KINETIC DOUBLE SKIN FAÇADE AS AN ENVIRONMENTALLY RESPONSIVE STRATEGY TO REDUCE ENERGY AND IMPROVE LIGHT COMFORT IN AN OFFICE BUILDING IN DUBAI - UAE

الواجهات الخارجية المتحركة كاسلوب معالجة استجابة بيئية لتقليل الطاقة وتحسين الانارة الداخلية للمباني المكتبية في دبي – الامارات العربية المتحدة

by

MOAMIN ALSALEEM

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Prof. Bassam Abu-Hijleh

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Abstract

Façade technique as a response to the external climate factors has been discussing tremendously by many studies and in many regions with various weather conditions. However, in particular, the subject of the kinetic facade as a strategic solution to enhance the building energy efficiency have a shortage data for the researcher, especially in the region of the middle east. However, the performance of the kinetic façade is still questionable due to the lack of the experience, recorded data especially regarding high rise office buildings in Dubai, UAE and GCC area.

These motivate the research to select an existing high rise office building with almost 65 floors as a base case model to demonstrate the dynamic louver system as a strategic environmental solution by enhancing the energy efficiency and scale the potential power saving. The building is allocated in Dubai, UAE which classified as hot, arid climate. The study accordingly establishes the baseline model as per the conditions and considering the local climate factors.

The research validates the model by comparing the first energy simulation results against the actual record of the energy demand according to local Authority DEWA. Subsequently, the study develops the baseline by incorporate the configuration of the dynamic louver system to all façades. The model has been tested to figure out the optimal louvers configuration with various inclination started from 15, 30, and 45 till 180 degrees where the system performed as second skin scenario.The kinetic louver position as a double skin has been considering in three various scenarios (600, 1200 and 1800 mm). These simulations have been conducted within different seasons, different façade orientations on three different floors.

The different Kinetic skin setting aims to demonstrate the effect of the model on total heat gain and heat loss of the building envelope and enhance total saving of power consumption by reducing the cooling load in additional to enhance the daylight level in the office building. The kinetic façade illustration and outcomes

compared to the baseline model of existing building and the option of baseline with light control scenario.

The research used Autodesk software to build the baseline model and take advantage of the software platform to simulate the model accordingly. Auto CAD and Revit software used to build the model; Flow Design software used to run the wind flow simulation and scale the effect of the system, and in particular, the optimal performance of façade as double skin with best cavity distance. The wind test results end up with the best cavity as 1800mm due to the optimal air velocity and air pressure in the cavity. CFD software used to measure the stack effect of the double skin, and the simulation concurs the disadvantage of high rise scale of double skin façade due to chimney effect factor where wind temperatures increased drastically.

The Light performance simulated by Revit light analysis where the criteria of the test identified by scale useful daylight illuminance UDI factor and high level of illuminance HDI and below threshold light factor LDI. Also, HVAC system simulated by Revit software, and then, the total energy efficiency have been tested by same software advance by the Green studio and Insight 360 platform.

The results of the research illustrate the kinetic façade system as quite challenged but presenting promised outcomes within a certain time in explicit and during a different season of the year. Specifically, the saving of the HVAC system reach 40-45% with double skin scenario, and in another hand, the balance between the daylight and the HVAC load presented by the dynamic louvre with inclination 75 –105 degrees lead to saving 20-35% of the total energy demand in average as an optimum efficiency and functionality. Moreover, in December the kinetic louvre system contribution in the total energy demand have mostly equal values with the same percentage of daylight and HVAC load. Therefore, 45-degree inclination presents the best scenario. Base on the result analysis of air flow test, light analysis, HVAC demand and the total energy portfolio, the research highly recommended the combination of the different scenarios which will enhance the system performance significantly with potential saving up to 40% of total power demand.

نبذة مختصرة عن البحث

تقنية الواجهة وارتباطها بالعوامل المناخية الخارجية تم دراستها بشكل هائل من قبل العديد من الباحثين وفي العديد من المناطق ذات الظروف الجوية المختلفة. ومع ذلك، وعلى وجه الخصوص، هنالك قلة في البجوث المتعلقة بموضوع الواجهة الحركية باعتبارها حلا استراتيجيا لتعزيز كفاءة استخدام الطاقة في المبنانى وخاصة في منطقة الشرق الأوسط. الا ان أداء الواجهة الحركية لا يزال موضع شك نظرا لعدم وجود الخبرة، والبيانات المسجلة والتجارب الخاصة فيما يتعلق بالمباني متعددت الطوابق وذات ارتفاعات عالية و خاصة ابنية المكاتب في دبي والإمارات العربية المتحدة بالخصوص ودول مجلس التعاون الخليجي و المنطقة بالعموم.

وعليه فقد حفز البحث على اختيار مبنى مكتبي بارتفاع ما يقرب من 65 طابقا كنموذج للدراسة و البحث و اضافة اللوفرات الديناميكي المتحركة كحل بيئي استراتيجي لتعزيز كفاءة الطاقة وتوسيع نطاق توفير الطاقة المستخدمة في المبنى. يقع المبنى في دبي، الإمارات العربية المتحدة التي تصنف على أنها مناخ حار وجاف. وبناء على ذلك، فقد حددت الدراسة النموذج الأساسي للبحث وفقا لشروط المبنى القائم مع الاخذ بنظلا الاعتبار العوامل المناخية للمنطقة.

لقد تم اولا التحقق من النموذج الاساسي للمبنى المستخدم والذ تم اعداده للبحث عن طرق مقارنة نتائج محاكاة الطاقة الأولى مع السجل الفعلي للطلب على الطاقة الذي المسجل لدى هيئة كهرباء ومياه دبي والتاكد من مطابقة النتائج. و عليه فقد تم بناء النموذج الاولي للبحث مع تطور النموذج من خلال دمج تكوين نظام اللوفرات الديناميكية المتحركة لجميع الواجهات.

وقد تم اختبار هذا النموذج لمعرفة التكوين الأمثل للوفرات العمودية والأفقية مع عدة زواية مختلفة بدأت من 15، 30، و 45 حتى 180 درجة حيث سيكون أداء النظام كواجهة تغليف مزدوجة. بالإضافة إلى ذلك، فإن الواجهات المزدوج المكونة من تشكيل اللوفرات قد تم اختبارها في ثلاثة سيناريوهات مختلفة (600، 1200 و 1800 ملم). وقد أجريت هذه المحاكاة في مواسم مختلفة، اتاجاهات مختلفة للواجهة في ثلاثة طوابق مختلفة.

ويهدف وضع اللوفرات المتحركة المختلفة لإظهار تأثير النموذج على مجموع مكاسب الحرارة وفقدان الحرارة عند واجهات المبنى وتعزيز الادخار الكلي لاستهلاك الطاقة عن طريق الحد من حمل التبريد الزائد بالإضافة إلى زيادة منسوب الانارة الطبيعية في البيئة الداخلية للمكاتب.

تم استخدام برنامج Autodesk لبناءالنموذج الأساسي للبحث والاستفادة من منصة البرمجيات لمحاكاة النموذج وفقا لذلك. وكذلك برنامج AutoCAD و برنامج Revit تم استخدامها لبناء النموذج و برنامج Flow Design لمحاكاة قياس تاثير الرياح لتوسيع تأثير الواجهة الحركية وعلى وجه الخصوص الأداء الأمثل للواجهة مواجهات مزدوجة مع تحديد أفضل مسافة للبعد بين الواجهات الرئيسية و اللوفرات المتحركة. وكانت نتيجة محاكاة الرياح بان أفضل مسافة تجويف هي 1800ملم وذلك بسبب سرعة الهواء الأمثل وضغط الهواء في منطقة التجويف. تم استخدام برنامج CFD by Autodesk لقياس تأثير الارياح للواجهات وبالاخص المنطقة

بين الةاجهة الريسية و اللوفرات المشكلة كطبقة مزدوجة، وكانت نتيجة التحاليل والمحاكاة بان هنالك مشكلة في زيادة سرعة الرياح و درجة حرارة الرياح في منطقة التجويف في الواجهة المزدوجة بسبب الضاهرة المعرفة بتأثير المدخنة حيث ارتفعت درجات الحرارة الرياح بشكل كبير.

أداء الضوء في النموذج الأساسي تم محاكاته باستخدام برنامج تحليل الضوء حيث تم تحدبيد معايير الاختبار من خلال مقياس ضوء النهار المناسب و قياس مؤشرات الإنارة الاخرى. أيضا، نظام التبريد و التكييف الداخلي تم محاكاته من قبل برنامج متخصص لقياس البيئة الداخلية للمبنى، وبعد ذلك، قد تم اختبار كفاءة الطاقة الإجمالية للنموذج و تحديد كفاءت استخدام الطاقة.

وتوضح نتائج البحث أن نظام الواجهات الحركية يواجه تحديا كبيرا ولكنه يعرض نتائج جيدة خلال فترة زمنية محددة وخلال مواسم مختلفه من السنة. على وجه التحديد، فإن توفيرفي نظام التكييف تصل إلى 40-45٪ مع سيناريو الواجهات المزدوج، ومن ناحية أخرى، فان التوازن بين ضوء النهار وحمل التكييف التي يقدمها اللوفر المتحركة مع زاوية 75 -105 درجة تؤدي إلى توفير 20-35٪ من إجمالي الطلب على الطاقة و كأفضل كفاءة ووظائف. علاوة على ذلك، وبالخصوص في كانون الأول / ديسمبرفي فصل الشتاء فان مساهمة نظام اللوفرات المتحركة في إجمالي الطلب على الطاقة لها قيم متساوية في معظمها مع نفس نسبة التوفير في كفاءة الانارة الطبيعية والتوفير في حمل التبريد. لذلك، فان الواجهات المتطركة ذات الميل 45 درجة يعرض أفضل سيناريو.

واستنادا إلى تحليل نتائج اختبار تاثير الرياح، وتحليل الضوء، وتحليل نظان التكييف و كمية الطاقة الإجمالية، فان البحث يوصي باستخدام مزيج من السيناريوهات المختلفة التي من شأنها تعزيز أداء النظام بشكل كبير مع توفير المحتملة تصل إلى 40٪ من إجمالي الطلب على الطاقة.

Acknowledgments

I would like to thank my supervisor, Prof. Bassam Abu-Hijleh, and to BUID family for their support and guidance.

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LIST OF ABBREVIATIONS

WORD	DEFINITION
ABI	Adaptive Buildings Initiative
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BREEAM	Building Research Establishment Environmental Assessment Method
CFD	Computational fluid dynamics software by Autodesk
DHI	Direct Horizontal Irradiance
DNI	Direct Normal Irradiance
DEWA	Dubai Electricity and water Authority
DETI	Dubai Economy Tracker Index
GHI	Global Horizontal Irradiance
GCC	Gulf Cooperation Council
GIS	Geographic information system
GISS	Goddard Institute for Space Study
HDI	High daylight illuminance
HVAC	Heating, ventilation, and air conditioning
IES	Integrated Environmental Solutions, a software and consultancy company that specializes in building performance analysis.
ISO	International Organization for Standardization
KLS	Kinetic Louver System
LDI	Low daylight illuminance
LEED	Leadership in Energy and Environmental Design, ND: For Neighbourhood Development
NDCs	National Determined Contributions
UDI	useful daylight illuminance

Chapter One: Introduction

3.1 Global Context

On June 15, 2017, NASA announced that the 2nd warmest May chronicled till date is May 2017, the record range of last 137 years considered the analysis of global changes in the temperature periodically every month. These chronicles based on recorded data and analysis by NASA scientist at NASA's GISS "Goddard Institute for Space Study" in USA, New York (Figure 3-1). ("Data.GISS: GISTEMP Update: May 2017 Was Second Warmest May on Record" 2017)

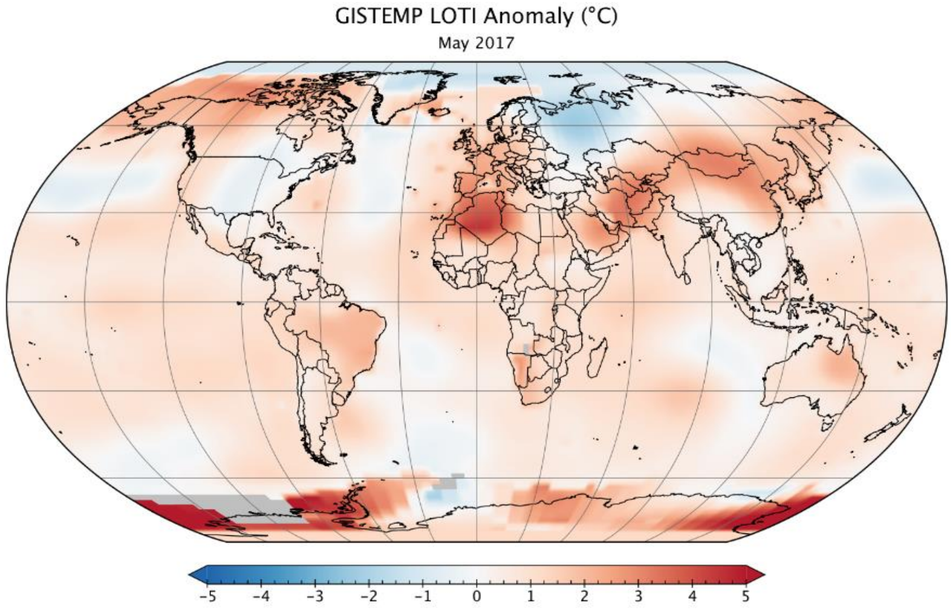


Figure 3-1 the GIS temperature Map as of May 2017 ("Data.GISS: GISTEMP Update: May 2017 Was Second Warmest May on Record" 2017).

Have a close look at Figure 3-1 finding that the GCC in general and particularly UAE allocate in the red zone where the highest record of temperature is appeared (Studies 2017).That indicates a serious alarm that needs to cogitate globally and in national scale as well.

Recently, the climate agreement has taken place in Paris, France declared a forceful target of setting a borderline for the global warning average to achieve a lower 2 °C globally. As an initial step, the greenhouse gas emission level in all countries should be respected and set to levels of abatement pledges by all parties in the form of NDCs (“National Determined Contributions”) for the next decade till 2030 (Rose et al. 2017). These goals to reduce the regional emissions by national participation and ambitions looking beyond the global emissions and long-term temperature and the subsequence of the energy and associated costs.

Many studies discussed in detail the delivers that multidimensional the classification of the county contribution factors that effort associated climate consequences specifies the factors vitally related to decision-makers. The researcher considered the goals of the mid-century production as short-term goals and in long-term the environment aims and intentions. (Diffenbaugh et al. 2017).

Green gas emission comes mainly from the construction sector, wherein 2009 the record shows that total carbon dioxide CO2 emission of the global construction industry was 5.7 billion tons. These records present 23% of the activities drive the international economics. In the USA for instance, the construction registered 39% of CO2 emission per year which is more than any other sector records. The 39% record cover mainly the commercial and residential sectors (Piccirilli Dorsey 2017). Moreover, the projection of coming 25 years cultivate significantly in the construction industry than others reaching 1.8% annually in 2030. (Piccirilli Dorsey 2017).

The Gulf Arab countries where the area of research allocated, the percentage of the energy consumption is greater due to the local hot climate as classified climatically as hot, humid, arid climate. (Cherian, Jacob & Farouk 2017). Electricity demand in GCC County like Qatar, Kuwait, KSA, Oman, and UAE registered a higher demand than the world average. The records on average consumption per capita are higher than the USA. Particularly, in UAE, the power demand is greater, and the total energy consumption per capita is twice that of the United States of America (Hudson & Kirk 2014).

To an extent, the local power energy consumption in UAE comes into the higher pattern of the energy demand and electricity consumption per capita due to the harsh local weather. Most of these emanations originate to afford to tolerate internal climate condition of the building which covers cooling, lighting, other user demands and electrical facilities in GCC area (Osman, Gachino & Hoque 2016). In UAE specifically, the cooling power consumption has the higher percentage of the total demand. Thus, the construction industry regulation plays a crucial factor to maintain the request. (Osman, Gachino & Hoque 2016).

By altering the built environment higher power-proficient with more climate-friendly, the consultation sector could perform a fundamental role in dropping the threat of environmental alteration and climate changes. (Piccirilli Dorsey 2017). A building envelope that works as a shell protecting the indoor environment from the extreme harsh external weather plays a key factor in deducting the total power consumption.

Researchers, Architects, and Engineers collaboratively work on developing Construction systems that enhance the building performance. The building shell & Skin is one of the areas that drawn up and take the attention of the builder for a lifetime of the construction industry. Also, the industry directed for more valuable and efficient solutions to maintain the control of the building power demand and total energy consumption (Aksamija. 2013).

Taking advantage of the ease developed technology and substantiation merge with the construction industry, there are much advanced and intergrade solution comes through to the building system by introducing an interactive façade that interacts with the external environmental conditions like the Kinetic Facades (Aksamija. 2013).

3.2 Glance at building shell and skin

The human species needs to be translated into the history in many forms, starting with the means of a shelter protecting the external environment, competitors, and for other human requirements as well. These requirements have appeared with the development of the human life and behavior. Therefore, that represents the key and most important motive for the building. (Farrelly 2012). Within the local environment of the people, humans take shelter provided naturally, like the holes in the ground, caves, and very dense plants and wherever the survival means granted.

The first start of the human owned shelter was when lifestyle of people changed to be sedentary rather than nomadic. People depend on their environment and naturally available resources to build their shelters where the researchers found many types of shelter depending on these resources like stone, clay, wood, and other natural resources and diverse from hot, warm and cold weather to extreme weather like the Arctic area (Figure 3-2). These shelters developed with a proper built process to fulfill functions and protect people from external climate. Within this development, the walls and roofs started to appear with people shelters. (Farrelly 2012).

Figure 3-2 Stonehenge Wiltshire, England 2600 BC (Farrelly 2012).

Historically, the construction techniques that were used by a human were mainly depending on bearing wall structure to build their shelters by transferring dead load directly from roof to walls to foundations.

Those bearing wall classified into external and internal walls were external ones determining the nature of the building to the surroundings. People develop the process by adding additional values while decorating the building skin and the internal spaces when they start with their dressing by adding their identities. These applied to simple homes and shelters with different tactics contingent on the culture, and location like China, Greek, European and the Middle East area.

That steps develop buildings architectural design potentially, where the style of the structure started to be recognized within the civilization beginning like the Mesopotamia, Egyptian civilization, Indian civilization and ancient Chinese and later the Romans and Greeks, and other areas. (Farrelly 2012).

Despite all these developments of the human-made building process, the structure process developed further when new materials induced to the construction industry. The huge evolution of the building methods and the architectural style depended on the availability of local building elements and lifestyle in response to local environments.

The building skin design and the architectural styles had been divided into two main category's theory by Gottfried Semper in the mid-19th century. The two styles were the load-bearing structure (the ancient style) and cladding structure. The theory is still valid until today within the architectural building style inspiration more than the date of it was.

With the development of the human requirements and civilization development more additional requirement from the building, the skin had added that enhance the performance of the building envelope. In addition to the building structural support and external architectural aesthetic, the envelope development toward more performance on environmental factors like temperature, lights, water penetration, air tightness, and infiltration, and beyond the environmental factor like security, and protection from the external physical factors as a fire safety.

The noticeable change in the building shell and structure starts to spread when the reinforced concrete innovated. The discovery of Steel and mixed concrete impacted the structure of building significantly where no more need for heavy mass for the bearing wall required anymore. Builders and Engineers initiate additional theories for the building styles when the new architectural style starts to present in the urban. Thus many studies take place to enhance the performance of external envelope to more individual style to the building functionality especially with the newly developed materials integrated by the reinforced material innovation.

Building skin revolution started when Iron and glass induced to the construction industry in the 19th century where the world has been changed significantly by the industrial revolution. The iron and glass material encourage new opportunities and present entirely new production style of building (Figure 3-3) ("Engineering Timelines - Chatsworth Conservatory and Lily House, site of" 2017). The process melts the skin and shell of the building from bearing load method that previously the construction was depending on by delinking the skin into two systems. At the same time, the new regime tackled new challenges to designers and producers towards the performance of the building envelope.

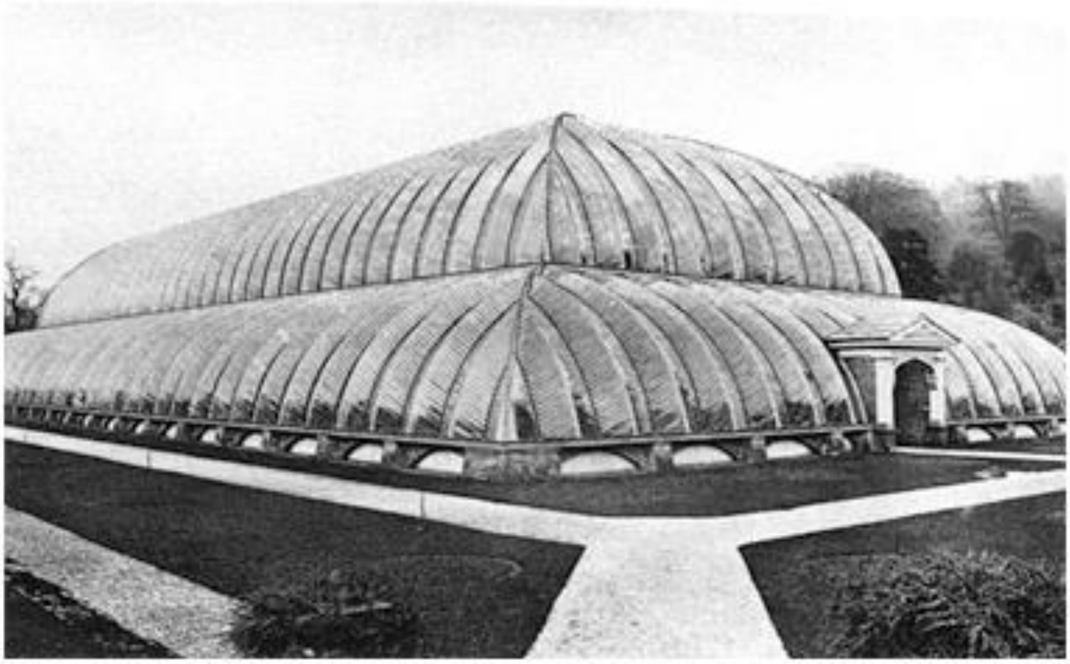


Figure 3-3 Chatsworth Conservatory and Lily House 1830-1850s (("Engineering Timelines - Chatsworth Conservatory and Lily House, site of" 2017).

Moreover, the greenhouse and sunspaces were one the events that change the style of building skin construction by adopting new materials in the European architectural style. The new style achieves the maximum level of direct sunlight into the building through the skin and introduces the lighter massive feature in the building design (Figure 3-4). These challenges considerably recorded within the environmental factor like radiation, the cause of heat gain, heat loss, and the critical element of dealing with the solar gain and visual impact. (Fortmeyer & Linn 2014).

Last five decades the development of construction method by complained fixation of the external glazing system with the bearing wall method and other developing techniques takes part in serious building styles. The cladding of entire building skin, facades, and the roof has the same material of soft skin or other architectural materials. These styles exterminated the regularity of building styles and new developed architectural skins and form stated at that time (Fortmeyer & Linn 2014).

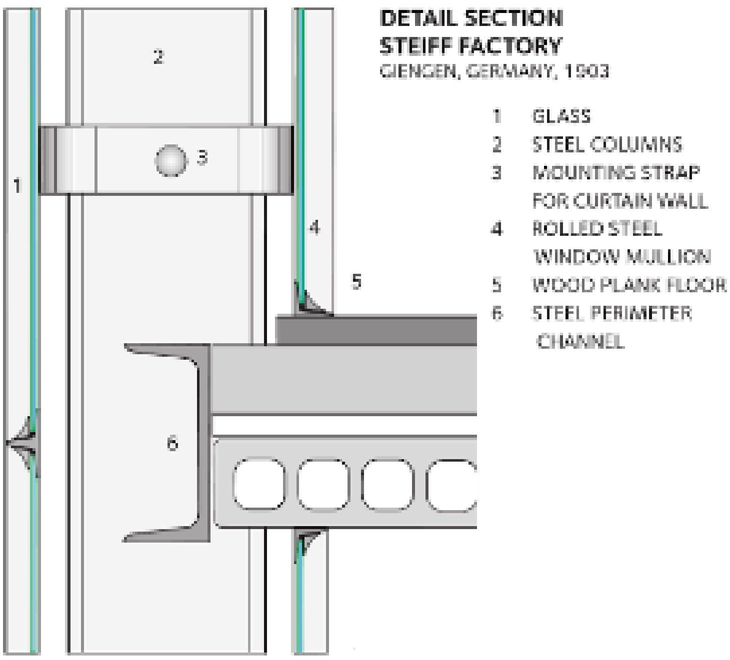


Figure 3-4 Developed Architectural Detail shows the new construction developments (Fortmeyer & Linn 2014)

The developments of building skin and shell and construction materials take another route when the economy crises revealed in the 1970s. Energy efficiency and request for more efficient building designs were raised and questioned by the scientist. Therefore, the construction industry had been driven by that facts at that time and developed further up to dates.

Engineers and advanced technologies with the last decades developed the material of glazing systems that significantly influence the designer to embrace more sophisticated building design with building enveloped trend. At the same time the innovation going toward more optimized glazing solution to ensure that the façade of the building was environmentally approachable, interactive and even smart aiming to enhance the building performance and the energy efficiency of the building (Sharaidin & Salim 2012).

3.3 UAE and Emirates of Dubai Setting

UAE country notices a significant development and growth in last decades in industrial, commercial and other sectors. Practically, Dubai Economy raised potentially at the last decades in the non-oil sectors. According to the Emirates National Bank of Dubai reports, the Economy Tracker Index (DETI) have been amplified in average to 56.7 in the first quarter of 2017 point out the fastest evolution within the last year ("Dubai Economy Tracker: Q1 2017 growth strongest in 2yrs | Emirates NBD Research" 2017).

These records demonstrate bigger needs for the power generations as stated by Dubai Electric and Water Authority (DEWA) within the last decade; the electricity generation grows up more than double in 2015 compared to 2004 records (Figure 3-5). Whereas, the demand was progression 150% in 2015 compared to 2004 ("Dubai Electricity & Water Authority (DEWA) Annual Statistics" 2017).

Electricity		2014		2015		الكهرباء
Installed Capacity	MW*	9,656		9,656	ميجاوات	القدرة المركبة
Gas Turbines	MW*	7,104		7,104	ميجاوات	توربينات غازية
Steam Turbines	MW*	2,542		2,542	ميجاوات	توربينات بخارية

*MW - Megawatts

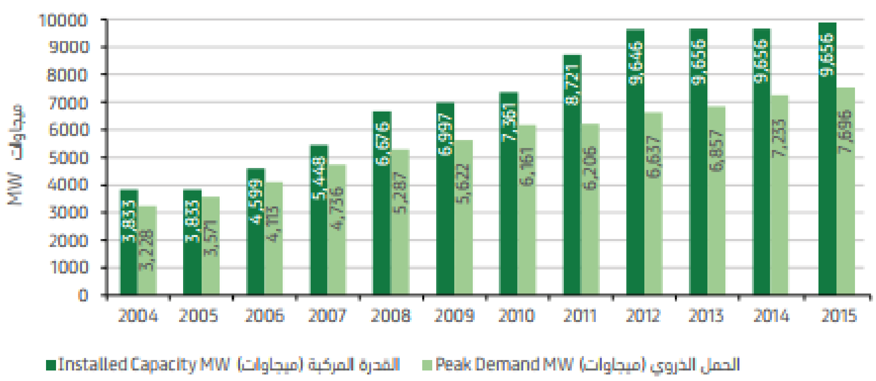


Figure 3-5 Electricity consumption records of the last decade for Dubai, UAE ("Dubai Electricity & Water Authority (DEWA) Annual Statistics" 2017).

DEWA statistics present the power consumption in 2016 had a boost in the demand where the total consumption in 2016 was about 43093 GWh, while in 2015 about 42006 Gwh, and in 2014 about 39599Gwh ("Dubai Electricity & Water Authority (DEWA) Annual Statistics" 2017).

Growth is predicted in the emirate of Dubai in specific and UAE in general within the next decades. The trend of the power demand would continue growing, and the total consumption would dramatically have a severe environmental impact in term of CO2 emission and other environmental factors harming the station of the country environment.

Electricity		2015	2016		الكهرباء
System Energy Requirement	GWh*	42,006	43,093	جيجاوات ساعة	الطاقة الكهربائية المطلوبة

*GWh - Gigawatt hours

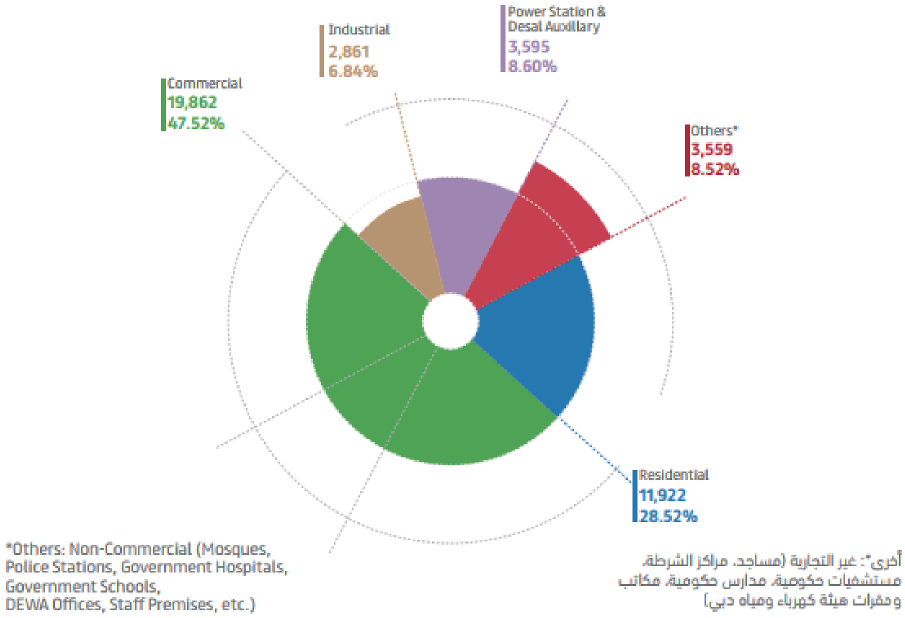


Figure 3-6 Electricity consumption demand (Gwh) 2016 for Dubai, UAE ("Dubai Electricity & Water Authority (DEWA) Annual Statistics" 2017).

DEWA statistics demonstrate that the presentation of the commercial and residential consumption about 76.04% respectively of the total demand (Figure 3-6) ("Dubai Electricity & Water Authority (DEWA) Annual Statistics" 2017).

Thus, Dubai Government, other Emirates authorities, and local Authority have recently taken an advanced step and start to regulate rules and policies on the road to more sustainable developments in the construction industry specifically. These steps are coming with the global awareness of the global warming and the race of the sustainable solutions.

The need for an environmentally-friendly solution for the building has been more interested in the construction industry and chasing the market demand, relevant technology, and system earner to find environmentally-friendly solutions to deliver a superior building performance with high power efficient demand.

3.4 Research inspiration and motivation

The construction industry is one of major participant redirects the prosperity of the economy. The industry has remarkable figures of power demand with the full percent of the entire electricity consumption, as the buildings account for 40% of energy use worldwide (WBCSD). Consequently, the enhancement of energy efficiency of the sector is crucial to diminish the energy demand.

Therefore, building skin and envelope as a focal part of the building structure takes the prodigious effort of the investigator for additional improvement due to the structure functions as separate the inner building climate from outdoor environmental conditions and additional as a decisive feature of building form and aesthetical architectural scheme.

Thus, approachable or interactive façades are attractive an innovative exploration subject that reports aim to cover, due to the inevitability of reducing building energy request and improve the visual occurrence and architectural integration. Presently, response methods are implemented by architects and engineers in building sectors to regulator the solar gains, inside light level, passive natural ventilation, ornamental the building thermal behavior, and energy saving. Particularly, in the peak time, when an extreme usage of Ventilation and Air Conditioning (HVAC) systems require in a hot climate like Dubai, UAE (Radhi, Sharples & Fikiry 2013). Some fact demonstrates that energy used during its lifetime causes as much as 90% of environmental impacts from buildings. Furthermore, Building operations consume more than 2/3 of all electricity demand (BuildingScience.com).

Most of applicable data and researchers discuss the subject of the Kinect Façades performance are limited in hot and humid climate like our region. Furthermost of the literature and study takes the issue of kinetic facades in the temperate environments. The most critical dimension of the dynamic louver performance as a double skin façade has been neglected in many studies and rarely studied in our area. Thus the deficiency of academic research discuss kinetic as a double skin façade and experiments the performance of the system within a hot, climate in Dubai, UAE atmosphere specifically generated a motivation to the author to pursue the research.

The research will discuss in-depth the performance of the Kinetic double skin façade in details by a simulation study taking into consideration the best operable scenario of the movable louver and the best distance between kinetic louver and the façade. The research concentration would be in the review of literature and papers in that field by taking the advantage and lesson learn from their conclusion along with their recommendations if applicable.

The research selects an existing high-rise office building in Dubai as a case study and builds the research baseline model. The dynamic louver system will be assembled with different configuration and place different scenarios. The model will be tested to figure out the optimal configuration in term of louver position and best distance as a second skin.

Kinetic skin strategy results should demonstrate the effect of the model on total heat gain and heat loss of the building envelope where the thermal exchange could effectively lead to reduce total energy demand. In hot, arid climate are presented as Dubai area, the proposed strategy could enhance total saving of power consumption and reduce the cooling load in additional to as effective daylight presents to an office building.

Finally, the report will conclude the effect of such model as a climate responsive solution toward a sustainable building environment in the field of building construction industry in hot, arid climate in general and in particular in UAE region.

3.5 Aim and objectives

3.5.1 Dissertation aims

The dissertation seeks to investigate façade performance by adopting kinetic louver device by way of a double skin façade schemes as architectural design solutions for an office building in Dubai. The performance will be measured by the follows:-

- Comparing the level of efficiency of a different configuration of façade's outer skin that could change as a response to climate condition. Examine the system to find the contributions of kinetic to appropriate indoor thermal gain by enhancing the thermal performance of building façade.
- Enhance the indoor light level by achieving best penetration of the natural light.
- The impact on total building energy demand by reducing cooling load and artificial light for the indoor spaces.

3.5.2 Dissertation objectives

The research objectives are the crucial parts that would guide the researcher to grasp the essential aims of research process completion. The objectives of the listed as follows:

- Generate climate model of the local area in Dubai, UAE
- Build the base case model of double skin façade for an office building in Dubai and exam the skin performance at different building orientations, in term of thermal comfort, visual comfort, and total energy demand.
- Analyze and discuss the literature findings.
- To build a new kinetic double skin façade and exam the influence of different configurations of Kinetic louver system as double skin façade (with

changed movable options of vertical and horizontal louver) at all orientations (East, West, South, and North) in diverse level by considering the follows:-

- Air Flow design and CFD simulation to show the air flow pattern influence and what the best configuration of the kinetic façade within the different scenarios is.
- Light level analysis for the indoor space with different façade configuration.
- Thermal modeling to predict and estimate cooling load and total energy demand.
- Compare different kinetic configuration analysis and emulate the energy load and potential energy savings.

3.6 Dissertation organization

Dissertation have mainly seven chapters which could be listed as follows:-

The first chapter offers a topic of the subject background and takes the local region of the study as a reference and elaborate some statistic and facts about the area. Motivation and research inspiration is also highlighted to demonstrate the need for the research.

Secondly, in chapter two, the literature review of previous researchers in the subject area are discussed. Definition of the kinetic façade along with their associated building envelope technology will be debated to deliver a better sympathetic to the logic of the system. That will discuss with a review of the previous model chosen around the world and within the region of UAE parameters. The local climate and an environmental factor of Dubai, UAE will be discussed as well to provide a clear environmental parameter to the research. Defending the research parameter will identify the aims and objectives of the research at the end of the chapter.

The methodology of the research will affirm in the Third chapter with a clear description of the research steps. The steps of the method will build on the previous practices that have similar parameters and share the same objectives.

The fourth chapter will build the base case model of the research where the simulation will conduct on with different parameters as described early. The chapter will end up with the base case model validation to make a sound basis for the next level of simulations and exams.

Next, chapter Five conducts the model simulation with different scenario considering the research aims followed by the comparisons analysis of different scenarios results and identified the valuable findings. The chapter will determine the best simulation results with the best compurgation in compare to the research parameters.

Lastly, in Chapter Six, the research set conclusions and further recommendation and shadow the gap of the research for the further future researchers.

The new challenges of kinetic double skin façade strategy and the research results should demonstrate the effect of the model on total heat gain and heat loss of the building skin and envelope where thermal exchange could effectively lead to reduce total energy demand. In hot, arid climate zone presented as Dubai area, the proposed strategy could enhance the total saving of power consumption by strengthening the availability of the natural daylight and reduce the cooling load in an office building.

Finally, the dissertation will conclude the effect of such model as a climate responsive solution toward a sustainable building environment in the field of building construction industry in hot, arid climate in general and in particular in UAE region.

Chapter Two: Literature Review

4.1 Introduction

The gap between the up-to-date knowledge of the similar research could be a review of the literature research. The review explores the research within same topics that have a close parameter to the area of the study aiming to provide a full understanding of dynamic façade as a general system and the verity of the scheme compositions. Besides, the performance of kinetic façade and system feature was one of the subjects of research within the selected area.

Newly, most of the research conducted internationally or locally in the GCC region experienced the performance of kinetic façade in term of practicality, operability and viability of adopting a simple system in term of the scheme component and another sophisticated scheme with many component and high-technology.

The research appraisal with selective concentrations is principally related to dynamic double skin façade, and reviewing the system performance in general and particularly, the contribution of the airflow in double skin cavity area to reduce the heat gain and heat loss in a high-rise building in the region of UAE. The most vital portion of the section is the outcomes of various researchers were the motivation of the research accrued to frame out the explicit aim and objectives.

4.2 Kinetic façade antiquity

Engineers and designer deal with the building façade differently when they think about making an environmental response structure. They defined façade as an interactive system that furnishes building a structure with the urban and climate rather than the old understanding of façade as a separated element between the outside and the internal building spaces. (Tzempelikos et al., 2007). Facade system is measured as an uninterrupted skin of environmental and aesthetical relationship between the interior and the exterior (Bougiatioti et al., 2009; Rafael, 2010).

Kinetic in related to Architecture as a term was induced in the early seventies by William Zuk and Roger H. Clark (Ramzy and Fayed, 2011) when they confronted design challenges related to dynamic spatial within the interface of mechanical design.

Theoretically, kinetic façade has been practiced by engineers, designers, and architects with movements and period of the interval but takes many approaches (Moloney 2011). Throughout the antiquity, a clear understanding of the term explained by researchers like Bios and Shepley (1984) defined as “physical movement of the surveyor” (Bois and Shepley 1984). Mostafavi and Leatherbarrow (1993) as the enduring of materials and belongings of deterioration (Mostafavi and Leatherbarrow, 1993). Marche & Tschumi says a building as an artifact awaiting alteration concluded by happening of occupation (Marche & Tschumi 1995). In 2006. Others stated s sense of actions due to visual effects of variation in light or existence of wetness (Holl, Pallasmaa & Perez-Gomez 2006). That references are required to deliver a strong distinction between the active and other approaches where all of these methods taking the shape of transformation as a reference.

Moloney in 2011 categorized three diverse methods to kinetic façade with entirely new understanding and scheme (Moloney 2011). First system developed by implementing mechanical, light and flexible component that used to form a dynamic structure induced by an international designer in kinetic. The technique concept created by a motion of single movement of façade elements folds around their center. Second category classified by other kinetic designer providing a taxonomy of regulatory system for dynamic movement of the façade components. The system program the structure positions and control accordingly (Fox 2003). The third was utilize by Oosterhuis and Xia (Oosterhuis and Xia 2007) where the system drew collaborating software built on algorithms data. The active system in projects depended on enabling technology to form a double curved surface by inflation elements and shape it with a possible range of profiles (Moloney 2011), (Fiorito et al. 2016).Other categorization of dynamic façade established by a study in 2012 (Sharaidin & Salim 2012) specified five models according to operation technique like rotating, elastic, retractable, self-adjusting and sliding systems.

Researchers also highlighted the essential for environmental mediation structures affirming, the application and integration of computational system throughout architectural modules as a climatic moderating system pose a new level of evolving prospects. (Moloney 2011; Schumacher et al. 2010).

4.3 Kinetic façade functionality and performance

The main objective of the kinetic architectural façade inspected by several researchers looking for strength of the idea from a diverse aspect, test augmentation of buildings power efficiency and occupant experience on the visual and thermal level of comfort in multi-used structures (Shen and Tzempelikos 2013).

More than functionality and system performance, numerous studies were touching the dynamic operation method of shading device system, motivation, and flexibility that light the aesthetic presence of the engineer's mobility where they track for the choice of shape, façade component, and specifications. (Ramzy and Fayed 2011).

In 2016, a research studied the performance of kinetic façade with local climate parameter in "Delta bioclimatic zone" Cairo, Egypt, (Mahmoud and Elghazi 2016). The paper selects a location where the main façade orientated to south direction with a highest solar gain to investigate the daylight performance. The research applied two investigation methods were first analysis built on a real physical mockup and second analysis conducted in simulation base. The study concluded that the daylight improved by 50% in summer and springs whereas other orientation touched nearly 30%. The results prove the additional values of the kinetic system expressly when the system developed in initial design stage by the simulation program.

Additionally, the paper experiences a complicated geometry and chosen design parameters according to façade efficiency and aesthetic simultaneously. The method test varied boundaries, parameters, and lines that shaped many selections and variables to facilitate the designers to operative conclusions at the initial design phase of a stylishly sustainable scheme.

Johnsen and Winther studied the regulatory style for falling the energy request for an office building in Denmark in 2015. The research relies on the natural ventilation, natural light, reduce heat gain, and heat penetration to enhance the level of comfort of the internal environment (Johnsen and Winther 2015). The research outcome ended up with a potential energy saving on total consumption influenced by the dynamic façade performance. The total demand declined to almost half of normal usage in comparison to traditional façade.

Hammad & Abu-Hijleh in 2010, presented a paper that exploring an office building in Abu Dhabi, UAE and studies the electrical saving base on the assuming of active louvre system (Hammad & Abu-Hijleh, 2010). The outcome of the research demonstrates the inference on power claim by 28-34% within the different orientation by using the combination of the active device and light dimmer system. Furthermore, the verdict of the investigation illustrates that fixed louver with ideal inclination reached almost the same figure of power deduction in comparing to the dynamic scenario.

In 2014, in United Kindom (Hasjemii 2014) exam active shading device and daylight penetration by a study took a case study of an office building. The paper interrogated if the kinetic façade would take part in support the engineers to lessen electric request by improving the expected light penetration with a level of comfort. The research is captivating advantage of the integration and collaboration of different methodology and the outcomes detailed that the system meaningfully improved the daylight luminance at the office space and decreased the request for artificial lighting by 60%.

In hot, arid climate, Giovanni and researchers explore the optimization of the movable shading device with acceptable light level functionality (Giovannini et al. 2015). The study build model base on an existing office building in Abu Dhabi, UAE and explore the functionality of active system presented as a novel design. The functions of the novel kinetic system were tested and record the overall saving on power demand and the enhancement of natural light level in the offices. The paper outcome proves the saving of different configuration of the façade and scales energy performance. The demand is enhanced significantly with percent between 67.9% with various scenarios, in comparison to other technologies in addition to maintaining an acceptable visual level.

(Lee et al. 2015), in this paper, another factor has been tested by verifying the effect of airflow in double skin movable louver system in Kansas, United States of America. The study objective is to explore the total power saving by screen out undesired solar transmission and heat gain throughout façade system. Diverse louvre positions tested, and the effect translated into a total reduction in heat gain. The result shows a decent reduction in power consumption by 0.4%, 2.6%, and 6.4% respectively than 0-degree position.

(Nielsen et al. 2011), the paper approaches different forms of flexible shading system and scale the effect on an office building in Denmark. Through integrated simulation tool, the research explores daylight and energy and aims to benchmark several façade alternatives and evaluate the total power consumption and internal comfort levels like the available natural light level, indoor air quality, and visual comfort level. The research results highlight prominence of contributing design options in the initial design stage. These will help the designer with their critical decision on the design of façade base on quantified performance within given context instantaneously attaining the harmony between design and building function.

To conclude, the demonstration of dynamic façade system performance by researchers are achieved in no less than one of the fifteen areas (A to N) presented in Figure 4-1 (Loonen et al. 2013). Where the thermal, optical, airflow and electrical factors are contributed and merge to enhance the overall performance factors. An additional valued feature that originates with the kinetic solution is the aesthetic and visual presence of construction that funds architects and engineering scene to complete design with an elegant architect stylish building (Figure 4-1).

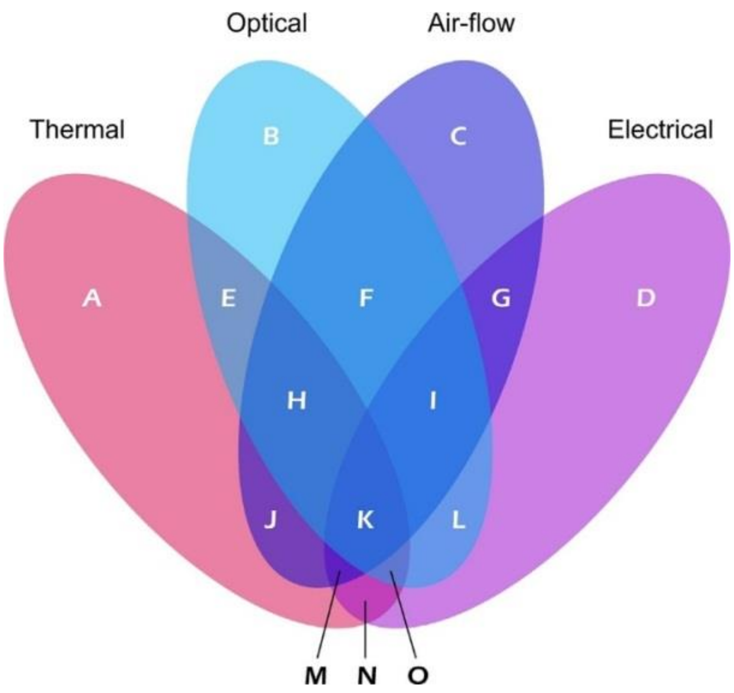


Figure 4-1 Sorting of the applicable area for performance of the active façade system (Loonen et al. 2013).

4.4 Kinetic façade as double skin performance with wind velocity and stack effect.

4.4.1 Overview

The building façade system in general consist of the outer skin that collaboratively works as a shelter system protecting the internally controlled environment from the external atmosphere. The dynamic louver system behaves as a variable with pivoting louver segmented and has the possibility of variable design configuration where it could perform for each floor or extended across the whole external skin (Lee, Alshayeb & Chang 2015).

In general, a cavity within double skin configuration influenced by external environmental factors, as the main function of the skin is to work as a barrier between two different conditions. The characteristic of skin is mainly affected by external climate, configuration, assembly of the system and responded accordingly. (Figure 4-2) (Choi et al. 2012).

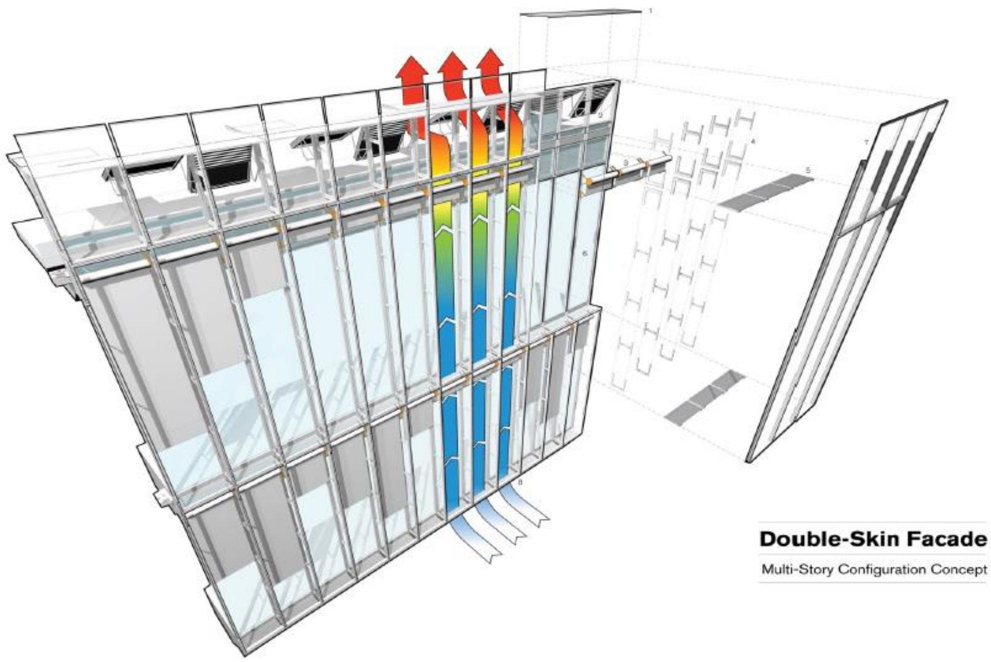


Figure 4-2 the cavity details within the double skin configuration (Choi et al. 2012).

