doha __ 1 Jan To 31 Dec: No shading _ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 402.85 (kwh/ m^2)



Doha __ 1 Jan To 31 Dec: Full shading _ Concave hexagon 0.2_Opaque_ Trp LoE (e5=.1) Clr 3mm/13mm Air

Total Energy Consumption: 295.43 (kwh/ m^2)

Figure 5.21. Total Energy Consumption Charts _ glazing with/without shading _ Doha

Select the effective hot discomfort period: Adaptive comfort analysis

For Doha;

The hot discomfort period in Doha generally spans from 09:00 until the 18:00. But, the effective hot discomfort period, which the shading can improve it positively, considered from 10:00 to 18:00 (see Figure 5.22.).

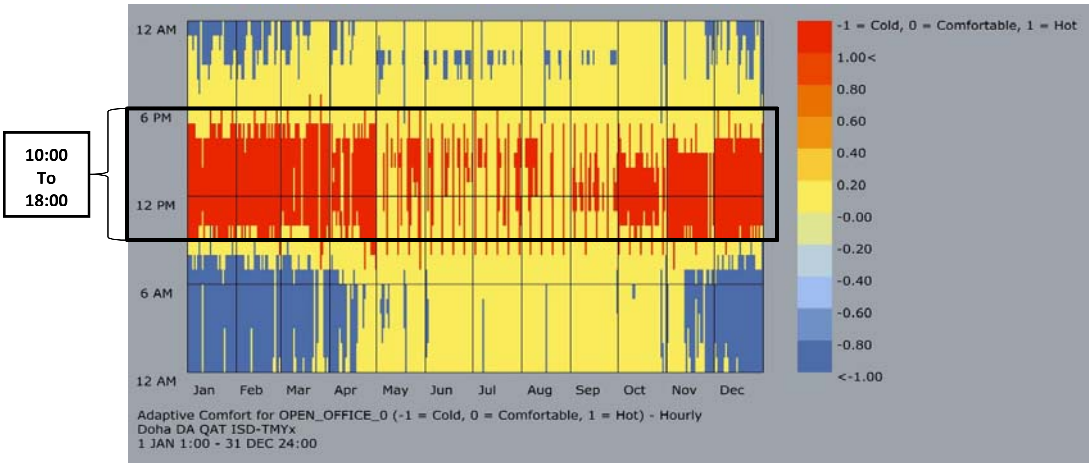


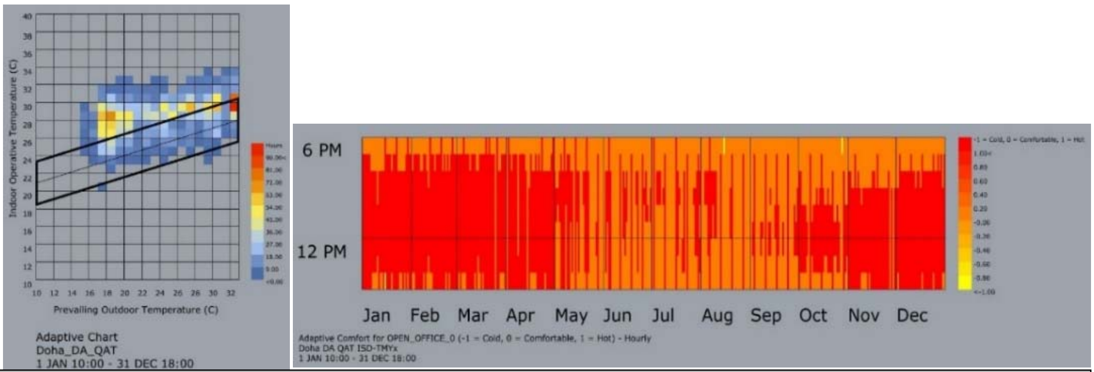
Figure 5.22. Doha_ Discomfort period: annule analysis_Trp LoE (e5=.1) Clr 3mm/13mm Air - No shading.

Adaptive comfort analysis (Comparison)