Cavity shaft should take advantage of stack effect to improve air velocity at the space in between the two-layer of building façade. Natural air passes through the shaft from lower levels and extracted vertically to the upper level by the effect of the difference in pressure and air temperature. These circulations exploit temperature differences between the lower level and higher level along with the gap between external skin temperatures to the inner skin to accelerate the air velocity in the cavity and enhance thermal uplift.

Specialist consultant firm ("HL-Technik Engineering GmbH Innovative Gebäudetechnik" 2017) proved that the air velocity would increase at the high level due to the buoyancy effect on façade. Also, the air volume on the upper floors of the high-rise building is much greater due to the thermal buoyancy effect on the main elevation (Figure 4-3). The highest airflow volume and air velocity could enhance the skin performance is considered as one of the vital design parameters.

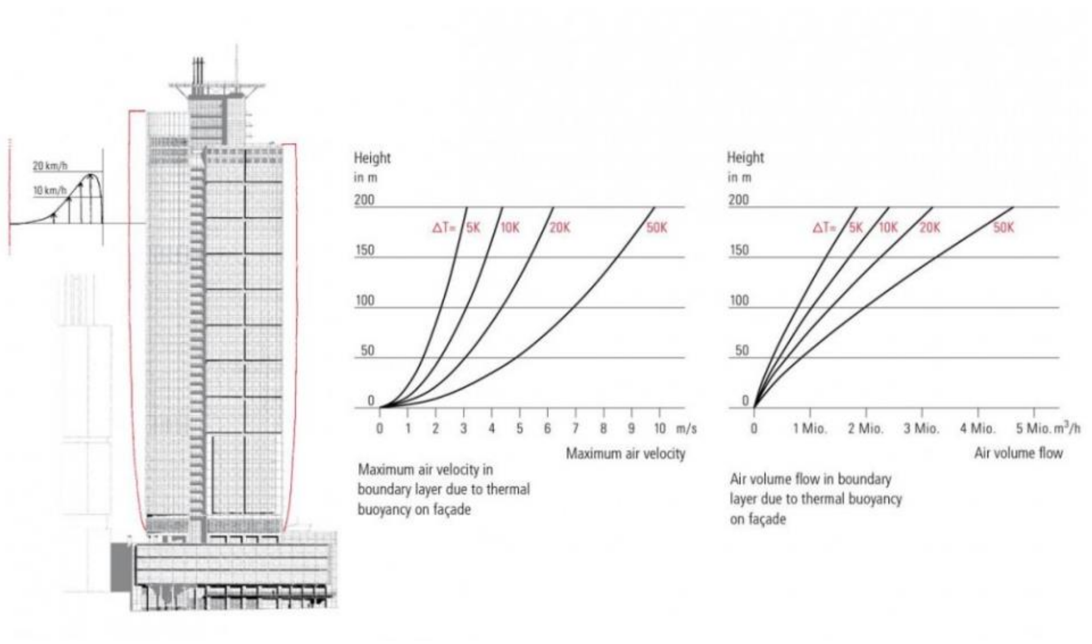


Figure 4-3 Airspeed and volume trend in the high-rise building ("HL-Technik Engineering GmbH Innovative Gebäudetechnik" 2017)

4.4.2 Stack effect and solar chimney properties

One of the most particular factors in the double skin façade is stack effect where the effect ensues due to warm and humid air with less density replaced with the cold, dry air contentiously. Especially in a high-rise building, where hot air rises and generate outward pressure effect at a high level and negatively inward pressure in lower levels. The line between the two different pressures identifies as a neutral plane. That determines the wind flow in between the two separate pressure and air circulation caused from inside to the outside section of the building and vice-versa (Etheridge 2012).

In hot and humid arid climate, airflow is predominately preferable to move from the cold controlled environment inside the building too hot external environment. Therefore, the level of the natural plane line could be moved lower as much as possible. While another cold climate, the case is opposite, where the concept comes from presenting warm and humid air moving from the inside to outside environment. Therefore, the advantage of having the natural plane at the upper level is more by having more air exhaust from the interior relative to the incoming fresh air (Figure 4-4) (Etheridge 2012).

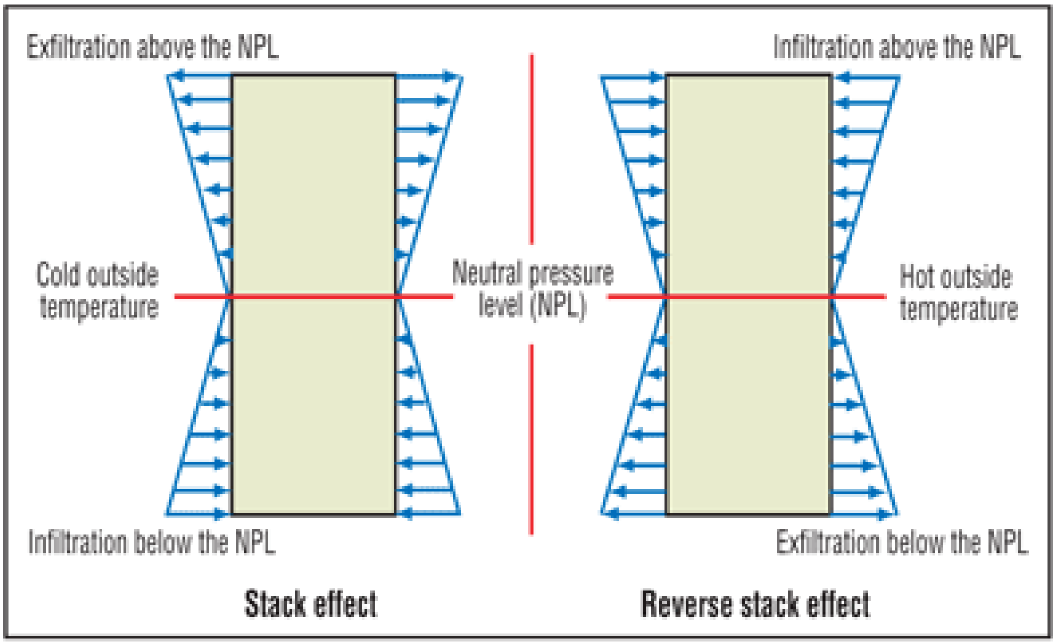


Figure 4-4 Stack Effect illustration present the two different scenarios in hot and cold weather (Etheridge 2012).

Another fact that caused by the act of double skin configuration is solar chimney effect, where the naturally ventilated facade is operable to allow the introduction of outdoor air at base and relief air at the top level through stack effect act as a solar chimney. In that basis segmentations of the cavity might be necessary to reduce the effect of an undesirable boost in air temperature in a hot region like GCC country.

4.4.3 Advantage, disadvantage, and limitation of the system.

- Major Advantages

The benefits are mainly revealing in enhancing the thermal level of comfort and insulation by better air quality, reduce the noise level and odder, moisture, level of humidity and risk of condensation in the main façade. The systems are an advance term of operation which has variable settings respond to climatic conditions. Moreover**,** the scheme is a consistent, weather protection with many structural opportunities.

In specific, stack ventilation has numerous noteworthy reimbursements, from the sustainable and environmental point of view that liberated from wind effect.

The system can offer a stable air flow in compared to natural wind and has a greater mechanism for selecting areas of the air intake.

- Major disadvantages.

While the most disadvantaged of the system is the cost, complexity of construction, operation, maintenance, and other code requirements to protect the system, like fire and life safety and. More unbenefited value is the lateral and vertical transmission of sound and odor via cavity when the cavity closes.

- System limitations.

The system has other factors that limit the ventilation performance like, design restrictions, lower magnetite in compare to natural passive wind ventilation system. The system relies on differences in temperature between inside and outside of the structure. However, the quality of the air might be affected by the external pollution.

4.5 Building envelope evolution.

Kinetic facade system has a range of features that consolidate an example of original envelope responding automated to the physical and environmental factors. As described by Wigginton and Harris the features give an interpretation of what known as “Genetic Characteristics” (Wigginton & Harris 2006). Features classified according to functionality provide a wide functional categorization (Table 4-1).

Table 4-1 the kinetic features classification according to their functionality called as Genetic Characteristics by the researcher (Wigginton & Harris 2006).

Intelligent Feature	Description
Building Management Systems (BMS)	The brain of the whole system. The BMS is the central processing unit, receiving all of the information from the various sensor outstations and determining the appropriate control response to the actuating elements
Learning Ability	Via Neural networks and algorithms, it provides buildings with the ability to learn their energy status and thermal characteristics.
Environmental data	Typical measurements of various environmental data will determine the control decision of intelligent technology.
Responsive Artificial Lighting	The ability to deactivate or dim itself in response to adequate sensed natural lighting levels.
Daylight Controllers	Systems operate in response to information provided by sensors that measure outside Light and solar intensity, and inside light levels and temperature.
Sun Controllers	Computer algorithms can determine real-time solar angles by the input of time, latitude and longitude data. Computer-controlled blinds, louvers and other protective shades, all of which can be regarded as solar control.
Occupant control	The ability for manual override control which often provided by on-screen control panels and hand-held remote control units.
Electricity generators	Generating electricity by renewables. As the intelligent building evolves, it may develop some of the in-built efficiencies of the human body –using every available resource through maximum conservation and recycling.
Ventilation Controllers	Ventilation can be automatically regulated for increased effectiveness and greater occupant control by operable elements of the building fabric, such as retractable roofs, motorized windows and pneumatic dampers.
Heating and Temperature controllers	Reducing the significant demands for space and water heating through the use of passive solar strategies, provided with more precise motorized control.
Cooling Devices	Computer-controlled night-time ventilation for pre-cooling of the thermal mass. Cooled water distribution is optimized in the same way as the heating circuits.
Double Skins	In the summer, the double façade can reduce solar gains by the ventilated cavity and stack effect. In the winter, the double façade will act as a buffer zone between the building and the outside, minimizing heat loss, and improving U-values. Intelligent control mechanisms have been used to regulate the admittance of air into the cavity automatically.

Other meanings to building envelope have been pursuing new tools, smart resources and distributed schemes that have urged the premise of biological prototypes for sympathetic the design of construction elements and management controls.

Moreover, the borders among multi-discipline engineers elaborate the need for clear characterization of their particular roles, responsibilities and specific accountability (M. Addington and D. Schodek, 2005). The literature term that identifies the system detailed by (M. Addington and D. Schodek, 2005) could be listed as follows:-

4.5.1 Smart

Klooster paper classified “smart materials” as a system possessing “embedded technological functions” that involve specific environmental responses, operating either through internal physical property changes or external energy exchanges (Klooster, 2009). (Addington and Schodek, 2009) Define the characteristics of smart materials as “immediacy” (real-time response). Smart surfaces and materials can play a significant role in intelligent, adaptive and responsive envelopes due to the intrinsic properties that provide an ability to transform their physical properties and shape to exchange energy without requiring an external source of power.

Doris Sung, the director of DO|SU Studio Architecture, explore solar bi-metals material for fitting a self-supporting system that capable to self-operate their pores to self-ventilate (Figure 4-5).

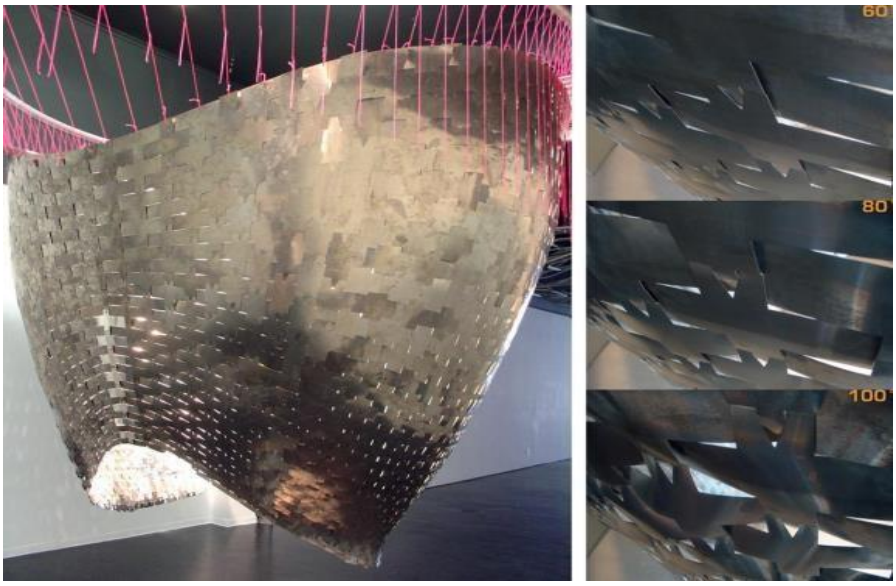


Figure 4-5 Smart Thermo bi-metal Self- Airing system. (D. K. Sung, 2010).

4.5.2 Responsive

The term “responsive” frequently swap with “adaptive” term. Nonetheless, the term describes, “How natural and artificial systems can interact and adapt” (Beesley, S. Hirosue, and J. Ruxton, 2006).

The same characteristics shared with “smart” skin but contain interactive features, like, computational algorithms for self-adjust mechanisms and the ability for occupants to environmental regulatory settings (R. Cole and Z. Brown, 2009).

Manuel Kretzer and scholars from Zurich, Germany industrialized an example of skin called “Shape Shift” (Manuel Kretzer, 2010); a layered, of elastomeric films that reshaped when externally charged by power (Figure 4-6).

Figure 4-6 Shape Shift’ prototype, consisting of 36 individual EAP elements, as exhibited at the Gallery Stark Art in Zurich, (Addington and Schodek, 2010).

4.5.3 Intelligent

The term “Intelligent” used broadly in the construction diligence from the time structure automation, and communications grow into more pervasive. Relative to building skins, the term intelligent implies a higher order of organization and performance than smart. Mainly, intelligent envelope objective to enhance building efficiency in relative to climate, energy balance and human comfort, naturally grounded on analytical models. Smart and intelligent have different functionality results from intrinsic material properties where the intelligent skin is further variable and more flexible to control and required a source of power for operation. Figure 4-7 show an original building skin of automatic wood louvre s integrated with a photovoltaic create a continuous façade for “TU Darmstadt’s in 2007 Solar Decathlon House” (R. Cole and Z. Brown, 2009).

Figure 4-7 Intelligent façade of automatic wood louvre s with building integrated photovoltaic panels, TU Darmstadt's 2007 Solar Decathlon House (R. Cole and Z. Brown, 2009).

4.5.4 Adaptive

The term "adaptive" describes a design approach that seeks to unite multi-scalar factors in response to the environment to reach a higher building competence and mutual energy efficient design solution.

Engineering firm called Buro Happold, in collaboration with deployable structures innovator Chuck Hoberman, has established an intelligent surfaces unit called the Adaptive Buildings Initiative (ABI). The unit has developed some dynamic shading and cladding systems, including the Strata™ System, which consists of electronic modular kinetic units that can retract into a slender profile (Figure 4-8) (Hoberman and B. Happold, 2010).

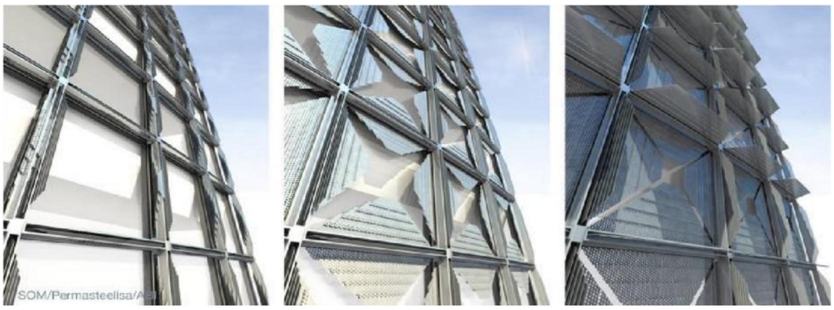


Figure 4-8 Heliotrace system (Hoberman and B. Happold, 2010)

Additionally, Aschehoug et al. (2005) listed additional synonyms in the literature of the concept of building skin as described in Table 4-2.

Table 4-2 Intelligent building skin definitions as described by the researcher. (Aschehoug et al. 2005)

	Terminology	Definition
1	Advanced Facades	Distinguished from conventional ones
2	High-performance Facades	Assuming conventional facades are low-performance
3	Innovative Facades	Conventional facades are per definition no innovations
4	Smart Facades	Implying automated computer-based controls
5	Intelligent facades	Normally understood as identical to "smart"
6	Active Facades	Which only means dynamic in character
7	Interactive Facades	Implying reactions to external situation and user demands
8	Responsive Facades	Normally understood as identical to "interactive"

Finally, this terminology will be advanced further whenever a new technology and techniques introduced by the researcher or embraced by the engineer.

4.6 Kinetic facades samples and previous experience.

Several researchers have discussed the kinetic technology and espoused by numerous firms around the world in diverse locations and different climate factors. That provides us with a level of acceptance to the system as one of a promised solutions that could furnish the construction industry with a new approach within the sector. Especially, several of these architectural buildings have certified as sustainable buildings as per the international codes or by local standard. Sample of the buildings discussed as follows:-

4.6.1 The Devonshire building – Newcastle University, United Kingdom.

One of the listed building as a green building that auto-response to the sun position and operate the shading device in the south façade. Tracking of the sun and façade movements managed by an intelligent system tackle the sunlight, time, and date and response accordingly. The active system enhances the overheating and relief the cooling system (Figure 4-9) (Fortmeyer & Linn 2014).

Figure 4-9 Devonshire building in Newcastle University, United Kingdom (Fortmeyer & Linn 2014).

4.6.2 Institut du Monde Arabe – Paris, France

The first attempt at investigating Kinetic façade adopted in France 1980-1987 by an architect called “Jean Nouvel, a French architect.”. The designer presents a robotic louvre screen at the façade which seems the most well-known kinetic design. The system inspired by the idea of lattice Arabic Mashrabiya and customize the kinetic skin in the south façade to provide a comfort level of light and privacy. The designer installs a significant control system to operate the kinetic screen and enhances building performance by adequate energy consumption and by reduced solar heat gain (Figure 4-10) (Moloney 2011).

Figure 4-10 Institut du Monde in Paris, France (Moloney 2011)

4.6.3 Burder Phoenix Library, Phoenix USA.

In 1995, the library of Burder designed by DWL Architects and AURP firm. The building located in a hot, arid climate in the USA, and the orientation of the main façade toward east and west. The designer comes with two different automated louver systems and install the horizontal metal louver in the south and use a vertical fabric on the north to control the morning and late day sunlight effect (Figure 4-11) (Fortmeyer & Linn 2014).

Figure 4-11 Burder Phoenix Library in Phoenix, USA (Fortmeyer & Linn 2014).

4.6.4 Manitoba Hydro Place – Manitoba, Canada.

The architect firm called KBMB Kuwabara Payne Mackenna Bulmberg design the building in 2010 in humid continental with warm, hot summer and cold winter. The design analyses the variety of the climate data and building sustainable design strategies.

The engineer implements many strategies that include maximum harnessing of solar, wind and geothermal energy, a high-performance building envelope, and a natural ventilation strategy that incorporates a solar chimney and operable windows. (Figure 4-12 and Figure 4-13). The building classified as a LEED platinum office building (Fortmeyer & Linn 2014).

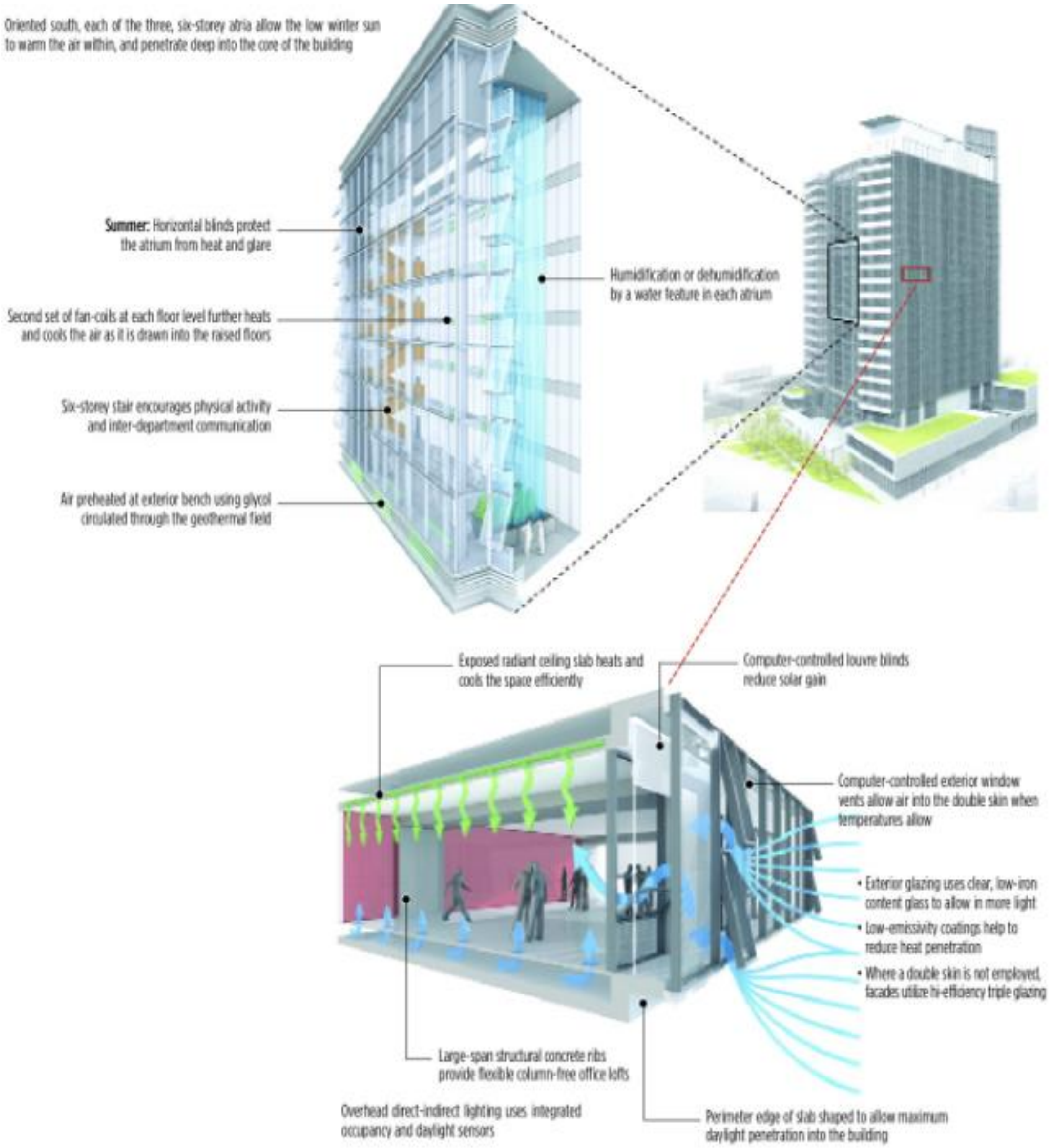


Figure 4-12 Manitoba Hydro place, detail of the sustainable solutions, Manitoba, Canada (Fortmeyer & Linn 2014).

Figure 4-13 Manitoba Hydro Place, Building sustainable solutions, and perspective, Manitoba, Canada (Fortmeyer & Linn 2014).

4.6.5 CJ Cheiljedang Research and Developments Centre in Seoul, South Korea.

In 2014, Yazdani Studio of Cannon Design in collaboration with ARUP firm, the façade designer, projected to design an office building in Seoul where the climate classified as humid continental. The firm was designing the building envelope not only to reduce the heat gain and decrease the HVAC load but also to enhance the microclimate of the building. The façade design selected and operable façade that responded to climate. So, the designer installed a glazing curtain wall as a static layer and operable screen layer that react to the solar radiation and tenant's response (Figure 4-14) (Fortmeyer & Linn 2014).

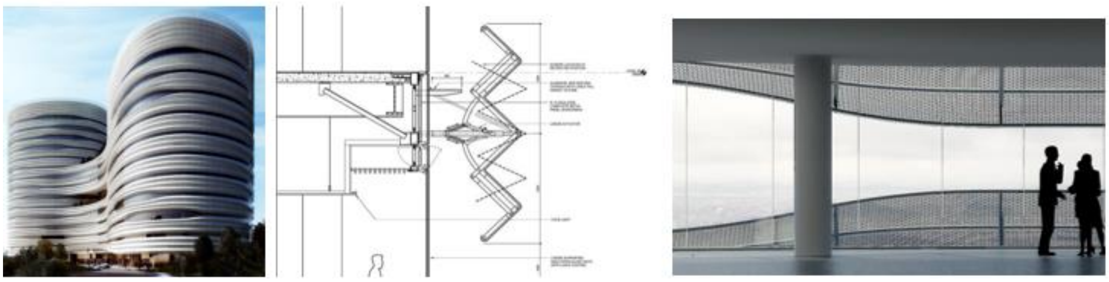


Figure 4-14 CJ Cheilijedang Research and developments center details of elevation, interior, and perspective, Seoul, South Korea (Fortmeyer & Linn 2014).

4.6.6 Kolding Campus, the University of Southern Denmark in Kolding, Denmark.

Henning Larsen Architects target to meet the Danish 2012-2014 building energy code when they start the project with the client. The building facade designed in a sustainable manner that used the local material of perforated metal structure actively responded to external climate and regulation the indoor temperature. The building is classified one of the best sustainable development in 2015 (Figure 4-15) (Fortmeyer & Linn 2014).

Figure 4-15 Kolding Campus SDU, Kolding, Denmark (Fortmeyer & Linn 2014).

Finally, to summarize the architectural building paradigms, where all the buildings design and in particular the facade configuration have been considerably contributing to add value in Enhancing the natural light penetration like Burder Phoenix Library, Institut du Monde Arabe. Moreover, the system reduces the demand of the electricity by adopting a passive design technique in cooling/ heating the building by adopting the kinetic façade system in various climate zones like Kolding Campus, CJ Cheiljedang Research and Developments Centre, Manitoba Hydro Place and The Devonshire building as demonstrated earlier.

4.7 Dynamic facades in UAE

Particularly, Emirates of Dubai and UAE, in general, were the highest recorded around the world have been broken, like, highest skyscraper, tallest office building, and residential tower, and another construction. That generates more demand for energy and as a novel efficient construct system. Throughout the expansion progression, a rapid evolution in Gulf region perceived a vigorous construction and economic growth that abandoned the influence on another factor of climate and social activities.

Recently, with a compilation of one of promised Kinetic double skin façade in UAE, the building designer who design the TIC building in Barcelona as well announce that the active envelope system has multi-functions in addition to aesthetic and energy efficiency. Those functions, like daylight control, enhance internal comfort level fully achieved (Figure 4-16) (Sharaidin & Salim 2012).

Sharadian & Salim (2012) discuss the evaluation of the kinetic façade in the early stage of the project in Al Bahar tower in Abu Dhabi. The research found the dynamic façade system design as a double skin facade add real value to the building in term of the power consumption by examining the building competence in the early design stage with a simulation software. That results provide the decision maker tools to build an environmentally friendly building contributes to reduce energy demand by lessen the cooling load and improve the internal situation with more natural light (Figure 4-16).

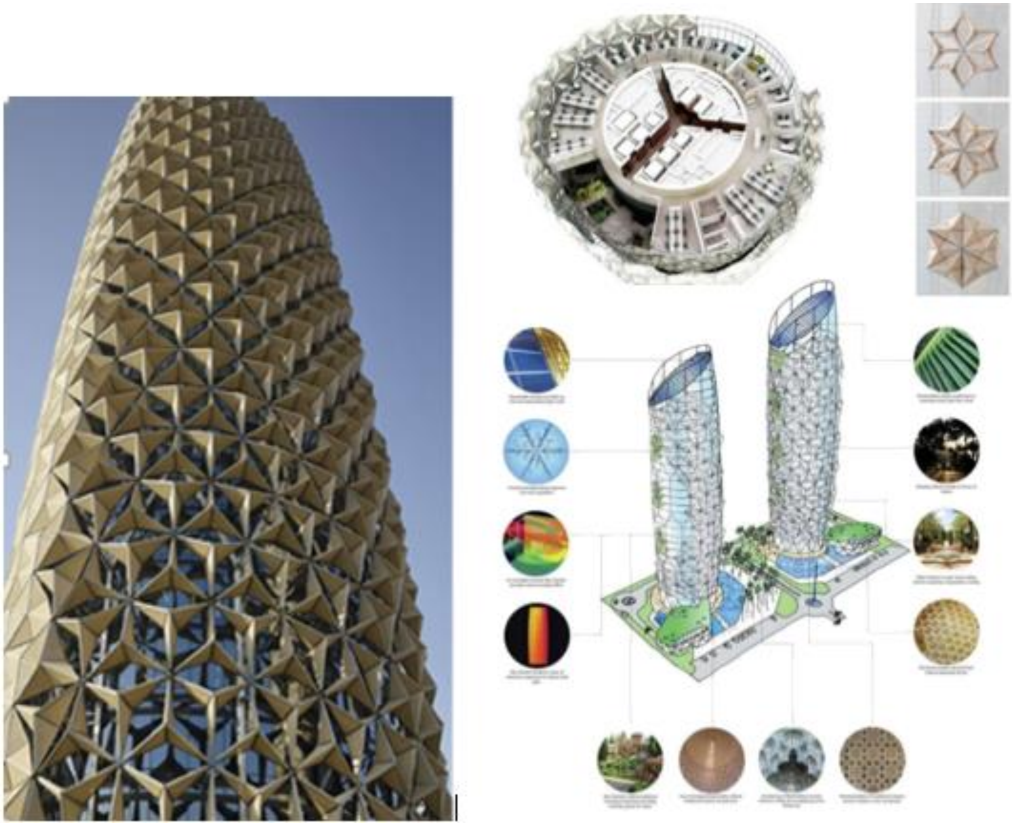


Figure 4-16 Al Bahar Tower in Abu Dhabi, UAE (2017) (Sharadian & Salim 2012)

Hammad & Abu-Hijleh in 2010, presented an investigation to the potential energy saving of active louver device in Abu Dhabi, UAE (Hammad & Abu-Hijleh 2010). Simulated software tested the impact of the dynamic concept, and the research results show the inference on the total electrical bill by 28-34% within the different orientation through install the mixture of the active device and light control. Moreover, exploration illustrates the static louver with right angle realized a close figure of energy inference within the total demand.

Radhi, Sharples & Fikiry 2013 questioning if saving of power consumption would be achieved through reducing cooling demand by the multi façade system. They realized the impact of global warming and increases of pollution figures within UAE and the region. The study present that the high-level decision maker in government sector could facilitate the regulation and set sustainability goals for an environmental friendly demand in the construction industry in general and with other areas on which the emission of CO_2 could potentially decline.

Lately, there are buildings design with a kinetic façade like the Apple retail store in Dubai. The designer firm illustrates the layout as a highly innovative reaction to the culture and weather of the Emirates that enrich the natural light and provide another source of power. The façade design has solar wings that dynamically moved with sun direction and provide a soft shade to the indoor environment. The wings design mimic the concept of Arabic Mashrabiya that allows the daylight to penetrate through to interior space (Figure 4-17) ("Apple Dubai Mall with one of the world’s largest kinetic art installations | Foster + Partners" 2017).

Figure 4-17 Apple Store in Dubai Mall, Dubai ("Apple Dubai Mall with one of the world’s largest kinetic art installations| Foster + Partners" 2017).

4.8 Problematic statement and finding

Recently, there are divers building implement the system of the kinetic double skin façade in the region and internationally but, the challenges are obvious to the extent of system reliability, capability and environmental efficiently effect. Many researchers test the transfer of conventional system of double skin façade to receptive dynamic façade exploring the achievement against the system responsive to external environment factors like the Air, thermal radiation, Daylight, and level of comfort of the internal environment, and other parameters like the operations, durability, maintainability and the system cost.

Prominently, the available studies have limited data within GCC in general and Dubai, UAE local environment as hot, arid climate specifically. Numerous researchers discuss the temperate and cold climate of Europe, USA, and another area. Despite the fact of limit study in hot air climate, the potential of the demand for more energy-efficient building and environmentally friendly construction is growth potential. Especially, the experience of the local architectural, historic building has a broad range of passive design technique that could positively integrate with a new adaptive system rather than active design. Nonetheless, in Dubai, UAE there is no kinetic façade adopted in a building within the borders of the research objectives.

Energy performance of the kinetic façade has studied with approximate similar climate to UAE in general. The study outcome counsel with a promising future for kinetic solutions, in particular with the advanced technology that offers today and available resource.

Contentiously, the need for the study become energetic to explore the competence of the kinetic double skin façade within Dubai, UAE's environmental parameters and local conditions. Energy performance is the main valuable factor that will be justified in the research by enriching the thermal building performance and reduce a total load of HVAC system, also, to improve the internal environment of an office building by control the daylight level.

4.9 Challenges of kinetic systems

The new construction technology façade a considerable resistance in the sector, as usual, the market appears to available conventional systems as a stress-free resourced than the novel system. Dynamic façade system has been investigated by many researchers to study the system performance within life cycle starting from design stage up to the operation time (Sharaidin, 2014). Some of the challenges list as follows:-

4.9.1 The Design stage and initial project concept.

(Sharaidin, 2014) Implementing kinetic facade for building to react to climate factors, becomes more challenging in evaluating the façade's performance within initial design phase. The ability to deal with the increasing complexity of scale and diversity of component. Figure 4-18 encapsulates the dynamic indication and details attribute that is possible in the design phase. Structures and material specs mainly prejudice These. These values take extensive time and effort from engineers to study and evaluate in early design stage where the time is limited in most of the project due to client outlook. Additionally, that is the potential elevated cost associated with the study and resources available that elevated queries about the system viability.

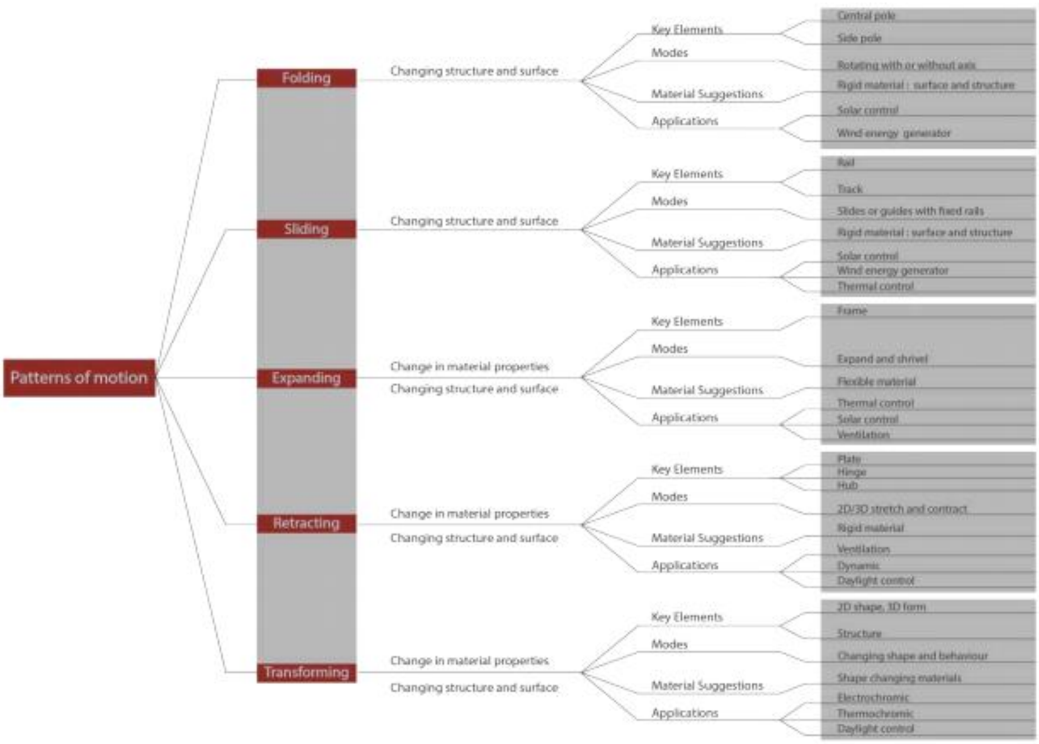


Figure 4-18 the Kinetic façade system indication and details attribute (Sharaidin, 2014).

(Park, 2011) Stated that engineers investigate design principles and construction methods of kinetic façade as a demand considered toward an accepted environmental response technique. However, the challenges are elaborated with the complexity of the system, the kinetic mechanism and the availability of the resources. Especially, where most of the dynamic parts are costume made to the projects. Moreover, the movable parts, Motors, actuators response to control system have other challenges for automation and monitor the substance for optimal operations that required special resources and additional associated cost.

4.9.2 Maintenance of system, operation, and life cycle.

Dynamic envelope and moveable parts became an impressive vulnerability to interruption and required a maintenance regime with skilled resources. The services availability is questioned in various areas and required a potentially high budget. These complement extra challenges and elaborate requisite for further intelligent; smart systems reported periodically to support a smooth operation and strong maintenance system.

Finally, elements availability, resources, and cost have significantly advanced a resistance against the concept of adopted the system within any project as an environmental responded scheme. However, the feasibility is not just a cost or complexity it is more related to the valuable sustainable aspects like reducing the CO2 emission by power demand deduction, enhance the level of comfort of the internal environment, enhance occupant level of comfort, and another factor. Additionally, the design flexibility and architectural aesthetic which is not comparable to a cost when evaluating the overall project ambition.

4.9.3 Challenges of the Kinetic system within UAE conditions.

The application of Kinetic system has extensively applied in order to mitigate the building settings alongside excessive heat gain, heat loss, light, and glare. However, there are some challenges inherent to these systems that should be considered as demonstrated earlier in general and in particular to the local climate conditions and local circumstances. Particularly the challenges, limitations, and opportunities of dynamic systems in UAE and in Dubai specifically could be listed as follows:-

- The climate conditions that affect the performance of the system where the climate is classified as the hot arid climate where the mutable external environments could bound the competence and the movement of the movable shading devices.

- The local regulations don’t support such innovative system and not cover such systems which make the adaptation of such design hard to achieve the acceptance level within the local authority.
- Climate Conditions and the location of Dubai close to the gulf sea, more than the harsh summer weather, the Dusty climate and humidity are the most vital factors concerns the designers. The dust accumulation and the limited tolerance to overheating will restrict the expected performance and lower the efficiency of the system in general.

4.10 Climate of the UAE region

United Arab Emirates (UAE) is amid latitudes 22.5°, 26.5° north and amid 51.0°, 56.25° East with a border of southeastern part of Arabian Peninsula (Figure 4-19). The approximate area of the country is close to the 88600-kilometer square, and Abu Dhabi is a capital and the largest emirate. The other UAE emirates are Emirates of Dubai, Sharjah, Ras-al-Khaimah, Umm-Alquwain, Fujairah, and Ajman (Emirates.org). The area of Emirate of Abu Dhabi is embraced approximately 80% of the UAE’s total area, about 67,340 square kilometers, followed by Dubai the second and the third biggest area in Sharjah.

UAE bordered by Sultanate of Oman from south and Kingdom of Saudi Arabia from west and south directions and, the coastline border with a total length of approximate 1318 kilometer. The seaboard within UAE prolonged along the southeastern portion of Arabian Gulf to western shorelines of Sultanate of Oman coast.

Figure 4-19 The United Arab Emirates, Dubai regional map (kästle 2017).

UAE has a hot and arid climate. The climate “manakh” is prejudiced by environmental changes endure by the Indian Ocean, over the Bay of Oman. Climate records show uppermost temperatures in summer up to 48°C in August. Mid-range seasonal records were 40°C - 35°C. December until February was the period for winter when temperatures dropped, and weather becomes more moderate. Figure 4-20 displays the data records for the period 2003 to 2016 with temperature, Rainfall, humidity, wind speed and solar radiation on a monthly basis over the years ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

	Temperature					Humidity				Wind			
Month	Max	Mean Max	Mean	Mean Min	Min	Mean Max	Mean	Mean Min	Rainfall	Mean	Max	Mean Max	Solar Radiation
January	31.3	22.5	20	17.6	12.9	80	67	51	9.8	13.5	50	23.2	4183.4
February	36.2	24.2	21.1	18.6	13.2	81	66	48	3.2	14.9	54.4	25.7	5082.1
March	40.2	27.1	23.6	20.8	13.4	80	63	42	6.6	14.7	63.4	26.4	5883.7
April	43	31.2	27.3	24.5	17.5	77	59	36	7.5	13.4	68.9	26	6467.4
May	45.7	35.5	31.4	28.3	23.8	76	58	34	0	12.7	49.7	24	6911
June	46.7	36.5	33.1	30.3	25.3	78	62	41	0	13.6	47.9	24.7	6753.2
July	47.9	38.7	34.9	32.2	28.5	78	62	40	0	13.7	47.1	25	6448.8
August	48	40.2	35.5	32.8	29.1	78	60	34	0	13.7	41	25.7	6314.8
September	45	37.1	33.6	31	27.4	79	63	41	0	13.1	47.4	24.3	5908.5
October	41.6	33.7	30.8	27.9	24	78	63	44	0	12.6	62.3	22.5	5322.6
November	37.4	29.5	26.9	24.2	19	76	62	46	2.5	13.2	64.8	22.9	4398.5
December	31.6	24.5	22.4	20	12.6	79	66	53	16.1	13.7	51.1	23.2	4078.3

Figure 4-20 Climate data table from 2003 to 2016 ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017)

The seasonal wind gusting to Emirates in spring reaches highest in April with an approximate speed of 68.9 Km/h and in the autumn season the wind speed about 64.8 Km/h in November. Prevail wind categorized into two types, dry northern wind with mild temperature and east wind with a high level of humidity.

The records of Precipitation is very little and occasional occurred in Dubai. December and January's months are the thunderstorms rainfall time, and the average of rain is recording squat records at below 6.5 centimeters annually. Northern Emirates of UAE have more rain records about 18.8 millimeters annually as the highest record in UAE. Humidity records in summer sit amid 60 % up to 100% expressly on coast area. Relative humidity minutes are less in a desert area, which is fairly far from coastal effect. Solar radiation detailed to be extreme in May at 6911 and least in December at 4078.3. ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

4.10.1 The microclimate

The UAE in general and Dubai, in particular, has a plain coastal with the south side shore of the Arabian Gulf Sea. The topography of the coastal line is almost flat in level with no slopes and without any vegetation area. The south zone of the UAE has a higher solar radiation, so the temperature record is greater than north area. The sea breeze effect within the coastal line area raises the humidity level potentially. Additionally, AlKhor area along the downtown of Dubai increase the degree of humidity in the area. This consequence impacts the urban heat islands and marks the atmospheric temperature higher than the region's records.

4.10.2 Temperature

Dubai Atmospheric temperatures are diurnal with high daytime records and minimum after night-time. Figure 4-21 demonstrations norms over several years from 2003 until 2016. Illuminating the warmest and rough dated is presented in July and August. Comfort climate began with mid-November to the end of April approximately. So the need for heat system is not recommended in Dubai while designing the urban constructions.

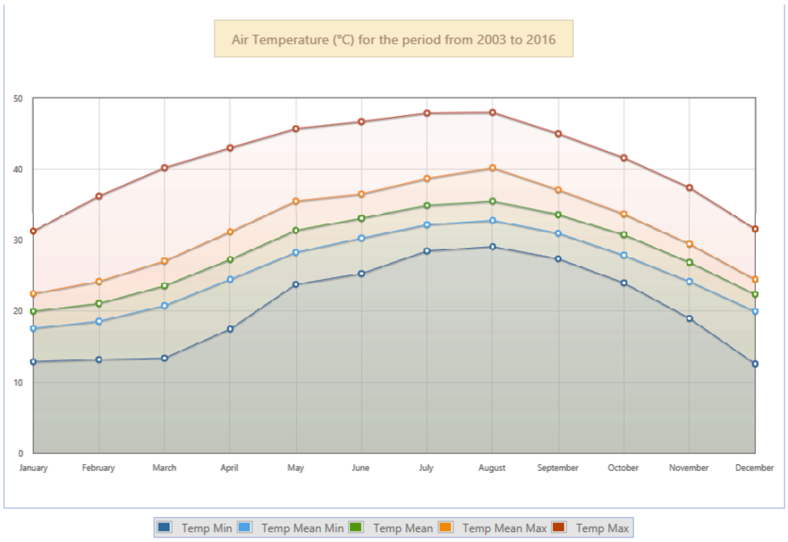


Figure 4-21 Annual temperature chart ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

4.10.3 Humidity

Figure 4-22 displays relative humidity means with an annual average below 70%. Dubai being a coastal urban is precise for a higher level of relative humidity. The highest records show near 80% in first quarter of the year and in July to September. Consequently; it is vital to delivering dehumidification approaches in the early design process of buildings in Dubai.

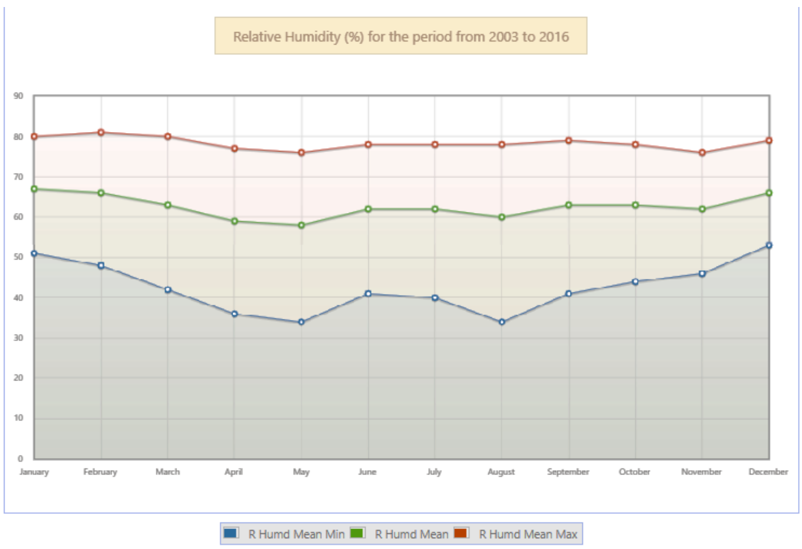


Figure 4-22 Annual moisture chart ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

4.10.4 Wind

The records demonstrated in Figure 4-23 showing wind speed in km/h from the era of 2003 until 2016. Comfort zones spread from mid- September until mid- April with breezes. High winds could cause an inconvenient experienced once or twice during the year, specifically in April and about end of March

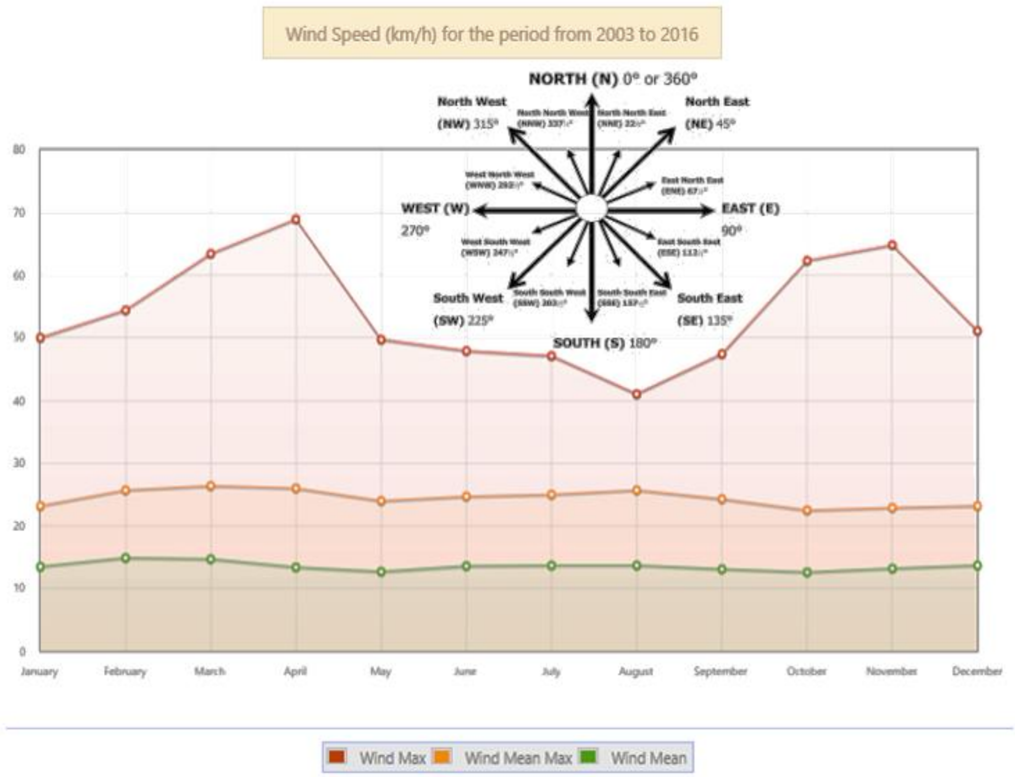


Figure 4-23 Annual Wind speed and direction charts ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

4.10.5 Sunshine chart

Annual solar radiation reveals in figure 2-28, where highest record presented in May near 7000 Wh/m2 and lowest showed 4200 Wh/m2 in December. Winter seasons have lower radiation at the period from October till February within the range of comfort zone annually. (Figure 4-24).