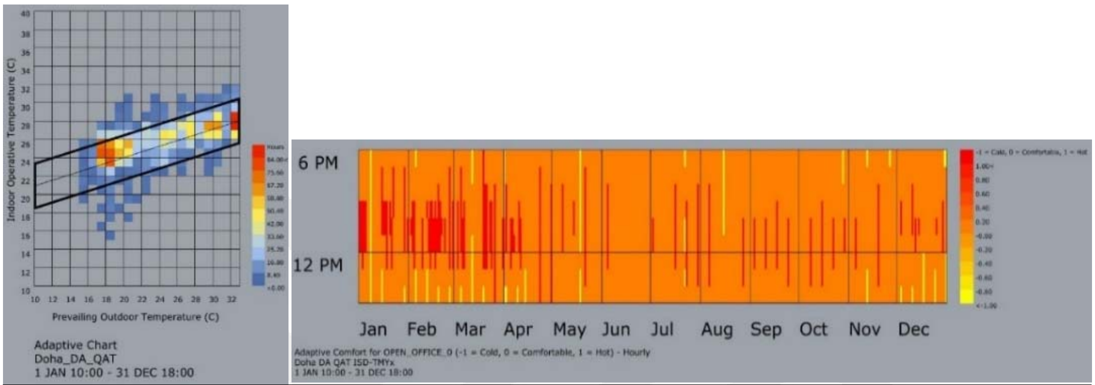
The process of the Adaptive comfort analysis during (10:00-18:00) period in Doha shows an improvement in the time comfortable percentage which is increased significantly from 46.60% when the office building with the chosen glass type (Trp LoE (e5=.1) Clr 3mm/13mm Air), to 89.68% when the office building with the optimized custom shading system (chosen glass+ opaque shading + form) (see Table 5.11.) and (see Figure 5.23.).

Table 5.11. Adaptive comfort analysis _ Doha.

3	**Glazing and Shading**	**Analysis period**	**Percentage Of time comfortable**	**Percentage of Time too hot or too cold**
No shading	TripleLowE(e5=.1) Clear3mm/13mmAir	Annual (10:00-18:00)	46.605784 %	53.394216 %
TripleLowE(e5=.1) Clear3mm/13mmAir	**Full shading** **---** **Concave hexagon** **(9.76 degree)** **(0.2m depth)**	Annual (10:00-18:00)	89.680365 %	10.319635 %
Adaptive Comfort advantage after applying shading and glazing systems		89.68% - 46.60% = **43.08 %** TripleLowE(e5=.1)Clear3mm/13mmAir Percentage of time comfortable (with shading-without shading)		



Doha __ Trp LoE (e5=.1) Clr 3mm/13mm Air - No shading



Doha __ Trp LoE (e5=.1) Clr 3mm/13mm Air – Full shading 0.2 concave hexagon – Opaque

Figure 5.23. Comparison of the Adaptive Comfort Percentage Charts _ glazing with/without shading _ Doha.

Daylight Autonomy (comparison)

For Doha,

The results show that the daylight autonomy has been decreased from 63.84 % (Trp LoE (e5=.1) Clr 3mm/13mm Air) to 36.84% after applying the optimized custom shading system (chosen glass+ opaque shading + form). While, changing the opaque material to translucent material with just 5% VLT increase the daylight autonomy to 43.54% (see Table 5.12.) and (see Figure 5.24.).

Table 5.12. Daylight Autonomy analysis _ Doha.

3	Shading and Glazing	analysis period	Daylight percentage less 100LUX	Useful Daylight percentage between 100-2000LUX	Daylight percentage more 2000LUX	Daylight autonomy The percentage of receiving light more than the illumines threshold
No shading	TripleLowE(e5=.1) Clear3mm/13mmAir	Months: 1 to 12 Time: 1 to 24	32.049554 %	46.478571 %	21.56875 %	63.849107 %
Full shading Concave hexagon (9.76 degree) (0.3m depth) ---- Trp LoE (e5=.1) Clr 3mm/13mm Air	Opaque Material	Months: 1 to 12 Time: 1 to 24	44.866071 %	48.058929 %	7.057589 %	36.840179 %
	Translucent Material 5% VLT DT,ST 0.05 Refl 0.70	Months: 1 to 12 Time: 1 to 24	39.250446 %	52.186161 %	8.548661 %	43.542857 %
Daylight Loss		Opaque shading material	36.84 % - 63.84 % = **- 27 % (loss)**			
		Translucent Material VLT0.05	43.54 % - 63.84 % = **- 20.3 % (loss)**			