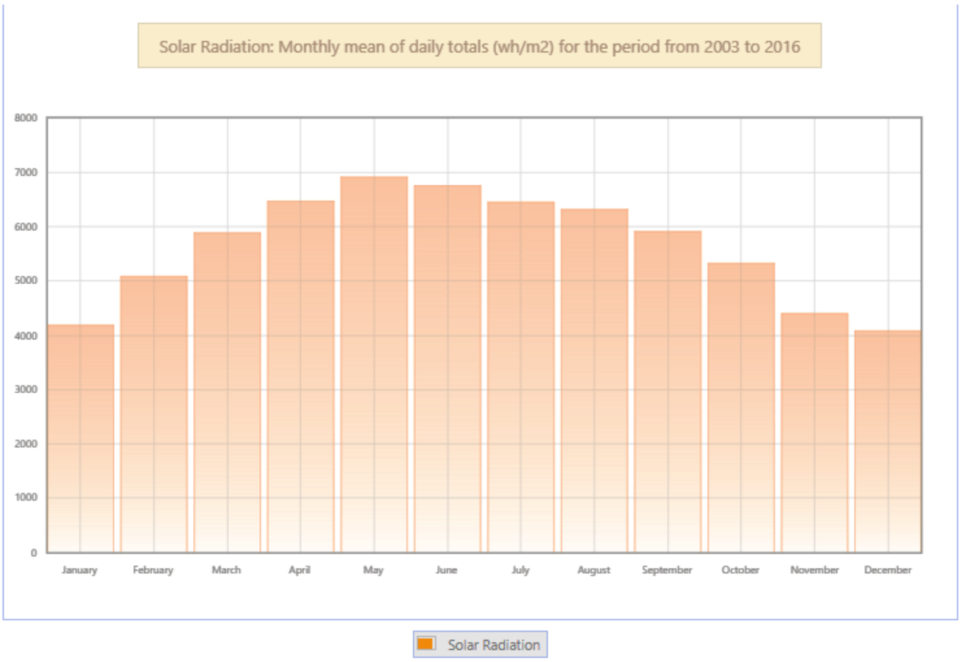


Figure 4-24 Annual solar radiation chart ("Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index" 2017).

Chapter Three: Research Methodology

5.1 Analysis of research methodologies applies to similar subject area

Data collection and literature review of the previous work with diverse research methods have been conducted in details to explore their approach to study the kinetic solution as responsive façade. The variation of selected methods largely links to the field of search where detailed inquiry of study should report. Predominantly, the majority of researchers explore the functionality of the system as one of the vital elements of building architecture. Those present the main envelope role as a thermal barrier between the external climate conditions and internal spaces by maintaining the comfort level of inside environment. Also, other details explored in many papers, like natural light and related luminance level and how the dynamic louver performs significantly to enhance the interior daylight level with comfort visually and mitigate glare consequence. However, topic related to the cost, system life cycle reviewed in precise aiming to explore the feasibility of the system, structure complexity, material, and operation mechanism which is related to toughness, maintainability, operation cost on lifetime span factors. Furthermore, papers deliberated the active devices as an architectural theme that influences the exterior melody and level of acquiescent in the context and urban design.

The review aiming to identify the best practice within the numerous methodologies show by the investigators that address the research question and elaborate the best approach to ascertain the research results. Nonetheless, the paper will focus principally on the main three research methodology that itemized as follows:

5.1.1 Experimental methodology.

The method takes place by building a physical mockup, existing building or an area in the field of test or either lab test and install all the equipment within premises of test parameters. These setting as presented by several studies furnish researchers with multiple devices manage a variety of limitations and collectively study the equation and bond factors.

One of the paper was conducted in Denmark by Johnsen and Winther in 2015, carry the experiment in the lab with a real mock-up to investigate the power consumption deduction by installing a dynamic louver system (Johnsen and Winther 2015). The test demonstrates the benefit of the kinetic system by scaling the thermal efficiency of building envelope along with advanced daylight in the interior spaces. The outcome presents a potential energy saving and perfection of air ventilation mechanism and other advances.

Other experiment experienced testing whether kinetic louver system expertise would participate in funding researchers to evaluate the power reduction through enhancing natural light level in an office building. The paper was drive in the United Kingdom, executing an experimental examination of a prototype in connection with simulations to evaluate the variety of the diverse climate factors (Hashemi 2014).

5.1.2 Simulation methodology.

These researchers mainly build on simulation experiment where software customized for a research purpose that customization developed by specialized companies while others depending on a standard software. Numerous statistics demonstrate, there is about 24 software deal with the subject of the thermal efficiency analysis, daylight factor and façade performance.

A paper published in 2016, by Mahmoud and Elghazi select the experimental method to explore the effect of the movable louver system and studied in detail the thermal and light efficiency. The different approach of the façade design was exam by the simulation software taking many parameters into consideration like the different seasonal climate data and façade formation scenarios (Mahmoud and Elghazi 2016). The designated software by the researcher was Rhino, DIVA, and Grasshopper to support emerging the optimal design formation with a complex algorithm of parameters.

Further paper selected IESVR software to discuss the thermal performance of the system and the reduction in total power consumption (Hammad & Abu-Hijleh, 2010). The research motivated to review and investigate the dynamic louver in hot, arid climate in Abu Dhabi, UAE and set the research parameter accordingly.

One of the crucial factors in an office building design was daylight availability and that been reviewed by researcher Giovannini and others in 2015 (Giovannini et al. 2015). The paper set their limitations base on annual climate data and test the CBDM the daylight metrics and DA the daylight Autonomy by using the DIVA – Rhino and Daysim. Additionally, Energy Plus software was used together with Daysim to assess the total power demand and electrical efficiency.

Sharaidin (2015) presents an algorithmic and parametric scheme procedure advanced in Rhino/Grasshopper, Galapagos simulations software as formula verdict tools, simultaneously, other software like Ecotect for a natural light simulation. The research is aiming to study the tools that sustenance designer to appraise dynamic façades performance by using an integrated method of numerical simulation and design development parametric (Sharaidin, 2015). The software simulates the effect of natural light and response of the movable louver with a set of time frames concurrently and evaluates the efficiency of different parametric forms.

Kim, Asl & Yan (2015) in their paper aims to examine an innovative practice for test energy performance of structures with complex dynamic façades. The paper discusses the motion of each part of the kinetic system in connection to total ratio of fenestration and tracking the sun position in the atmosphere. BIM model on Revit program was used to build base-case model and simulate the performance of façade into two scenarios (static and movable system). The result demonstrates the difference in total energy demand of the building between both scenarios (Kim, Asl & Yan 2015).

Further study practice other cohesive simulation approaches that deliver qualified simulation outcome like, Grasshopper, Rhino in integration to other software like, Galapagos and Ecotect, to quantify the natural light efficiency of selected movable facades systems. The assimilate simulation procedures prove the strong point of the simulation as a tool to test both climate and design restrictions (Sharaidin et al. 2012).

(Nielsen et al. 2011) In that paper, the software had been programmed and initiated by the organization in Denmark. The simulation consists of two programs where first measure thermal performance called BuildingCalc and the other called LighCalc scale the daylight intentions.

In conclusion, diversity of programs demonstrations the strength of the tools that deal with a wide series of verify and parameters to concealment. All of these factors present the benefits of simulation methodology in compared to other methods. Deal with a vast number of parameters in combination with a variable factor on one platform and holistically approach is a powerful tool that expressively supports researcher with their investigation and ends up with a decisive decision in short time and minim effort.

Although the difficulty and variation of the features like the level of relief in the internal atmosphere aspects and exterior weather settings, different louver formation through numerous parameters, the software and programs offer meaningful integration of those elements and investigate the circumstances to the end. Moreover, elaborate the results with smart solutions for best thermal performance and other enhanced functionalities.

5.1.3 Mix use methodology

Responses to simulation approaches are proximate to real-life circumstances. Nevertheless, the limitation does permit researchers to elaborate numerous factors to appreciate their values in research.

Building envelope field and in particular active system ground the observation of mix-method by merge both experimental and simulation is common (Lee et al. 2015). The paper utilized both methods, to figure the end optimized outcomes. Façade formation, louver positions, wind velocity, climate temperature's effect, and the assessment of thermal construction performance were exam by simulation software CFD Autodesk and FloVENT, While the experimental was approached a real scaled prototype (Lee et al. 2015). Furthermore, the research carried several simulation testing for varied settings of louver configuration and figure the connection of the wind flow pattern by adopting CFD Autodesk analysis software. Moreover, the wind velocity, and temperature scaled by FloVENT scheming whereas, safari software utilized to exam the thermal efficiency in addition to annual consumption of HVAC system.

The key factors for appraising that different methodological approaches classified like the dependability, reliability, budget, question to disturbance and faults, the practice of resources, control of variables, easy to practice, period, reality, validity, sympathetic future performance, and capability to measure substances.

5.2 Selected research methodology

Base on the finding of the previous paper, the research will conduct simulation methodology as base approach supported by the literature review. The selection forms due to the capability of the simulation methods and the abilities to mimic the complexity of model conditions with different parameters, and collaboratively, the research will meaningfully maneuver with to address in details and answer the research aims and objectives.

5.2.1 Literature review

Literature review finding described in detail in chapter two that stand on the performance of the kinetic façade system with different parameters. The review induces a background of the system performance and offers summary and recommendation of the previous study. Especially, studies investigated close parameters to the research question that related to kinetic system features in an office building within UAE climate and conditions. These finding potentially support the research approach by identifying the gaps in kinetic façade studies and accordingly, planned the research wide line method with complete exploration cycles.

5.2.2 Computer simulation

The researcher explained the simulation terminology as steps of advanced procedures to mimic a prototype of a complex structure and built, analyses, validate and forecast the system responses in realism (Aburdene 2001).

The research will conduct a computer simulation software to construct the case study and scale system performance within research parameters. The simulation outcome could reach via numerical, or from measurements made from an analogous setting or computer Model. Furthermore, the process of simulation will furnish study with full picture about system performance within the various setting and appraise the strategies by assumptions of parameters and relationship of all relative data.

The steps will start with identify the first research parameters by data collection, analysis and prepare the base-case model of the research and move toward the process as follows:-

- Site selection, select one of the existing building to be the base-case model of the study.
- The first step to model the existing building with 3d modeling program to build the base-case model (Autodesk software Revit, AutoCAD and, 3D max).
- Collect the current site parameters like climate data and other present conditions like occupancy level, operation hours …etc. (climate consultant software and Revit database, regular site visit)
- Feed all data to the model and simulate by Revit software to furnish the study with the core model with all relevant information related to power consumption, Ac load …etc. (Revit Software).
- Collect the actual power consumption demand from the local Authority (Dubai Electricity and Water Authority DEWA).
- Compare the baseline model simulation results to actual DEWA data to validate the base case model.
- By validating the model with actual readings, the model will be ready for the next simulation steps with the novel design approach of kinetic façade.
- Design trials.

- Perform simulation.
- Gather output data and result.
- Document the results, analyze the documents and expand the Model.

Figure 5-1 highlights the different stage of research investigation and stimulation levels that elaborate the research mind map. These steps will be discussed in details in the next chapters and discussed further with results analysis, comparison matrix and detail outcome (Figure 5-1).

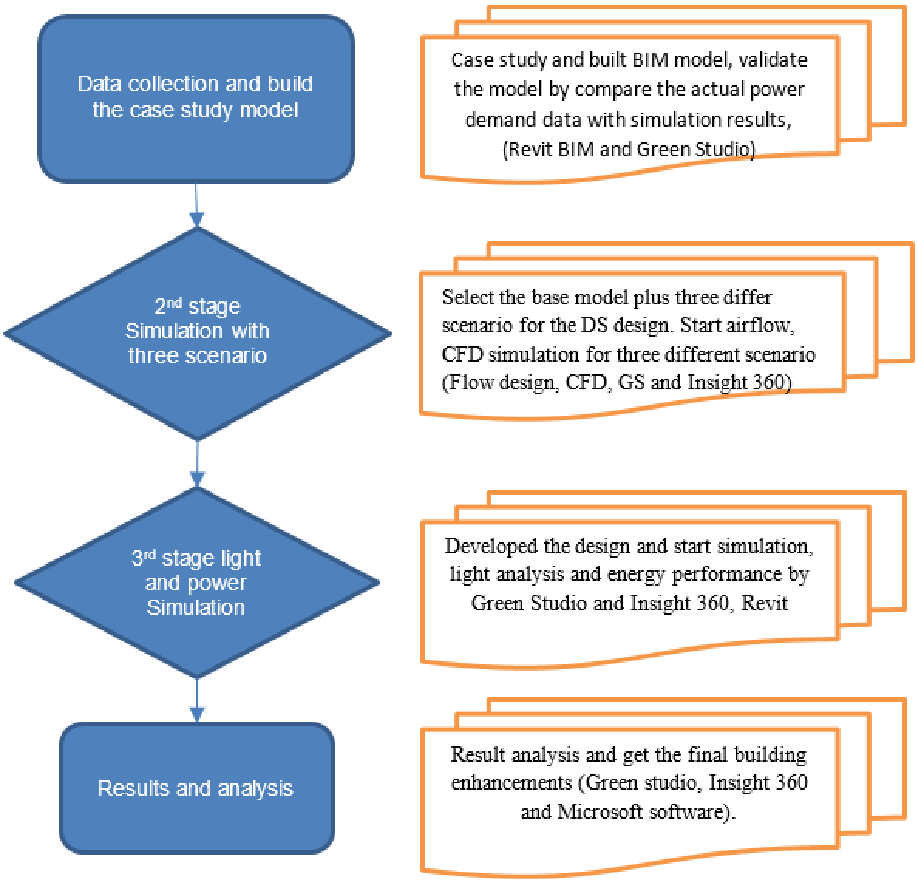


Figure 5-1 Research investigations and simulations mind map and stages (Author).

The simulation will investigate the building settings with different orientations, west, south, east, and north, during the designated date of the year to figure the four distinct local climatic seasons (March, 21st for Spring, June, 21st for Summer, September 21st for winter and December 21st for winter). In the daytime, the simulation will conduct in two-hour scenarios for a total of eight hours which is the normal daily operational hours for the local office's activity in Dubai.

Finally, the simulation steps diagram presented in Figure 5-2 contains the brief description and design decision for the next step, and all of these measures will elaborate and detail in the coming chapters (Figure 5-2).

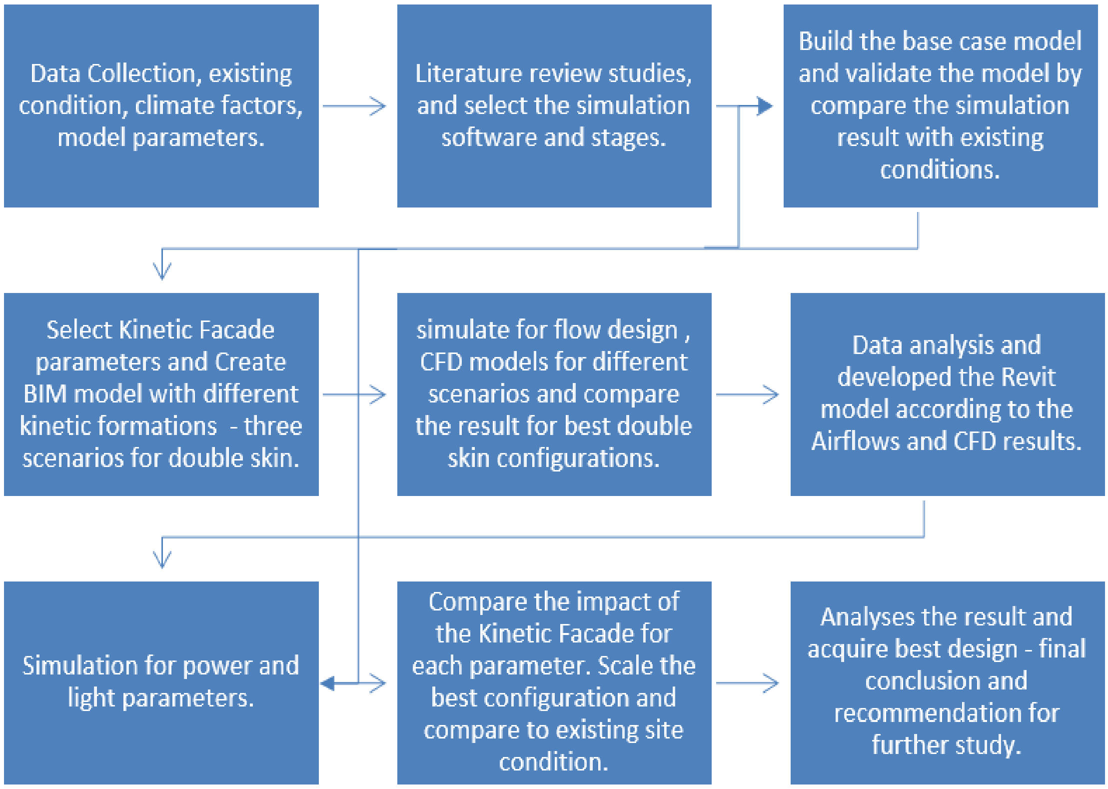


Figure 5-2 Simulation Steps from inaugurate the baseline model to conclusions step (Author).

5.3 Simulation limitation, Practice and tool assortments.

The complexity of kinetic double skin façade system required adaptable simulation programs that capable to test various parameters and integration between different software. The kinetic façade system has many parameters to test. Therefore, there is a certain essential precondition and limitations that should cover with the progression of the research. The program's details as follow:

- Model the virus formation of the movable louvers.
- The condition of the internal space and power demand calculations that cover the HVAC, Lighting system, office equipment, etc.
- Cover the different operation schedule according to the space usage and draw clear profile for each scenario.
- Reliable program and developed by certified and specialized third party.
- User-friendly and easy to practice for a scholar with different knowledge.

As stated earlier there is about 24 software dealing with the subject of study but with a verity of research parameter, the limitation and difficulty appeal with many software. The limitation linked to the capability of the software to integrate with another program to merge the research parameter in one platform that could synchronize the result and data smoothly is one of the vital factors. Therefore, after reviewing the available software, the research elite Autodesk Revit, AutoCAD, Green Studio, Flow Design and CFD to perform the research objectives. Autodesk software has one platform offers the user to transfer files to load program easily and synchronize their data. Moreover, the software has an interface management panel to load easily, unload and transfer Microsoft program like word, excel, where the research could sort the result and analysis with other database software.

Nonetheless, with all of these measures The limitation of the digital simulations have in their capability to appraise the efficiency of the façade system in response to the climatic performance deprived of seeing other features such as material specs and dynamic movable part in addition to other factors related to the system mechanism and operation consequences. Other factors that limited the research methodology related to the time and cost concerns which are not discussed in the study and recommended as potential topics for further future research area.

5.4 Autodesk software and capability relevant to the research objectives

As of today, Autodesk developed many programs deal intensely with sustainable requirements as a response to market demand to cover the essential needs of Architect, Engineer and other disciplines for an integrated management tool. These tool castoff by the designers to validate their approach to the requirement of local and international authorities. Eventually, Autodesk developer diverts their product and advance the graphic, design and 3D software with tools to fulfill mainly different disciplines necessities toward more sustainable and environment-friendly constructions and systems.

Within the premises of the program, simulation built-in tools furnish the research with an excellent environment to start to build the research base-case model and load the existing design parameters like building sizes, locations, detail of construction elements and systems, material specs, and others. The validation of base-case model will provide a solid state to build an initial start base of the research by comparing model simulation results to actual reading figures like the total power load and electrical consumptions. Subsequently, a program like Autodesk Revit could provide many options in comparison to green building factors by sharing simulation results with the Green Studio Platform that provides the designer with many choices and proposals to develop the design efficiently and sustainably. Especially, when the data contain a different proposal and calculate the energy demand, fuel consumption, Co2 emission, life cycle, solar and light analysis and more valuable factors. Moreover, the software has other plugins that link the program to an integrated Data Model IDM. The Autodesk software consist of the follows:-

- AutoCAD, 2D, 3D software to build the model of the building.
- Revit, start to create the model and load building parameters and urban context, climate factors, and more, as fixed model parameters.
    - Energy Analysis.

- o Light analysis and solar shading efficiency and dynamic formation performance.
- o HVAC calculation, heat, and cooling load.
- o Perform different kinetic scenarios with different configurations.

- Flow design, airflow, velocity and pressure simulation analysis with various double skin scenarios.
- CFD, Air Flow Pattern and air influence on the building façade with - various double skin scenarios.
- Green Studio and Insight 360 applications, life cycle study with different sustainable options in comparison to the design parameters and cost breakdown.

5.5 Programs validity and reliability.

The outcome of the research could be questioned if the software was not reliable. Therefore, the researchers highlight many steps to exam reliability of the selected program. Hamza (2007) outlined three stages required to validate a simulation software:

1) Demonstrate and investigate the building conditions and factors.
2) Validate the structure and audit the steps.
3) Lastly, the result of the total power consumption related to the existing records of actual usage by the tenants will be compared to the simulation outcome to validate the simulation model.

These steps provide comparable measures that could closely rely on to build confidence in the software abilities.

Chapter four: Identify Research Parameters and Structure the Baseline Research Model

6.1 Identify research parameters and build the base case model with descriptions

6.1.1 Data collection, location and site conditions

The research builds the simulation baseline model to initiate the reference model. The model will demonstrate the characters of the construction in the region in general and in particular in Dubai, UAE. In more details, the materials and finishes have been carefully studied to show the common practice in office buildings and with such high-rise buildings in Dubai.

However, the model builds based on a selected existing multi-story office in the trade center first at the Shk Zayed road and generate the layout according to plot area and present conditions (Figure 6-1).

Figure 6-1 Trade center area location map (kästle 2017).

6.1.2 Plot details and building orientation.

Mainly, Shk Zayed road has the main circulation that connects north of emirate to the south side and considers one of the busiest highways in that area, but the center line of the road have tilted angle with relative 43.8°degrees to the north. So the main elevation of the case building is faced the south-east direction with the tilted angle (Figure 6-2).

Figure 6-2 Plot location and the main facade orientation (kästle 2017).

On that basis and for research point of view, the study will adjust the main plot orientation and consider the main elevation of the plot faced the South Direction and the rear elevation will exactly face the north direction as exposed in Figure 6-3.

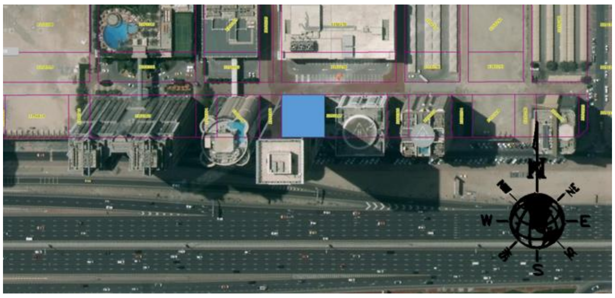


Figure 6-3 Adjusted Plot orientation (kästle 2017).

6.1.3 Office layout modular and baseline model details

The referenced existing high-rise building consists of a basement, ground, mezzanine, two services floors and 56 typical floors with an approximate plot area of 900 square meters. The model presents the typical design of high-rise tower where most of the buildings have the same plot size with the virtually identical heights.

6.1.3.1 Building layout details and selected floors.

The ground floor includes the main entrance and public facilities services and the typical floor layout designed for an office building with a typical floor design consists of mainly four offices as detailed in Figure 6-4 and Figure 6-5.

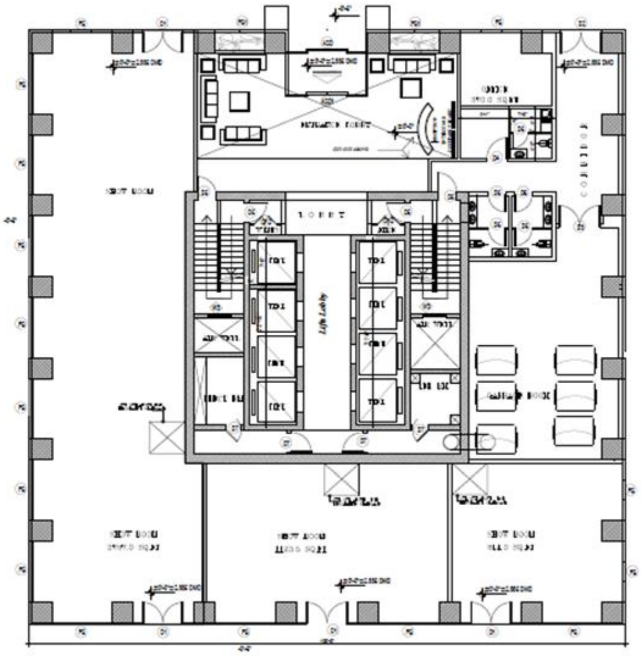


Figure 6-4 Ground floor level of the existing building (AutoCAD software).

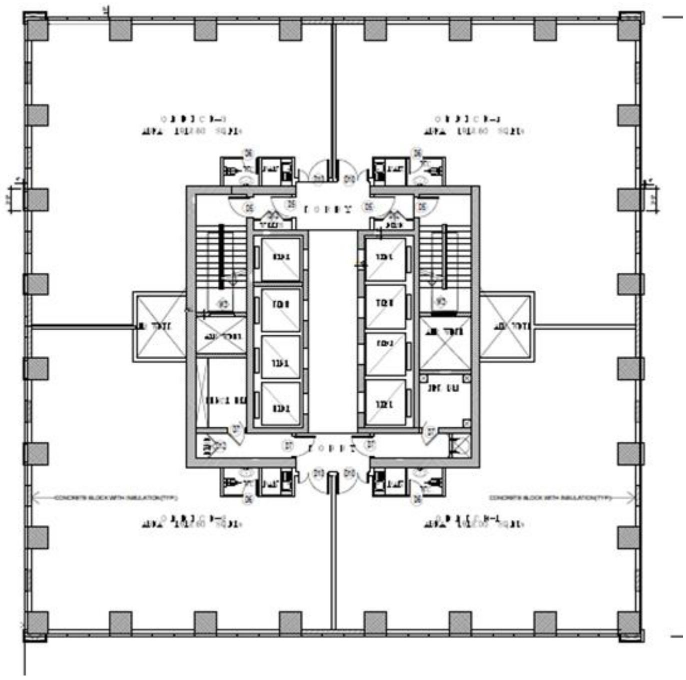


Figure 6-5 Typical floor level of the existing building (AutoCAD software).

The study will mainly focus on the typical floor design as a baseline for the simulation and exams, and in particular, the models will choose different levels to examine the effect of the dynamic façade with movable louver on the total power consumption closely.

The typical floor has a dimension of 30 meters widths by 30 meters length, as precise square shape. The floor consist of four offices and main vertical circulations and services core in addition to the central corridor serve the floor. The area of each office is about 178 square meters and the total office's clear space around 710 square meters. The offices have an approximate of eight meters depth to the center of the building along with 3.6 meters floor to floor finish height and a clear internal space height 2.8 meters approximate. The external façade of the offices is detailed as glazing curtain wall covered the entire external façade with full heights (Figure 6-6).

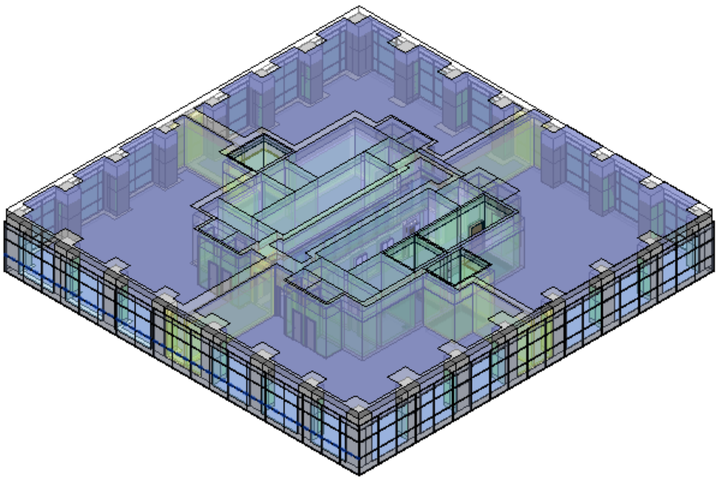


Figure 6-6 3D view of typical floor demonstrates the setting of the office's area (Revit software).

Figure 6-6 present actual configuration of regular offices building in that area. The occupancy level for each office is assumed around eight persons and total 32 individuals for all offices per floor.

6.1.3.2 High-rise building façade details and build the kinetic Louvre system.

The typical floor façade have the same length of the plot (thirty meters), and the high is typically matching the typical floor height (3.6 meters). The four elevation of the building is equal in size and dimensions. Therefore the simulation model will systematically figure the four different façades (Figure 6-7).

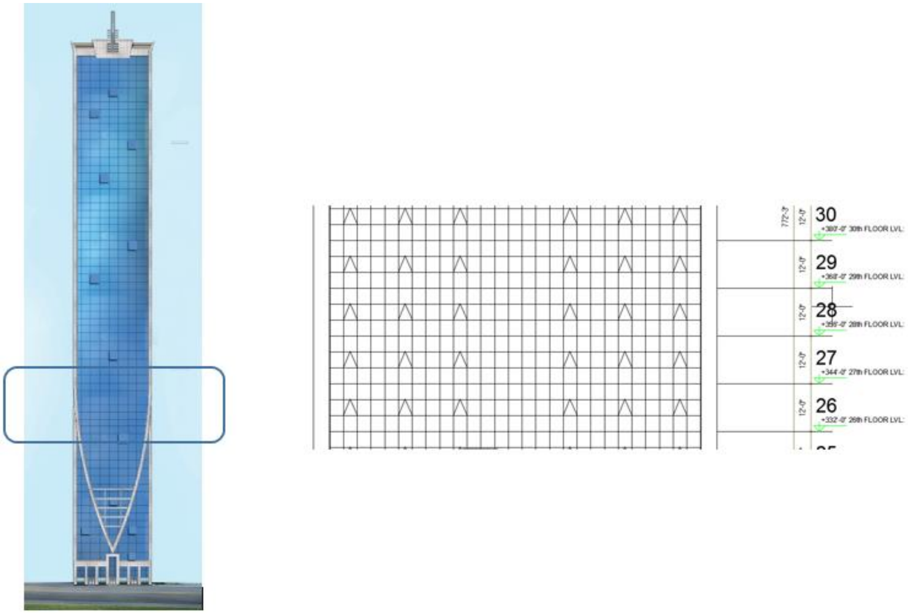


Figure 6-7 Main Facade Details (AutoCAD Software).

The base case tower model will divide vertically into three main parts for research purpose. These main sectors will split depending on the total height about 60 floors. Therefore the first part will include the first 20-floors start from the ground floor and the floor no 10^{th} selected to present this section. The second part has similar floor number started from floor 21^{st}, and floor no 30^{th} presents this section. The last part will start from floor 41^{st} to upper floor level, and floor 45^{th} submit the section as demonstrated in Figure 6-8.

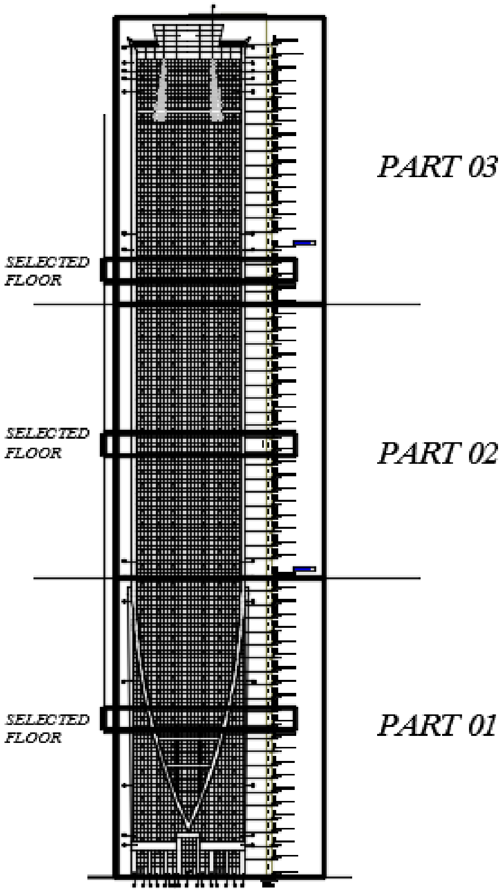


Figure 6-8 Main Facade Sectors and divisions (AutoCAD Software).

This separation aims to evaluate the wind flow and stack effect caused by kinetic louvre facade and stand on the influence of total heat gain and heat loss of the external building envelope specifically.

The external kinetic louver will split base on orientation detailed as follow:-

- South and North elevations formations.

Louvre at these faces will build as a horizontal louver as demonstrated in Figure 6-9. Vertically the floor elevation will be divided into sixty-centimeter distance separate the louver slots so that the louver size will be sixty centimeters in width by almost four panels of glass length with a total of 3.6 meters. North façade will follow mainly the same configuration, and the research will detail the formation behavior of the Louvre facade in simulation section.

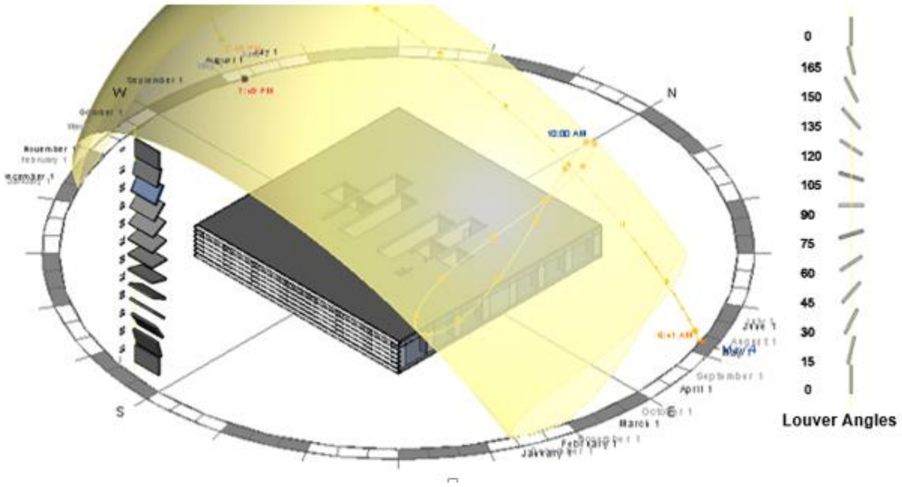


Figure 6-9 3D view detailed the South elevation louver configurations with the sun path (Revit Software).

- East and west elevations formation.

Kinetic louver in east façade will vertically position as demonstrated in Figure 6-10. Louvre slots width will be sixty centimeters so that the louver size will be sixty centimeters in width by almost the height of the floor in length.

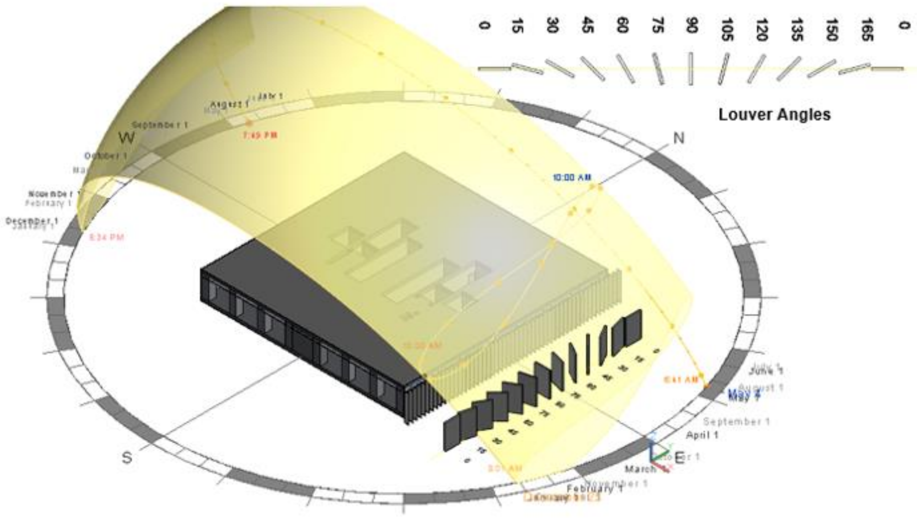


Figure 6-10 3D views detailed the North elevation louver configurations with the sun path (Revit Software).

The louver formation of West façade will mostly follow the same principles of East façade. Louvre size and position presented in detail in Figure 6-11.

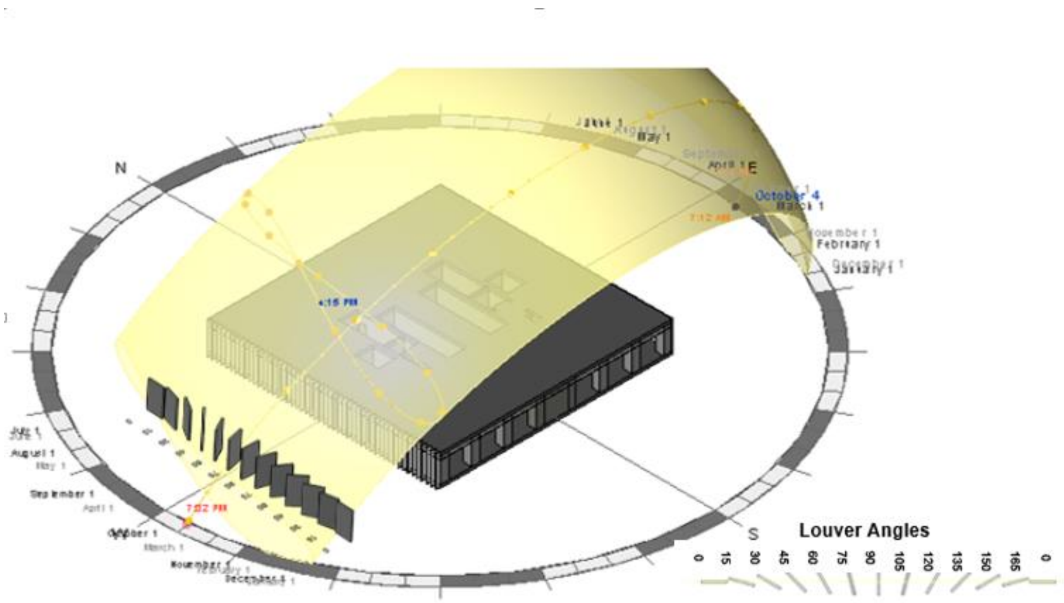


Figure 6-11 3D views detailed the West elevation louver configurations with the sun path (Revit Software).

6.1.4 Model material and finishes.

The baseline model is typically designed for an offices operation facilities. Therefore, materials and finishes mimic the actual material of the existing building. Model materials are one of the parameters that should accurately define and fixed according to the material specification comply with regulations and local authority requirements.

The research model builds on Revit software that load with the material specs of the existing building. Model components consist of a material of main structure along with finishing systems. Those will define the thermal property of building envelope like the façade curtain wall and interior material (floor, wall, and roof) (Figure 6-12).

Analysis Properties

By default, analysis properties are generated from information in Conceptual Types.
Properties of Schematic Types are used when override is selected.

Category	Override	Analytic Construction
Roofs	☑	Ballast, 4 in polystyrene, screed, concrete, plaster (U=0.3000 W/(m²·K))
Exterior Walls	☑	Brick, medium concrete block, foam insulation, light plaster (U=0.5487 W/(m²·K))
Interior Walls	☑	Frame partition with 3/4 in gypsum board (U=1.4733 W/(m²·K))
Ceilings	☑	Ceiling below joists, R-15 blanket or loose fill (U=0.3917 W/(m²·K))
Floors	☑	Passive floor, R-8 board insulation, any cover (U=0.5507 W/(m²·K))
Slabs	☑	Un-insulated solid (U=0.7059 W/(m²·K))
Doors	☑	Metal (U=3.7021 W/(m²·K))
Exterior Windows	☑	Large double-glazed windows - reflective coating (U=2.9191 W/(m²·K), SHGC=0.13)
Interior Windows	☑	Large single-glazed windows (U=3.6898 W/(m²·K), SHGC=0.86)
Skylights	☑	Large double-glazed windows (reflective coating) - industry (U=3.1956 W/(m²·K), SHGC=0.

Figure 6-12 Material Specs of baseline model as per local authority requirements loaded in Revit Software.

6.1.5 Internal comfort level, HVAC and lighting assumptions

Level of the comfort of internal space is one of the key factors to demonstrate the correctness of the design and replicate the perfect functionality of the building. The factor demonstrates the scale interrelated to physiological reactions, comfort, and health of the tenant (Figure 6-13).

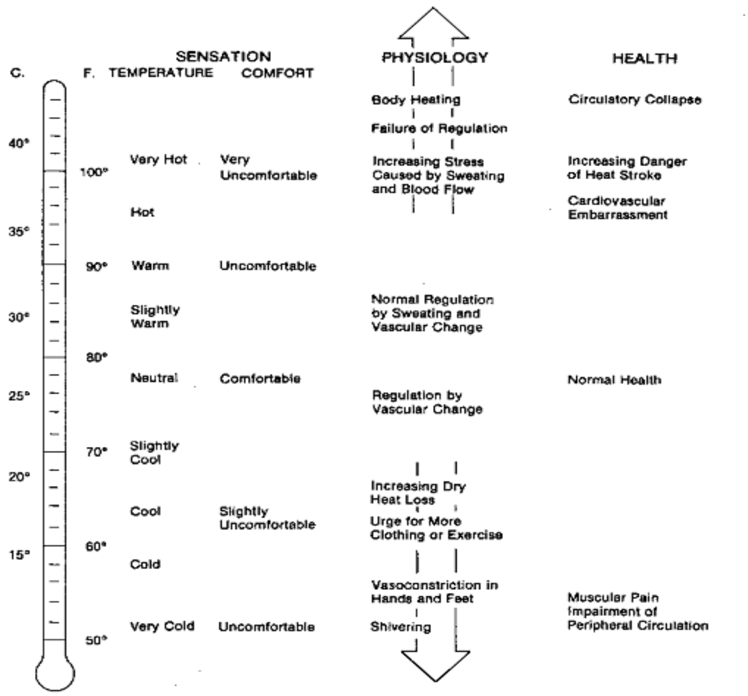


Figure 6-13 Internal climate classifications with physiological feedback (Etheridge 2102).

The parameter of the internal space of office building could be measured as demonstrated in the psychrometric chart (Figure 6-14) that detail level of comfort in different seasons.

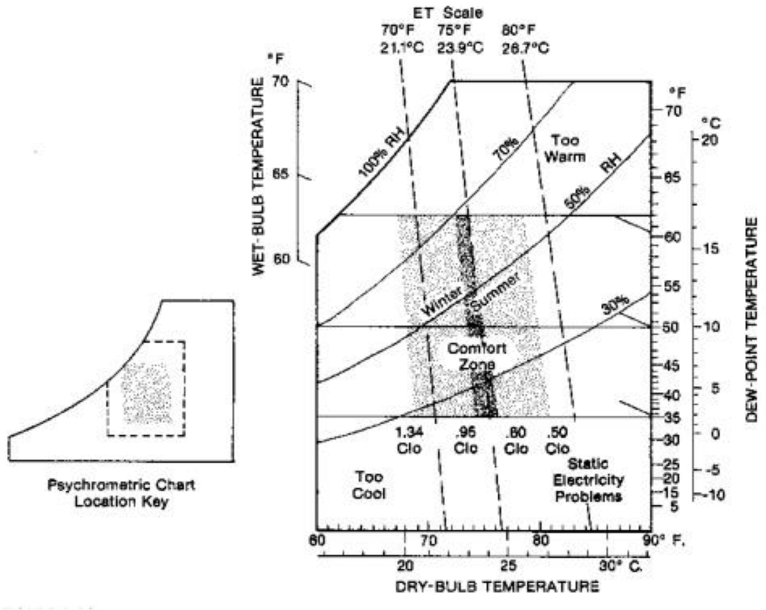


Figure 6-14 Psychometric chart (Etheridge 2102).

Therefore, design parameters of the baseline model will be identified and fixed the principles as follows:-

- Occupancy level of the floor equals 32 persons.
- The temperature of internal space fixed at 24 °C.
- Infiltration of air per hour is 0.25 ACH.
- Light level and illumines about 500 lux as a base for an office space.

These parameters will be linked to louver configuration to demonstrate the operation parameter and classify the optimal formation of kinetic louver facade.

6.1.6 Kinetic façade strategy and control options.

The operation options of the external kinetic façade mainly classified in two scenarios. Firstly is manual operation system that depends on the human response to the external environment parameter and internal level of comfort. The best example of the manual operation system of the dynamic louver is internal louver curtain or similar system. The second is automated system considering complicated algorithms of different external and interior environmental parameters and other values to set up the control of louver formation.

The research will focus on the maximum potential saving in energy demand achieved by adopting kinetic louver façade in compare to the regular façade without shading device or fixed louver shading device neglecting the operation technology and mechanism technique.

6.1.7 Weather data

Revit simulation software from Autodesk has the weather database in details include the local region. The data content the follows:-

- Monthly design data with heating and cooling dry bulb.
- Annual and monthly wind velocity and direction details.
- Diurnal weather, accurate temperature reading with the wet and dry bulb.
- Direct solar w/m2 and diffuse solar w/m2.
- Daily, monthly humidity average with morning/afternoon average details.

6.1.8 Orientation and time

The research customary the base-case model in the position where the main façade will face South direction. Study parameters will test in three main directions (South façade and the side elevations in east and west directions). The north façade will test within the light parameters, and the result will be distinct the performance of active louver system and decide for future investigation level (Figure 6-15).

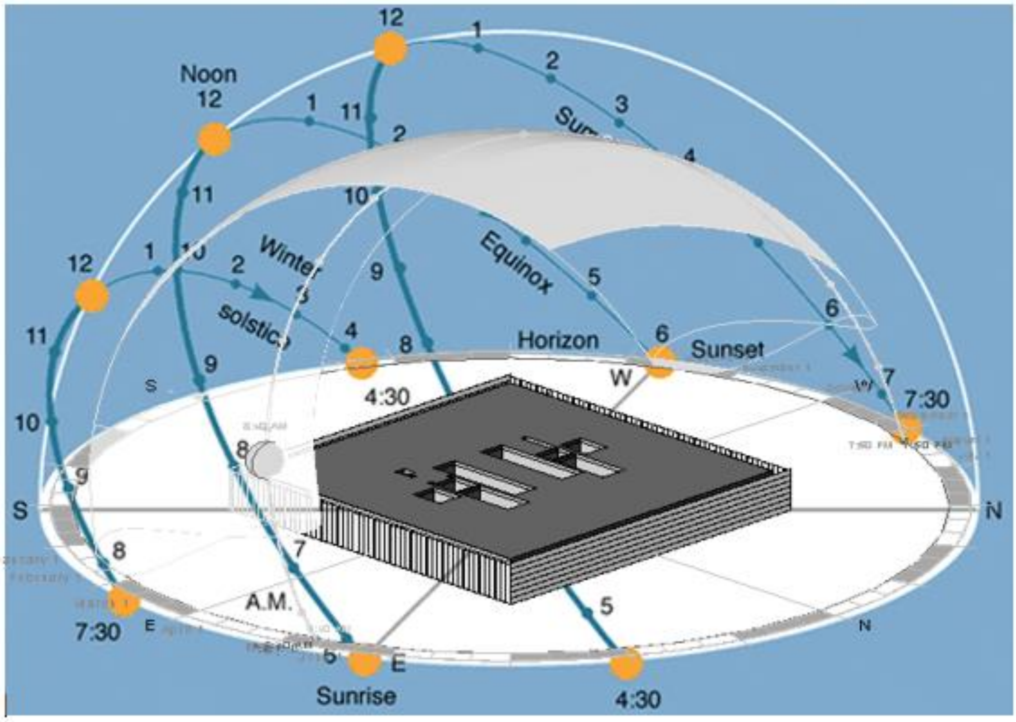


Figure 6-15 The Seasons, the Equinox, and the Solstices Diagram.

However, Figure 6-15 presents the solar radiation effect at early morning time and late afternoon, which obviously seen the minor effect of the solar radiation. These effects could be neglected or extend the kinetic façade only to the extent of the previous area (Figure 6-16).

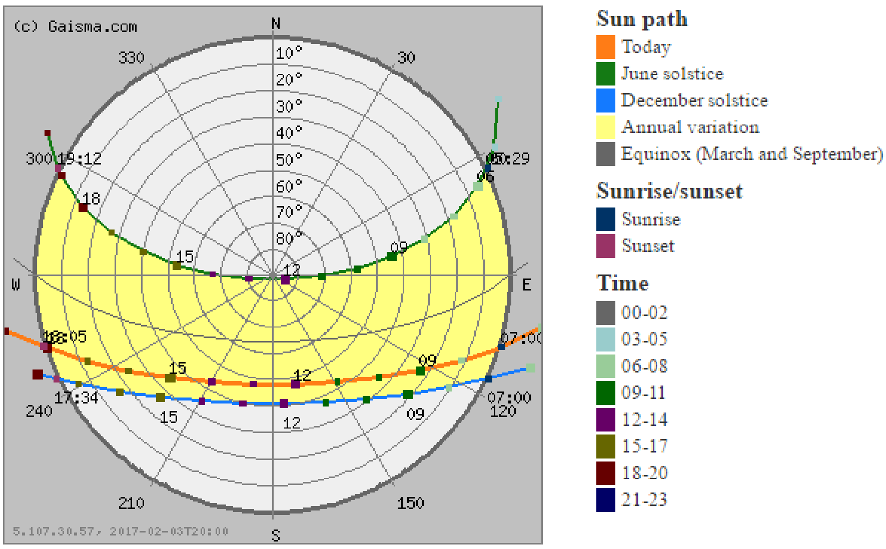
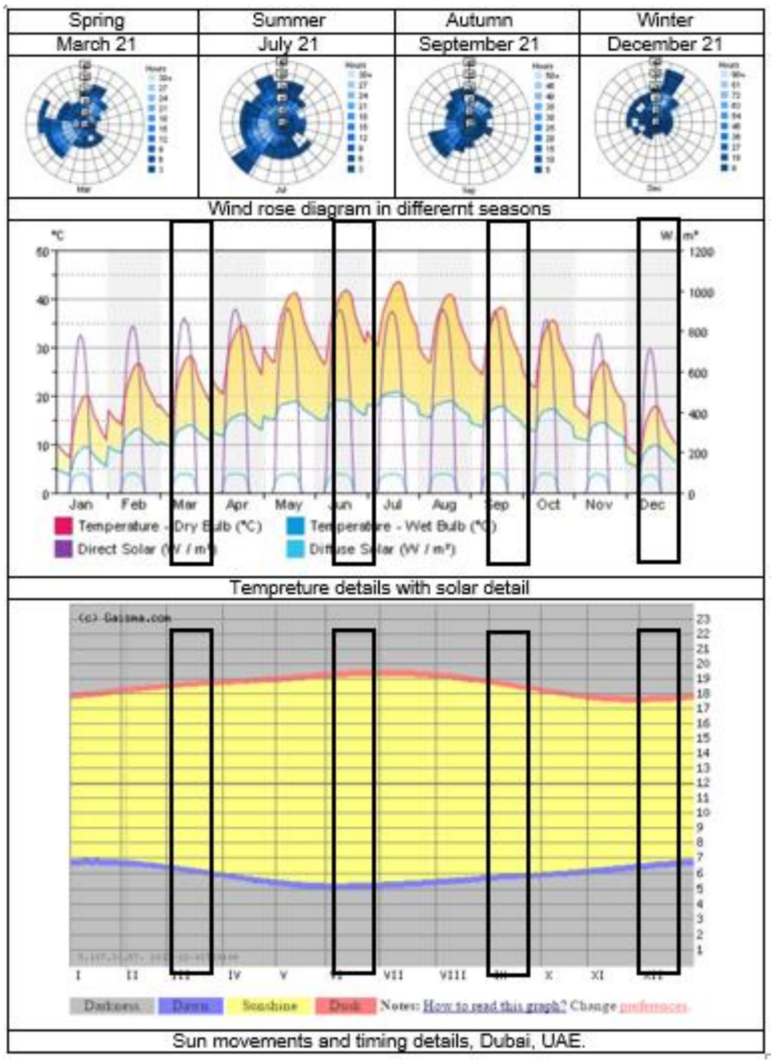


Figure 6-16 Sun path diagram for Dubai, UAE (Revit software).

Moreover, the simulation will consider the four different seasons around the year and select a date to imitate the various climate data with near an ideal condition of clear sky and non-unforeseen conditions. The detail of selected dates and the environmental data tabulated in Table 6-1.

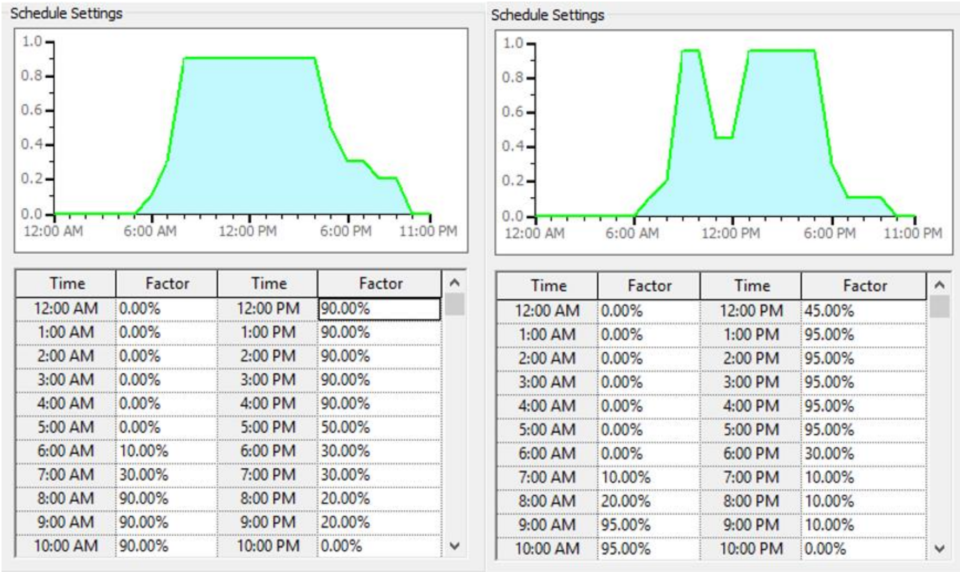
Table 6-1 the detail of selected dates as per the local climatic data extracted from Revit software database (Author).



6.1.9 Operation scenarios and occupancy level

The office building operation has different timing like as per local authority rules. Weekday timing scenario from Sunday till Thursday started at 8:00 am to 5:00 pm which considers the high operation hours. Occupancy level followed the operation timing and reflected on the light schedule as well. So, the Revit

Autodesk software has the built-in data for each scenario and necessary analysis that values with their default parameters (Figure 6-17). The figures presented the operation and occupancy trend from early morning till the peak hours and declined the office timing after operation hours till midnight.



Time	Factor	Time	Factor
12:00 AM	0.00%	12:00 PM	90.00%
1:00 AM	0.00%	1:00 PM	90.00%
2:00 AM	0.00%	2:00 PM	90.00%
3:00 AM	0.00%	3:00 PM	90.00%
4:00 AM	0.00%	4:00 PM	90.00%
5:00 AM	0.00%	5:00 PM	50.00%
6:00 AM	10.00%	6:00 PM	30.00%
7:00 AM	30.00%	7:00 PM	30.00%
8:00 AM	90.00%	8:00 PM	20.00%
9:00 AM	90.00%	9:00 PM	20.00%
10:00 AM	90.00%	10:00 PM	0.00%

Time	Factor	Time	Factor
12:00 AM	0.00%	12:00 PM	45.00%
1:00 AM	0.00%	1:00 PM	95.00%
2:00 AM	0.00%	2:00 PM	95.00%
3:00 AM	0.00%	3:00 PM	95.00%
4:00 AM	0.00%	4:00 PM	95.00%
5:00 AM	0.00%	5:00 PM	95.00%
6:00 AM	0.00%	6:00 PM	30.00%
7:00 AM	10.00%	7:00 PM	10.00%
8:00 AM	20.00%	8:00 PM	10.00%
9:00 AM	95.00%	9:00 PM	10.00%
10:00 AM	95.00%	10:00 PM	0.00%

Figure 6-17 the figure on the right is the light schedule and left figure present the occupancy level for office area as per Revit software database.

Weekend considers low operation hours as most of the office is closed as per the rules. Base on that the operation scenario of the kinetic façade could classify into two scenarios. The first is high demand and the second is low demand operation scenarios.

6.1.10 Outcome in measurements against investigation parameter

The key parameters of research investigation are the power demand records and potential energy saving influenced by the HVAC demand and natural daylight perception. These factors will be used as fundamental features for assessments the different kinetic facade options and system performance as a double skin façade, the interpretation of optimal kinetic louver position and distance between the kinetic louver and building glazing façade.

Brief descriptions of the main variables that could stimulate the main outcome are defined as follows:

- Louvre configuration, the angle of slats for effective shading that reduces the direct radiation, heat gain of building façades, and enhance the daylight level in the office spaces.
- Louvre position and cavity gap between kinetic louver system and building façade. Also, defined the best cavity distance that influences the air velocity, pressure positively, air pattern with solar chimney effects for the double skin scenario and delivered optimal performance.
- The position of lighting sensor to measure the desired natural light level work plane and that will demonstrate with the software parameters.
- Orientations, These variables will be verified independently for all façade configurations. Additionally, all cases will be examined during the daytime (morning 9:00 am and afternoon 3:00 pm) on four pre-selected days in the year (in March, June, September, and December).

6.2 An exploration by simulation of diverse Louvre forms.

The configuration of dynamic louver facade will investigate in details by simulating the base model with many formations. The simulations will measure the system efficiency and impact of different louver formations in different timing, seasons, orientations in three levels of the building floor as comprehensive discuss formerly.

The modifications of configuration will consider as louver formations where the louver inclination will start from zero degrees to 165 degrees. Additionally, the cavity distance between the louver system and glazing façade will be scale in three categories like 600 mm, 1200mm, and 1800mm.

The cavity verifies started with a minimum distance of 600mm which required to provide flexibility for the louver manipulation with an acceptable area for maintain the system and seek easy accessibility to the system component. The 1200 mm is the common option where the 1800mm is the optimal option due to many factors like, area requirements, availability and associated cost of the plot area, the complexity of the system structure and fixation detail which required a huge effort that could potentially impact the building structure.

The simulation results will be recorded and classified within different parameters and analysis accordingly. The results will demonstrate the best Louvre configuration (angle of the slats) at a certain time and date.

As discussed formerly in chapter three, the methodology approach will take three main stages listed as follows:-

6.2.1 Stage one: Baseline simulation – present the base-case reference scenario.

Base-case simulation presents the existing building conditions. The simulation will conduct with different research parameters as demonstrated in detail earlier (orientation, timing, level and different seasons). The result will consider as baseline result for the research.

6.2.2 Stage two: Kinetic façade as standard double skin simulation - full closed louvers with three cavity scenarios.

In this proposal, the simulation analysis will test the kinetic system as totally closed louver where façade behavior performed as a double skin façade. The façade formed with a close louver system in two louver types (vertical and horizontal louver). The test will consider three different scenarios for the cavity depth (the distance between the Louvre and the glazing façade) the scenarios will reflect 600mm, 1200mm and 1800 mm.

6.2.3 Stage three: Different configuration of external louvers – various louvers inclinations.

Kinetic louver façade will test with various formations where the slats started inclination from 15, 30, 45, 60, 75, 90-degree and conversely till 165 degrees (vertical and horizontal louvers). Also, these will be conducted base on the best cavity depth recommended in stage two.

The final analysis will demonstrate the effect of the kinetic façade considering different parameters and the conclusions will present the optimal scenario and conclude whether the kinetic façade will enhance the potential power saving or not along with another margin of recommendations.

6.3 Key research considerations

The report will consider the different climate seasons, taking the high records as a reference to simulate the base-case model that presents the monthly timeline around the year.

The simulation will conduct the hourly records matching the Office's facility operating hours, by which the reading will be discussed and adequately compares with an acceptable level of details. Consequently, the choosing time will cover daily, monthly, and yearly records to investigate an acceptable result in compared to the baseline case model. Additionally, the paper will take different façade orientations and different floor levels to demonstrate the difference between readings in total power consumption and investigate what's an adequate configuration for the dynamic louver position.

Secondly, the area that was selected in the research present the typical floor level for high-rise office building with certain plot size. That demonstrates the most conventional design of office spaces in the region where the plot size is similar, and building height is commonly closer to each other.

However, the research elite three different floor levels by divided the office tower into three parts (level 10, 30, and 45) to demonstrate the influence of the prevailing wind pattern, air velocity, pressure and the stack effect on each facade. The site constraint related to the building surrounding and the shading effect is neglected as the baseline model take the most appropriate typical design that could allocate in any plot along the area. However, in the result details, the demonstration of the analysis will show the advantage of that shaded spaces and definitely, the recommendation will cover this aspect.

The third crucial parameter that will be cover in the research is the sunlight influence and the natural light penetration during operation hours. The daytime period is the major key factor and particularly, the operation hour for the office time in the region (8:00 am to 5:00 pm). Another consideration of the material and finishes are already defined. The material that mainly used in the existing base model and typically used in office spaces. These factors are fixed in all model and consider as standard in all simulation run.

Finally, the research will focus on the result of the total potential saving of power consumption where all factors are considered fixed while the louver setting modified. So another factor that might be affected due to the louver formation like the visual aspects and level of sociological of users and more which will not discuss in this paper.

6.4 Modelling and simulation steps

AutoCAD and Revit software from Autodesk are modelers of research models where all the details will load. The model will demonstrate all the components of the existing reference building in addition to the new configuration of the dynamic louver.

As evidenced earlier, all mock-up fixed parameters will include in the model. These will cover the Location details, orientation, and weather data from climate consultant software, building sizes and volumes as per the current construction along with the material specs and details of constructions system.

Wind flow and stack effect will be tested by flow design and CFD software to demonstrate the wind tunneling effect and the potential heat loss and heat gain that will cause the conduction and conductive effects. These will discuss within different louver arrangements in many levels, different timing and different orientation.

Revit Light analysis will be conducted as well to demonstrate the best louver design that provides the efficient light and lux level inside the office spaces at the same time measure the power demand and the total energy saving due to the convenience of the natural light.

In parallel, Revit HVAC, Power consumption, and energy demand will test with a different configuration of the external louver compositions. The results will record and segregated into three broad categories, which is the time of the trial, louver angle, and the energy demand. These will be repeated in different directions and with different seasons.

Result analysis will be compared, study, and govern the best scenario of each setting. The conclusion will show the prime potential energy saving with best louver position along with the finest internal daylight level. These result will classify in different building levels and façade orientations. However, Figure 3-1 demonstrate the research modeling configuration and the simulation steps at each phase.

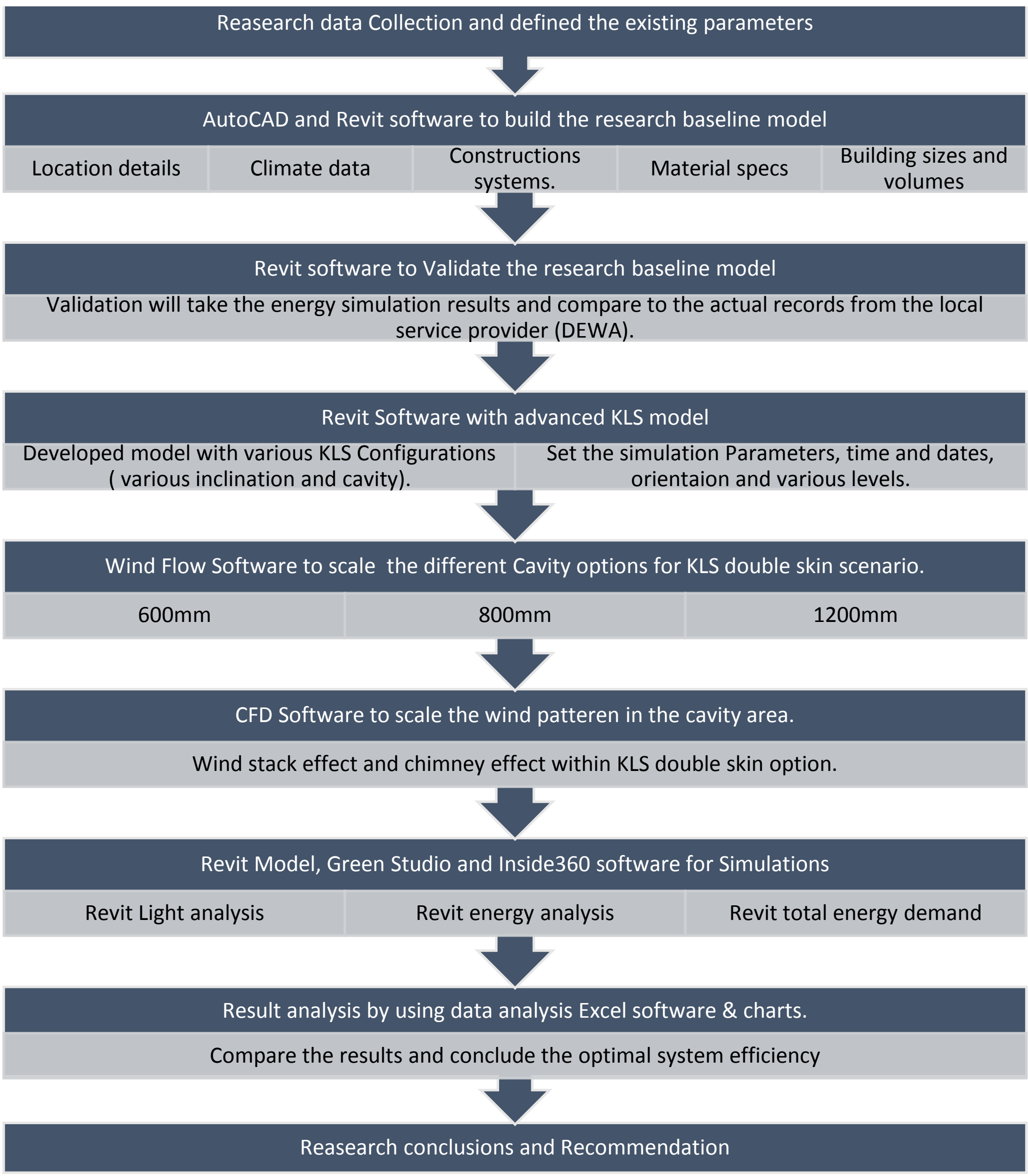


Figure 6-18 Modelling parameters and simulation steps (Author).

Chapter five: Simulation and Discussion

7.1 Stage one: Baseline simulation – Validate the baseline model to profile the reference scenario.

Baseline model builds according to existing constructed tower designed by a local consultant. Research starts modeling depending on actual design drawings and shop-drawing. Additionally, a site visit was conducted to stand on system components, material and all other specs that might be important to consider within research parameters.

Initially, AutoCAD software was used to build the existing model with all data as quantified in as-built drawings. Subsequently, model converted to Revit software to start the configuration of research baseline model advance by all parameters. Moreover, Revit model detailed by all data related to existing building details like location, plot size, areas, and construction element and plans as discussed earlier in chapter three and chapter four.

Furthermore, to validate the baseline model, the first simulation steered to scale the total power consumption. Concurrently, the Author communicates the local Authority DEWA (Dubai Electrical and Water Authority) to support the research with complete power consumptions of an existing building (the reference research model) for the last year. Additionally, electricity demand records on a monthly basis were requested. DEWA actual reading for present power consumption is listed as follows:-

7.1.1 Existing building power reading (DEWA records)

Power consumptions of last years listed as follows:-

7.1.1.1 2016 Building's power consumptions units.

Power bill of the year 2016 proves a steady increase in energy consumption started from almost 19300 kWh in January up to 280154 kWh in December with about 50% rise in total demand (Figure 7-1). Despite the fluctuation of application, but the overall consumption increased rapidly.

Total Building Consumption Unit		
	Calendar month	Consumption Unit
Electricity	Jan-16	192,453 KWH
	Feb-16	205,698 KWH
	Mar-16	208,507 KWH
	Apr-16	217,015 KWH
	May-16	228,914 KWH
	Jun-16	254,558 KWH
	Jul-16	287,577 KWH
	Aug-16	296,316 KWH
	Sep-16	311,965 KWH
	Oct-16	290,707 KWH
	Nov-16	287,267 KWH
	Dec-16	280,154 KWH
	Total Consumption	2,780,977 KWH

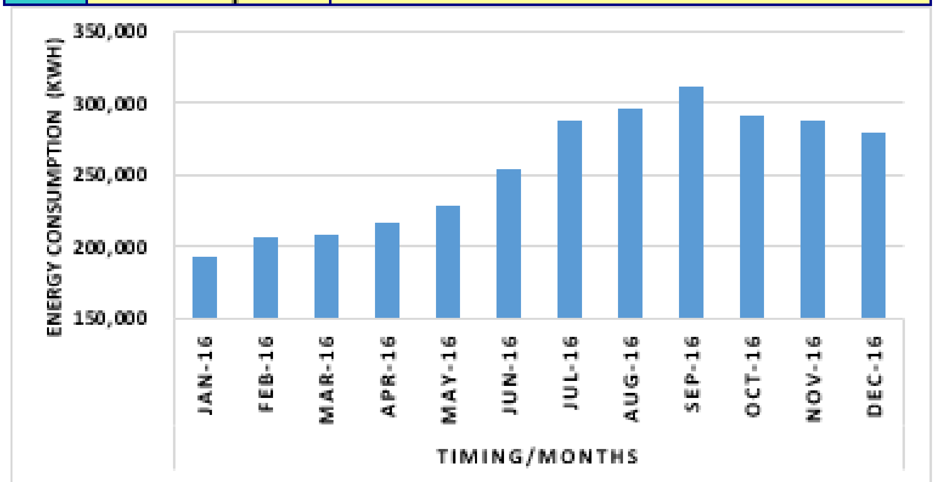


Figure 7-1 Existing building power demand of the year 2016 (DEWA records).

Overall, power consumption detailed in Figure 7-1 displays a trend with a noticeable difference in last years. That augmentation is harmonized with facts related to author’s investigations present that the tenancy level has a fluctuated and lately increased rapidly according to real-estate Company who’s operated the building facilities. The occupancy level has an enormous impact on total energy demand as presented earlier where the differences prevail in winter and summer seasons and with complete demand trend. However, the records reflect the actual data as received DEWA.

7.1.1.2 Detail Power Consumptions for selected floor

Energy consumption of separate floors delivered by DEWA for last year (2016). Floor no 30th have chosen to stand on the actual electricity records in office space and figure the demand trend. However, the readings show a certain deviation in distinct seasons as demonstrated in Figure 7-2. the variation in record between summer and winter seasons is evident due to the power demand level.

Total Building Consumption Unit		
	Calendar month	Consumption Unit
Electricity	Jan-16	3,828 KWH
	Feb-16	3,924 KWH
	Mar-16	4,596 KWH
	Apr-16	5,024 KWH
	May-16	5,240 KWH
	Jun-16	6,200 KWH
	Jul-16	6,500 KWH
	Aug-16	6,168 KWH
	Sep-16	5,694 KWH
	Oct-16	5,200 KWH
	Nov-16	4,888 KWH
	Dec-16	4,500 KWH
	Total Consumption	61,762 KWH

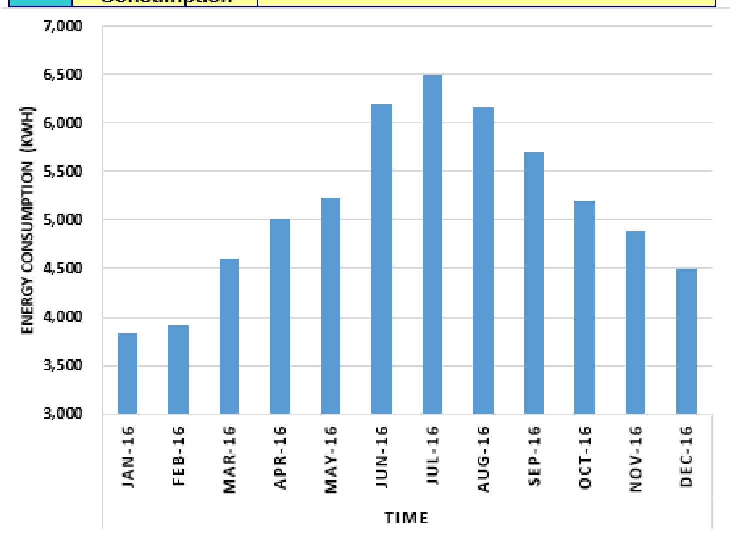


Figure 7-2 Floor 30 Energy consumption (DEWA records).

In conclusion, the Energy demand of the floor shows reasonable records with an almost consistent range of 3800 kWh in low seasons and up to 6500 kWh in high demand seasonal time in summer.

7.1.2 Baseline model simulation - Energy demand results

Research conducts the first energy simulation by Revit software aiming to compare the simulation results to DEWA reading to match the difference if any.

The simulation picked floor no. 30th and test the energy demand and the results expressions majority of power demand driven by the heat, ventilation and air conditioning system (HVAC) with almost 68% of total energy consumption while lighting system about 15% and other equipment records about 17% (Figure 7-3).

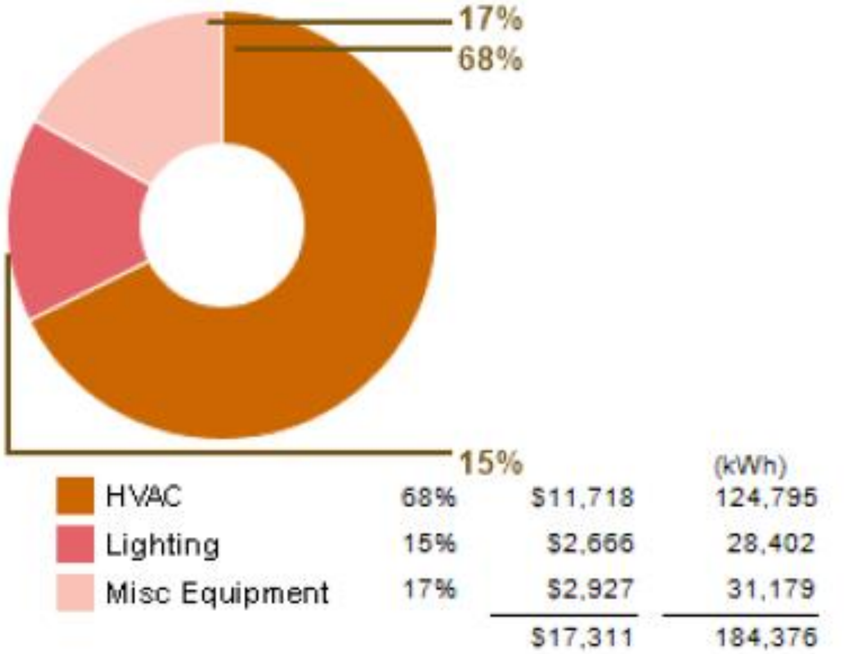


Figure 7-3 Annual energy analysis for floor no 30th (Revit energy report).

Close view of monthly energy chart presents the energy load variation between summer and winter seasons. In detail, the maximum peak record is presented in summer seasons in July about 16000 kWh. Whereas, the winter reading was registered about 6500 kWh in December with almost 250% difference in total demand as detailed in Figure 7-4.

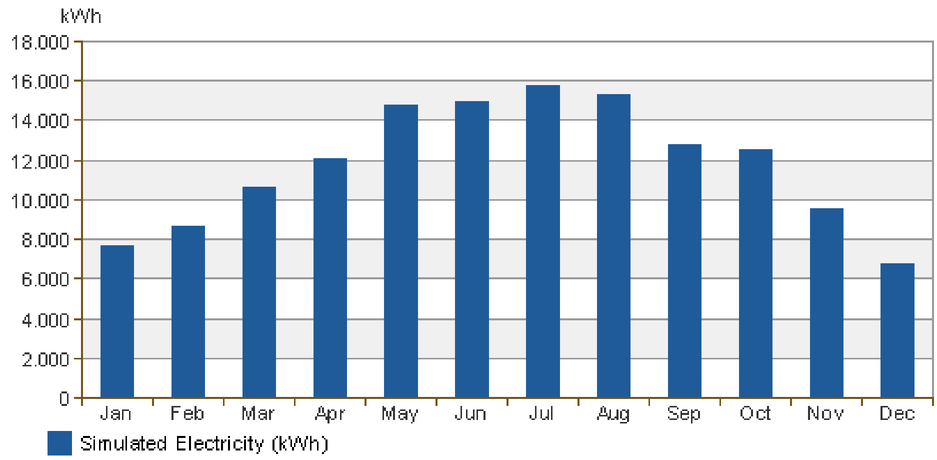


Figure 7-4 Monthly energy demand for floor no 30th (Revit energy report).

To conclude, the peak demand is demonstrated in Figure 7-5 with a max load of 35 KW in summer and lowest record in winter about 24 KW. Simulation results indicated a similarity in total energy demand trend, monthly consumption, and monthly cooling load.

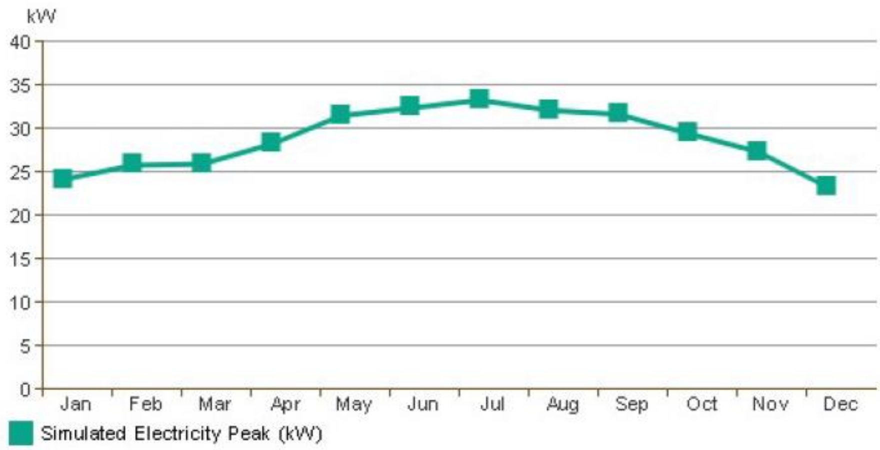


Figure 7-5 Electricity peak demand for floor no 30th (Revit energy report).

7.1.3 Compare the existing records with the simulation results

The results equated to DEWA reading to validate the simulation outcome that indicates nearly 100% alteration. These records present the HVAC claim scenarios where HVAC requisite more than 60% of annual power consumption.

Therefore, both results are thoroughly accurate if the annual HVAC demand abandoned.

Finally, despite the differences in records, a specific excise have been conducted to originate a breakdown of power consumption in particular. Therefore, the study calculates the office equipment total load as listed in Figure 7-6 and add to the total HVAC load. The overall results present the load demands as detailed in Figure 7-7.

$$E_{(kWh/day)} = P_{(W)} \times t_{(h/day)} / 1000_{(W/kW)}$$

Equipments	E(KWH/Day)	P(W)	t (H/Day)	Working day/Year	Numbers	Total E/Month	Total E/Year
Desktop	192	100	8	240	4	64	768
Laptop	96	50	8	240	2	16	192
Refrejrator	1752	200	24	365	1	146	1752
TV	134.4	70	8	240	1	11.2	134.4
Vacuum cleaner	768	1600	2	240	1	64	768
Printer	192	100	8	240	2	32	384
Communication	96	50	8	240	1	8	96
Total / for one office	(kWh/Day)					**341.2**	**4094.4**
Total / for all offices	(kWh/Month)					**1364.8**	**16377.6**

E = Power consumption P = Power demand T = Time

Figure 7-6 Power consumptions for an office equipment and total load.

Accumulatively, the comparison between the four results as demonstrated in Figure 7-7 spectacles a comprehensive view. Specifically, simulation result trend in compared to the power consumption trend (the figure with office equipment demand) presents almost identical outcome with a negligible variation due to the daily human behavior. Successively, the research considers the outcome as a baseline records.

Total power demand				
Calendar month	Sim result	W/O AC&vent	Dewa	with Equipments
Jan-16	7,500 KWH	2,625 KWH	3,828 KWH	3,990 KWH
Feb-16	8,500 KWH	2,550 KWH	3,924 KWH	3,915 KWH
Mar-16	10,500 KWH	3,150 KWH	4,596 KWH	4,515 KWH
Apr-16	12,000 KWH	3,600 KWH	5,024 KWH	4,965 KWH
May-16	14,200 KWH	4,544 KWH	5,240 KWH	5,909 KWH
Jun-16	15,000 KWH	4,800 KWH	6,200 KWH	6,165 KWH
Jul-16	15,500 KWH	5,115 KWH	6,500 KWH	6,480 KWH
Aug-16	15,800 KWH	5,056 KWH	6,168 KWH	6,421 KWH
Sep-16	13,000 KWH	4,030 KWH	5,694 KWH	5,395 KWH
Oct-16	12,500 KWH	3,750 KWH	5,200 KWH	5,115 KWH
Nov-16	9,000 KWH	2,790 KWH	4,888 KWH	4,155 KWH
Dec-16	7,000 KWH	2,730 KWH	4,500 KWH	4,095 KWH

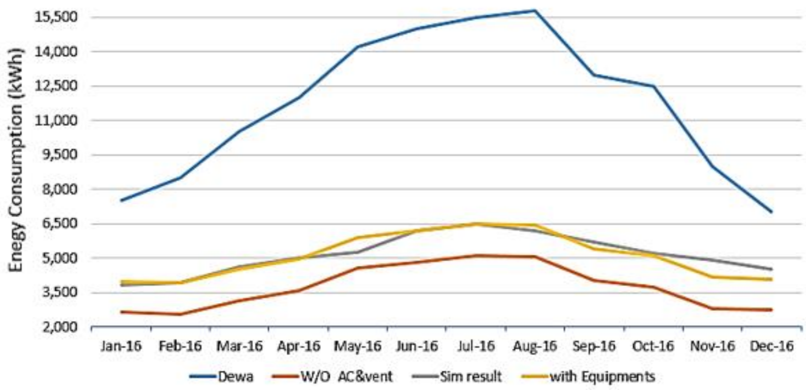


Figure 7-7 Detail comparisons among the four different results.

7.2 Stage two: Kinetic façade as a double skin simulation - full closed louvers with three various scenarios.

Baseline model has been tested to indicate the kinetic façade efficiency as a second skin with totally closed louver to validate the system behavior and scale the wind effect specifically by different means of louver formations.

The baseline upgraded further by integrating the kinetic louver façade (KLS) in Revit software. The upgraded model detailed the KLS system as a double skin façade that identified by three distinct scenarios (600mm, 1200mm, and 1800mm) depend on cavity distance between KLS and glazing curtain façade. Furthermore, the simulation results of the model will be compared to the baseline model built in stage one.

The following step will be taken to study the wind influence on-site in general and to explore KLS competence as double skin in particular.

7.2.1 Overview of wind flow parameters

Wind effect on buildings is an environmental key factor that courtesy designer and deed significantly to enhance/deplete widely to build performance. Numerous aspects could be affected by wind influence on buildings and then occupant's comfort.

Building models created in Revit and transfer to flow design simulation software specifically to visualize the airflow interactive nature of the building. Simulation results and analysis air velocity and air pressure by identify wind behavior, pattern and present a valuable view of understanding with a clear depiction of the wind uniform speed and associated effect.

7.2.2 Built the baseline model of Flow design software

Existing building location has been inspected to depict an approximate data of conditions on site. Annual prevailing wind direction, wind speed as one of the first conditions have been identified along with wind pattern, profile, and flows on wind tunnel setting. The common wind speed around 10 m/s as recorded in climate analysis of the location as stated in Figure 7-8.

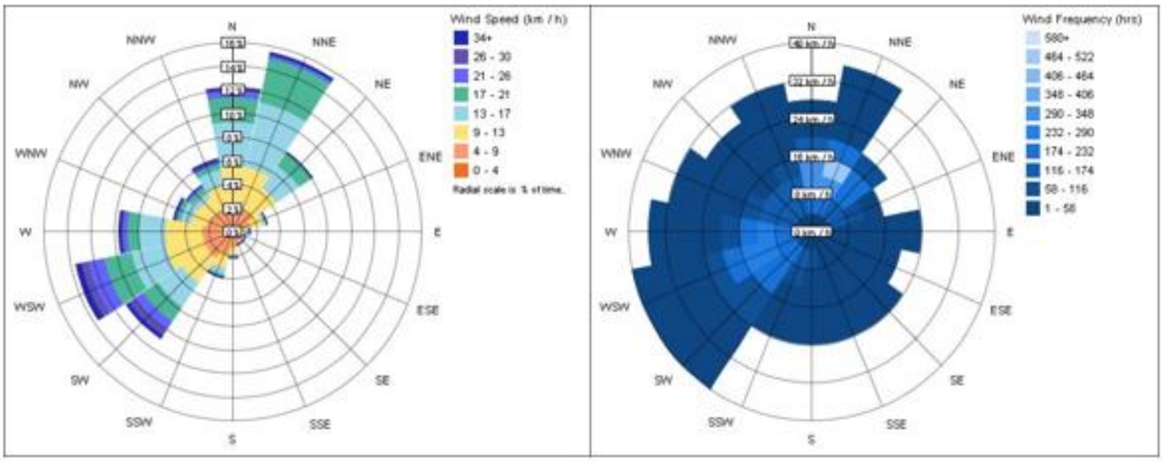


Figure 7-8 Annual Wind Rose (Speed and Frequency Distributions) as per Revit software climate database.

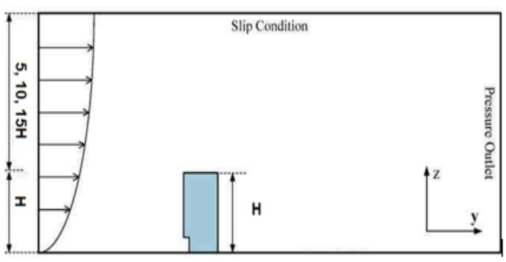
Wind tunnel domain size of airflow have different measurements and consideration which reliant on the model scale. So, to conclude and scale the identical size of the wind tunnel, research concur several steps to adequately size the wind tunnel to state the desired wind profile.

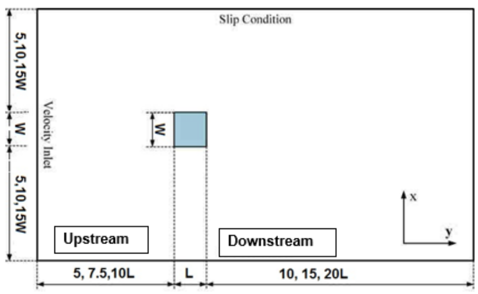
7.2.3 Airflow and wind tunnel simulation validation "Computational Domain Size.".

The study validated the most proper scale of domain size in which the simulation software furnished almost a satisfactory result thru several setting taking into account the model height (H), width (W), and length (L) as main parameters. The steps were done to ensure an independent domain simulation where the results will not affect/tainted by the selection of the size of the simulation domain. Table 7-1 Alternatives of Domain size detailed the main setups base on simulation configurations.

Table 7-1 Alternatives of Domain size

Steps	The Zones	Options for the Domain size			
		Min.	Ave.	Max.	Extra.
1st	Domain Height	5 H	10 H	15 H	20H
2nd	Upstream length at the front zone of the building	5 L	7.5 L	10 L	15L
3rd	Downstream length at the Rear zone behind the building	10 L	15 L	20 L	30L
4th	Side zones	5 W	7.5 W	10 W	15W





The initial step has been taking to simulate the model with an average value (7.5W, 7.5L, 15L, and 10H) as a reference simulation. Other simulations will be compared to the base model and discussed accordingly along with the research recommendations. Figure 7-9 and Figure 7-10 shows the wind flow on plan and elevation where the wind flows record. The elevation wind patterns present almost steady area in level 3H and above with an average prevail wind speed about 10m/s, and on the plan, the air flow and pressure is not entirely steady in the downstream zone. However, a comprehensive analysis result tabulated in Appendix A, (Figures A-1 Air flow pattern with average domain values as the first step to domain size validation (Flow design software).

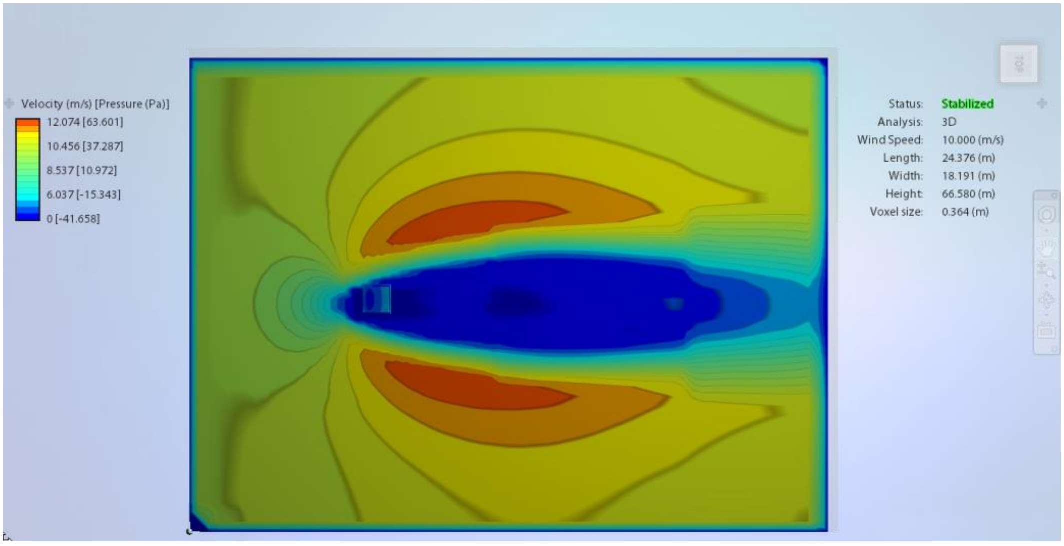


Figure 7-9 Plan View presents the total size of the wind domain tunnel in average domain values (flow design software).

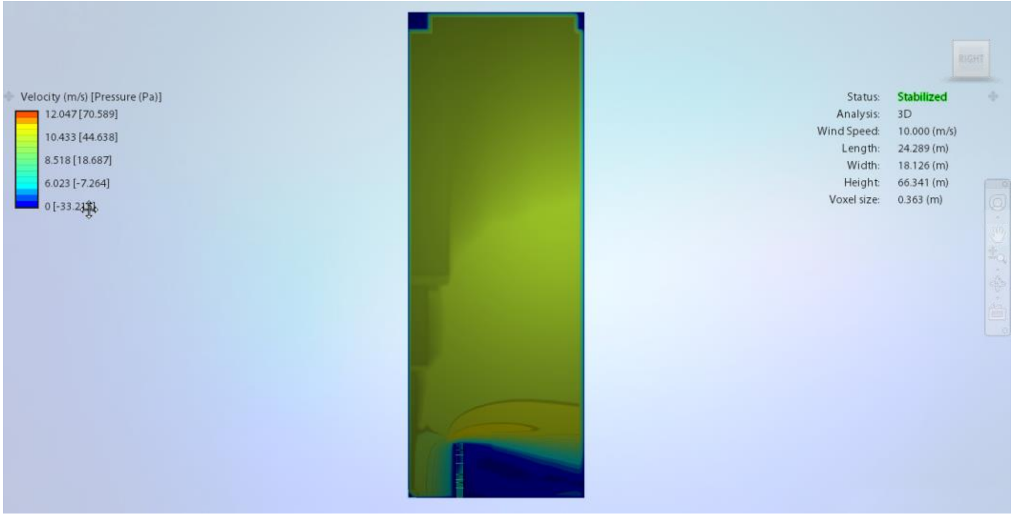


Figure 7-10 Air Side view present the 3D wind pressure zones and air flow pattern with average domain values (flow design software).

7.2.3.1 First step scenario discussed height options and zones above the model.

The simulation picked building height as the first demonstration of flow domain size. Simulation initiated firstly with 10H and second simulation with 5H, and an average of other values (W, L). Subsequently, Result concurs the best effective value that could be considered is 5H where the airflow presents a steady level in the upper zone from 3H and above with mostly the same ambient speed of 10m/s. Whereas, the results of the second option presented on the average model (10H value) did not show a significant impact on domain box comparing to a 5H height. The air velocity in both scenarios has the same pattern (speed and pressure) (Figure 7-11). However, comprehensive analysis results referenced in Appendix A, (Figure A-1 and Figure A-2).

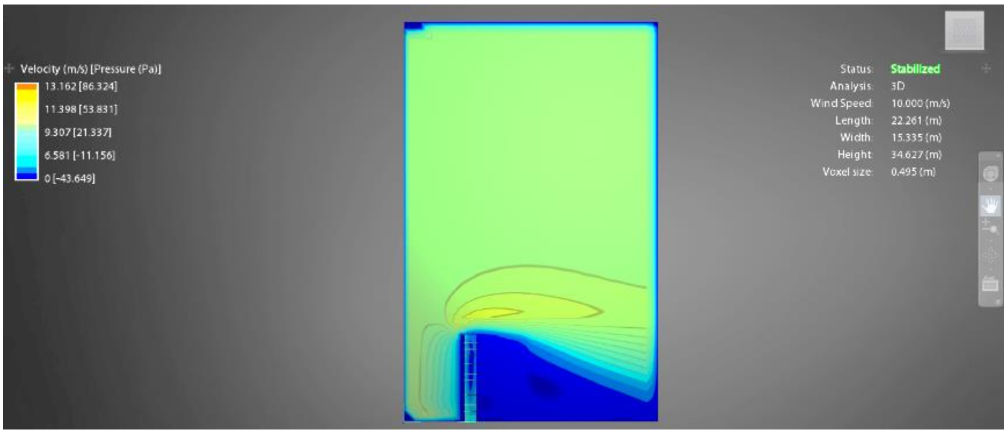


Figure 7-11 Air flow first step scenario with 5H domain height value (flow design software).

Therefore the research recommends 5H height as a base parameter and neglects other values like 10H and 15H which demonstrate a same consequence on the model.

7.2.3.2 The second step discussed length options of the upstream zone.

The simulation receipts 5L along with the first step recommended of 5H and average of the other value. Subsequently, simulation lunch 10L and the result shows the best effective value equal to 7.5L where the air velocity present steady records close to 10m/s with stable pressure (Figure 7-12).

The result recommendation is to select a 7.5L value for airflow box domain due to reluctant air velocity and neglect the impact of other factors that don't illustrate any noticeable difference as demonstrated in Figure 7-12. However, comprehensive analysis outcome referenced in Appendix A, (Figure A-3).

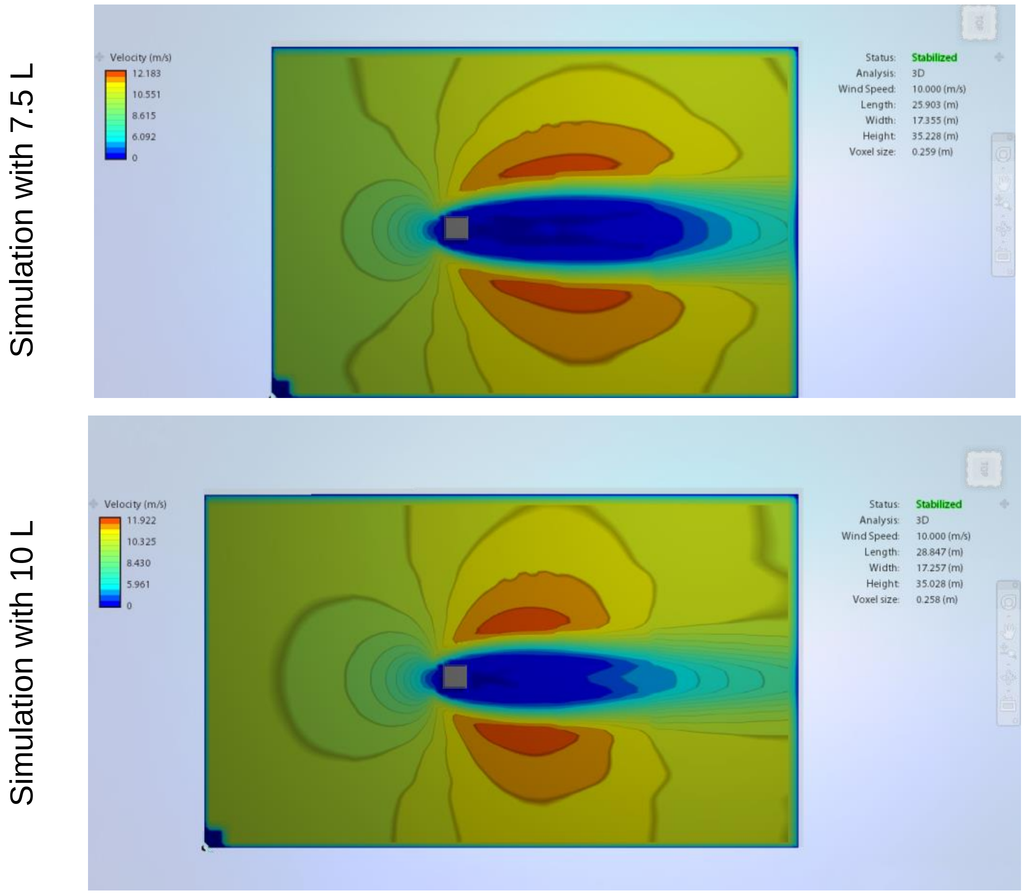


Figure 7-12 Comparison of different length options of the upstream zone (flow design software).