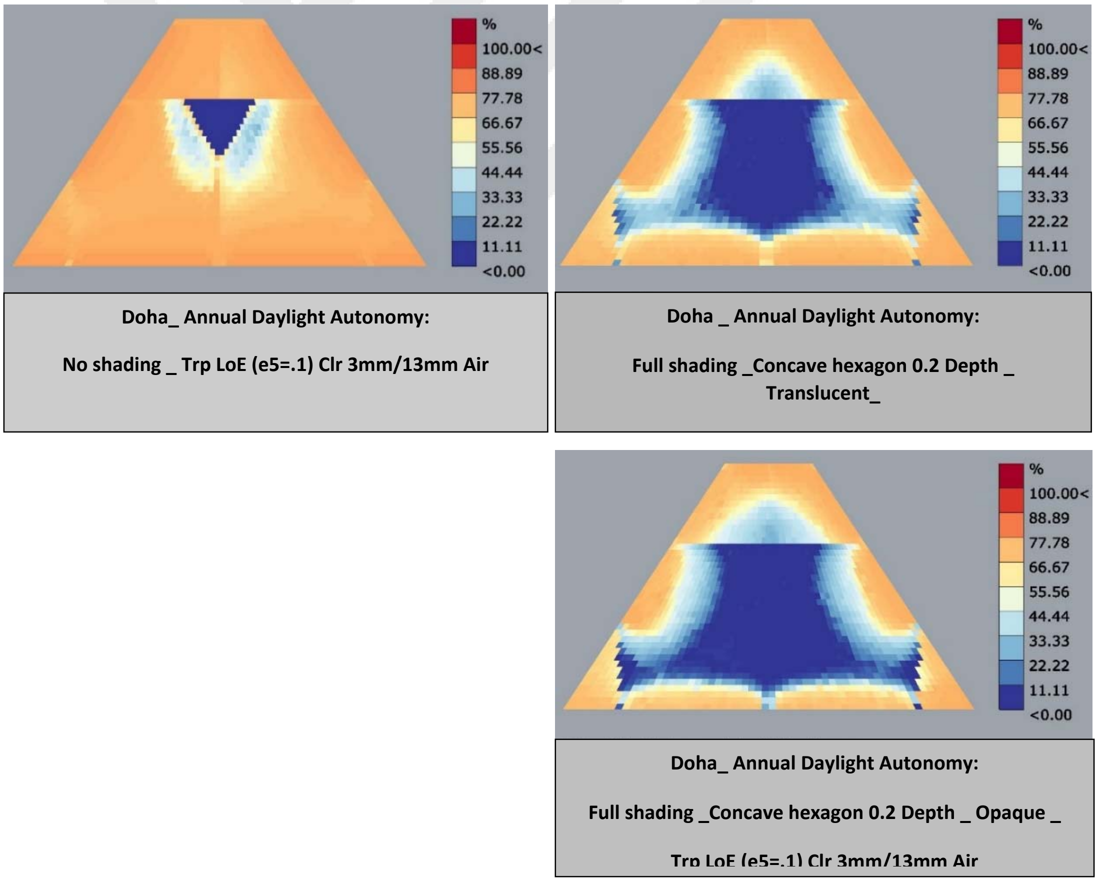


Figure 5.24. Comparison Charts of the Daylight Autonomy Analysis_ Doha

CHAPTER 6

CONCLUSIONS

The proposed design has defined in many levels to meet the computational tools abilities within an architecture perspective. Also, the proposed design has detailed constructional and potential. The final design decision has produced integrative shading units with four potential functions as main purposes (shading, Daylight, Ventilation, energy generation). The integrative shading units influenced the glazing system and affect the glass type option. Therefore, the integrative shading units' concept expands to include the glazing system and that makes the concept sort of façade design. But, the research process based on the limitations will be focused on the integrative façade system as (shading units and glazing system) only. While the other façade items will not be included in the improvement process. Instead, the other façade items will be designed with one option available in the computational tools to complete the definition of the computational model used for simulation. Therefore, the improvement process will be conducted based on the relative results of the proposed design which gives a logical method to handle the design process of this research at an early stage. In other meaning, the results related to the improvement process within architecture perspective and are not considered as inevitable values for the reality consideration within engineering perspective due to the fact that the research scope bounds the improvement process with just the integrative shading system and glazing type. So far, it is clear that the research process will cover two potential functions (Shading, Daylight) with its related issues as major determining factors. While, the other two potential functions (Ventilation, energy generation) considered as a potential for future studies with the adoption of the wind profile and global horizontal radiation analysis in the research improvement process as another determination factors related to both of the (Ventilation, energy generation) potential functions which give an estimation vision to evaluate.

In general, the improvement process methodology includes three case studies as potential hot cities which are (Dubai, Baghdad, Doha). The improvement process methodology comprises a number of analysis steps to get many determination factors and make the decision more accurate.

* Temperature analysis.

* Humidity Analysis.

* Radiation Analysis.

* Wind profile.

* Integrated Energy-Daylight improvement process:

* Select the effective hot discomfort period: Adaptive comfort analysis:

* Adaptive comfort analysis (Comparison).

* Daylight Autonomy (comparison).

From all the eight analysis steps, there are five main determination factors responsible for final selection decision:

* Integrated energy/daylight simulation: energy consumption improvement

* adaptive comfort analysis: improve the effective hot discomfort period

* daylight autonomy: estimate the daylight autonomy loss

* wind profiles: the potential of each case study to generate electricity by wind turbines.

* Average global horizontal radiation: the potential of each case study to generate electricity by solar panels.

6.1. Results Comparison & Selection Decision

The improvement process and determination factors in each of the three cities gives different levels of responsiveness and interactivity for the integrative façade design as (shading units with glazing option) parameters. So far, to choose the best potential city that fits the integrative façade system properties, a comparison process must conduct as below (see Table 6.1.).