7.2.3.3 The third step discussed length options of the downstream zone.

Simulation repeats the same scenario to upstream zone and starts the simulation with a domain size of 10L, 5H, and 7.5L upstream (recommendation of step 1 and 2) and an average of other parameters. Subsequently, the simulation deliberates the 20L (Figure 7-13). The result proves the 15L length have a paramount flow in comparison to 10 L where the wind flow is not steady and the option of 20L where the wind flow take long path with minimal impact on the model as detailed in the plan views and the longitudinal sections (Figure 7-13).

Plan with 10 L upstream

Plan with 15 L upstream

Plan with 20 L upstream

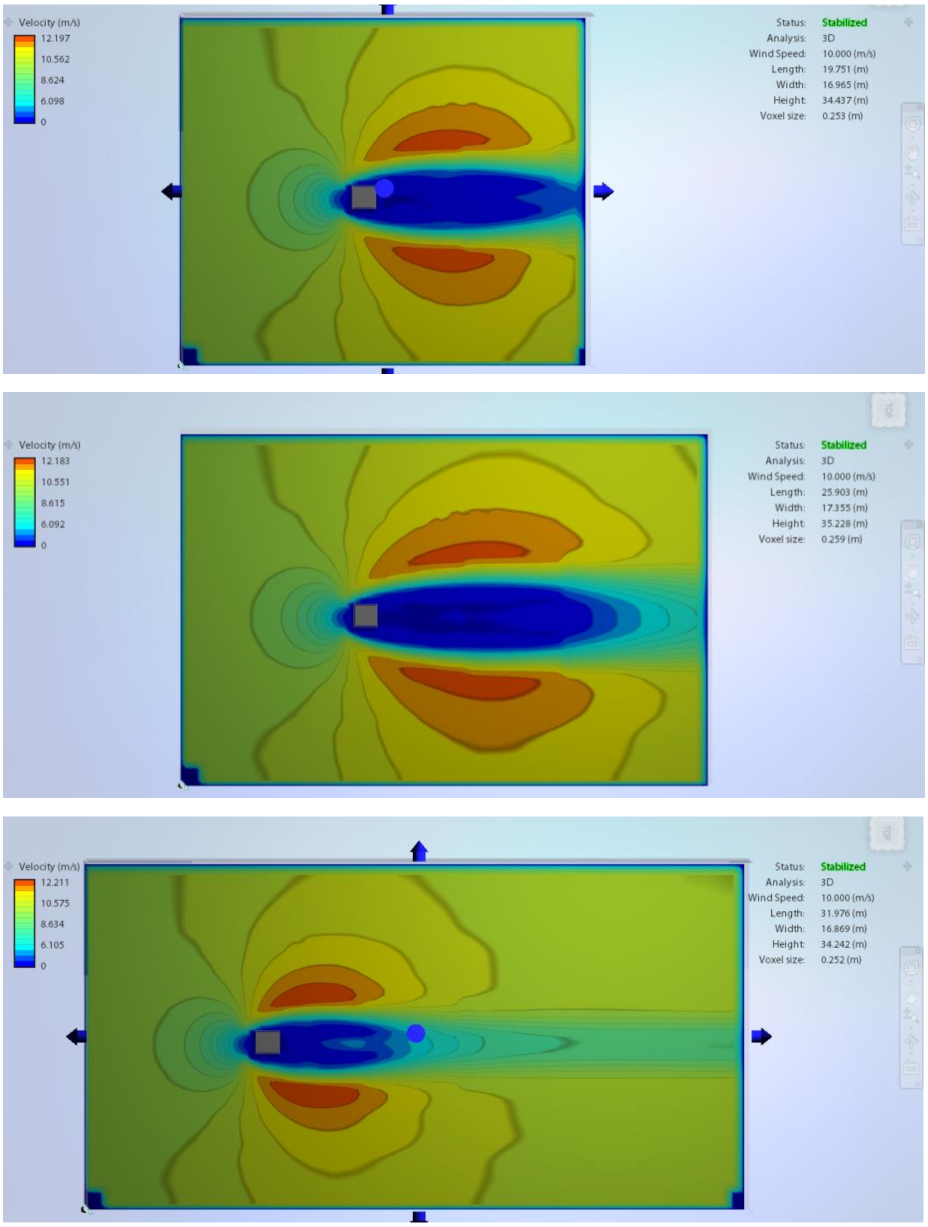


Figure 7-13 Comparison of the three scenarios (10L, 15L, and 20L) of the downstream domain.

Base on the simulation results, the recommendation is to select 15L as the best option for downstream of air flow box domain. Nonetheless, full test results referenced in Appendix A, (Figure A-).

7.2.3.4 The fourth step discussed width and side zones options.

Simulation considers 5W value for the width of the domain, with the recommendation that has nominated in the previous steps (5H, 7.5L for the front zone and 15L for the rear zone). Later, the simulation takes 15W, up to 20W if required. The simulation results present the best effective value that could be considered is the 7.5W where air flow pattern illustrates a uniform pattern with relaxing air flow about 11 m/s within plot edges. Whereas, the 5W setup has a full red zone on both side with speed more than 12m/s and the 15W has an enormous un-affected area that could be neglected (Figure 7-14). However, full analysis marks tabulated in Appendix A, (Figure A- 5).

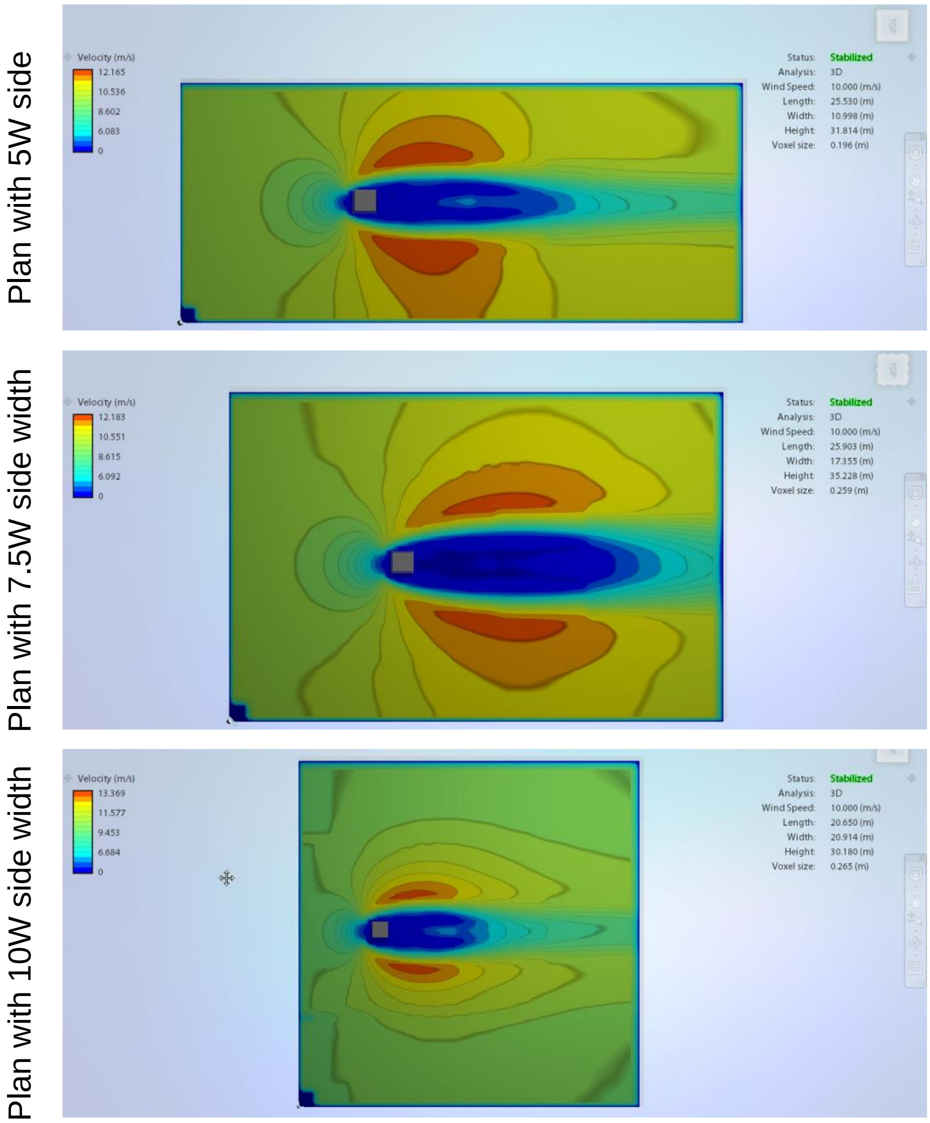


Figure 7-14 Comparison of side zone width options (flow design software).

Base on the model simulation outcomes, the recommendation is to select the 10W value for the airflow box domain due to the air velocity reluctant. Finally, the finding of the simulation result is recommended the size of computational domain box to be a 5H for the height, 7.5L for the Upstream and 15L for the downstream zone and 7.5 W for the side zones of the plot.

7.2.4 Airflow simulation analysis and the best KLS position scenarios.

In this section, the precise objective is to evaluate the wind effect on the model and occur an ultimate efficiency of KLS configurations. Therefore, the baseline model has developed by adding KLS as open louver formation and tested to novelty wind flow effect on the building as a stand-alone structure. The simulation considered the recommended domain size as demonstrated earlier. The simulation results present the following:-

- The 3D wind tunnel presents a quite offered wind pressure on façade faced wind flow along with a negative pressure in different elevation. The pressure significantly varies from lower to higher levels as demonstrated in Figure 7-15.

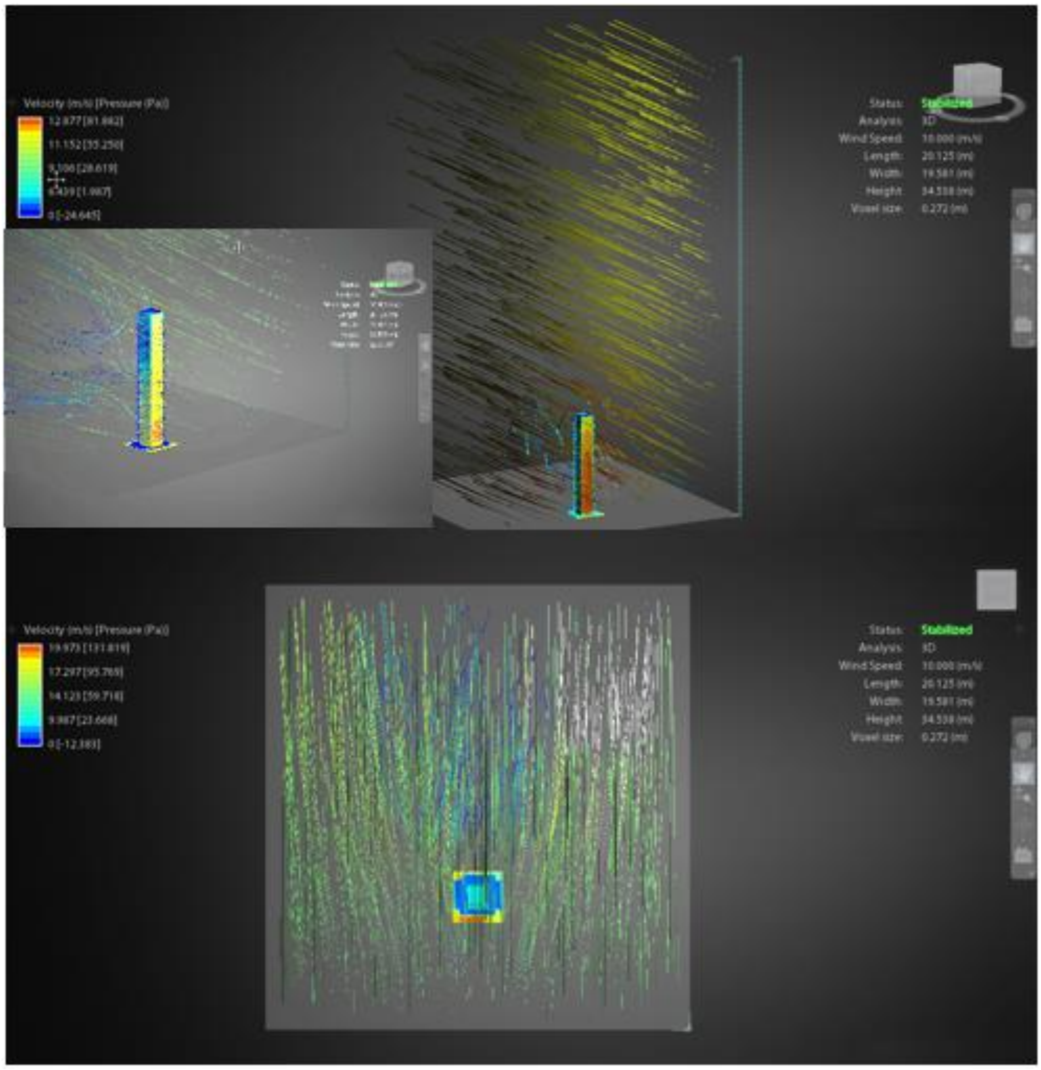


Figure 7-15 Plan view for wind flow simulation with detailed 3D views (flow design software).

- Close view to façades presents that the lower level has been affected by highest pressure than upper level with almost 25% in the record as shown in Figure 7-16. Moreover, the side facades affected by a wind velocity with different scale of pressure which mainly varies from main facade record.

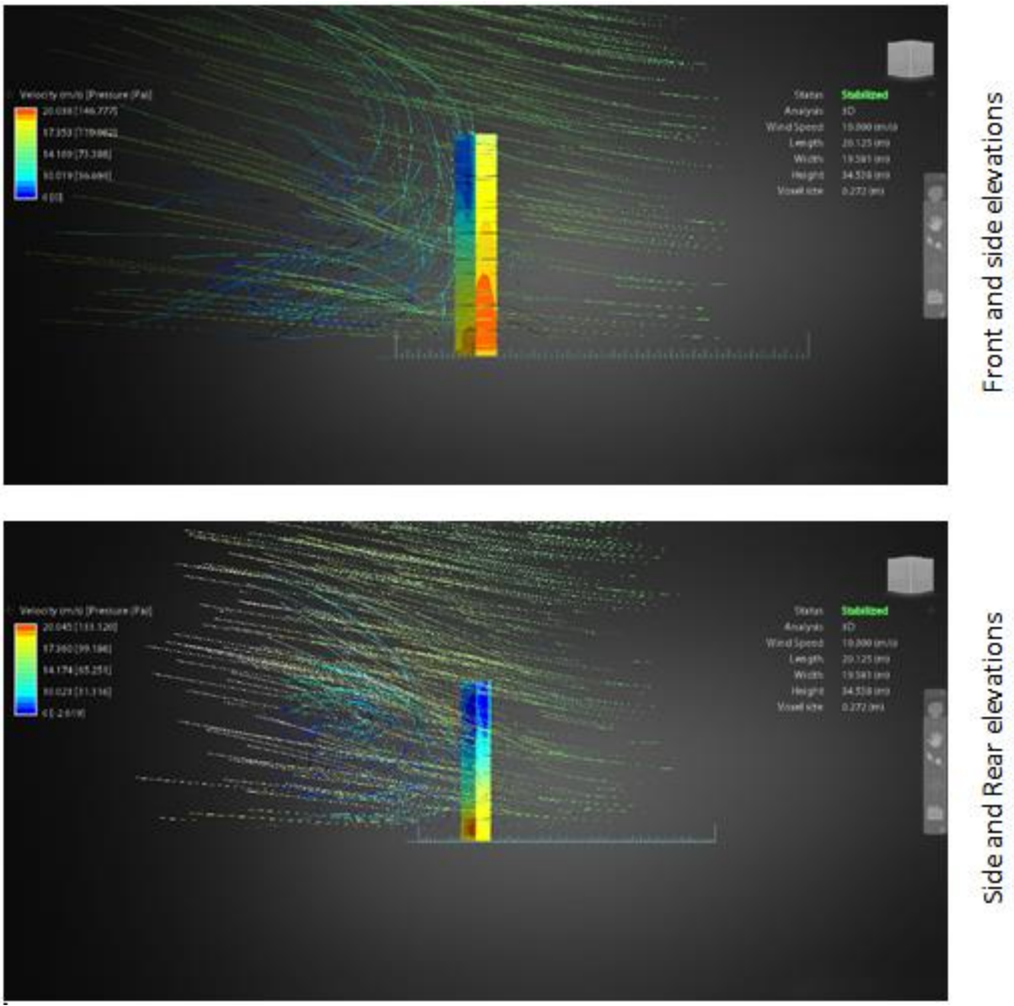


Figure 7-16 3D views present the four side of the building and the wind effect on each façade (flow design software).

The results display the wind flow influence on building’s facades that could be one of the main strategies to enhance the facade efficiency. Nevertheless, despite the fact that the building will have a different KLS’s configurations, the wind effect will take place with the almost same stimulus.

Kinetic Louvre System position as a factor within building façade was set in three different positions depending on the distance between glazing curtain facade and KLS as demonstrated in Figure 7-17.

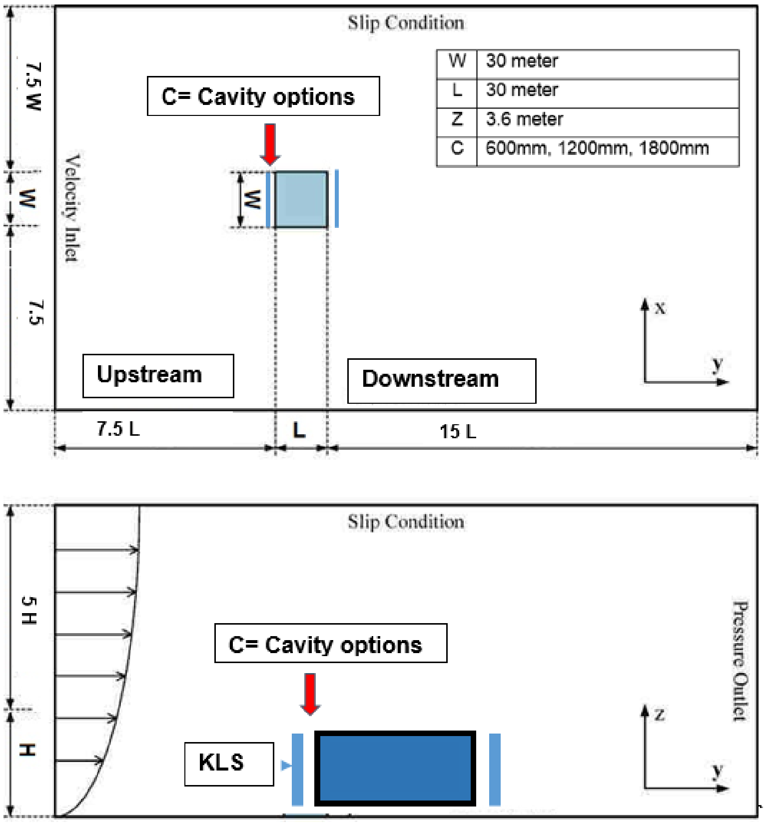


Figure 7-17 KLS position scenario and the detail of domain size

Consequently, the detail of the KLS position scenarios as a factor within building façade set in three different positions depending on the distance between glazing curtain facade and KLS which as follows:-

- 1st scenario – 600mm.
- 2nd scenario – 1200mm.
- 3rd scenario – 1800mm.

- **Simulation results, comparison and recommendations.**

Simulation replicates the test to investigate a feature wind influence on KLS and in particular the cavity between glazing façade and external kinetic louver. the simulation started with the 600mm option where the results display a uniformed wind pressure values for the entire area (Figure 7-18). Moreover, the air circulation in cavity gap almost neglected due to air volume and airspeed that present a minor charge. Close view of the 600mm introduce the cavity area behind louver has a very minimal wind effect with speed of 0-6m/s and a very low pressure. However, full analysis marks tabulated in Appendix A, (Figure A -).

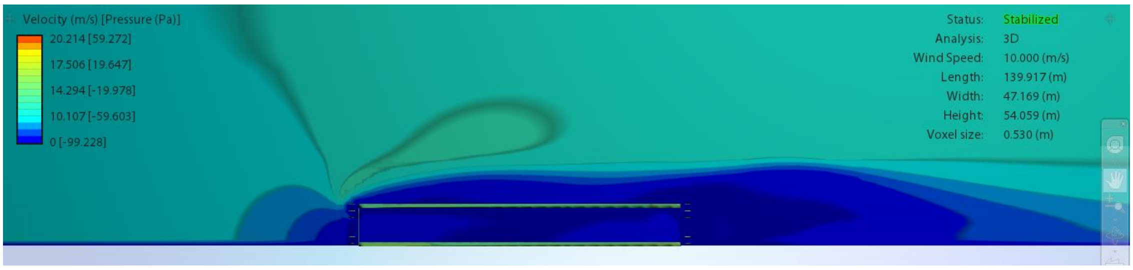


Figure 7-18 Wind simulation shows the 600mm KLS setting result (flow design software).

The simulation replicates the test with cavity distance of 1200 mm and presents a considerable volume of wind pressure in the area along with noticeable wind speed as detailed in Figure 7-19. Moreover, air circulation at cavity gap shows different air pattern with a recorded speed of 2-5m/s perceptible different pressure around 30-50. However, full analysis marks tabulated in Appendix A, (Figure A - 7).

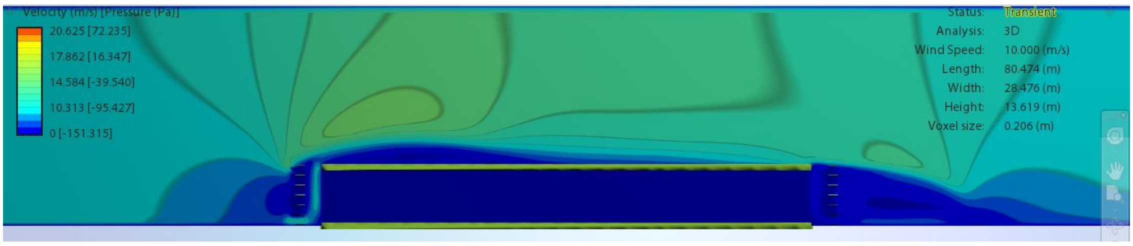


Figure 7-19 Wind flow simulation shows the 1200mm KLS setting result (flow design software).

Whereas, the option with 1800mm cavity presents a significant air circulation with double skin compared to other scenarios (Figure 7-20). Close view to the outcome shows a higher wind velocity around 1-10 m/s in the cavity with a detectable level of wind pressure about 30-65 Pa. Moreover, the air circulation shows a substantial value in air volume present a precious amount of flow with various pressure and rapidity. Nevertheless, packed test marks tabulated in Appendix A, (Figure A-).

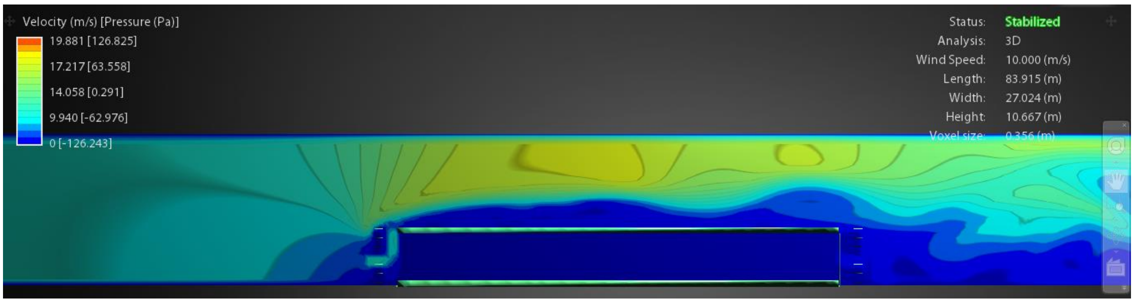
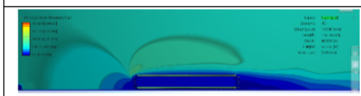
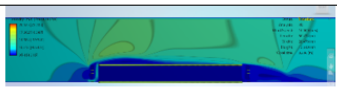
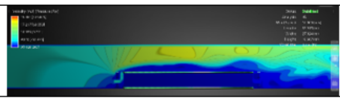


Figure 7-20 wind flow show the 1800mm KLS simulation result.3D view and elevation view (Flow design software).

Finally, Among three different scenarios, results display that 1800 mm position of KLS is the best position to motivate air circulation as verified in the following table (Table 7-2). The table illustrates the 1800mm scenario has more advantages in term of airspeed and noticeable difference in air pressure that introduce the possibility of an optimal solution in comparison to other options.

Table 7-2 Flow design results comparison presents three different scenarios of the double skin configuration.

1st Scenario 600 mm	2nd Scenario 1200 mm	3rd Scenario 1800 mm
		
Very slight air flow at the cavity.	Air volume is recorded.	An advanced air volume.
Air speed is 0-1 m/s	Air speed is 1-5 m/s	Air speed is 1-10 m/s
Air pressure is neglected	Air pressure is 30-50 Pa	Air pressure is 30-65 Pa

The study recommendation is to first-rate the third scenario (1800mm) of the KLS setup. The investigation outcome with associated parameters (wind direction, velocity, and pressure) will consider as a baseline for next level of wind flow analysis with CFD models.

7.2.5 CFD Analysis and stack effect of different KLS as double skin configuration.

In this section, the research will discuss the performance of double skin façade as far end of façade configuration scenarios with a cavity distance of 1800mm as recommended by the outcome of airflow analysis.

Generally, within research model, the cavity of KLS as double skin façade generate a thermal buffer area which called a “thermal blanket” by numerous studies. The zone has no horizontal or vertical partition’s and works as air gap blocked direct radiation, convection, contribute to decreasing the heat gain in summer and heat loss in winter potentially. These contributions provide sufficient values in summer cooling demand which depends on the system performance as a double skin kinetic facade.

Air extraction and air circulation in the cavity created by the natural airflow in additional to physical effect by buoyancy and thermal chimney influence. Air infiltration goes from a cold area toward a high-temperature area due to the difference in pressure levels. Therefore, the cold air will replace escalating hot air at a higher level (Figure 7-21).

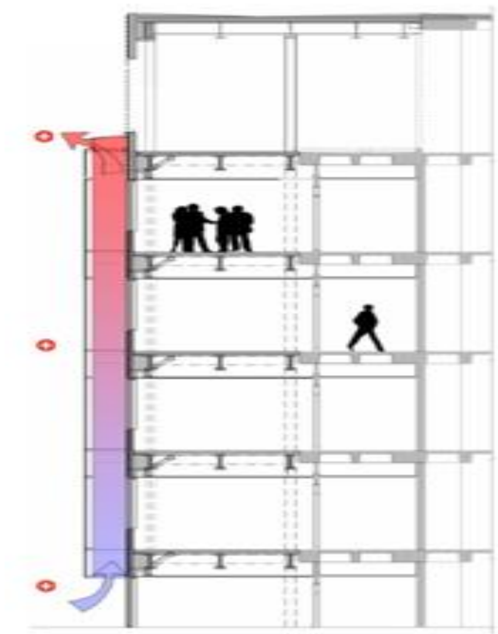


Figure 7-21 Double Skin façade present the stack effect and wind flow within the cavity area.

However, these thoughtful of control strategy of air infiltration in inlet and outlet along with airflow could easily manage by operable louver system where the façade operated as a response to the climate conditions.

Therefore KLS performance as double skin façade scenario will be influenced by wind stack effect which requires altered considerations. These considerations might address the changes in façade formation and behavior due to air velocity and temperature within the cavity zone in comparison to ambient conditions.

7.2.5.1 CFD simulation and analysis.

The stack effect on façade with double skin design has simulated by CFD Autodesk software which is compatibles with Revit software by transfer the baseline model to CFD software directly. The software uploads model parameters and analysis the double skin behavior and possibilities.

The baseline model with double skin façade as recommended earlier by airflow study with 1800 mm cavity that has tuned to typical ten floors height only to explore the stuck effect in more detail. However, the ten floors model height demonstrates the full scenario of double skin and the real size of conditions as demonstrated in Figure 7-22.

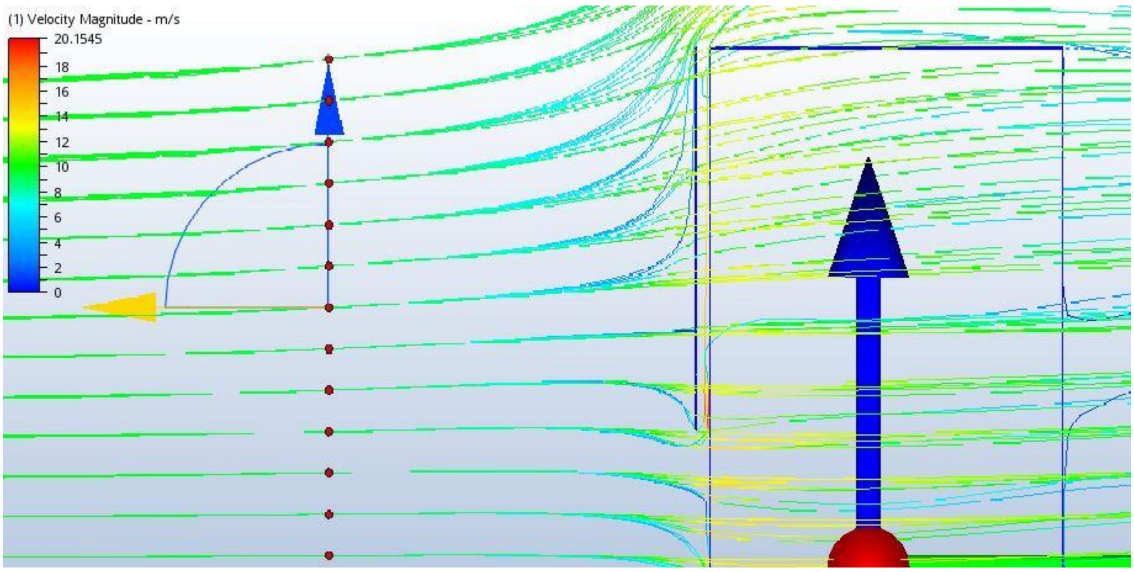


Figure 7-22 CFD simulation results for ten floors only of the baseline model with the cavity of 1800mm demonstrate the high air velocity pattern within the cavity space. (CFD Software).

Simulation result presents a significant air velocity in the cavity area which comes close to Flow design software results presented earlier. At the same time, stack effect prevailed and scaled clearly as demonstrate in Figure 7-22 and Figure 7-23 and f. Moreover, the wind velocity increased potentially in cavity zone as demonstrated in the figure where yellow-red colors presented airspeed of more than 14m/s while ambient airspeed around 10 m/s.

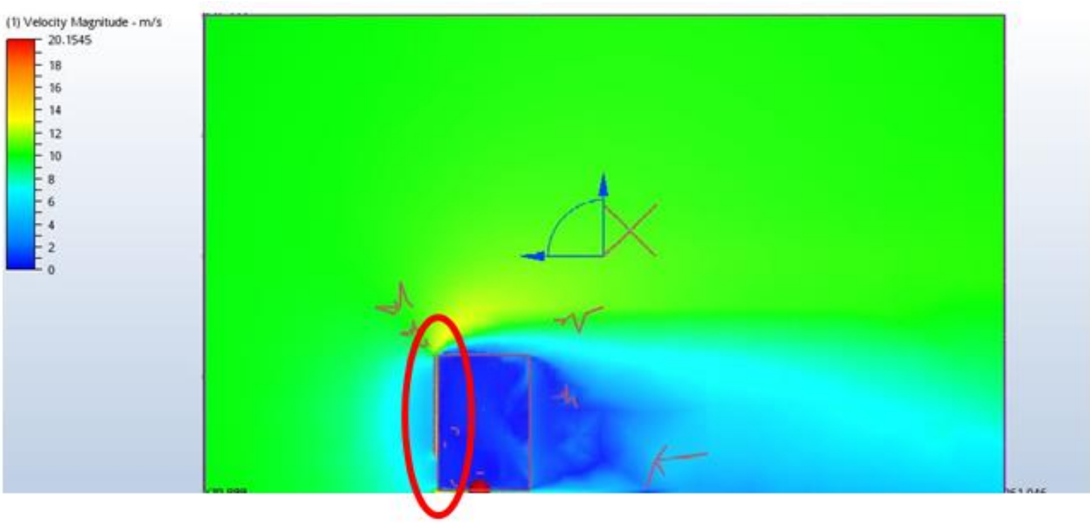


Figure 7-23 CFD simulation results introduce the wind flow effect on the baseline model with the cavity of 1800mm (CFD Software).

However, the wind flow induces a high temperature at the cavity due to the chimney effect and heat gain effect within the façade scale (approximate ten floors height) (Figure 7-24).

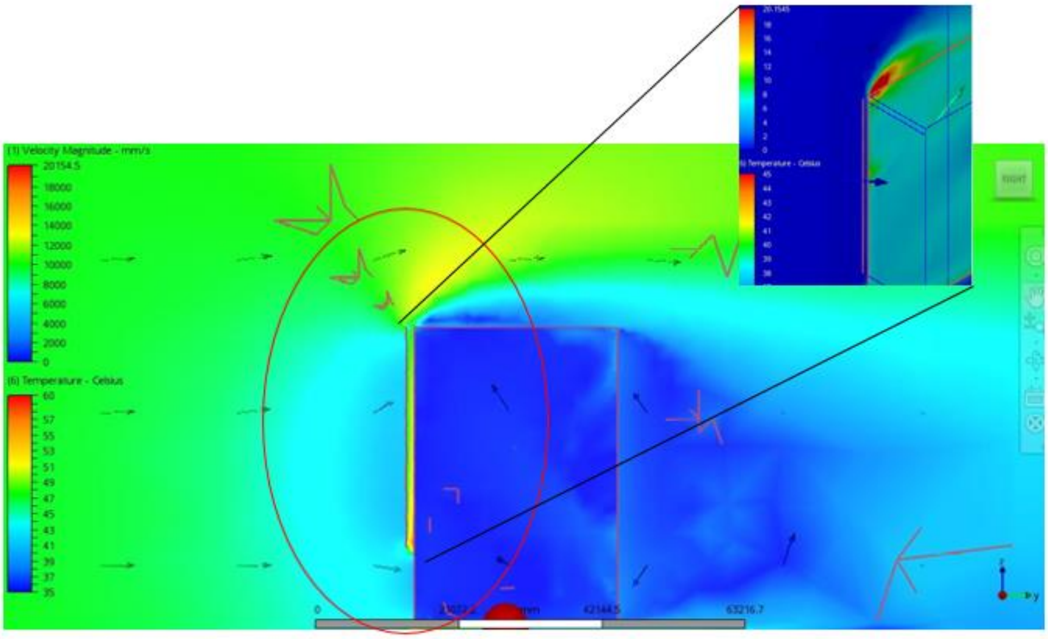


Figure 7-24 CFD analysis illustrate the wind velocity, wind temperature and close 3D view of the double skin facade (CFD Software).

To conclude, a detailed view of the simulation results found that the stack effect took place at the cavity area where the wind speed increase significantly at the same time the temperature present a high record around 50 degrees in the cavity whereas the ambient temperature around 35-40s degree.

Nonetheless, the result presents the chimney effect in the cavity where air velocity is greater and recorded a higher temperature degree as detailed in the enlarged figure (Figure 7-24).

7.2.5.2 CFD analysis Summary and Recommendations

Apparently, the double skin façade influenced by chimney effect and potential wind temperature increases which will increase the cooling load in summer significantly and total energy demand. Moreover, the consequence will be more if simulation proceeds more floors which will reveal further impact due to chimney effect and wind heated expressively, especially, on summer season where the ambient temperature reaches 47 degree. Moreover, during the winter months the advantage of stack effect and chimney effect is insufficient due to the short time of the cold season and need for the heating system within local climate is abandoned due to the moderate temperature rate at winter seasons.

To conclude, the research simulation results demonstrate airflow effects on ultimate response configuration of KLS presented as double skin facade. Based on the result analysis and considering the climate condition of the local environment (Dubai in particular and UAE region in General) as a hot climate and the simulation demonstrates of the wind behavior and associated effects, the researchers recommend the following:-

- As the building consider as high rise building and have almost 60-floor heights, the study recommends to neglecting the upper floor separate analysis due to the chimney effect in the cavity area, if the entire façade performs as a double skin, the wind temperature will increase significantly and efficiently decrease the façade performance.
- The cavity area should be a limit to the area of floors and will not consider within the entire façade in a condition that double skin facade scenario does not prevail. Therefore, the behavior of KLS will be uninformed at different floor level.

Though, these initial research recommendations subjective to further investigations. The investigations will demonstrate the performance of KLS double skin option in more details within the next sections where the light and energy demand will discuss in particulars by quantified the potential total energy saving

7.3 Stage Three: Analysis setting of daylight and energy performance.

7.3.1 Simulation baseline model conditions

From a research point of view, the next stage of the simulation will consider the baseline model as stand-alone building with an exact orientation to the south as demonstrated in Figure 7-25. The next level of details will considerably discuss the illuminance light level in the internal office space and potential power saving and total energy demand.

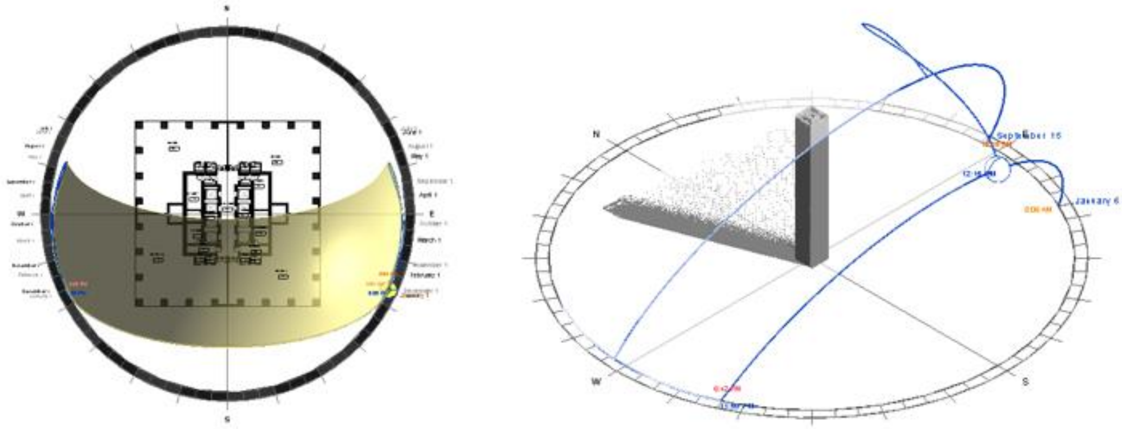


Figure 7-25 Existing building orientation and condition-Revit graph present the sun path during the year.

7.3.2 Simulation configuration and matrix

Diverse set-ups have planned to observe daylight and power efficiency of KLS on facades. The variations of formation considering the louver configuration, inclination, orientation, and light control in the best optimal cases.

Research set criteria to establish a comparative analysis of simulation results to categorized the variety and furnish the research with a full understanding of the outcome and outline the best configurations. Therefore, the analysis will be divided into two phases. The first phase will discuss the light analysis and the second phase will exam system energy performance.

However, as detail earlier in chapter 3, the simulation sequences will start with baseline model and followed by KLS diver’s configuration models till extreme situation where KLS behave as a double skin façade. Despite the fact that each stage has a minor change in configurations and outcome results, the wide line simulation matrix detailed in Appendix B, (Table B-1).

7.4 Stage Three: Daylight analysis

7.4.1 Useful Daylight Illumination (UDI) as appraisal criteria.

UDI is one of the main criteria to evaluate the comfort level of daylight and solar penetration in spaces. Revit Software built-in climatic dataset for model location (Dubai, UAE) and defined the parameters of solar values (W/m2) base on Global Horizontal Irradiance GHI, Direct Normal Irradiance DNI, and Diffuse Horizontal Irradiance DHI, where these factors variant according to time, date and locations.

These factors furnish the investigation with a clear picture about daylight distributions and uniformity along with solar heat gain within the premises of office spaces. That will provide the study with a tool to equate the results and highlight the best values for a presence of comfort level, potential high-level and below threshold values and evaluate the results accordingly.

7.4.2 The evaluation criteria.

The base model is categorized as an office building and as identified earlier the acceptable lux level of the internal space is around 500 Lux and up to 1000 lux could be acceptable within the comfort zone. However, 2000 lux level is set to the comfort value for human scale but effectively increase heat gain values which should be considered when looking at the daylight figures.

The results will be presented in groups consisting of three broad classifications, where is the UDI, (below the threshold as Low Useful Daylight LDI) and second is set with threshold called as Useful Daylight Illuminance UDI and last called high daylight illuminance HDI which comes above the threshold. The results will be classified into three main areas as follows:-

- Below threshold level where the daylight set below 200 Lux (LDI)
- Within threshold level where lux level set between 200 – 1000 Lux (UDI).
- Above threshold where the lux level above 1000lux. (HDI).

These reading will be practiced with the 12-inch grid at the height of 32 inches above the ground. Regular illuminance levels were logged at the grid in two periods of time (morning at 9:00 am and afternoon 3:00 pm) periodically. The office plan will have an indicator of each grid with color according to the illuminance level where normally the area close to the external glazing façade has HDI level (record of the lux level exceeded the 2000 lux), and lux will decrease toward opposite side till end wall with LDI level below 200 lux. However, the average of the area that allocated with the UDI 200 to 1000 Lux will be recorded accordingly.

The final results will illustrate the percent of each category (UDI, LDI, and HDI) within the office space during daytime considering other parameters of a model like the inclination of the active louver system.

7.4.3 The research model

The plan of the baseline model as described earlier have mainly four offices where each facade has access to two offices. Therefore, each office orientation classified as follows:-

- Office 01, SW. Allocate on the south and west façades.
- Office 02, SE. Allocated to the south and east facades.
- Office 03, NW. Allocate on the west and north façades.
- Office 04, NE. Allocated to the north and east facades.

The average of the acceptable light level of UDI allocated between 60 – 80 percent of total space plan as stated by numerous researchers as an excellent daylight concept (Giovannini et al. 2015). However, that is debatable in our case as the study discuss an existing office space that has many neglected areas considerably recorded as below threshold. The research will compare baseline model to an advanced scenario where the KLS will take place with different configurations.

The Researcher's study will investigate each façade separately. The study will test the KLS various setting. The facades forms will begin with an open façade system without any treatment, till the extreme façade option where the double skin KLS closes the other façade. Subsequently, the louver configuration will be changed by altering the louver inclinations.

7.4.4 Baseline model simulations.

Baseline model established in the software as detailed earlier, and tested by using light analysis plug-in into Revit software. The result is highlighted in Figure 7-26.

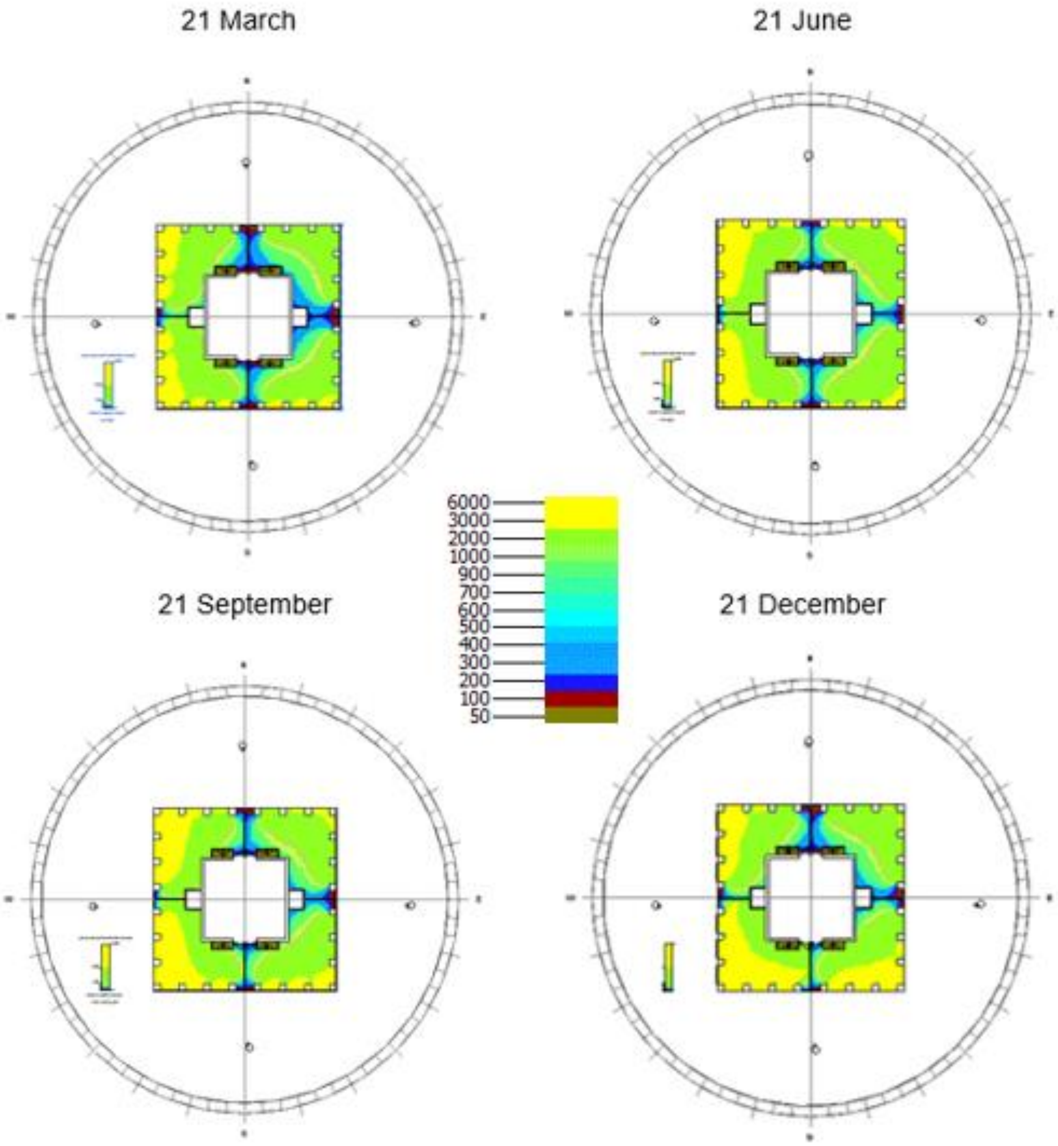


Figure 7-26 base model light simulation, Revit software.

Figure 7-26 reveal an obvious over illuminance area with a yellow label where lux level exceeded 3000 lux and mainly 90 percent of spaces allocated between yellow and green zones with a range of 2000 lux and more. These readings are cause a potential heat gain and extensively increase HVAC load and power demand. The detailed reading of the simulation listed in Appendix B, (Table B-2).

The results show, mainly all facades practices an extreme daylight illuminance in June to December. While in Winter season, the office's space is less exposed in comparison to other time, but stagnant above threshold mostly. However, low sun angle provides an intensely light ray penetrating into office spaces. KLS model simulations

7.4.4.1 21 December - All façade model simulations

Research exam facades separately and started with no louver in the precise façade and then apply the KLS configuration started from 15 degrees up to 165 degrees. A comprehensive analysis outcome referenced in Appendix B, (Table B-3 and Table B-4).

The simulation outcome for east façade shows the best record allocated to KLS range 45 to 120 degrees where UDI recorded above 50% at morning time. However, there are finding of HDI with KLS position in 45, 60 and 75 degrees with almost 15% and lowest LDI value come in the 60, 75 and 90 degrees, around 20%. At afternoon time, the best UDI and LDI comes with KLS inclined of 75, 90 and 105 degrees. Therefore the best east facade records for KLS inclination is the 90 degrees. Similarly, the west façade results record almost the same trends but with different timing. KLS from range 75 to 120 degrees have the best records at 9:00 am, and LDI is considerably high within entire façade. At 3:00 pm timing, the best UDI goes with position 60 to 90 degrees with 65-72% approximate (Figure 7-27).

South façade outcome presented by KLS with a range of 60 to 120 degrees where UDI recorded around 55%-75% at morning time. However, HDI records with KLS of 105, 120 degrees reached 19%, and LDI comes within 90, 105 and

120 degrees around 15-25%. At 3:00 pm timing, the best UDI goes with the louver position 75 to 120 degrees. Whereas, LDI records are considerably high around 17-30%, and the lowest comes with louver position 90 and 120 degrees. Therefore, the best records for KLS inclination at 120 degrees (Figure 7-27).

The North façade results present 90 and 105 degrees of KLS formation have the best record with UDI at morning time. Though, the model with non-louver has a better result close to 48%. Similarly, non-louver have a better value of lowest LDI around 53%. At 3:00 pm timing, present the same finding regarding the non-louver scenario. Therefore in comparison to the several louver positions in the north facade, the non-louver scenario has the best UDI records within the daytime (Figure 7-27).

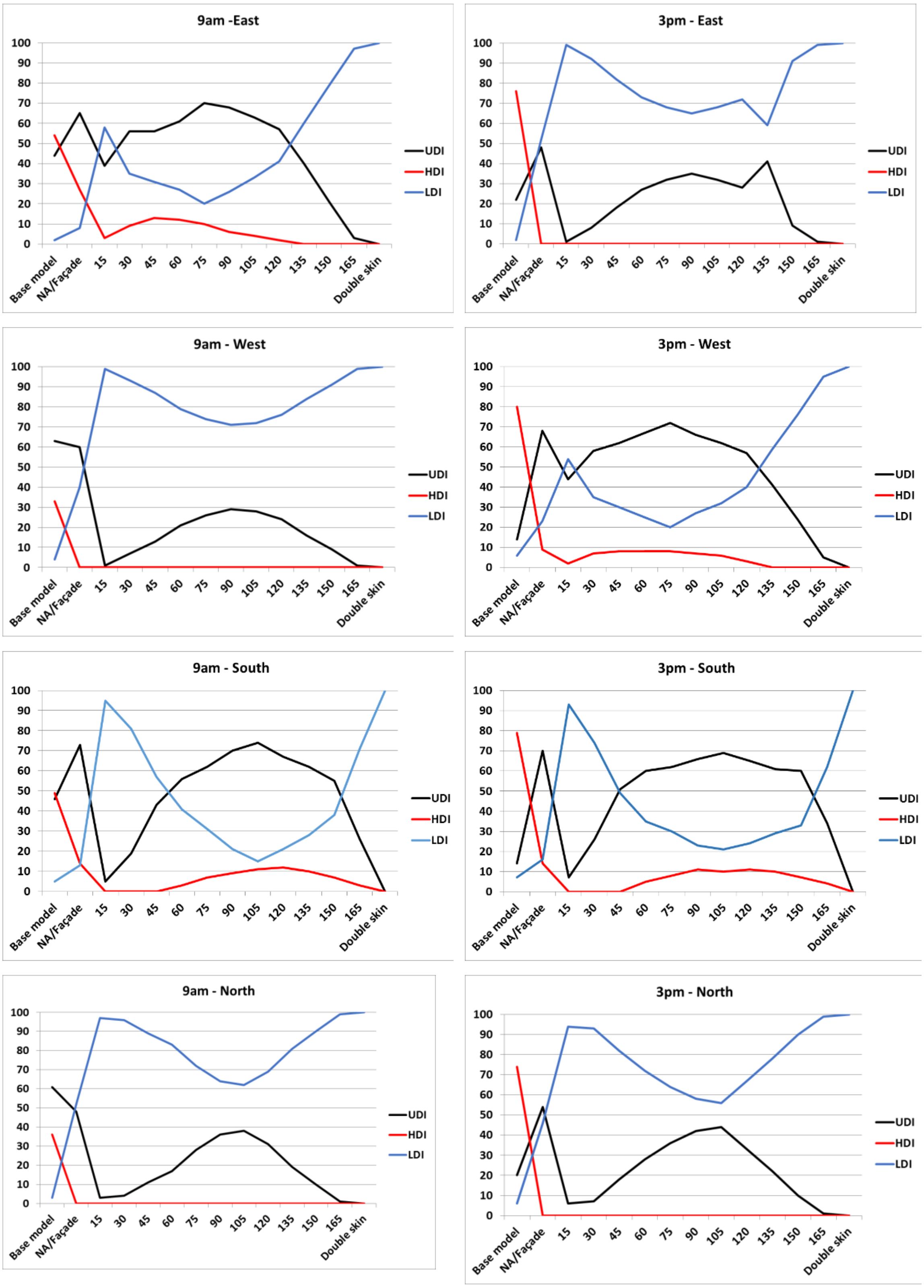


Figure 7-27 Daylight simulation result on 21 December presents all façade illuminance level at morning and afternoon time (Revit light analysis).

7.4.4.2 21 September - All façade model simulations

Similarly, the investigation takes similar steps of exam scenarios and a comprehensive analysis outcome tabulated in Appendix A, (Table B-5 and Table B-6).

East façade results present KLS with inclination range of 45 to 120 degrees have the best records where UDI recorded above 60% at 9:00 am in comparison to baseline model and no louver scenario. However, HDI in 75 to 105 degrees has almost 12% and LDI best value registered in 75 and 90 around 16%. At 3:00 pm, the best UDI derives with louver position 90 degrees with 43% approximate. While HDI is mostly not presented and lowest LDI level comes with the same louver angle. Therefore, the best records for KLS inclination at 90 degrees. Similarly, the west façade Louvre at 90 degrees, where UDI recorded above 43% at 9:00 am, is the highest despite the no Louvre façade records about 61%. HDI is mostly zero, and LDI is considerably high within the entire façade however. At afternoon time, the best UDI comes with KLS position at 75 and 90 degrees with 70%. HDI record 10% and LDI records are registered the lowest with the 90-degree position. In conclusion, the best records for KLS formation position at 75 and 90 degrees (Figure 7-28).

South façade KLS with inclination range of 75 to 135 degrees is the best where UDI recorded 60% at 9:00 am, and HDI recorded almost 4%. LDI lowest value recorded at 120 degrees around 30%. At 3:00 pm, the best UDI comes with louver position at105 and 120 degrees with 70% approximate. While HDI is 10% mostly, and LDI level comes with the same extent record around 25%. Therefore, the best records for KLS inclination at 120 degrees (Figure 7-28).

Nevertheless, North façade KLS does not add any value to façade efficiency in compared to the non-louver model as illustrated in the results. However, the Louvre with an inclination of 90 degrees h UDI recorded above 47% at 9:00 am. Whereas, the non-louver model has an advanced record of 56%. Similarly, at 3:00 pm, the best UDI with a non-louvre record 60%. Thus, the best values considerably recorded with the model with no Louvre (Figure 7-28).

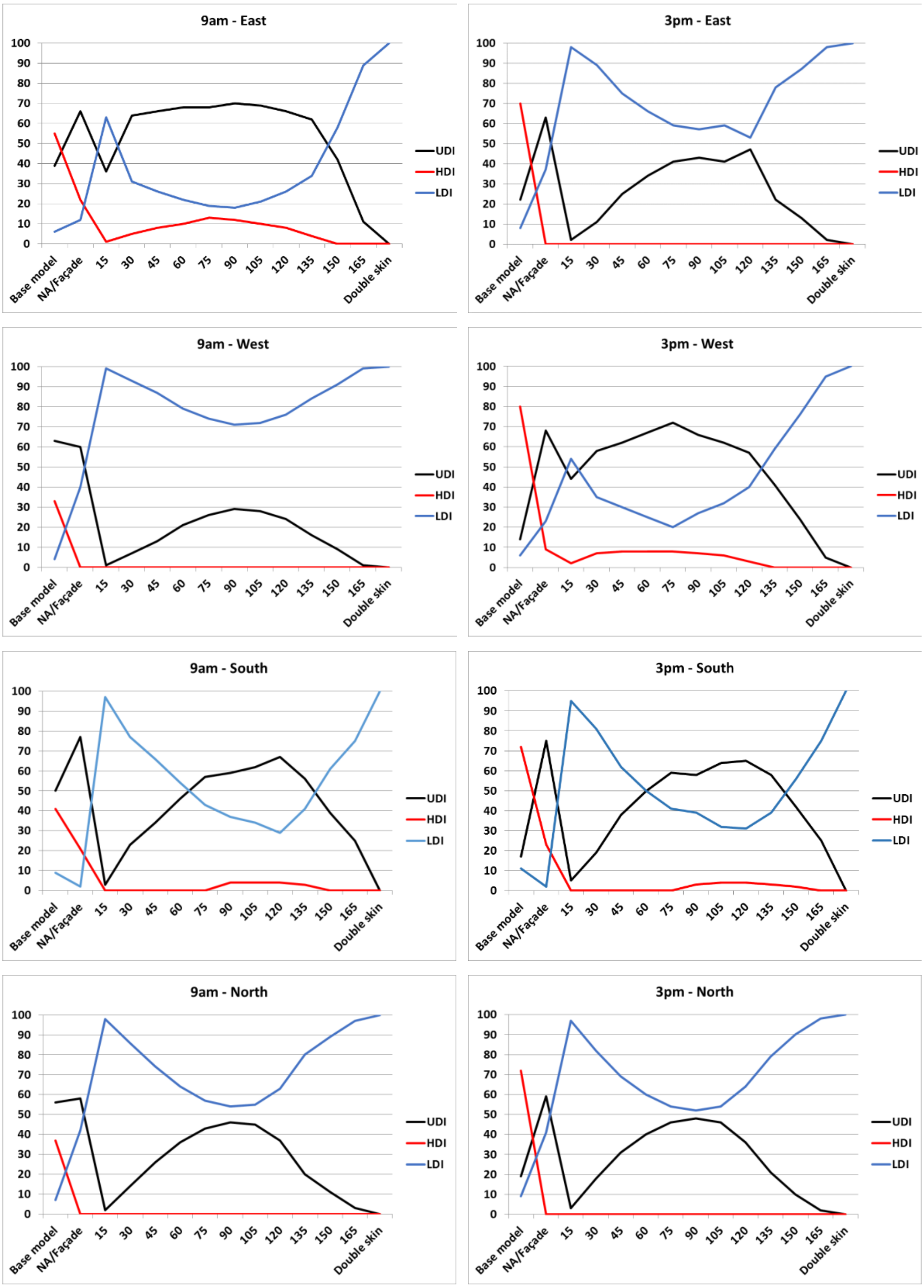


Figure 7-28 Daylight simulation result on 21 September presents all façade illuminance level at morning and afternoon time (Revit light analysis).

7.4.4.3 21 June - All façade model simulations

Summer season investigated with same and result stated in and tabulated in Appendix B, (Table B-7 and Table B-8).

The result of East façade shows the KLS inclinations from a range of 45-135 degrees, where UDI recorded 66% at 9:00 am, are optimal in comparison to the base model and no louver scenario. At 3:00 pm, the best UDI registered in position 75, 90 and 105 degrees with 45 - 48% nearly. Lowest LDI level comes with a similar situation at 75 and 90 degrees. Therefore, the KLS with inclination 75 and 90 degrees are optimal in comparison to other configurations. Similarly, the West façade present the same trend where KLS in the inclination of 90 degrees have optimal records at 9:00 am. LDI lowest value recorded in 90 degrees around 59%. At 3:00 pm, UDI best records come with KLS position in 75, 90 and 105 degrees with 68 % (Figure 7-29).

South façade KLS position in the range of 90 degrees, where UDI recorded 50 % at morning and afternoon is a best, but no louver façade have close results with slight improvements. LDI lowest value recorded in 90 degrees as well, and the no louver façade records better records. Results of summer season where the sun position is almost vertical to the building, thus KLS results in some area registered lower values than façade with no louver scenario. However, the recommendation is to have louver as shows with best records at 90 degrees (Figure 7-29).

The results of North façade mainly imitate the same scenarios of the September and December where the louver position at the north façade does not add any value to façade configuration in compared to the non-louver model (Figure 7-29).

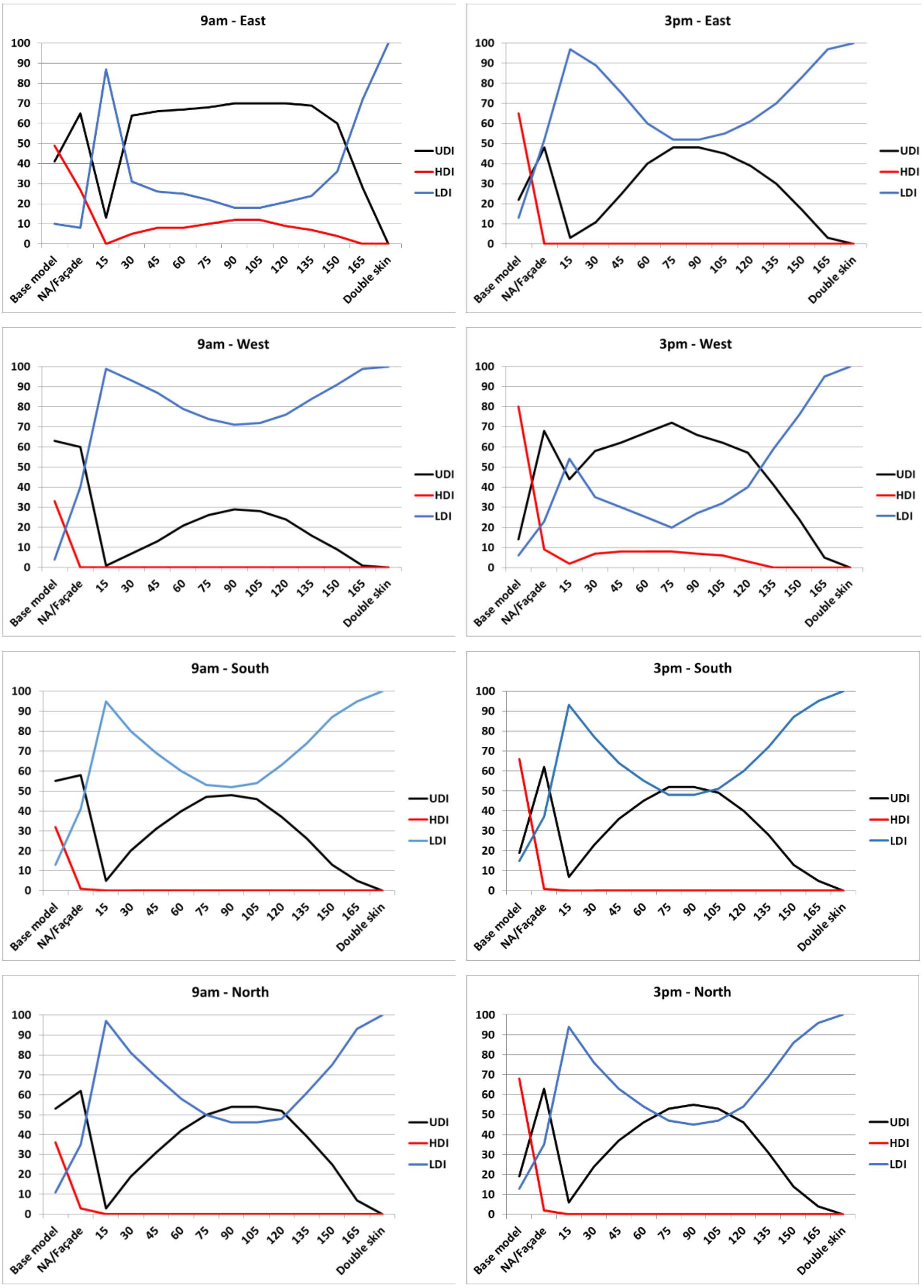


Figure 7-29 Daylight simulation result on 21 June presents all façade illuminance level at morning and afternoon time (Revit light analysis).

7.4.4.4 21 March - All façade model simulations.

The investigated at this calendar dates takes similar steps and results tabulated in Appendix B, (Table B-9 and .Table B-10). The East façade with 75-degree louver formation where UDI recorded above 70% at 9:00 am, is the best solution. At 3:00 pm, the best UDI comes with louver positions at 75, 90 and 105 degrees with 30% approximate in compare to non-louver façade value about 50%. Likewise, the west façade present almost same results. KLS sited at 75 and 90 degrees where UDI recorded 40 % at 9:00 am. At 3:00 pm similarly the best UDI come with the same position with 67% approximate. While the HDI figures around 9%, the lowest LDI level comes with the same louver and record around 40% and the façade with no Louvre have close records. Therefore, the best records for both KLS inclinations are setting at 75 and 90 degrees (Figure 7-30).

South KLS façade with an inclination of 75 to 120 degrees and non-louver façade have closed UDI recorded about 66% at 9:00 am and 3:00 pm. The HDI record around 5 to 10 % and the LDI lowest value recorded around 30 - 40% for all. The best outcomes considerably recorded with KLS model with 90 degrees. Repeatedly Northe KLS façade inclinations of 105 degrees have the optimal value where UDI recorded above 47% at 9:00 am but, the non-louver model record a 56%. LDI record with the non-louver model value is much better as well. The same results for afternoon time, thus the best records considerably recorded with the model of non-Louvre setting (Figure 7-30).

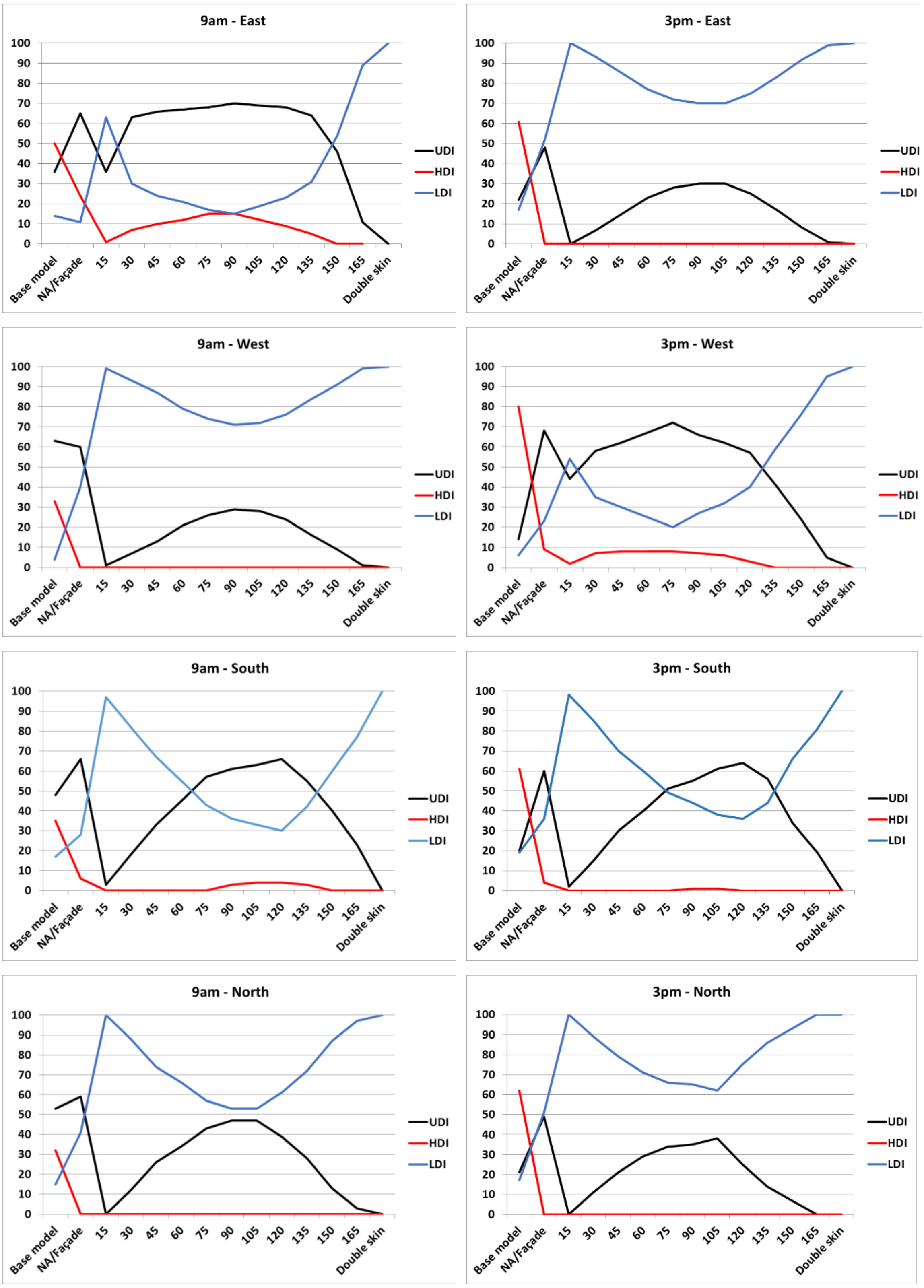


Figure 7-30 Daylight simulation result on 21 March presents all façade illuminance level at morning and afternoon time (Revit light analysis).

7.4.5 Double skin system with closed louver simulations.

This simulation is constructed to stand in the ultimate scenario where the louver system considered as closed double skin with full closed louver. The model has no daylight penetration and the total area depending on the artificial light source. However, A comprehensive analysis outcome tabulated in Appendix B, (Table B-11) for further details.

The research aims to cross-reference the simulation results and analysis all divers' scenarios comparatively to figure out the model with optimal outcome.

7.4.6 Summary of result analysis and comparison

Daylight analysis results illustrate the following findings:-

- North façade, the best configuration is façade with non-louver in different time of the year mostly. However result present an efficient daylight lead to comparing the baseline model where HDI is dropped significantly and maintained an almost adjacent level of UDI,
- East façade. The best louver angle in December is 75 degree while on September the 90 degree is best KLS configuration. However, in June and March, KLS inclination of 75-90 degrees records the optimal outcome.
- South façade, KLS inclination in 75 and 90 degrees have best records in December. March and June, the 90 degree is best while 120 degree is the best formation in September.
- West Façade, 75, 90 degree is best KLS formation in December, September, and March whereas, the best KLS angle recorded in June is the 90 degree.

To conclude, considering the simulation criteria of UDI, LDI and HDI values, the KLS with inclinations around 75, 90 degrees are the best façade formation during the year with trifling variations in the south facade in September.

7.5 Stage Three: Energy analysis

The research energy model was built in stage one and validated as detailed earlier. Model simulation test will continue with identical parameters to evaluate the influence of KLS formation and system efficiency.

7.5.1 The assessment criteria.

KLS efficiency will be studied by changing a form of kinetic façade and compare results to baseline model and extreme position of KLS as double skin. System efficiency will be assessed based on total energy demand and total power saving by delivering a comfortable internal environment and efficient daylight.

7.5.2 The research model

Research's investigation procedure will start with conditions to find a baseline model settings. Consequently, KLS will examine on three different orientations distinctly (East, South, and West) and North façade will be neglected due to the minimal impact of the direct sun radiation on façade as established and discussed earlier within the light analysis.

KLS investigations will begin with the inclination degree as specified initially while other façade stands without any treatment. Thus, louver configuration will transform by embrace louver inclination, till KLS form stands as a double skin with a closed system form.

7.5.3 Existing baseline model, energy analysis simulations.

Energy analyses of baseline model were conducted at the first stage of research while research was validating the model in chapter four. However, simulation results load at the matrix sheet as a benchmark of baseline power energy and for comparison record to the other results (Table 7-3). The comprehensive analysis results referenced in Appendix C, (Table C-1).

Table 7-3 Baseline model analysis along with baseline with light control scenario.

		Time 9:00 AM									Time 3:00 PM								
		Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
		East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
		kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
21st Dec	Base case with light control	187	187	187	170	185	175	566	581	571	187	187	187	170	184	174	566	581	571
	base model	193	193	193	175	191	180	583	599	589	193	193	193	175	190	180	583	599	588
21st Sept	Base case with light control	179	179	179	631	687	649	1051	1108	1070	179	179	179	631	685	648	1051	1105	1068
	base model	184	184	184	650	709	670	1083	1142	1103	184	184	184	650	706	668	1083	1140	1101
21st June	Base case with light control	170	170	170	800	872	824	1213	1285	1237	170	170	170	800	870	822	1213	1282	1235
	base model	175	175	175	825	899	850	1250	1324	1275	175	175	175	825	897	848	1250	1322	1273
21st March	Base Model with light control	178	178	178	424	463	437	849	887	861	178	178	178	424	461	436	849	886	860
	base model	184	184	184	438	477	451	875	914	888	184	184	184	438	475	450	875	913	887

Note:-

1237 Higher demand, longer the bar colour   170 Lower demand with longer color

Table 7-3 reveals details of main parameters of research which is light and HVAC power demand. Total energy consumptions of the baseline model and options detailed the demand were in June and September results are the highest while winter season in December is lowest and instigated to increase in March timing. Even with the light control option, the demand still exhibited the same trend, and the contribution of light control have minor percent in total demand (Table 7-4).

Table 7-4 the total energy potential saving by adoption the light control options. The results piloted by Revit software and Green studio Autodesk (Author 2017).

		Time 9:00 AM			Time 3:00 PM		
		Total Energy			Total Energy		
		East	West	South	East	West	South
		kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
21st Dec	Base case with light control	566	581	571	566	581	571
	base model	583	599	589	583	599	588
21st Sept	Base case with light control	1051	1108	1070	1051	1105	1068
	base model	1083	1142	1103	1083	1140	1101
21st June	Base case with light control	1213	1285	1237	1213	1282	1235
	base model	1250	1324	1275	1250	1322	1273
21st March	Base Model with light control	849	887	861	849	886	860
	base model	875	914	888	875	913	887

Note:-

1250	Saving Rating / high value
549	Saving Rating / low value

Table 7-4 presents the power saving in all seasons with different orientations. The potential energy saving is about 0.3 % of total electricity demand.

7.5.4 Kinetic louver model simulation

7.5.4.1 21st December - All façade model simulations

The model simulated by adopting KLS in Winter season to stand on the total potential power saving for light and HVAC systems demand. The tests assess the performance of the system considering the local moderate seasonal climate in Dubai and comprehensive analysis results referenced in Appendix C, (Table C-2).

East façade simulation results in instant potential saving with the light records around 40%. The saving concurs with KLS inclinations 75, 90 as the assumption of the base model consider full light demand as exposed in the green studio from Autodesk software. HVAC energy saving tabled in the double skin façade and with KLS forms in slight opening angles (15, 30, and 45) but, the light efficiency is not the optimal. However, total energy records present the best configuration systems which are the KLS with 60, 75 and 90 degrees inclination stated a total saving about 37%. While at afternoon time the best configuration is the 75-degree scenario where the total saving about 18% in comparison to the baseline model. Similarly, West KLS façade with louver form at 75 degrees is optimal during the day where aggregate demand for the power declined by 23% at 9:00 am and 32% at 3:00 pm (Figure 7-31).

Simulations of South façade reveal the impact of the daylight on the total energy demand and the HVAC demand is mainly steady at morning time. KLS formations in 90 and 105 degrees shows the optimal power saving during daytime with approximate 36% in the morning and 18% at afternoon, as demonstrated in Figure 7-31.

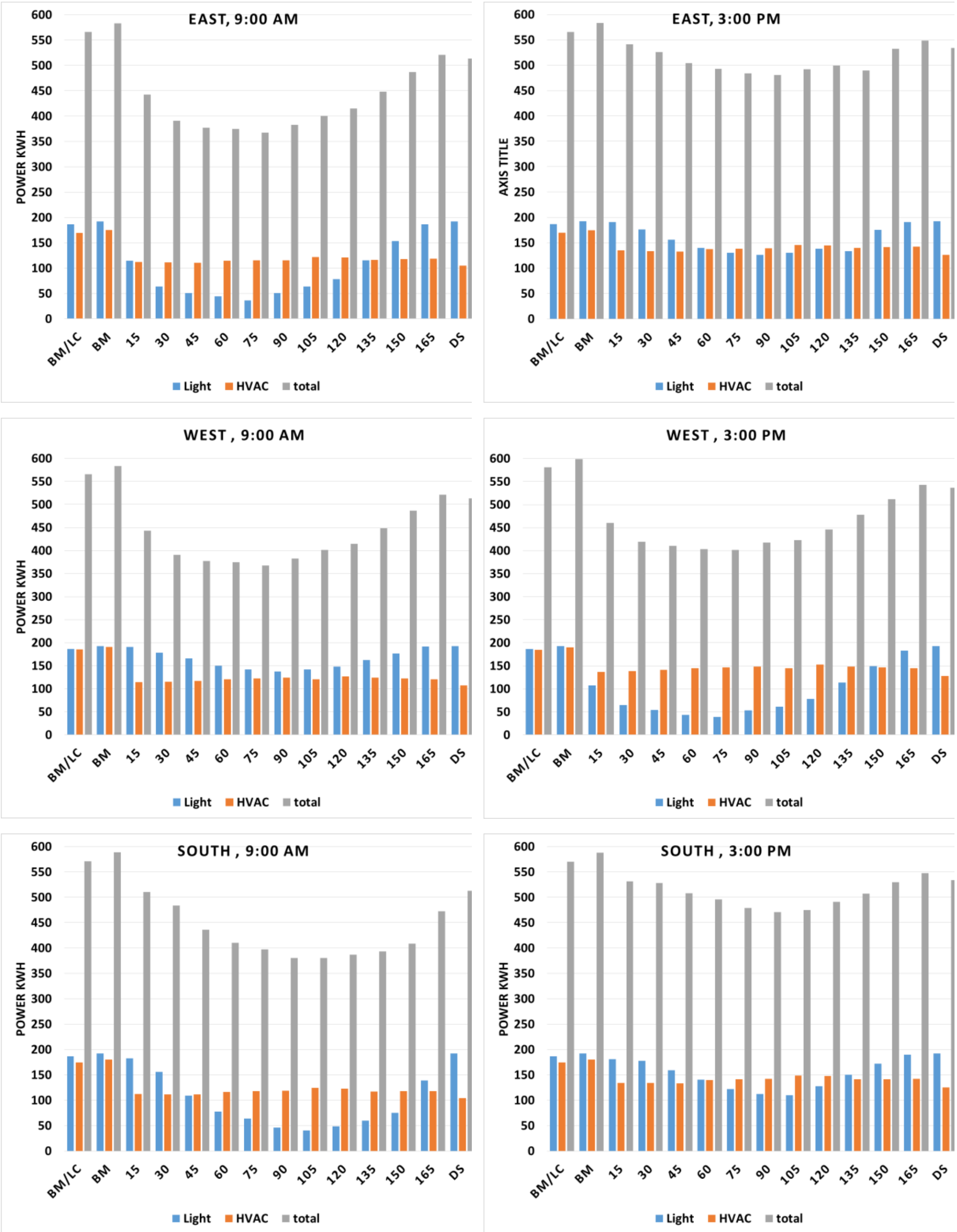


Figure 7-31 Total energy demand at 21st December for East, West and South facades (Revit energy simulation and insight360 Autodesk).

To conclude, In December, AC and total light demand in comparison to the total energy of the building are almost 50% (as detailed by the green studio analysis). Therefore, the energy saving in winter season is the minimum. However, as a sustainable approach, the KLS add a valuable saving around 37-23% at morning time and around 18-32% at afternoon. At the same time, enhance the daylight level and consequently the comfort standards of the internal building environment. Additionally, louver formations with 75, 90 and 105 degrees have a close contribution in total potential saving.

7.5.4.2 21 September - All façade model simulations

September model presents the autumn climate where power demand of baseline model recorded higher than December (about 1140 kWh). The HVAC system claimed almost 60% of the total power consumption and the light demand around 17%. Therefore the involvement of the KLS should take part in the total electrical saving potentially. The general analysis results referenced in Appendix C, (Table C-3).

East facade optimal records of energy conservation occurred by KLS with inclination 75 degrees at 9:00 am with total saving close to 30% and afternoon time with KLS forms in 75 and 90 degrees recorded saving close to 20% (Figure 7-32). While, The west façade result presents the high demand of the HVAC system, and the light demand percent is low in comparison to the total demand. KLS with configurations 45 till 90 degrees have the highest record at the morning time. At afternoon the 45, 60 and 75 degrees is the highest by recorded 28% of potential saving (Figure 7-32).

However, South façade investigation result presents the best potential saving with light and HVAC system by utilizing the 75, and 90-degree KLS during the day. The 9:00 am recording system efficiency about 31% and 21% at 3:00 pm of the potential saving in comparison to baseline model (Figure 7-32).

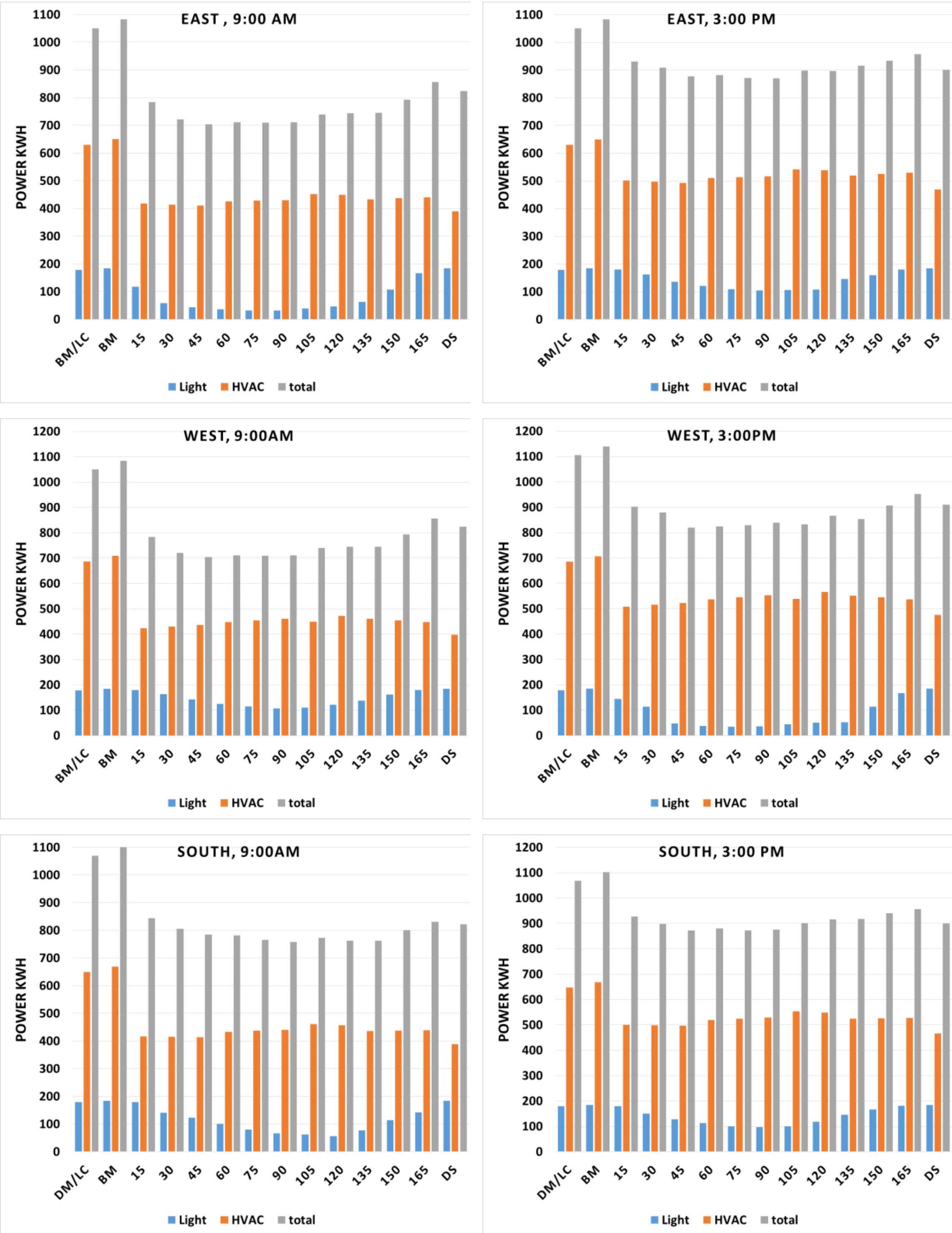


Figure 7-32 Total energy demand at 21st September for East, West and South facades (Revit energy simulation and insight360 Autodesk).

In details, on September, the AC and total light demand have a significant value around 77% of the total assumption. Therefore, the sustainable approach of KLS add a valuable saving around 30-35% at morning time and around 20-28% in the afternoon. KLS with louver inclination in 75, 90 and 105 degrees have a close contribution in total potential saving.

7.5.4.3 21 June - All façade model simulations

A model presents almost the highest temperature in summer season where power demand of baseline model recorded the highest value within the year around 1280 kWh. HVAC system claimed almost 66% of total energy consumption and light demand around 17%. Consequently, the participation of KLS would considerably stand as a crucial feature to potentially power saving. The general analysis results referenced in Appendix C (Table C-4).

The East façade examination results tabled in **Error! Reference source not found.**, presents the KLS with configuration from 45 - 90 degrees have almost same valuable potential saving within the day where at 9:00 am record 35-34%, and 3:00 pm records show 20% respectively. Similarly, at South and West façades, the same configuration of KLS have a closely valuable potential saving around 29 - 34% at 9:00 am and around 24% at 3:00 pm. (Figure 7-33).

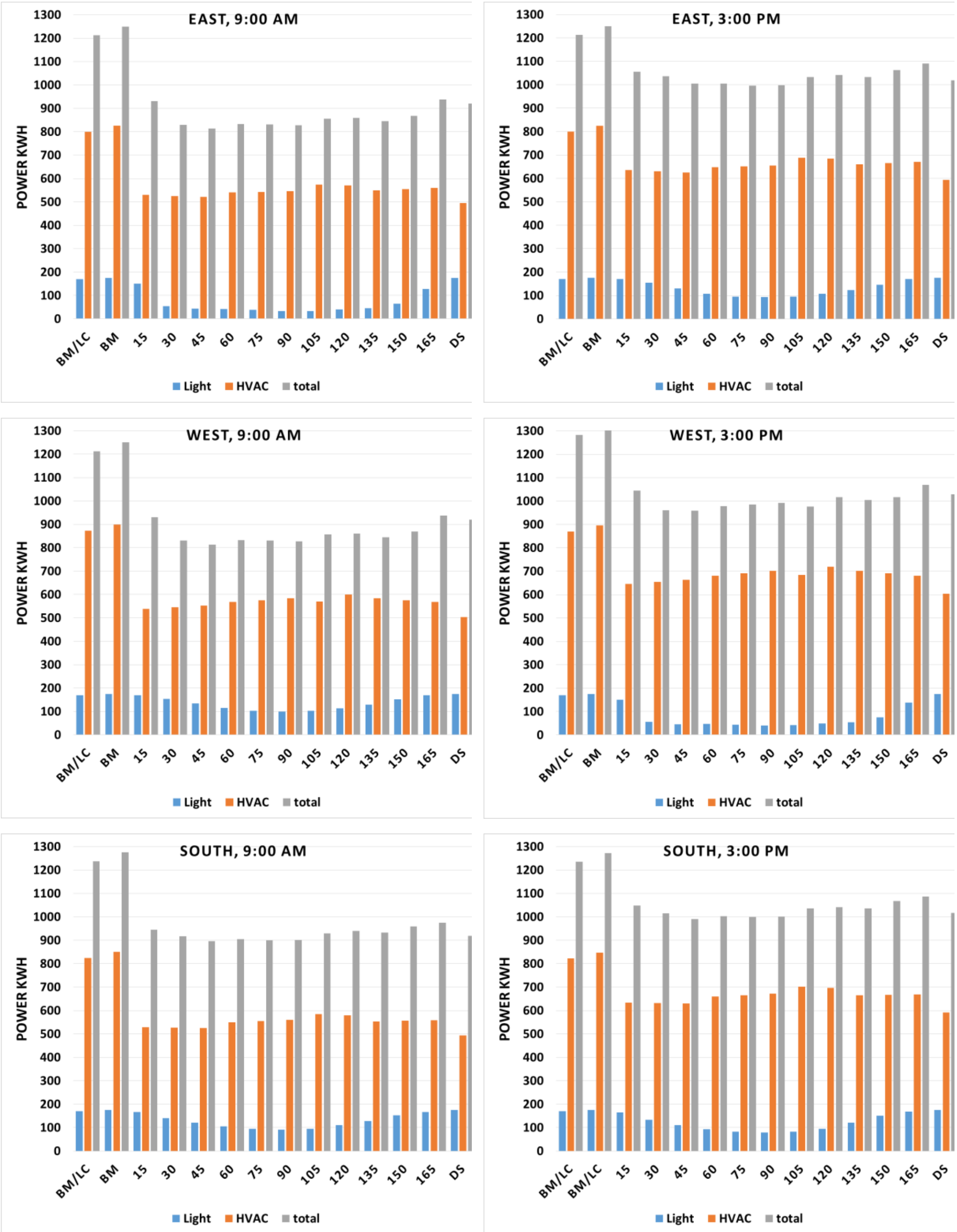


Figure 7-33 Total energy demand at 21st June for East, West and South facades (Revit energy simulation and insight360 Autodesk).

In summary, on June, HVAC and total light demand have a charge about 80% of total assumption within the year. Therefore, the sustainable approach to the environment responses façade adds a valuable saving. However, the KLS presents a potential saving with total demand around 30-35% at morning time and around 20-24% at afternoon. The KLS formations with 75, 90 and 105 degrees have a close contribution in total potential energy saving.

7.5.4.4 21st March - All façade model simulations

The simulation considered a seasonal climate where power demand of baseline model recorded an average annual record around 880 kWh. HVAC system claimed almost 50% of total energy consumption, and light claimed nearly 21%. The comprehensive analysis results referenced in Appendix C, (Table C-5).

East façade Results display the optimal KLS efficiency mature at 9:00 is with louver position in 45 – 90 degrees respectively and recording a potential saving around 35%. At 3:00 pm the optimal KLS louver angle is within a range of 60-90 degrees with saving around 17% (Figure 7-34). Likewise, Simulation outcomes of the West façade show the same results for the morning time. Whereas, 3:00 pm, the ideal KLS louver angle is in range of 45-60 degrees with saving around 27% (Figure 7-34).

However, The highest potential saving presented by the simulation results of the south façade concurred with a KLS configuration angle 75-135 degrees at 9:00 am and at 3:00 pm the best KLS inclination with 75 and 90 degrees that records the saving of 18% (Figure 7-34).

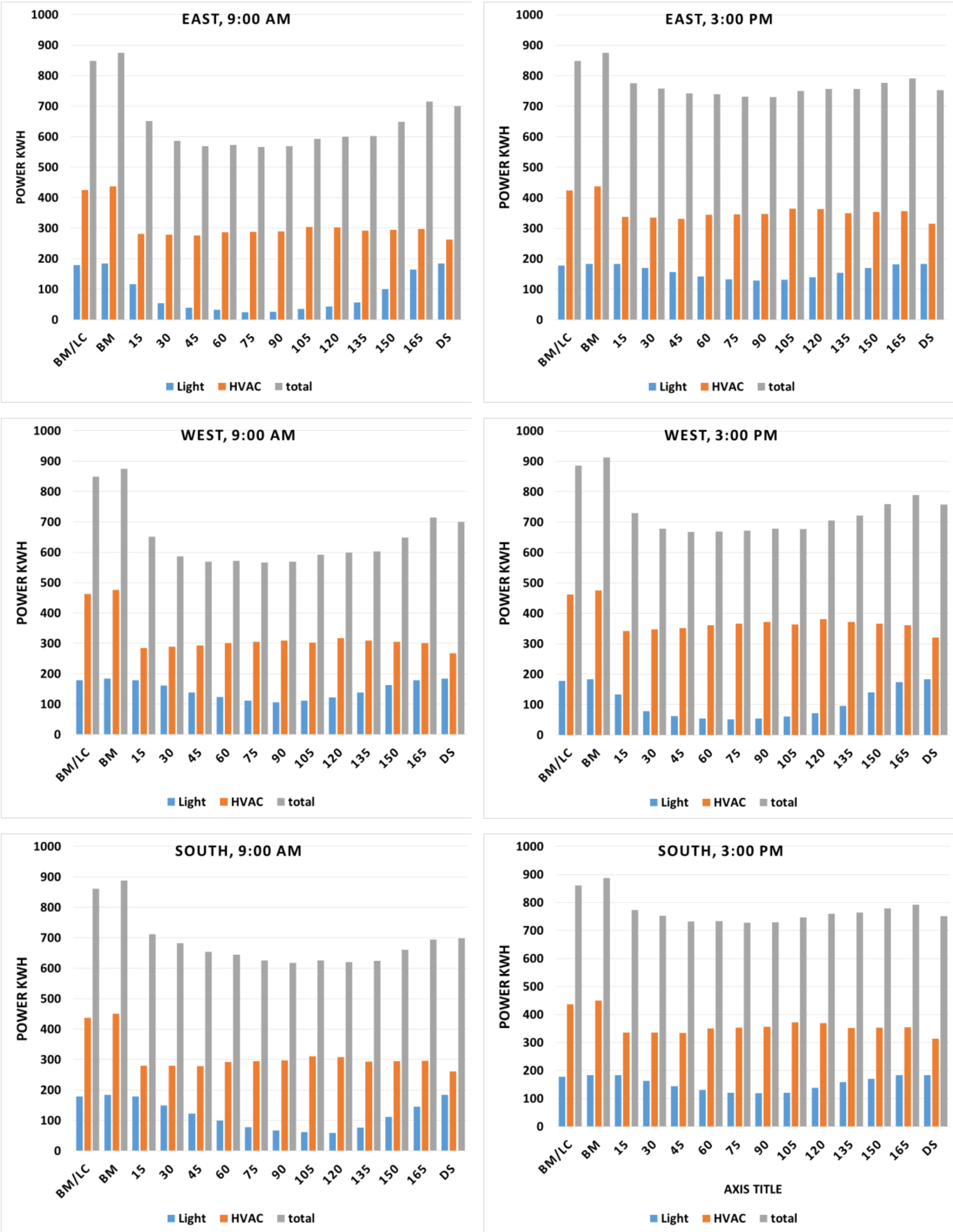


Figure 7-34 Total energy demand at 21st March for East, West and South facades (Revit energy simulation and insight360 Autodesk).

In summary, on March, HVAC and total light demand have 71% of total annual assumption which is close to September timing. However, KLS presents a potential saving with aggregate demand around 29-35% at morning time and around 20-27% at afternoon. KLS formations with 45 - 105 degrees have a close contribution in total potential energy saving.

7.6 Simulation results analysis and discussion

- Baseline model exam and validate simulations results

Stage one to three in chapter five conducts numerous levels of analysis that discussed the performance of KLS with light and energy parameters. The analysis starts with the site condition to stand on the existing building settings, study wind effect on buildings, site shade and a shadow beside the influence of adjacent existing structure. These investigations have delivered the research with a comprehensive understanding of site limitation and sustenance to mimic the conditions and build a baseline model associated with investigation parameters.

- Airflow simulation results and CFD analysis that figure the KLS model Positions and best configurations.

Subsequently, the research shaped the baseline model with different KLS formations and initiated the test parameters then started with the baseline model examinations. The result of baseline test become a benchmark for other results and subsequently check the different KLS formations and ended up with a double skin façade test to figure out the maximum kinetic louver inclinations.

These analyses furnish the study with a full understanding of KLS enactment and behavior. The analyses start with KLS forms in the optimal position as double skin but with a different cavity distance between KLS and building façade. Obviously, the airflow simulation results stated the optimal cavity distance of KLS position secured with 1800mm in compare to 1200mm and 600 mm due to the KLS performance a double skin façade where the wind velocity conquer in the cavity gap. The wind velocity pattern as demonstrated in stage two of the section figured the best performance of KLS as a double skin façade due to the wind availability, wind movement, speed and wind pressure. However, the CFD analysis presents the stack effect within the façade, and air temperature in cavity potentially increased which need a comprehensive reading of the performance of the double skin options. Therefore the research recommends neglecting the possibility of double skin façade for the entire.

- Light and Power analysis that figure the KLS model configurations and best formation.

The ideal solution discussed by scaling the total power demand where KLS substantially performed an ideal balance between the daylight penetrations with HVAC system and total energy demand.

The light analyses describe in detail the performance of the different KLS compositions. The baseline model analysis presents a very high daylight illuminance level. Close view of analysis result finds in December, HDI on South façade is more than another season due to the altitude of the sun at that time of the year. Similarly, HDI level was presented in West façade in June and September and relatively in March. Therefore, these façades have less light demand at these seasons. The present of DHI reduces the requirement for an artificial daylight. With the daylight control option, the dimmer will control the artificial light level by capture the lux level of daylight penetration. Subsequently, the power will be reduced potentially and contribute reducing cooling loads within a certain threshold. Thus, the scenario of the model with light control system presents an energy saving in comparison to the baseline model.

Furthermore, direct sunlight induces a solar gain to the façade by radiation that effectively increases the cooling load significantly. That has come with the first valuable consequence of KLS by enhancing the useful daylight level at the same time reduce the direct solar effect on the glazing façade. So, KLS with a different configuration has a significant impact on total energy saving.