Table 6.1. Final results comparison.

The results after applying the integrative façade system (shading units and glazing option)								
N.	Case studies		Determination factors Priority for decision making					EVALUATION RESULTS
			First	Second	Third	Forth	Fifth	
	Climate type	City	Energy saving	Daylight autonomy loss	Wind profiles analysis	Adaptive comfort improvement	Average Global horizontal radiation	
1	Hot-Humid	Dubai	**111.67 (kwh/ m²)** (333.11 kwh/m² after improvement)	**- 29.74 % (loss)** (37.18 % daylight autonomy with opaque shading)	**Low**	**34.47 % (value)** (91.23% adaptive comfort percentage)	**474.37 (Wh/m²)**	BEST ENERGY SAVING
2	Hot-Dry	Baghdad	**67.20 (kwh/m²)** (215.37 kwh/m² after improvement)	**- 28.97 % (loss)** (36.61 % daylight autonomy with opaque shading)	**Medium**	**37.42 % (value)** (80.30% adaptive comfort percentage)	**461.48 (Wh/m²)**	MEDIUM PERFORMANCE
3	Hot-Humid	Doha	**107.42 (kwh/ m²)** (295.43 kwh/m² after improvement)	**- 27 % (loss)** (36.84 % daylight autonomy with opaque shading)	**Best**	**43.08 % (value)** (89.68% adaptive comfort percentage)	**497.25 (Wh/m²)**	BEST PERFORMANCE & BEST ADAPTIVE

Color Measurement	Best	Medium	Lowest

After applying the integrative façade system (shading units with glazing option), The levels of responsiveness and interactivity of the results are different and not explicitly defined. The determination factors based on priority division, which classified the priority of the determination factors by the impact level on the energy consumption in hot tropical countries. Therefore, the priority classification puts heating/cooling loads as the first impact factor and first priority. The lighting load comes second (Katili, A. Boukhanouf, R. Wilson, n.d.).While we can consider the adaptive comfort level considered as a third priority which is also important to measure the improvement level of the adaptive comfort after applying the integrative façade system. Moreover, the wind profile and global horizontal radiation factors as fourth and fifth priorities due to its role to make the integrative shading units work efficiently based on (ventilation, energy generation) potential functions of the proposed design.

In Dubai, the results showed a variation in response. The energy-saving factor ranked first, while the other factors achieved the lowest potential. But, the energy-saving factor is the first priority at the same time it's important to fit the other factors. Therefore, Dubai considered as the best energy saving but not the best potential city can interactive with the integrative façade system (shading units with glazing option).

For Baghdad, the energy-saving and the Average global horizontal radiation factors ranked as the lowest potential. While the other factors ranked medium. In general, Baghdad showed a medium interactive and response level to the integrative façade system (shading units with glazing option).

Doha, has achieved remarkable results in different factors. The energy-saving factor achieved the second position with very little difference that the first position. While the other factors ranked the first potential. The results showed that Doha has a great potential to make the integrative façade system (shading units with glazing option) work efficiently. Doha is the best potential city that can fit the integrative façade system (shading units with glazing option).

In general, the first priority factor (Energy-saving) can achieve better results in the hot-humid cities than the hot-dry cities.

6.2. Future studies

The research explored all the potential concepts and abilities that the integrative façade system (shading units with glazing option) could have. The proposed design adopted four potential functions as design goals (shading, daylight, ventilation, energy generation). But, the limitation with research focused area and current computational tools capability imposed some restrictions on the design process to prove all the potential functions.

So far, if the computational tools abilities developed in the future, many concepts could be evaluated and examed to explore the proposed design with all the potential concepts has. For instance, the ventilation function concept with the integrative shading units can be explored and improved more with the analysis and simulation process. Thus, another energy consumption reducing factor (potential ventilation function) added to the advanced design process.

Furthermore, energy-generating potential functions (wind turbines and solar panels) could be evaluated to involve in the cost calculation process and decreasing the non-renewable energy demand.

In addition, the proposed integrative façade system (shading units with glazing option), might be using a translucent material for shading to increase the daylight efficiency and decrease the daylight autonomy loss. Also, using sun-path tracker sensors to control the folding and unfolding shading units' position for the same purposes. But, these potential concepts need to develop the computational tools capability to consider custom shading devises with different material types (translucent, opaque) and with different positions (transformable) at the same time.

Also, the integrative façade improvement process could expand to include all the envelope system with the shading units by optimizing the envelope construction (glazing, walls, roofs, ceiling, floors, etc...) based on the mutual effect with the shading system.

In general, the advanced design strategy can absorb many concepts (current and future). It could be developed more and more to help architects exploit the novel approaches and merge them with the design process which makes the architecture field of study more developed and more scientific especially with decision-making issues.

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