- Research motivate findings

One of interesting findings, even with the less demand for cooling load in December, the involvement of KLS effectively advance the UDI level and reduce the HDI. However, the analysis results present that in December, the best inclination for KLS with a daytime is 75, 90 and 105 degrees mainly within east-west and south. Similarly, in June, September, and March, the optimal KLS formation comes with an inclination between 75, to 105 degrees mainly within the same orientations. The result considerably feasible as KLS will have a larger opening to allow more daylight penetration. So that, the double skin option is not recommended that block the natural light unless the KLS materials have a transparency specs to permit lights infiltration.

The second finding occurred by the investigation results present the North façade with no louver is performing efficiently than KLS (refer to section 5.4.5 for detail review). Therefore the desires for KLS within North orientation is not essential and the research abandonment the façade from the energy analysis.

In term of energy performance, KLS extensively exam with diverse of possibilities of louver inclinations as stated earlier within the research study. Broadly, the trend of the system performance and results of the light and HVAC exam are customary within the same area and draw mostly parallel outcomes within the different time of the year and all orientations. The finding of results could be outstandingly noted that the louver systems with inclination 75 – 105 degree have the optimum efficiency and functionality in term of daylight performance, HVAC and total energy consumption depending on the orientation and daytime during different seasons.

On December, due to the moderated climate season in Dubai the best inclination within the light analysis set within the same range but the HVAC system comes with the double skin or within the low inclination system (Figure 7-35).

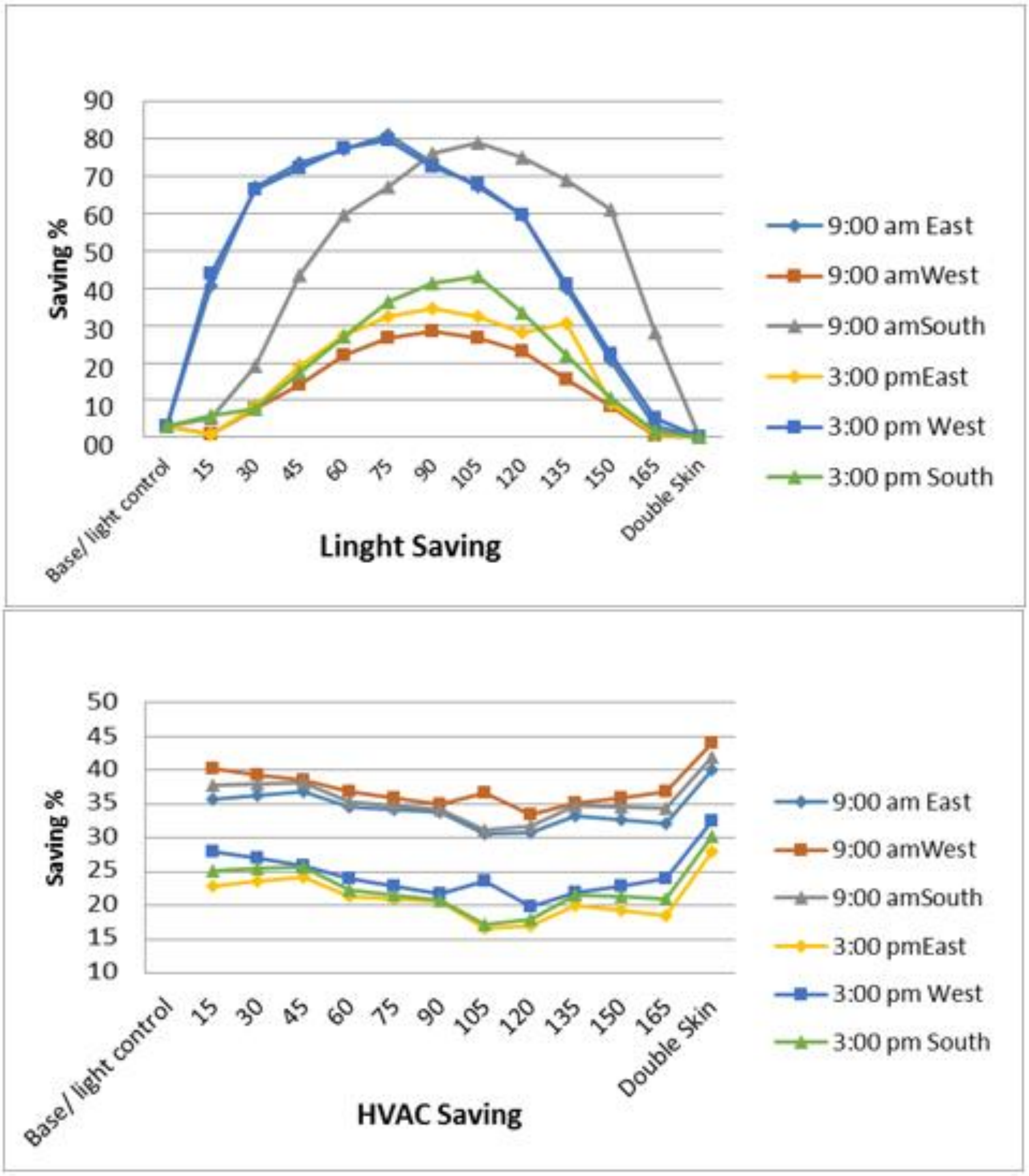


Figure 7-35 December light and HVAC analysis results.

Similarly, with the overall potential power saving as detailed in Figure 7-36 present shows the best system performance but with some fluctuation in the results with the daytime where the 45-degree present the best scenario. These fluctuations introduce the influence of daylight demand and overall light energy approaches and HVAC claim within the range of the building energy demand in December (Figure 7-36).

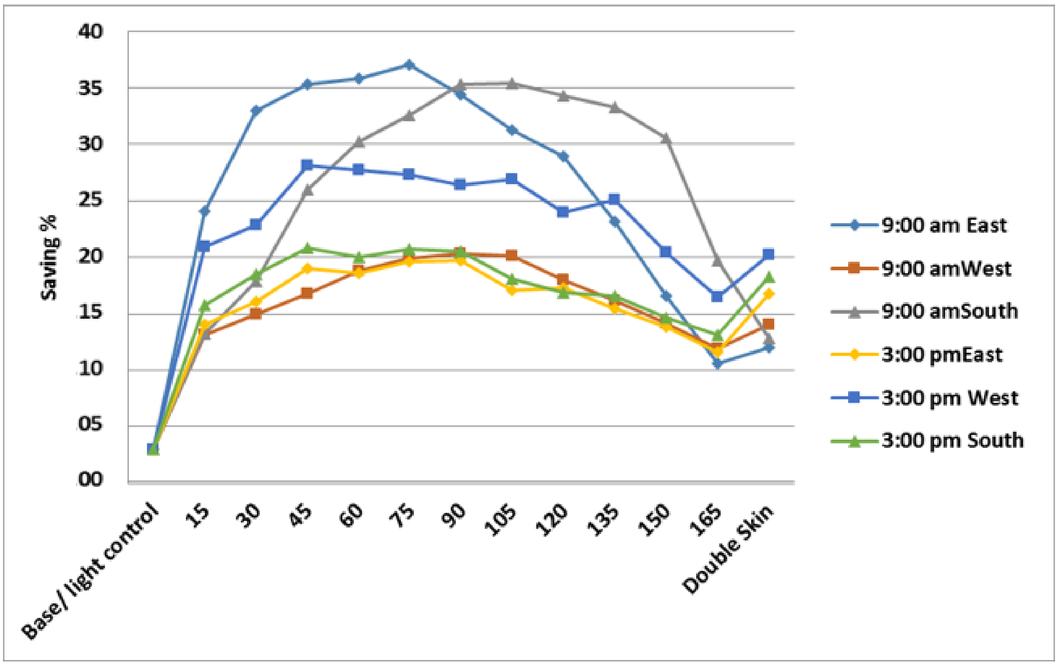
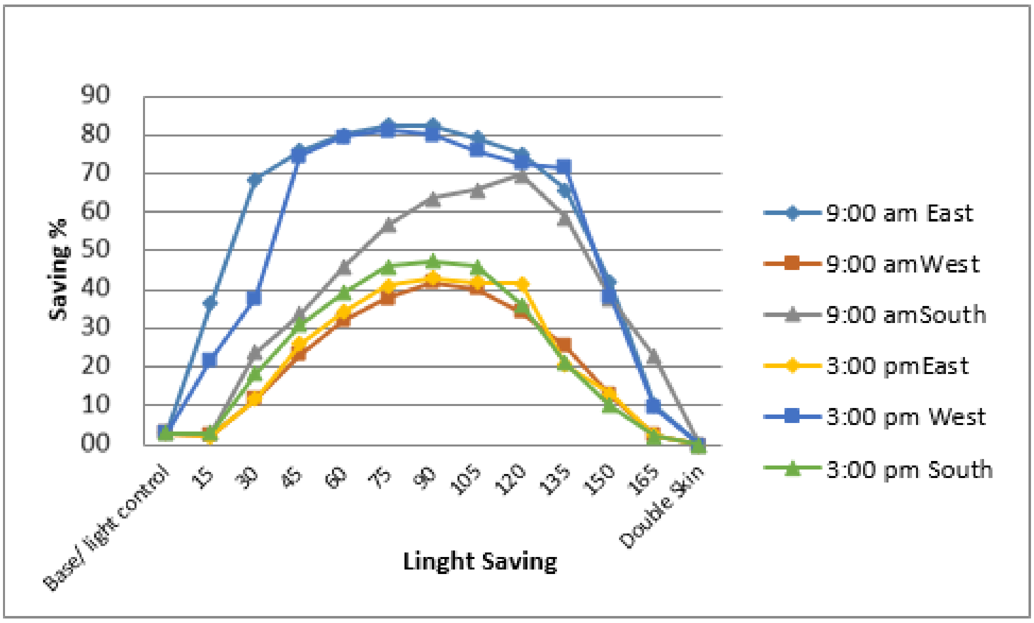


Figure 7-36 December overall energy saving illustrate the KLS efficiency.

On September, the analysis outcome presents close results that 75 – 105 degrees inclination are the best KLS formation despite the result of HVAC analysis where it is present a different attitude towards the system (Figure 7-37).



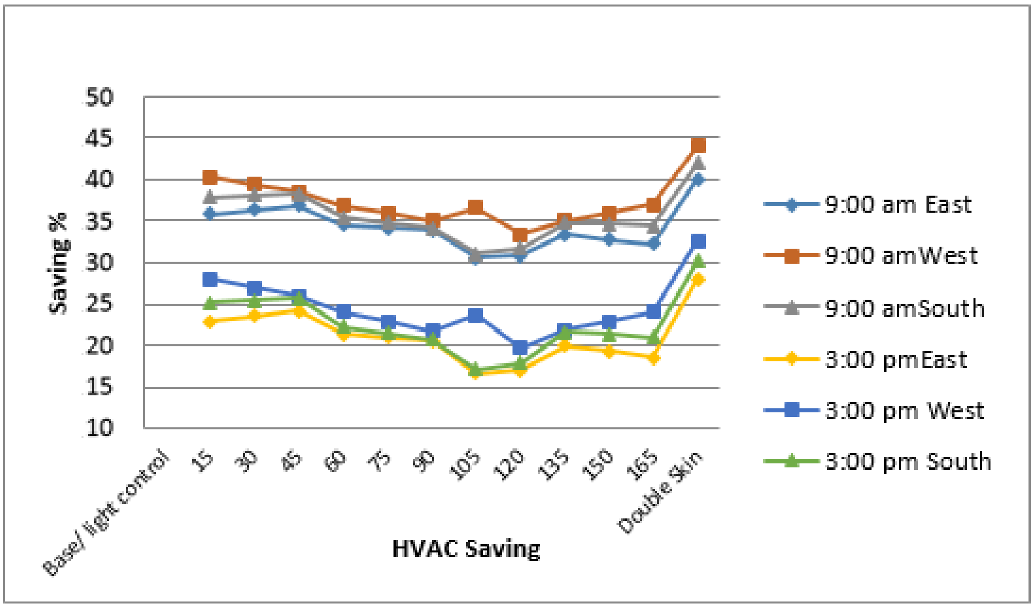


Figure 7-37 September light and HVAC analysis results.

However, the potential saving in overall energy consumption set with the range of 45-105 degrees mainly and in particular are the 45 degree is a best efficient system as demonstrated in the result of Southern façade (Figure 7-38).

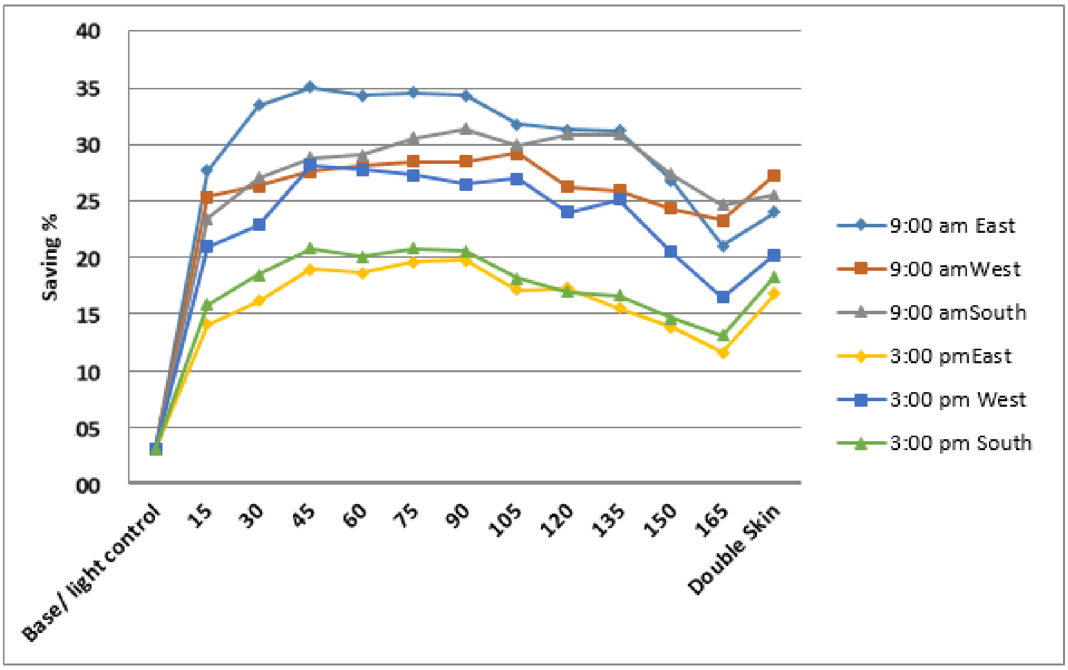
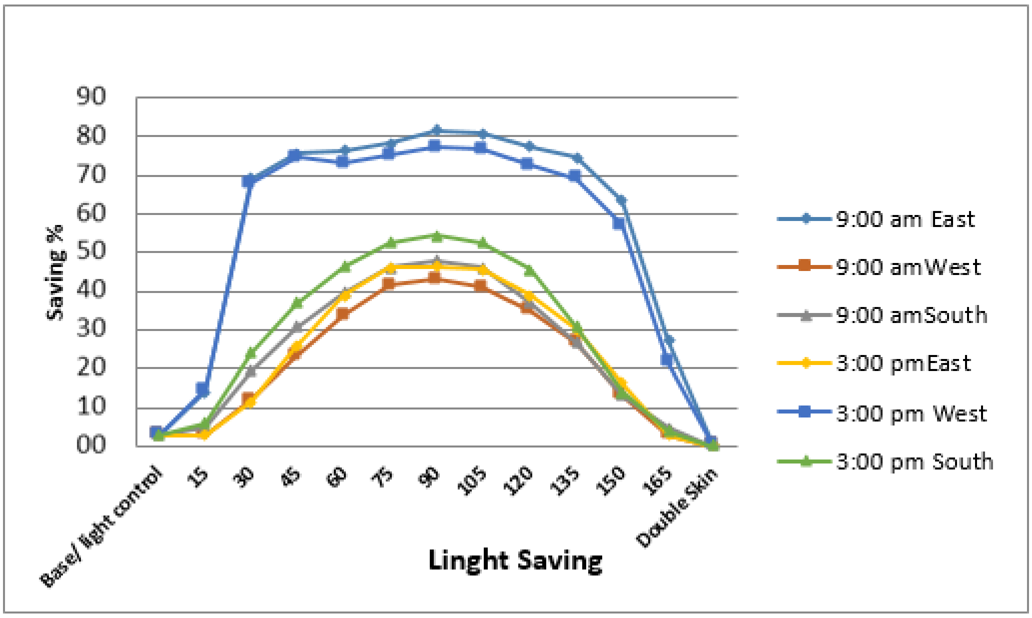


Figure 7-38 September overall energy saving illustrate the KLS efficiency.

Repeatedly, on June the best louver position presenting with the same angle as demonstrated in Figure 7-39 with the same finding regards the HVAC potential energy saving.



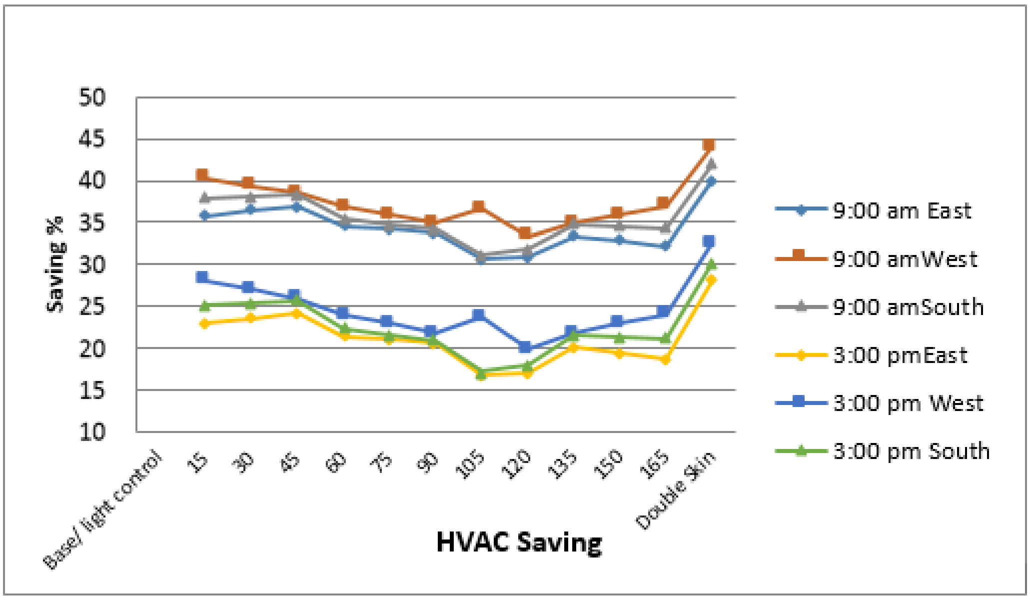


Figure 7-39 June light and HVAC analysis results.

The potential energy saving at the same time of the year shows a little deviation where the optimal, efficient system illustrated with louver inclinations 75 and 90 degrees, and in a certain time and orientation, the result shows 45-degree is the best as described in the outcome of West façade (Figure 7-40).

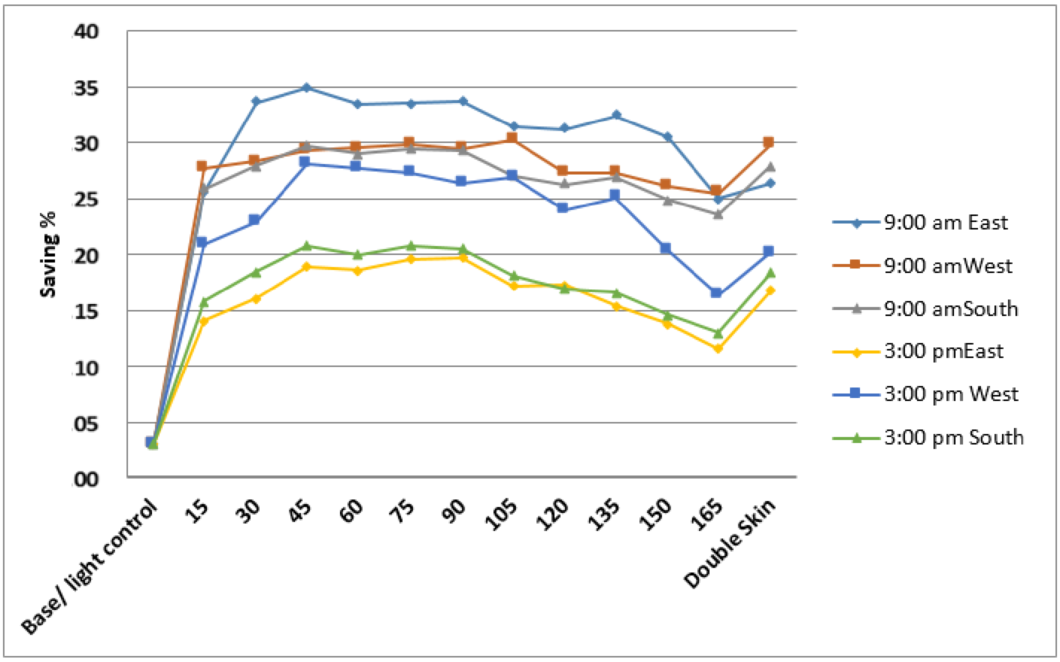


Figure 7-40 June overall energy saving illustrate the KLS efficiency.

The result of March seasons illustrate the same recommendation for light system performance, and HVAC result repetitively shows the opposite result (Figure 7-41).

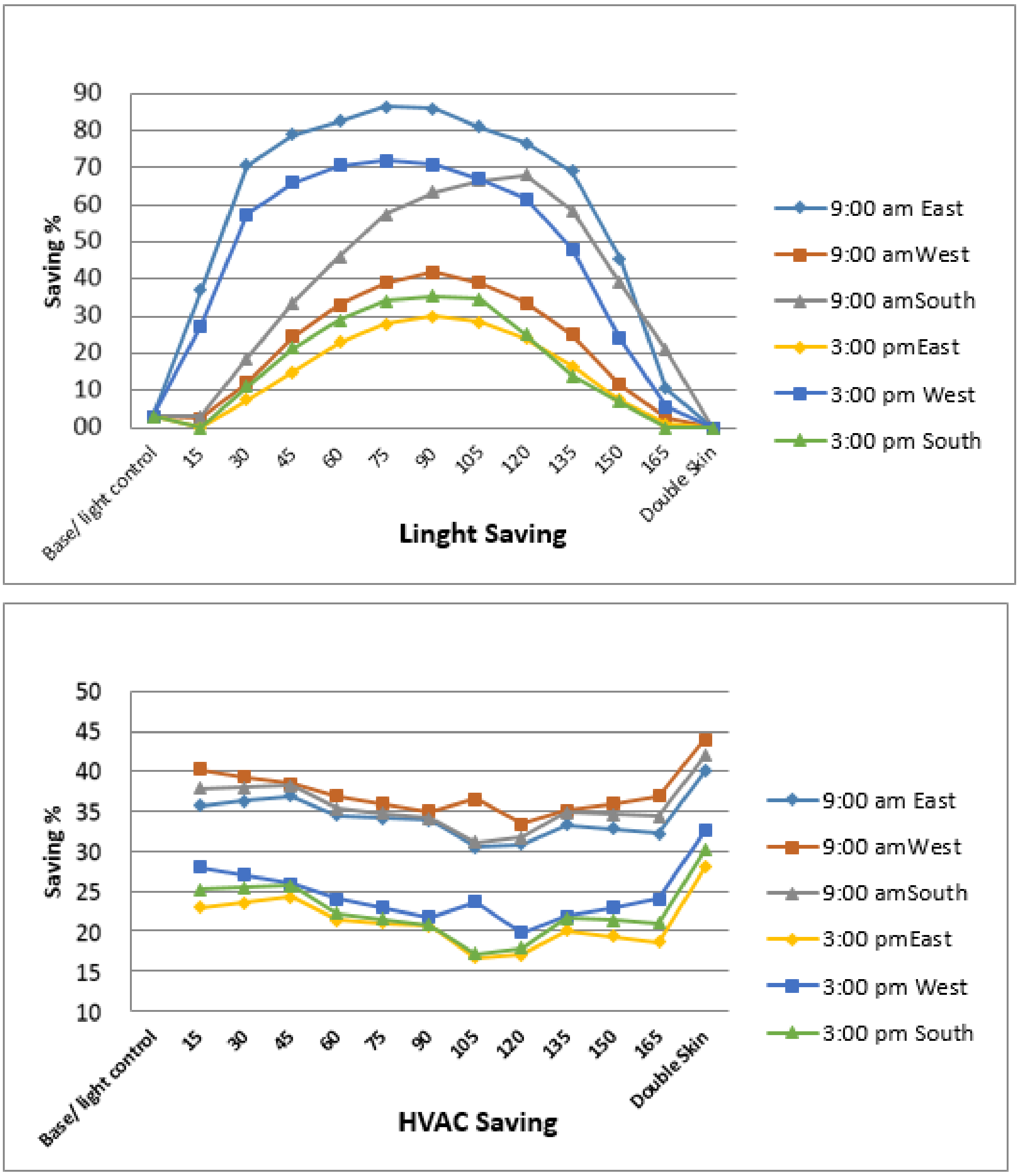


Figure 7-41 March light and HVAC analysis results.

However, the overall energy demand chart shows the best record of the KLS within 45-90 Degrees with some improved variation on Southern façade at morning time (Figure 7-42).

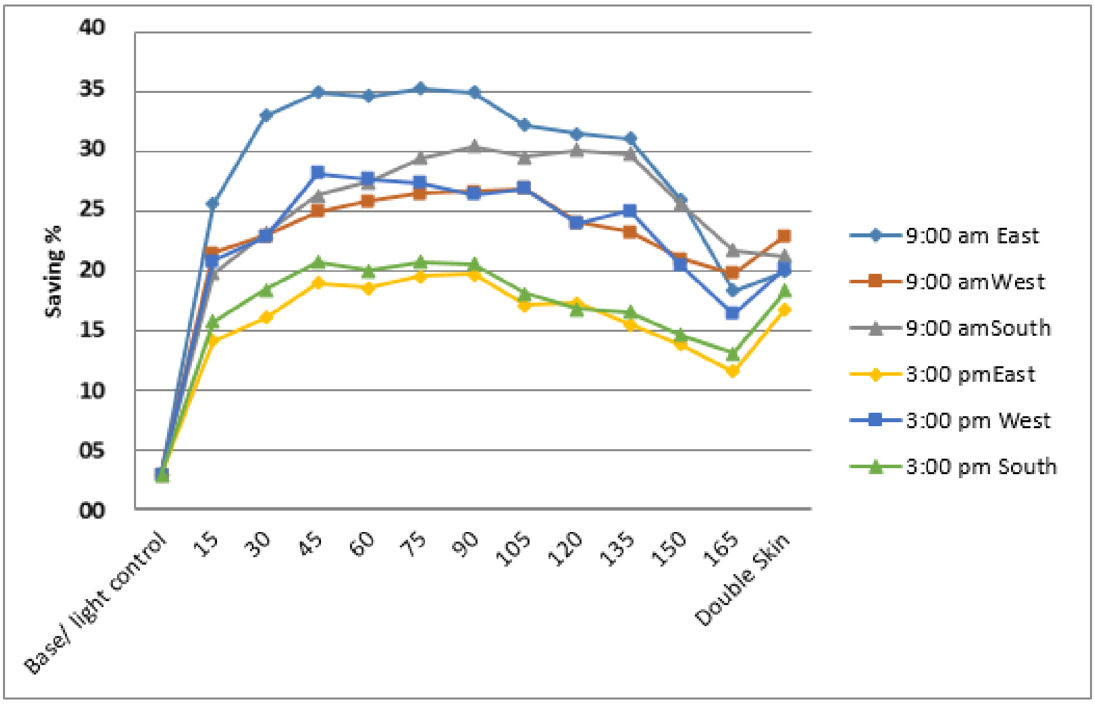


Figure 7-42 March overall energy saving illustrate the KLS efficiency.

However, the interesting finding when have an investigate analysis to the result of HVAC demand and the potential saving present that the ultimate scenario of the KLS when a double skin opportunity prevail (Figures 5-68, 5-70, 5-72 and 5-74). The double skin performance shows the ideal solution within HVAC analysis and conversely with daylight analysis recorded the lowest values. However, in the total energy consumption, the double skin options do not present the highest level but with the range of mostly 10-20% lower than the optimal finding (Figures 5-69, 5-71, 5-73 and 5-75). Moreover, the saving is very close to the optimal option potentially in the east and south elevations within the year.

Comprehensive interpretation of HVAC analysis of KLS as double skin scenario indicant a significant latent saving that opens the door to question the performance of the system.

The system with such solution is quite challenged but showing promised results within a certain time of the day in explicit and during a different season of the year. Specifically, the saving of the HVAC system reaches 40-45% of the total

HVAC demand at the afternoon time and around 25% of the morning time (Figures 5-68, 5-70, 5-72 and 5-74). However, the challenges are the daylight performance and internal natural light penetration that required an artificial light source. However, these challenges could be easily discussed by adopted translucent materials that allow the useful daylight to irritated over the double skin system and enhance the internal illuminance level significantly.

However, there are further aspects to come over these challenges like, adopt the system in the peak hour of the energy load from 12:00 to 3:00 PM as classified by the Local Authority or by partially closed the façade and maintained the fenestration opens for natural light penetration.

Nonetheless, by adoption the KLS as a double skin system solution, the total energy saving could achieve more than optimal KLS figures in summer for instance when the HVAC load presents 66% of total building demand. So, with the saving of 45% of the HVAC demand, the total energy conservation will be more than 30% of the building consumption (45% saving - divided by 66% of demand - equal to more than 40% of total building demand).

Chapter six: Conclusions and Recommendations

Introducing the KLS as a double skin façade to the building and scale the potential energy claim has been discussed within this research. The study investigates the performance of the scheme within a local climate condition in Dubai, UAE where the investigation select one of the existing high-rise building to structure baseline model of the research. The research objectives were outlined based on a literature review initiated and developed hypothetically and instituted the research methodology as well.

Baseline model built as per site conditions and validated by simulation tools and compared to an actual energy demand reading gained from the local authority. The research was introducing the KLS in various configurations and exam the models accordingly. Simulation results assessed the performance of the system by comparing the results to the baseline model. The simulation scaled prevail wind flow effect, natural light demand and HVAC plea and subsequently the overall power consumption.

8.1 Conclusions

KLS performed as a double skin when the optimal solution presented in the position about 1800 mm from the building façade in compare to 1200mm and 600mm. The cavity distance between kinetic louver and glazing curtain façade shows a valuable enhanced air velocity and air pressure that substantially reduce the convection heat gain as well as direct solar radiation that eliminated by the double skin system potentially, but the disadvantage prevails with daylight penetration. Accordingly, Comprehensive interpretation of the HVAC demand analysis of the double skin system indicates a significant latent saving that opens the door to interrogation the performance of the scheme. The result illustrates a perspective saving in HVAC consumptions reach up to 40-45% of the total HVAC demand at afternoon time and around 25% at morning time where HVAC load equal to 66% of the total building energy demand in summer seasons which extend to more than six months yearly. Nonetheless, these results do not match the optimal solution of the kinetic louver due to the performance of the double skin system with other parameters like the natural light availability and wind stack effect. Moreover, the saving is very close to the total saving accrued in optimal option potentially in the east and south elevations within the year. Therefore the system presented a robust saving figures but embedded with highly intellectual challenges.

KLS with the dimming light control as a first solution presents almost fixed potential saving around 0.3% in comparison to the original baseline model within different timing. However, the potential of adding the light control system methodology is valuable with other possible kinetic system formation as well to enhance the efficiency of power consumption.

Moreover, KLS performance investigated with light analysis and cooling energy demand. The results of light examination elaborate the desired achievement by enhancing the useful daylight level and eliminate the high daylight illuminance respectively in south façade and potentially within east and west façade by adopting vertical louver system. In more details, in December, the best inclination for louver system at daytime is the 75, 90 and 105 degrees mainly for all orientations and similarly, in June, September, and March. Another finding followed by the examination outcomes illustrate that the north elevation with no louver scheme is acting more competently than the dynamic louver structure with various inclinations. Therefore the requests for the kinetic façade in north direction is not vital and the study desertion the façade from the power investigation.

The energy performance of KLS have been analyzed, and the trend of light and HVAC efficiency results have drawn mostly parallel outcomes within the year that record a saving about 20-35% of total energy demand in average. The conclusion noted that louver with inclination 75 – 105 degree have the optimum efficiency and functionality in term of the daylight performance and total energy consumption depend on the orientation and daytime during different seasons. Moreover, in December the kinetic louver system contribution in the total energy demand have mostly equal values with the same percentage of daylight and HVAC load. The 45-degree inclination presents the best scenario at afternoon in west orientations due to optimal results in daylight performance. Similarly, other season's results present the same outcome where 75-105 degrees inclination are the best KLS configuration with minor fluctuation with the consequences.

KLS is quite challenged but showing promised results within a certain time of the day in explicit and during a different season of the year. Specifically, the saving of the HVAC system reach 40-45% of the total HVAC demand with double skin scenario and in another hand the balance between the daylight and the HVAC load presented by the dynamic louver lead to saving 20-35% of the total energy demand in average.

Base on the result analysis of air velocity, light, HVAC demand and the total energy portfolio, the research highly recommended the combination of the different scenarios which will enhance the system performance. The research endorses to exploit the double skin scenario at the peak energy consumption hours especially if the louver system has translucent panels or perforated panels to allow for natural light penetration. Moreover, the same scenario could be easily used with the entire façade as a double skin system except for the window panes. This solution will enhance the KLS performance and increase the total saving in the total power consumptions significantly.

Finally, from another perspective, all these aspects affect the final valuation of the system efficiency in addition to other parameters related to the operation, system life cycle and cost analysis. Nevertheless, the system delivers to the designers and the engineers a crucial sustainable tool that drives their approach toward environmental friendly results. These solutions are not only related to energy consumption and calculation of the power demand but are broadly related to more vital factors to the environment like the CO_2 footprint and matching the local authority mandate. Also, the dynamic effect of the façade advanced the designer to motivate their approach to more intelligent environmental responsible building that could be derived effortlessly with the new technology and availability of the novel configurations systems.

8.2 Recommendations for future study

The research inaugurates the performance of the KLS as an environmental response solution that elaborate potential power saving of total building consumptions. The system performance depending on the configuration of the louvres, orientation and time, but there are other parameters might be influenced system efficiency like for instance, the level of comfort of internal space as well as the occupant physical and visual levels. Additionally, other parameters link to the occupant behavior and production level of the space that might add more evaluation criteria to system performance.

Therefore the research found several additional areas of challenges that potentially could add more value to the system behavior. So the research flagged these areas as a potential opportunity for future studies listed as follows:-

- The detailed design of the KLS, in term of shape, size, and formations. These design factors are essential to detail the response of the louver to the external light source. These effects could enhance the system to provide more useful daylight to the internal space by reflect the sunlight and preventing the glare. Additionally, the louver system might consist of many sizes and a different shape that prevents the external heat gain by simple composition and less effort.
- KLS could investigate from another parameter like the level of comfort of the tenant inside the office space and the occupant behavior. These have a potential effect on the amount of the production of the offices. The parameter of the study could scale from occupant comfort, a visual degree in response to the external louver formation.
- System material and specifications, the construction industry induce many new materials that could respond to the direct heat gain and direct light and changed physically. Additionally, the form of the material might have deflection, and that could provide a self-operation system respond to external environment independently without any

automated system. These present another area to study in more details on a different scale.

- Other opportunity related to the system material, where the research could study in detail the parameters related to the materials in term of system constructability, cost and operation lifecycle.
- Another area of potential study is related to mechanism and detail operation scenario that could effectively enhance the power saving by optimal operation scenario that smartly considered the complexity of the system with the variety of parameters.
- Discuss the system parameters interim of building regulation with the local authority presented by Dubai Municipality. As of today, the regulations allowed just for 300mm as an architectural projected element from the building. Therefore KLS will be calculated as part of the FAR floor area ratio wherever takes more than 300mm. Therefore a study could be conducted to identify the system performance as a responsible environmental solution. This regulation could be developed to be part of the green building regulations induced by Dubai Municipality, and that will encourage the consultancy firms to add more effort for more study and investigate the subject meaningfully.

References

Aksamija. (2013). Sustainable facades. Design methods for high-performance building envelopes. Bognor Regis: John Wiley & Sons Ltd.

"Apple Dubai Mall with one of the world's largest kinetic art installations opens to visitors | Foster + Partners". (2017). [Accessed 12 July 2017]. Available at: http://www.fosterandpartners.com/news/archive/2017/04/apple-dubai-mall-with-one-of-the-world-s-largest-kinetic-art-installations-opens-to-visitors/

Bois, Y. & Shepley, J. (1984). A Picturesque Stroll around "Clara-Clara". October, vol. 29, p. 32.

Cherian, J., Jacob, J. & Farouk, S. (2017). A review of carbon trading: new age enterprise for sustainable development and profitability with special reference to UAE. World Review of Science, Technology and Sustainable Development, vol. 13 (2), p. 117.

Choi, W., Joe, J., Kwak, Y. & Huh, J. (2012). Operation and control strategies for multi-story double skin facades during the heating season. Energy and Buildings, vol. 49, pp. 454-465.

"Data.GISS: GISTEMP Update: May 2017 Was Second Warmest May on Record". (2017). [Accessed 9 July 2017]. Available at: https://data.giss.nasa.gov/gistemp/news/20170615/

"Data.GISS: GISTEMP Update: May 2017 Was Second Warmest May on Record". (2017). [Accessed 10 July 2017]. Available at: https://data.giss.nasa.gov/gistemp/news/20170615/

Diffenbaugh, N., Singh, D., Mankin, J., Horton, D., Swain, D., Touma, D., Charland, A., Liu, Y., Haugen, M., Tsiang, M. & Rajaratnam, B. (2017). Quantifying the influence of global warming on unprecedented extreme climate events. Proceedings of the National Academy of Sciences, vol. 114 (19), pp. 4881-4886.

"Dubai Economy Tracker: Q1 2017 growth strongest in 2yrs | Emirates NBD Research". (2017). [Accessed 9 July 2017]. Available at: http://www.emiratesnbdresearch.com/research/article/?a=dubai-economy-tracker-q1-2017-growth-strongest-in-2yrs-398

"Dubai Electricity & Water Authority (DEWA) Annual Statistics." (2017). [Accessed 9 July 2017]. Available at: https://www.dewa.gov.ae/en/about-dewa/about-us/dewa-publications/annual-statistics

Energy technology perspectives. (2014). Paris: OECD/IEA.

"Engineering Timelines - Chatsworth Conservatory and Lily House, site of." (2017). [Accessed 10 July 2017]. Available at: http://www.engineering-timelines.com/scripts/engineeringItem.asp?id=725

Etheridge, D. (2012). Natural ventilation of buildings. Chichester, West Sussex, UK: John Wiley & Sons.

Farrelly, L. (2012). The fundamentals of architecture. Lausanne: VA Academia.

Fiorito, F., Sauchelli, M., Arroyo, D., Pesenti, M., Imperadori, M., Masera, G. & Ranzi, G. (2016). Shape morphing solar shadings: A review. Renewable and Sustainable Energy Reviews, vol. 55, pp. 863-884.

Fortmeyer, R. & Linn, C. (2014). Kinetic architecture. [Melbourne], Australia: Images Publishing Group.

Giovannini, L., Verso, V., Karamata, B. & Andersen, M. (2015). Lighting and Energy Performance of an Adaptive Shading and Daylighting System for Arid Climates. Energy Procedia, vol. 78, pp. 370-375.

GmbH, E. (2017). "Dubai | Buildings | EMPORIS." Emporis.com [online]. [Accessed 9 July 2017]. Available at: https://www.emporis.com/city/100485/dubai-united-arab-emirates

Hammad, F. & Abu-Hijleh, B. (2010). The energy savings potential of using dynamic external louver s in an office building. Energy and Buildings, vol. 42 (10), pp. 1888-1895.

Hashemi, A. (2014). Daylighting and solar shading performances of an innovative automated reflective louver system. Energy and Buildings, vol. 82, pp. 607-620.

"HL-Technik Engineering GmbH Innovative Gebäudetechnik." (2017). [Accessed 22 July 2017]. Available at: http://www.hl-technik.de/

Holl, S., Pallasmaa, J. & Perez-Gomez, A. (2006). Questions of perception: the phenomenology of architecture. San Francisco: William Stout.

Hudson, M. & Kirk, M. (2014). Gulf politics and economics in a changing world. Singapore [u.a.]: World Scientific.

Johnsen, K. & Winther, F. (2015). Dynamic Facades, the Smart Way of Meeting the Energy Requirements. Energy Procedia, vol. 78, pp. 1568-1573.

Kasinalis, C., Loonen, R., Cóstola, D. & Hensen, J. (2014). Framework for assessing the performance potential of seasonally adaptable facades using multi-objective optimization. Energy and Buildings, vol. 79, pp. 106-113.

Kästle, k. (2017). "Google Map of United Arab Emirates (UAE) - Nations Online Project." Nationsonline.org [online]. [Accessed 20 August 2017]. Available at: http://www.nationsonline.org/oneworld/map/google_map_arab_emirates.htm

Khoo, C., Burry, J., Burry, M. & Ripley, C. (2017). "Soft Responsive Kinetic System: an Elastic Transformable Architectural Skin for Climatic and Visual Control." Cumulative Index of Computer-Aided Architectural Design [online]. [Accessed 12 July 2017]. Available at: https://cumincad.architexturez.net/doc/oai-cumincadworks-id-acadia11-334

Kim, H., Asl, M. & Yan3, W. (2015). Parametric BIM-based Energy Simulation for Buildings with Complex Kinetic Façades. In Proceedings of the 33rd eCAADe Conference, vol. Vol. 1, pp. 657-664. [Accessed 17 July 2017].

Lee, E., Gehbauer, C., Coffey, B., McNeil, A., Stadler, M. & Marnay, C. (2015). Integrated control of dynamic facades and distributed energy resources for energy cost minimization in commercial buildings. Solar Energy, vol. 122, pp. 1384-1397.

Lee, J., Alshayeb, M. & Chang, J. (2015). A Study of Shading Device Configuration on the Natural Ventilation Efficiency and Energy Performance of a Double Skin Façade. Procedia Engineering, vol. 118, pp. 310-317.

Loonen, R., Trčka, M., Cóstola, D. & Hensen, J. (2013). Climate adaptive building shells: State-of-the-art and future challenges. Renewable and Sustainable Energy Reviews, vol. 25, pp. 483-493.

Mahmoud, A. & Elghazi, Y. (2016). Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns. Solar Energy, vol. 126, pp. 111-127.

Marche, J. & Tschumi, B. (1995). Architecture and Disjunction. Journal of Architectural Education (1984-), vol. 49 (2), p. 132.

"Ministry of Presidential Affairs - National Centre of Meteorology & Seismology - Index." (2017). [Accessed 12 July 2017]. Available at: http://www.ncms.ae/en/climate-reports-yearly.html

Moloney, J. (2011). Designing kinetics for architectural facades. Abingdon, Oxon: Routledge.

Moloney, J., Globa, A. & Wang, R. (2017). Hybrid Environmental-Media Facades. KnE Engineering, vol. 2 (2), p. 190.

Mostafavi, M. & Leatherbarrow, D. (1993). On Weathering. M.I.T.P.

Nielsen, M., Svendsen, S. & Jensen, L. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. Solar Energy, vol. 85 (5), pp. 757-768.

O'Brien, W., Kapsis, K. & Athienitis, A. (2013). Manually-operated window shade patterns in office buildings: A critical review. Building and Environment, vol. 60, pp. 319-338.

Osman, M., Gachino, G. & Hoque, A. (2016). Electricity consumption and economic growth in the GCC countries: Panel data analysis. Energy Policy, vol. 98, pp. 318-327.

Pesenti, M., Masera, G., Fiorito, F. & Sauchelli, M. (2015). Kinetic Solar Skin: A Responsive Folding Technique. Energy Procedia, vol. 70, pp. 661-672.

Piccirilli Dorsey, I. (2017). "Environmental and Energy Study Institute | Ideas. Insights. Sustainable Solutions." Eesi.org [online]. [Accessed 10 July 2017]. Available at: http://www.eesi.org

Radhi, H., Sharples, S. & Fikiry, F. (2013). Will multi-facade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings. Energy and Buildings, vol. 56, pp. 179-188.

Radhi, H., Sharples, S. & Fikiry, F. (2013). Will multi-facade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings. Energy and Buildings, vol. 56, pp. 179-188.

Ramzy, N. & Fayed, H. (2011). Kinetic systems in architecture: New approach for environmental control systems and context-sensitive buildings. Sustainable Cities and Society, vol. 1 (3), pp. 170-177.

Rose, S., Richels, R., Blanford, G. & Rutherford, T. (2017). The Paris Agreement and next steps in limiting global warming. Climatic Change, vol. 142 (1-2), pp. 255-270.

Saelens, D., Parys, W., Roofthooft, J. & de la Torre, A. (2014). Reprint of "Assessment of approaches for modeling louver shading devices in building energy simulation programs." Energy and Buildings, vol. 68, pp. 799-810.

Sharaidin, K. & Salim, F. (2012). Design Considerations for Adopting Kinetic Facades in Building Practice. Digital Physicality| Physical Digitality: eCAADe. Viewed 12 July 2017.

Sharaidin, K. (2014). Kinetic facades: towards design for environmental performance. PhD. RMIT University.

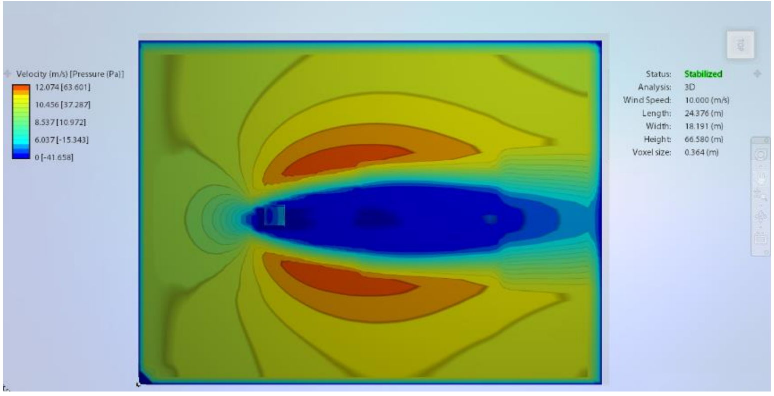
Shen, H. & Tzempelikos, A. (2013). Sensitivity analysis on daylighting and energy performance of perimeter offices with automated shading. Building and Environment, vol. 59, pp. 303-314.

Wigginton, M. & Harris, J. (2006). Intelligent skins. Amsterdam: Architectural Press.

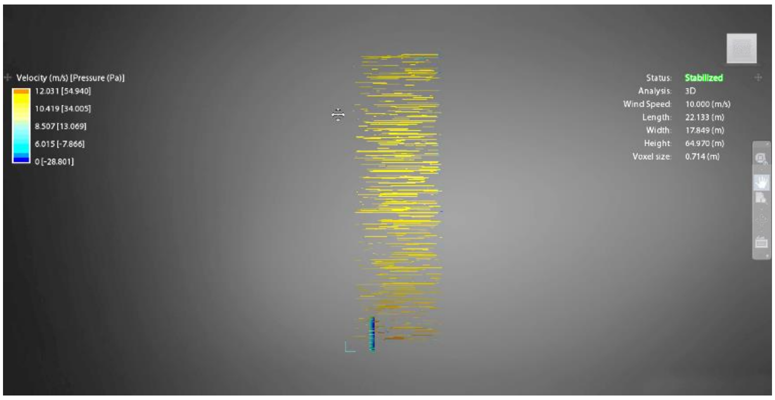
Zeebe, R., Ridgwell, A. & Zachos, J. (2016). Anthropogenic carbon release rate unprecedented during the past 66 million years. Nature Geoscience, vol. 9 (4), pp. 325-329.

Appendices

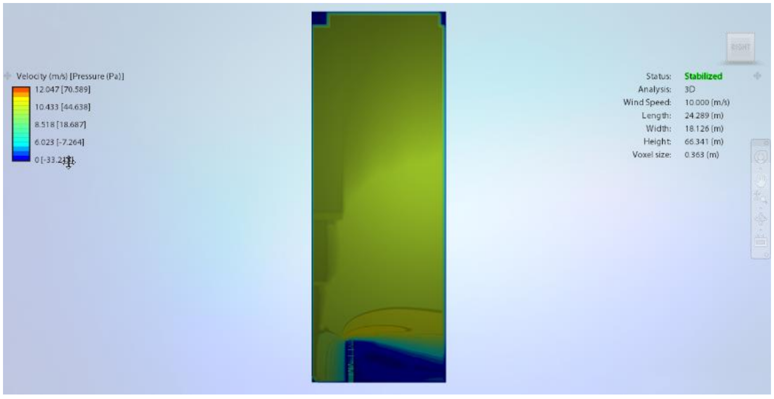
A. Appendix A: an Airflow simulation analysis.



Plan View presents the total size of the wind tunnel and 3D analysis of wind Effect.

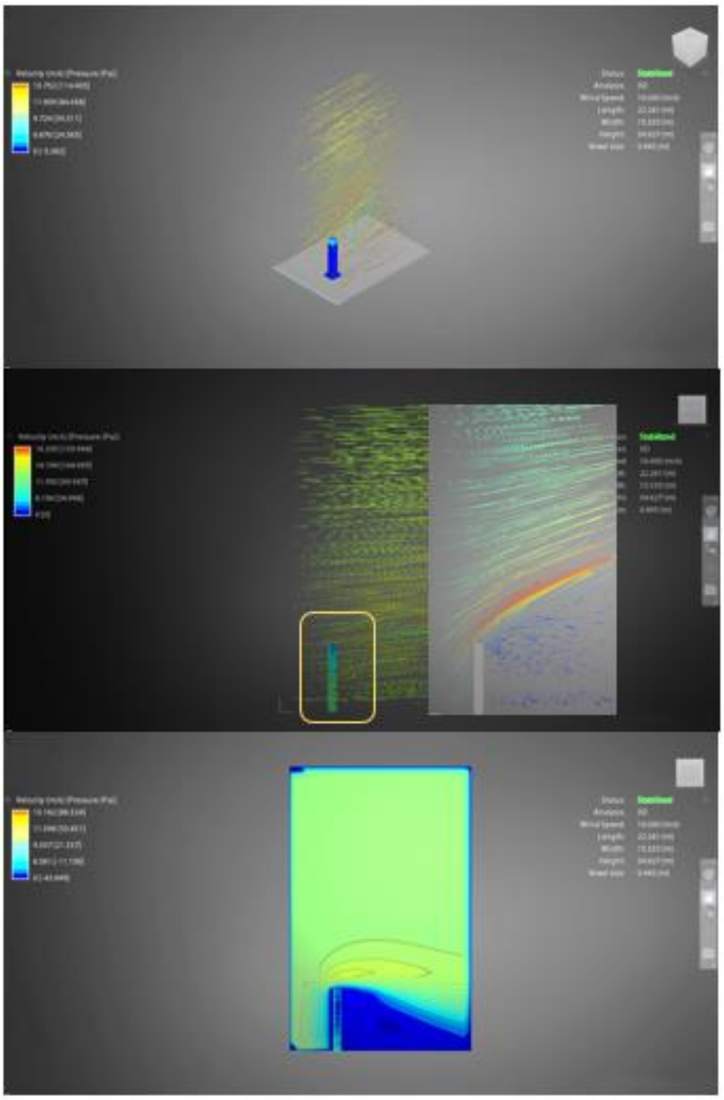


Side View demonstrates the wind tunnel effect.



Side view 3D and 2D wind pressure zones.

Figures A-1 Air flow pattern with average domain values as the first step to domain size validation (Flow design software).



Simulation Perspective.

Side View demonstrate the wind tunnel effect 3D, 2D with a steady upper zone.

Side view 3D wind pressure zones. The upper level zone is steady and the influence on the other is minimal.

Figure A - 2 Air Side view present the 3D wind pressure zones and air flow pattern with average domain values as the first step to domain size validation (Flow design software).

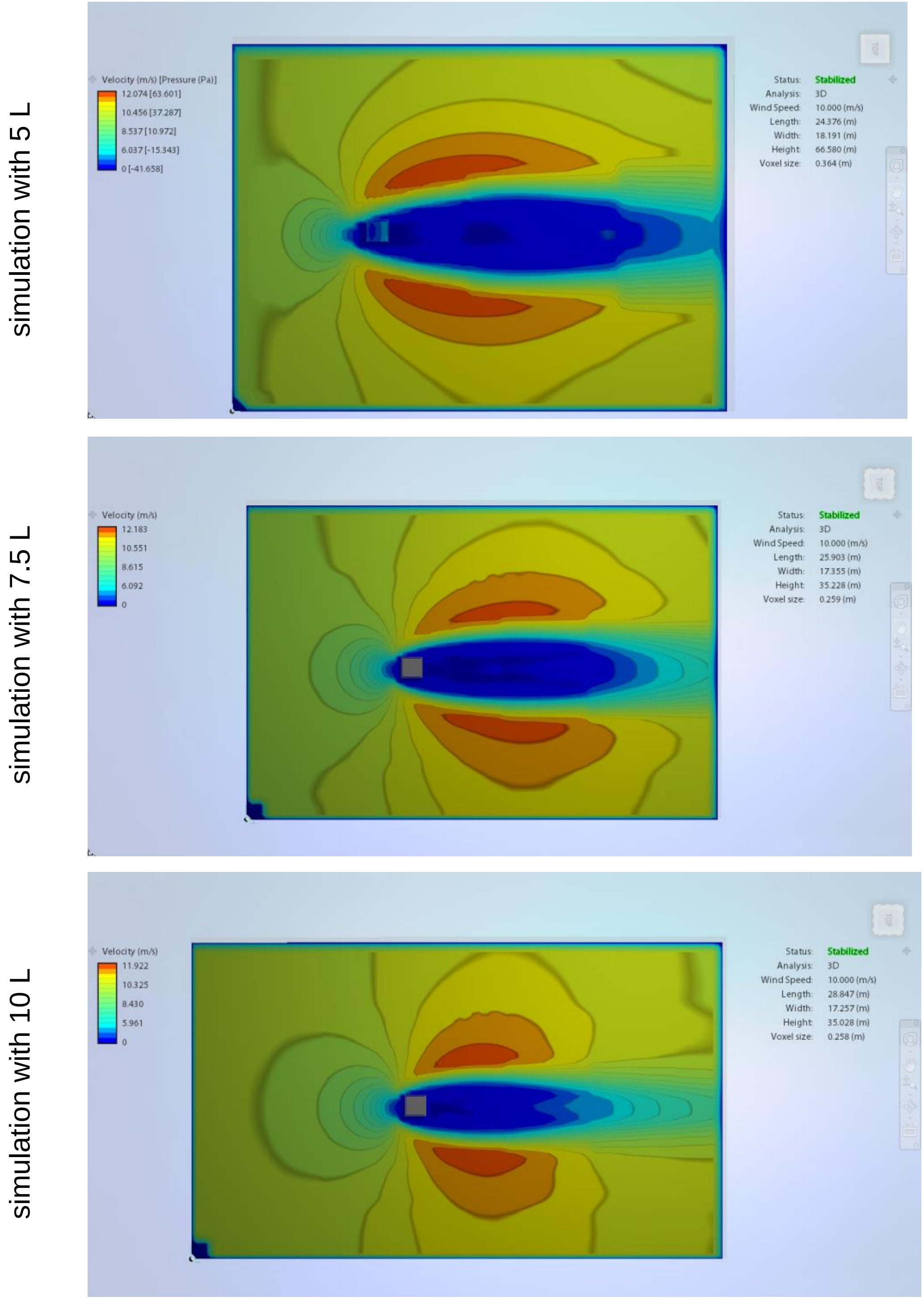


Figure A-3 Comparison for different length options of the upstream zone as the second step to domain size validation (Flow design software).

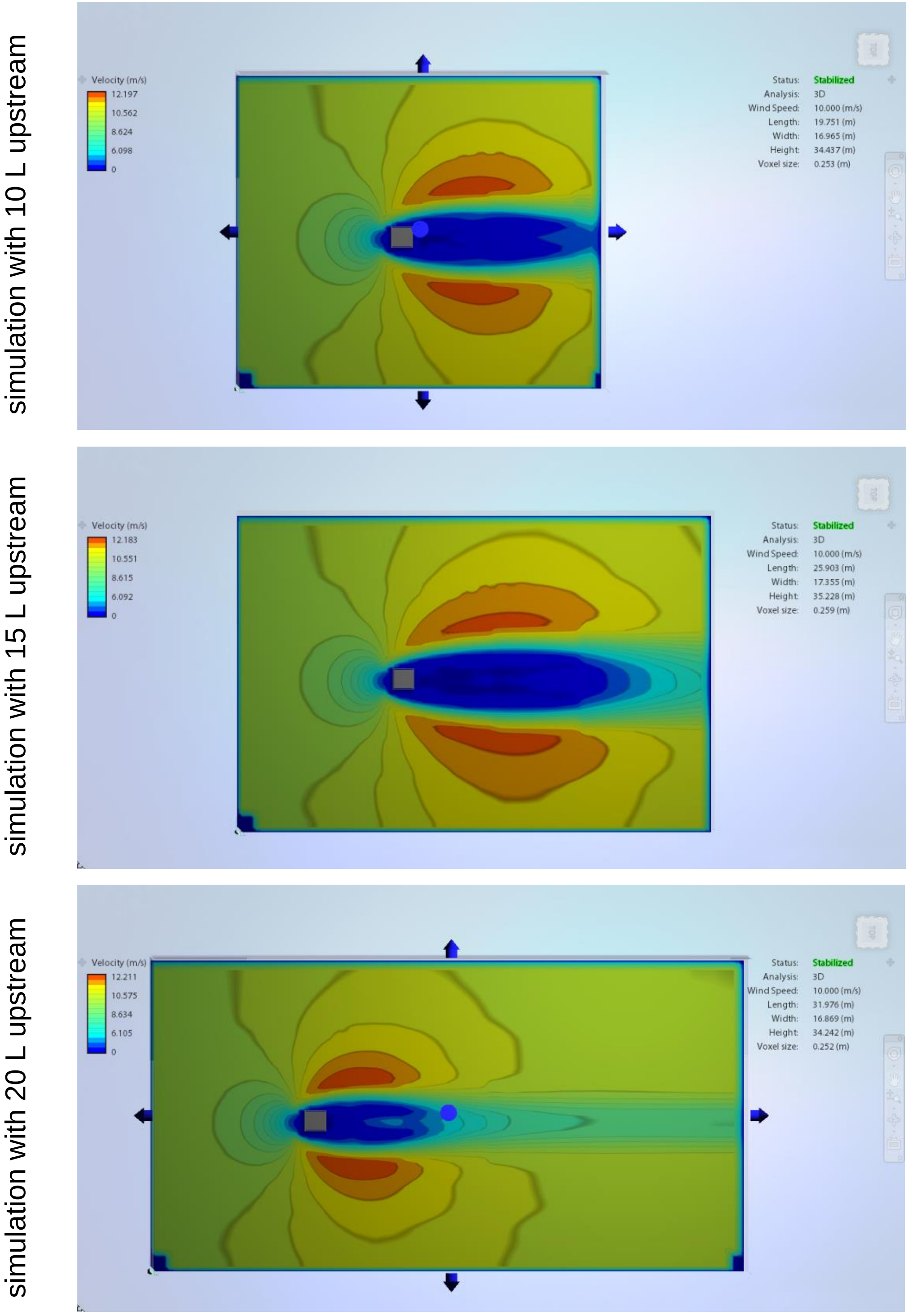
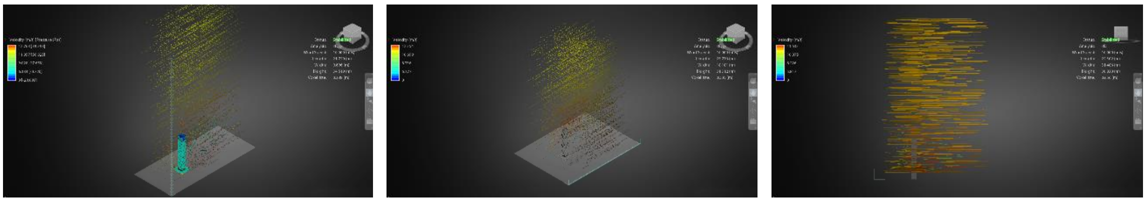
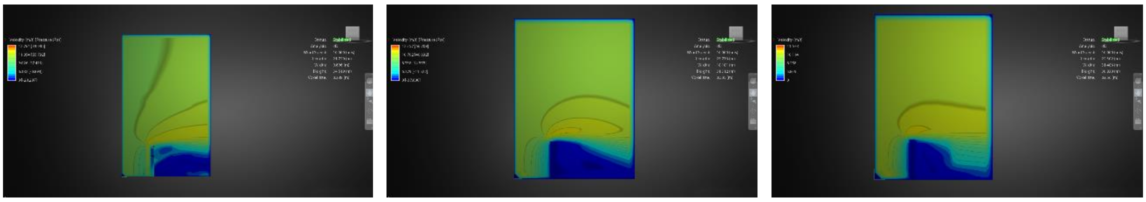


Figure A- 4 Comparison of the three scenarios (10L, 15L, and 20L) of the downstream as the third step to domain size validation (Flow design software).

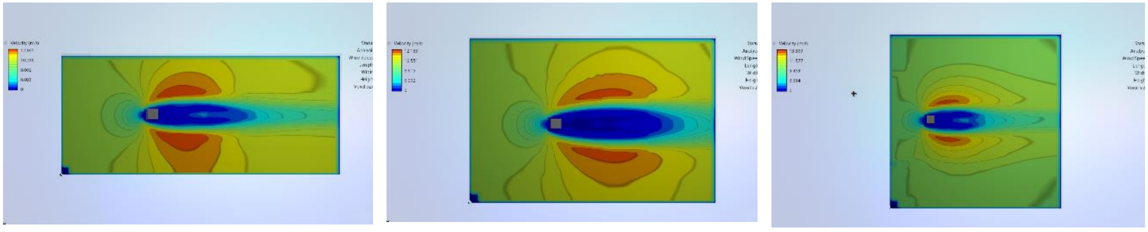
5W option for side width of domain	7.5W option for side width of domain	10W option for side width of domain



3D render for air velocity	3D render for air velocity	3D render for air velocity



Wind pattern on Section	Wind pattern on Section	Wind pattern on Section



Plan demonstrate the wind velocity	Plan demonstrate the wind velocity	Plan demonstrate the wind velocity

Figure A- 5 Comparison of the three width scenarios (5W, 7.5W, and 10W) as the fourth step to domain size validation (Flow design software).

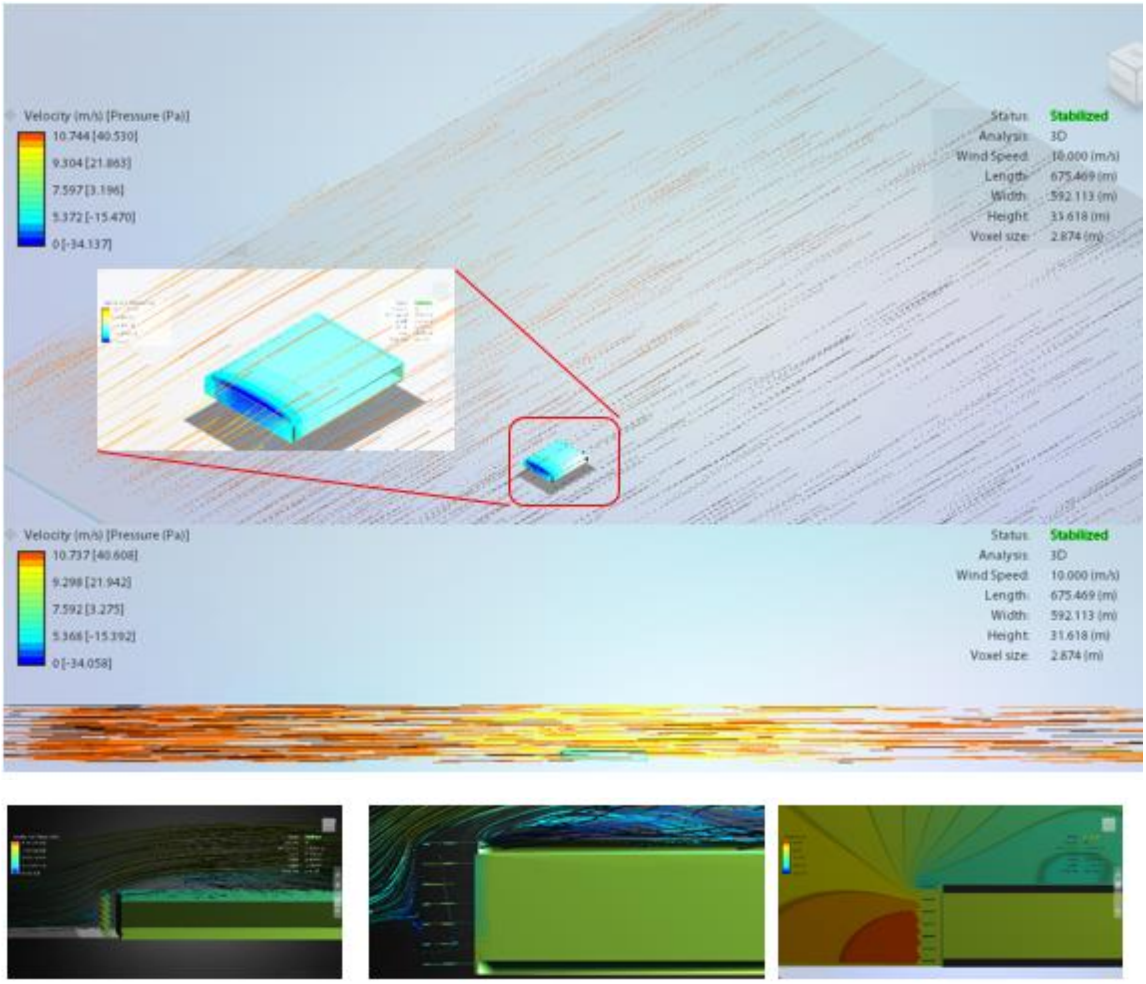


Figure A - 6 Wind simulation shows the 600mm KLS setting result, 3D view and elevation view (Flow design software).

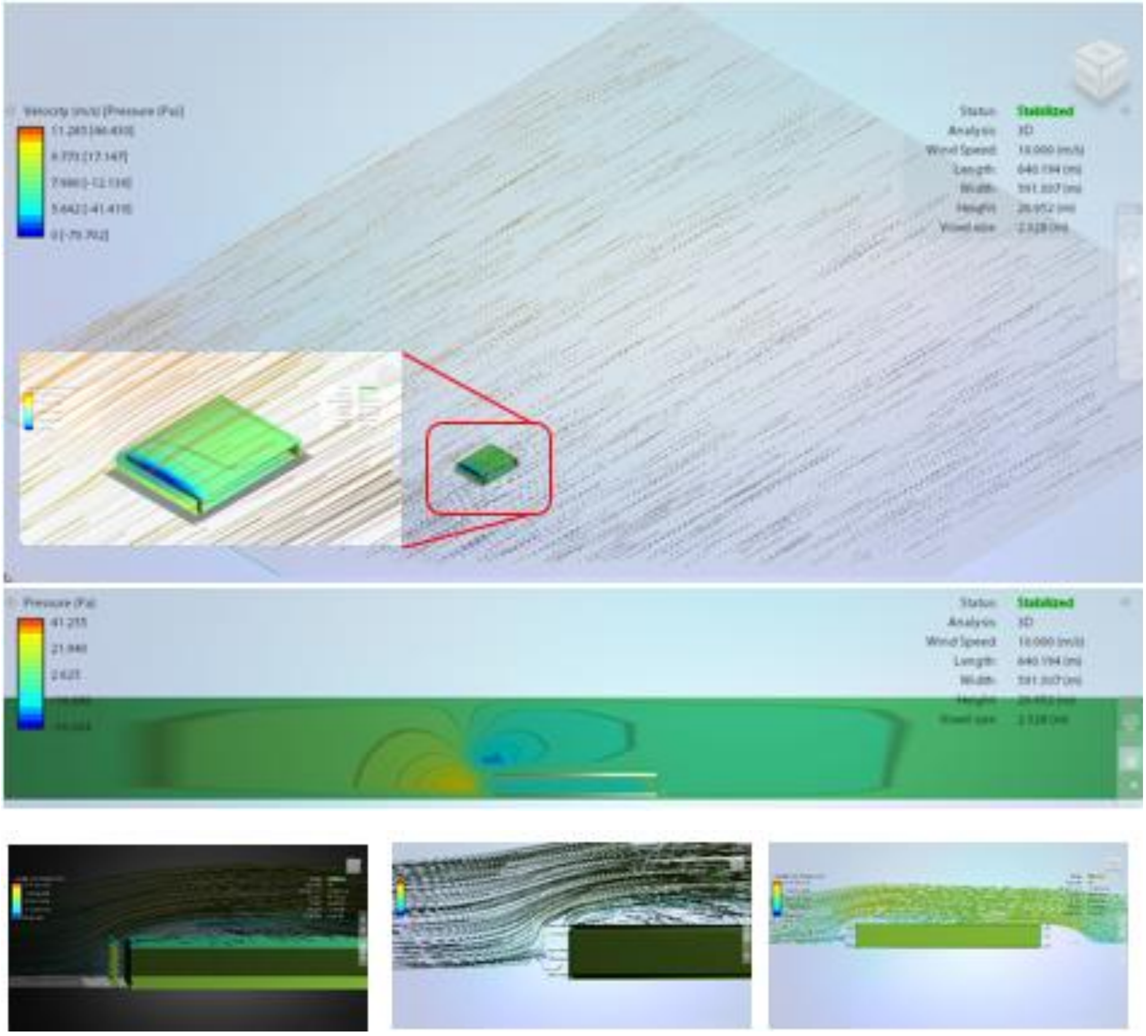


Figure A - 7 Wind flow simulation shows the 1200mm KLS simulation result.3D view and elevation view (Flow design software).

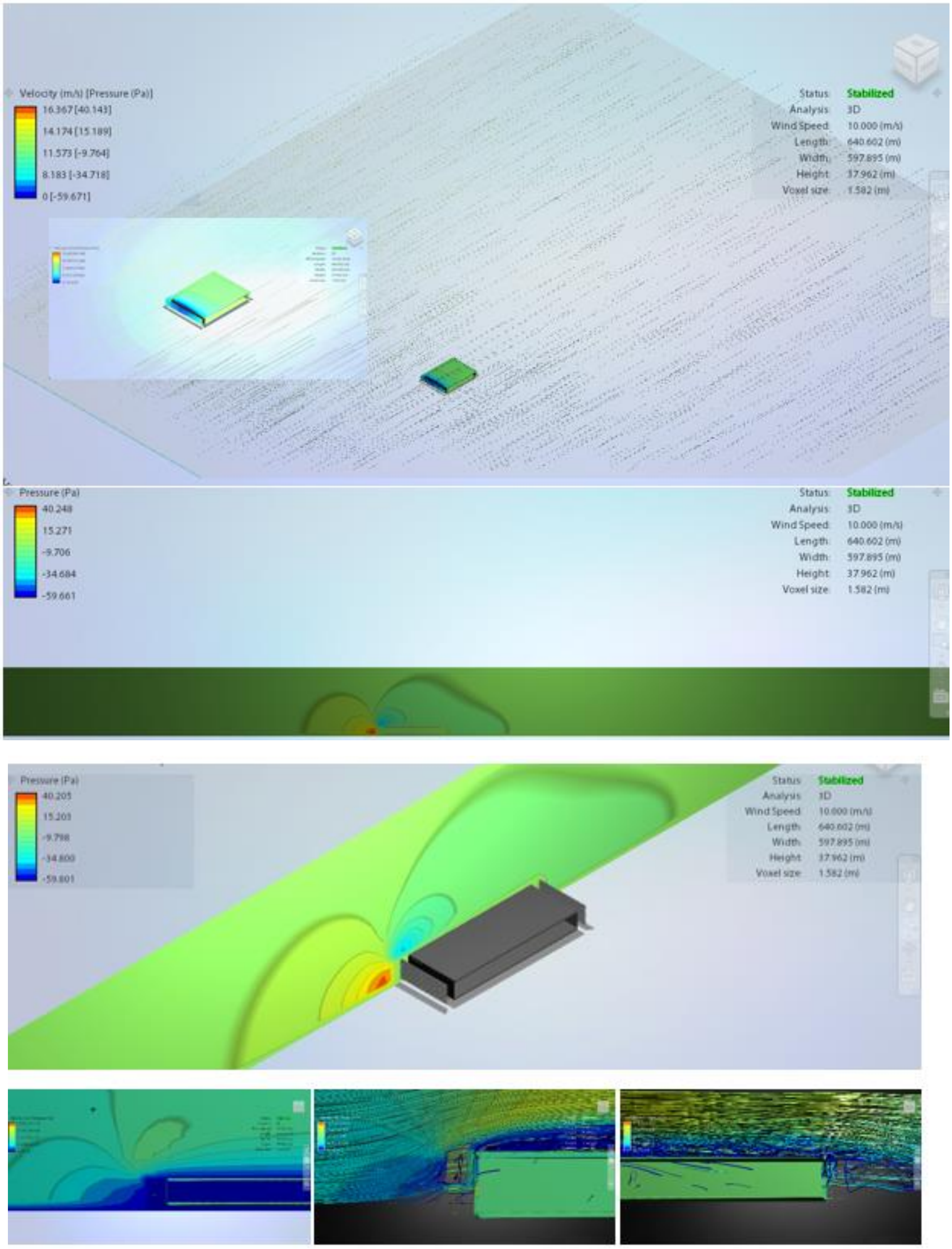


Figure A- 8 Wind flow show the 1800mm KLS simulation result.3D view and elevation view (Flow design software).

B. Appendix B: Daylight simulation analysis

Table B-1 Daylight simulation Matrix

	Configurations	Offices	Area	9am threshold results												3pm threshold results											
				within threshold				Above Threshold				Below Threshold				within threshold				Above Threshold				Below Threshold			
				East	West	South	North	East	West	South	North	East	West	South	North	East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Date/ 21th September	Base Case with light control	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
		OFFICE3 NW	155																								
		OFFICE4 NE	155																								
	Base Case W/O louver	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
		OFFICE3 NW	155																								
		OFFICE4 NE	155																								
	Not Applicable - no louver	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	15	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	30	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	45	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	60	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	75	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	90	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	105	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	120	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	135	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	150	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	165	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
	Double Skin	OFFICE1 SW	155																								
		OFFICE2 SE	155																								
		OFFICE3 NW	155																								
		OFFICE4 NE	155																								

Table B-2 Daylight simulation results of the baseline model at 9:00 am and 3:00 pm.

Configuration	Location	Area m2	9am threshold results											
			within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
			East	West	South	North	East	West	South	North	East	West	South	North
			%	%	%	%	%	%	%	%	%	%	%	%
base model	21-Dec	155	44	63	46	61	54	33	49	36	2	4	5	3
base model	21-Sep	155	39	67	50	56	55	25	41	37	6	8	9	7
base model	21-Jun	155	41	67	55	53	49	21	32	36	10	12	13	11
base model	21-Mar	155	36	65	48	53	50	19	35	32	14	16	17	15

Configuration	Location	Area m2	3pm threshold results											
			within threshold / UDI				Above Threshold / HDI				Below Threshold I LDI			
			East	West	South	North	East	West	South	North	East	West	South	North
			%	%	%	%	%	%	%	%	%	%	%	%
base model	21-Dec	155	22	14	14	20	76	80	79	74	2	6	7	6
base model	21-Sep	155	22	14	17	19	70	76	72	72	8	10	11	9
base model	21-Jun	155	22	15	19	19	65	70	66	68	13	15	15	13
base model	21-Mar	155	22	18	20	21	61	64	61	62	17	18	19	17

Note :-

50 Area above 50%   60 Area above 60%   70 Area above 70%

Table B-3 All Facade simulation results, the simulation considers the different Louvre formation in the date of December 21st, at 9:00 am.

	Configuration	Location	Area m2	9am threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 December	Base model	Floor Space	155	44	63	46	61	54	33	49	36	2	4	5	3
	NA	OFFICE1 SW	155	65	60	73	48	27	0	14	0	8	40	13	52
	15	OFFICE1 SW	155	39	1	5	3	3	0	0	0	58	99	95	97
	30	OFFICE1 SW	155	56	7	19	4	9	0	0	0	35	93	81	96
	45	OFFICE1 SW	155	56	13	43	11	13	0	0	0	31	87	57	89
	60	OFFICE1 SW	155	61	21	56	17	12	0	3	0	27	79	41	83
	75	OFFICE1 SW	155	70	26	62	28	10	0	7	0	20	74	31	72
	90	OFFICE1 SW	155	68	29	70	36	6	0	9	0	26	71	21	64
	105	OFFICE1 SW	155	63	28	74	38	4	0	11	0	33	72	15	62
	120	OFFICE1 SW	155	57	24	67	31	2	0	12	0	41	76	21	69
	135	OFFICE1 SW	155	40	16	62	19	0	0	10	0	60	84	28	81
	150	OFFICE1 SW	155	21	9	55	10	0	0	7	0	79	91	38	90
	165	OFFICE1 SW	155	3	1	26	1	0	0	3	0	97	99	71	99
	Double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% 60 Area above 60% 70 Area above 70%

Table B-4 All Facade simulation results, the simulation considers the different Louvre formation in the date of December 21st, at 3:00 pm.

	Configuration	Location	Area m2	3pm threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold I LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 December	Base model	Floor Space	155	22	14	14	20	76	80	79	74	2	6	7	6
	NA	OFFICE1 SW	155	48	68	70	54	0	9	14	0	52	23	16	46
	15	OFFICE1 SW	155	1	44	7	6	0	2	0	0	99	54	93	94
	30	OFFICE1 SW	155	8	58	26	7	0	7	0	0	92	35	74	93
	45	OFFICE1 SW	155	18	62	51	18	0	8	0	0	82	30	49	82
	60	OFFICE1 SW	155	27	67	60	28	0	8	5	0	73	25	35	72
	75	OFFICE1 SW	155	32	72	62	36	0	8	8	0	68	20	30	64
	90	OFFICE1 SW	155	35	66	66	42	0	7	11	0	65	27	23	58
	105	OFFICE1 SW	155	32	62	69	44	0	6	10	0	68	32	21	56
	120	OFFICE1 SW	155	28	57	65	33	0	3	11	0	72	40	24	67
	135	OFFICE1 SW	155	41	41	61	22	0	0	10	0	59	59	29	78
	150	OFFICE1 SW	155	9	24	60	10	0	0	7	0	91	76	33	90
	165	OFFICE1 SW	155	1	5	34	1	0	0	4	0	99	95	62	99
	Double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% 60 Area above 60% 70 Area above 70%

Table B-5 All Facade simulation results, the simulation considers the different Louvre formation in the date of September 21st, at 9:00 am.

	Configuration	Location	Area m2	9am threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 September	base model	Floor Space	155	39	67	50	56	55	25	41	37	6	8	9	7
	NA ON	OFFICE1 SW	155	66	61	77	58	22	0	21	0	12	39	2	42
	15	OFFICE1 SW	155	36	2	3	2	1	0	0	0	63	98	97	98
	30	OFFICE1 SW	155	64	11	23	14	5	0	0	0	31	89	77	86
	45	OFFICE1 SW	155	66	22	34	26	8	0	0	0	26	78	66	74
	60	OFFICE1 SW	155	68	32	46	36	10	0	0	0	22	68	54	64
	75	OFFICE1 SW	155	68	38	57	43	13	0	0	0	19	62	43	57
	90	OFFICE1 SW	155	70	43	59	46	12	0	4	0	18	57	37	54
	105	OFFICE1 SW	155	69	40	62	45	10	0	4	0	21	60	34	55
	120	OFFICE1 SW	155	66	34	67	37	8	0	4	0	26	66	29	63
	135	OFFICE1 SW	155	62	26	56	20	4	0	3	0	34	74	41	80
	150	OFFICE1 SW	155	42	13	39	11	0	0	0	0	58	87	61	89
	165	OFFICE1 SW	155	11	3	25	3	0	0	0	0	89	97	75	97
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% 60 Area above 60% 70 Area above 70%

Table B-6 All Facade simulation results, the simulation considers the different Louvre formation in the date of September 21st, at 3:00 pm.

	Configuration	Location	Area m2	3pm threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold I LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 September	base model	Floor Space	155	22	14	17	19	70	76	72	72	8	10	11	9
	NA ON	OFFICE1 SW	155	63	65	75	59	0	20	23	0	37	15	2	41
	15	OFFICE1 SW	155	2	36	5	3	0	1	0	0	98	63	95	97
	30	OFFICE1 SW	155	11	62	19	18	0	1	0	0	89	37	81	82
	45	OFFICE1 SW	155	25	65	38	31	0	8	0	0	75	27	62	69
	60	OFFICE1 SW	155	34	67	50	40	0	11	0	0	66	22	50	60
	75	OFFICE1 SW	155	41	68	59	46	0	12	0	0	59	20	41	54
	90	OFFICE1 SW	155	43	69	58	48	0	11	3	0	57	20	39	52
	105	OFFICE1 SW	155	41	67	64	46	0	9	4	0	59	24	32	54
	120	OFFICE1 SW	155	47	65	65	36	0	7	4	0	53	28	31	64
	135	OFFICE1 SW	155	22	66	58	21	0	7	3	0	78	27	39	79
	150	OFFICE1 SW	155	13	39	42	10	0	0	2	0	87	61	56	90
	165	OFFICE1 SW	155	2	10	25	2	0	0	0	0	98	90	75	98
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% 60 Area above 60% 70 Area above 70%

Table B-7 All Facade simulation results, the simulation considers the different Louvre formation in the date of June 21st, at 9:00 am.

	Configuration	Location	Area m2	9am threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 June	base model	Floor Space	155	41	67	55	53	49	21	32	36	10	12	13	11
	NA ON	OFFICE1 SW	155	65	60	58	62	27	0	1	3	8	40	41	35
	15	OFFICE1 SW	155	13	3	5	3	0	0	0	0	87	97	95	97
	30	OFFICE1 SW	155	64	12	20	19	5	0	0	0	31	88	80	81
	45	OFFICE1 SW	155	66	22	31	31	8	0	0	0	26	78	69	69
	60	OFFICE1 SW	155	67	34	40	42	8	0	0	0	25	66	60	58
	75	OFFICE1 SW	155	68	42	47	50	10	0	0	0	22	58	53	50
	90	OFFICE1 SW	155	70	43	48	54	12	0	0	0	18	57	52	46
	105	OFFICE1 SW	155	70	40	46	54	12	0	0	0	18	60	54	46
	120	OFFICE1 SW	155	70	35	37	52	9	0	0	0	21	65	63	48
	135	OFFICE1 SW	155	69	28	26	39	7	0	0	0	24	72	74	61
	150	OFFICE1 SW	155	60	14	13	25	4	0	0	0	36	86	87	75
	165	OFFICE1 SW	155	28	3	5	7	0	0	0	0	72	97	95	93
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50%   60 Area above 60%   70 Area above 70%

Table B-8 All Facade simulation results, the simulation considers the different Louvre formation in the date of June 21st, at 3:00 pm

	Configuration	Location	Area m2	3pm threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold I LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 June	base model	Floor Space	155	22	15	19	19	65	70	66	68	13	15	15	13
	NA ON	OFFICE1 SW	155	48	68	62	63	0	9	1	2	52	23	37	35
	15	OFFICE1 SW	155	3	14	7	6	0	0	0	0	97	86	93	94
	30	OFFICE1 SW	155	11	62	23	24	0	6	0	0	89	32	77	76
	45	OFFICE1 SW	155	25	65	36	37	0	8	0	0	75	27	64	63
	60	OFFICE1 SW	155	40	66	45	46	0	7	0	0	60	27	55	54
	75	OFFICE1 SW	155	48	67	52	53	0	8	0	0	52	25	48	47
	90	OFFICE1 SW	155	48	68	52	55	0	9	0	0	52	23	48	45
	105	OFFICE1 SW	155	45	68	49	53	0	9	0	0	55	23	51	47
	120	OFFICE1 SW	155	39	66	40	46	0	7	0	0	61	27	60	54
	135	OFFICE1 SW	155	30	64	28	31	0	6	0	0	70	30	72	69
	150	OFFICE1 SW	155	17	55	13	14	0	2	0	0	83	43	87	86
	165	OFFICE1 SW	155	3	23	5	4	0	0	0	0	97	77	95	96
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50%   60 Area above 60%   70 Area above 70%

Table B-9 All Facade simulation results, the simulation considers the different Louvre formation in the date of March 21st, at 9:00 am.

	Configuration	Location	Area m2	9am threshold results											
				within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
				East	West	South	North	East	West	South	North	East	West	South	North
				%	%	%	%	%	%	%	%	%	%	%	%
Date 21 March	base model	Floor Space	155	36	65	48	53	50	19	35	32	14	16	17	15
	NA ON	OFFICE1 SW	155	65	60	66	59	24	0	6	0	11	40	28	41
	15	OFFICE1 SW	155	36	2	3	0	1	0	0	0	63	98	97	100
	30	OFFICE1 SW	155	63	11	18	12	7	0	0	0	30	89	82	88
	45	OFFICE1 SW	155	66	24	33	26	10	0	0	0	24	76	67	74
	60	OFFICE1 SW	155	67	33	45	34	12	0	0	0	21	67	55	66
	75	OFFICE1 SW	155	68	38	57	43	15	0	0	0	17	62	43	57
	90	OFFICE1 SW	155	70	42	61	47	15	0	3	0	15	58	36	53
	105	OFFICE1 SW	155	69	39	63	47	12	0	4	0	19	61	33	53
	120	OFFICE1 SW	155	68	34	66	39	9	0	4	0	23	66	30	61
	135	OFFICE1 SW	155	64	26	55	28	5	0	3	0	31	74	42	72
	150	OFFICE1 SW	155	46	12	40	13	0	0	0	0	54	88	60	87
	165	OFFICE1 SW	155	11	3	23	3	0	0	0	0	89	97	77	97
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% 60 Area above 60% 70 Area above 70%

.Table B-10 All Facade simulation results, the simulation considers the different Louvre formation in the date of March 21st, at 3:00 pm

	Configuration	Location	Area m2	3pm threshold results: within threshold / UDI East %	West %	South %	North %	Above Threshold / HDI East %	West %	South %	North %	Below Threshold I LDI East %	West %	South %	North %
Date 21 March	base model	Floor Space	155	22	18	20	21	61	64	61	62	17	18	19	17
	NA ON	OFFICE1 SW	155	48	68	60	49	0	9	4	0	52	65	36	51
	15	OFFICE1 SW	155	0	26	2	0	0	1	0	0	100	43	98	100
	30	OFFICE1 SW	155	7	56	15	11	0	3	0	0	93	36	85	89
	45	OFFICE1 SW	155	15	61	30	21	0	5	0	0	85	30	70	79
	60	OFFICE1 SW	155	23	65	40	29	0	5	0	0	77	30	60	71
	75	OFFICE1 SW	155	28	65	51	34	0	6	0	0	72	28	49	66
	90	OFFICE1 SW	155	30	66	55	35	0	6	1	0	70	32	44	65
	105	OFFICE1 SW	155	30	62	61	38	0	5	1	0	70	38	38	62
	120	OFFICE1 SW	155	25	57	64	25	0	4	0	0	75	39	36	75
	135	OFFICE1 SW	155	17	48	56	14	0	0	0	0	83	52	44	86
	150	OFFICE1 SW	155	8	24	34	7	0	0	0	0	92	76	66	93
	165	OFFICE1 SW	155	1	6	19	0	0	0	0	0	99	94	81	100
	double skin	Floor Space	All	0	0	0	0	0	0	0	0	100	100	100	100

Note :-

50 Area above 50% | 60 Area above 60% | 70 Area above 70%

Table B-11 Simulation results of KLS as Double skin configuration for all Facade, the simulation considers the double skin Louvre formation.At 9:00 am and 3:00 pm.

Configuration	Location	Area m2	9am threshold results											
			within threshold / UDI				Above Threshold / HDI				Below Threshold / LDI			
			East	West	South	North	East	West	South	North	East	West	South	North
			%	%	%	%	%	%	%	%	%	%	%	%
Double Skin Façade	21-Dec	155	0	0	0	0		0	0	0	100	100	100	100
	21-Sep	155	0	0	0	0		0	0	0	100	100	100	100
	21-Jun	155	0	0	0	0		0	0	0	100	100	100	100
	21-Mar	155	0	0	0	0		0	0	0	100	100	100	100

Configuration	Location	Area m2	3pm threshold results											
			within threshold / UDI				Above Threshold / HDI				Below Threshold l LDI			
			East	West	South	North	East	West	South	North	East	West	South	North
			%	%	%	%	%	%	%	%	%	%	%	%
Double Skin Façade	21-Dec	155	0	0	0	0		0	0	0	100	100	100	100
	21-Sep	155	0	0	0	0		0	0	0	100	100	100	100
	21-Jun	155	0	0	0	0		0	0	0	100	100	100	100
	21-Mar	155	0	0	0	0		0	0	0	100	100	100	100

Note :-

50	Area above 50%	60	Area above 60%	70	Area above 70%

C. Appendix C: Energy simulation analysis

Table C-1 Baseline model analysis along with baseline with light control scenario by Revit software and insight360 Autodesk

		Time 9:00 AM									Time 3:00 PM								
		Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
		East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
		kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
21st Dec	Base case with light control	187	187	187	170	185	175	566	581	571	187	187	187	170	184	174	566	581	571
	base model	193	193	193	175	191	180	583	599	589	193	193	193	175	190	180	583	599	588
21st Sept	Base case with light control	179	179	179	631	687	649	1051	1108	1070	179	179	179	631	685	648	1051	1105	1068
	base model	184	184	184	650	709	670	1083	1142	1103	184	184	184	650	706	668	1083	1140	1101
21st June	Base case with light control	170	170	170	800	872	824	1213	1285	1237	170	170	170	800	870	822	1213	1282	1235
	base model	175	175	175	825	899	850	1250	1324	1275	175	175	175	825	897	848	1250	1322	1273
21st March	Base Model with light control	178	178	178	424	463	437	849	887	861	178	178	178	424	461	436	849	886	860
	base model	184	184	184	438	477	451	875	914	888	184	184	184	438	475	450	875	913	887

Note:-

1237 Higher demand, longer the bar colour

170 Lower demand with longer color

Table C-2 21st December analysis model for total potential energy saving. The result piloted by Revit software and insight360 Autodesk

Date	Façade Direction	Louver Type	Configuration	Time 9:00 AM									Time 3:00 PM								
				Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
				East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
				kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
Date 21st Decmber	Façade Direction / all	louver Type - H/V	Base/light control	187	187	187	170	185	175	566	581	571	187	187	187	170	184	174	566	581	571
			Base model	193	193	193	175	191	180	583	599	589	193	193	193	175	190	180	583	599	588
			15	115	191	183	112	114	112	443	520	511	191	108	181	135	137	135	541	460	531
			30	64	178	156	111	116	112	391	510	483	176	64	178	134	139	134	526	419	528
			45	51	166	109	111	117	111	377	499	436	156	54	159	133	141	134	504	411	508
			60	44	150	78	115	120	117	375	486	410	140	43	141	138	144	140	493	404	496
			75	37	141	64	115	122	118	368	479	397	130	39	122	138	147	141	484	402	479
			90	51	138	46	116	124	119	383	477	381	126	53	113	139	149	142	481	417	471
			105	64	141	40	122	121	124	401	478	380	130	62	110	146	145	149	492	423	475
			120	78	148	48	121	127	123	415	491	387	139	78	128	145	153	148	500	446	491
			135	116	163	60	117	124	117	448	502	393	134	114	150	140	149	141	490	478	507
			150	153	176	75	118	122	118	487	514	409	175	149	172	141	147	141	532	512	530
			165	187	192	139	119	120	118	521	528	473	191	183	190	142	144	142	549	543	547
			Double Skin	193	193	193	105	107	105	513	515	513	193	193	193	126	128	126	534	537	534

Note:-

1237 **Higher demand, longer the bar colour**

170 **Lower demand with longer color**

Table C-3 21st September analysis model for total potential energy saving. The result piloted by Revit software and insight360 Autodesk

Configuration				Time 9:00:00 AM									Time 3:00:00 PM								
				Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
				East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
				kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
Date 21st September	Façade Direction / all	louver Type - H/V	Base case with light control	179	179	179	631	687	649	1051	1108	1070	179	179	179	631	685	648	1051	1105	1068
			Base model	184	184	184	650	709	670	1083	1142	1103	184	184	184	650	706	668	1083	1140	1101
			15	117	180	179	418	424	416	784	852	844	180	144	179	501	508	500	931	901	927
			30	58	163	141	414	430	415	721	842	805	163	114	151	497	516	498	909	879	898
			45	44	142	122	410	436	413	704	827	785	136	47	127	493	523	496	878	819	872
			60	37	125	100	426	447	433	712	822	782	122	38	112	511	537	519	882	824	881
			75	32	114	80	428	454	437	709	817	766	109	35	99	513	545	524	871	829	873
			90	32	107	67	430	460	441	711	816	757	105	37	97	516	552	529	870	838	875
			105	39	111	63	452	449	461	739	809	773	107	44	99	542	539	553	898	833	902
			120	46	122	56	449	472	457	745	843	762	108	51	118	539	567	548	896	866	915
			135	63	137	76	433	460	436	745	846	762	146	52	145	520	552	524	916	854	918
			150	107	161	114	437	454	438	793	864	801	160	113	166	524	544	525	934	907	940
			165	166	180	143	441	447	439	856	876	831	180	167	180	529	537	527	958	952	957
			Double Skin Façade	184	184	184	390	397	388	823	830	822	184	184	184	468	476	466	902	910	899

Note:-

1237 **Higher demand, longer the bar colour**

170 **Lower demand with longer color**

Table C-4 21st June analysis model for total potential energy saving. The result piloted by Revit software and insight360 Autodesk

Configuration				Tmie 9:00 AM									Time 3:00 PM								
				Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
				East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
				kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
Date 21st June	Façade Direction / all	louver Type - H/V	Base case with light control	170	170	170	800	872	824	1213	1285	1237	170	170	170	800	870	822	1213	1282	1235
			Base model	175	175	175	825	899	850	1250	1324	1275	175	175	175	825	897	848	1250	1322	1273
			15	151	170	166	530	538	528	931	957	945	170	150	165	636	645	634	1056	1045	1049
			30	54	154	141	525	545	527	830	949	917	155	56	133	631	654	632	1035	960	1015
			45	43	134	121	521	553	525	814	937	895	130	45	110	625	664	630	1005	958	990
			60	42	116	106	540	568	549	832	933	905	107	47	94	648	681	659	1005	978	1003
			75	38	102	95	543	576	554	831	928	899	95	44	83	651	691	665	996	985	999
			90	32	100	91	546	584	560	828	934	901	94	40	80	655	701	672	998	991	1001
			105	33	103	95	573	570	585	856	924	930	95	41	83	688	684	702	1033	975	1035
			120	39	114	110	570	599	580	860	963	940	107	48	95	684	719	696	1041	1017	1041
			135	45	129	129	550	584	554	845	963	932	123	54	121	660	701	665	1032	1005	1035
			150	64	152	152	555	576	556	869	978	958	146	75	151	666	691	667	1062	1016	1067
			165	128	170	166	559	567	558	937	987	974	170	137	168	671	681	669	1091	1068	1087
			Double Skin Façade	175	175	175	495	504	493	920	929	918	175	175	175	594	604	592	1019	1029	1017

Note:-

1237 **Higher demand, longer the bar colour**

170 **Lower demand with longer color**

Table C-5 21st March analysis model for total potential energy saving. The result piloted by Revit software and insight360 Autodesk

Configuration				9:00 AM									3:00 PM								
				Light Energy			HVAC Energy			Total Energy			Light Energy			HVAC Energy			Total Energy		
				East	West	South	East	West	South	East	West	South	East	West	South	East	West	South	East	West	South
				kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h	kw/h
Date 21st March	Façade Direction / all	louver Type - H/V	Base case with light control	178	178	178	424	463	437	849	887	861	178	178	178	424	461	436	849	886	860
			Base model	184	184	184	438	477	451	875	914	888	184	184	184	438	475	450	875	913	887
			15	116	179	178	281	285	280	651	718	712	184	133	184	337	342	336	775	729	774
			30	54	162	150	279	289	279	587	705	683	170	78	164	334	347	335	758	679	752
			45	39	139	122	276	293	278	569	686	654	156	62	144	332	352	334	741	668	732
			60	32	123	99	287	301	291	572	678	644	141	54	130	344	361	350	739	669	734
			75	25	112	78	288	305	294	566	671	626	132	51	121	345	367	353	732	672	728
			90	26	107	67	289	310	297	569	670	618	129	53	119	347	372	356	730	679	728
			105	35	112	62	304	302	310	593	668	626	131	61	120	365	363	372	750	677	747
			120	43	122	59	302	318	307	599	694	620	140	71	138	363	381	369	756	706	761
			135	57	138	76	292	310	294	602	701	624	153	96	158	350	372	352	757	721	764
			150	100	163	112	294	305	295	648	722	661	170	140	171	353	366	354	777	760	778
			165	164	179	145	297	301	296	715	734	695	182	174	184	356	361	355	792	789	792

Note:-

1237 **Higher demand, longer the bar colour** **170** **Lower demand with longer color**