A Study on Reducing Heat Gains through the use of Bio-Climatic Facades

By

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Abstract

For centuries, humans have built shelters that were bio-climatic and adapted to the region they belonged to. They achieved comfort within their enclosures without the over-dependence on electricity. But since the advent of curtain walls and centralized air-conditioning, we have leaned towards aesthetics at the cost of performance. Pampered by the controlled internal environment, we started to live in isolation from nature, our whole existence became governed by machines and in time our lives have became an extension of the environment we now inhabit.

We have also paid the price for our choices. Today the very existence of all life on earth lies on a fragile lifeline of hope. We have used our resources beyond the limit and have poisoned every sphere of life on the planet. It is not certain if there is a way back, but we are left with no more choices, we have only one option. We need to change, now.

Buildings have been the surprise villains in the Carbon footprint story and we now know that much of the energy generated by man on earth goes into operating our buildings and its life supporting systems (HVAC). Today, most buildings cannot sustain life within it in the absence of energy to power the ventilation systems. By using sealed facades, we are cutting ourselves entirely from the surrounding environment. But this becomes an even bigger problem when one considers the generous use of glazing in urban architecture especially in some parts of the world like Dubai that are too hot and too bright for such architectural adventures.

The overuse of glazing also brings in excess glare and heat, which is often not anticipated or understood when the designer wills a gleaming glazed tower in the middle of a dessert. What then are the solutions if any? Are there any Bio-climatic Solutions to the designer’s dilemma?

In this research, the use of ETFE foil cushions as an external surface in a modular double skin façade system is explored. The material offers promising performance figures and could be a sustainable material on many fronts when compared to glass. But first it has to be tested to see whether it can help in reducing heat gains through the façade, which is often the weak point in a building's defense against the external forces. Simulation models are used to test the performance of ETFE skin with the help of ECOTECT5.5. Heating and Cooling load values will be compared for both glass and ETFE to analyze the effectiveness of both with regard to reducing heat gains. A present worth calculation for ETFE will also be carried out to assess the economic implications of using the material in place of the more conventional glazing.

Acknowledgments

I would like to acknowledge the role of all my professors at BUID especially my Dissertation Supervisor – Proff. Bassam Abu Hijleh, whose guidance was crucial in the completion of this dissertation.

I would also like to acknowledge my friends for their support throughout this journey and always, but above all else I would like to acknowledge my Parents whose commitment and support towards my best interest is unmatched and irreplaceable.

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1.1 Introduction –

Our world is getting warmer and the Intergovernmental Panel for Climate Change has raised a stark warning that our planet could experience rise in temperature from between 1.4º C to 5.0º C by the turn of the century. The catastrophic consequences of letting this global warming go unchecked has been well documented and debated across all levels of administrative and social hierarchy over the last few years and though the task of raising public awareness has been realized, not much action has followed.

The main contributor to climate change has been identified as the rising levels of Carbon emissions and the induced Greenhouse effect that leads to the entrapment of heat in the earth's atmosphere. These carbon emissions are the direct result of human activity and its relevant energy needs. Carbon emissions emanate from the combustion of fossil fuels to meet the energy hunger of the civilized world. While many activists have targeted fuel-guzzling vehicles as the villain, the startling revelation by the International Energy Agency (IEA), and reconfirmed in a press release on 20th March 2008 claimed that over 40% of overall global energy consumption is the result of the construction and normal operation of existing buildings.

According to the Energy Information Agency (EIA, 2000) an estimated 84% of a building's energy use over its lifetime can be attributed to its running costs which includes lighting and thermal control. It is quite clear that since the facades and roof of a building act as an environmental filter between the outdoor and indoor environments, the design and composition of these elements determine the extent of success in achieving efficient thermal control in a building. But despite the availability of necessary technology and well-documented guidelines, there is a tendency to use 'green technology' as simple gimmicks aimed at exploiting the loopholes present in present day rating systems for green designs and sustainable development.

Building Performance rating systems such as LEED in the U.S, The Honk Kong BEAM, and Greenstar of Australia offer guidelines on achieving energy efficiency and 'green' designs that are sustainable and helps to conserve the environment. Recently efforts to launch a green rating system specific to the Middle East has been initiated by the authorities in Abu Dhabi known as the ESTIDAMA or 'Pearl' rating system. Besides such efforts, government authorities in countries such as Germany and Holland are said to have strict building guidelines that limits the energy hungry ways of modern architecture. But yet, we are still to acknowledge 'Green' buildings as a way of life and seem unable to resist the temptation of maximizing profits on every investment we make and here lies the problem where buildings are seen as an element of economics and not as a humane shelter.

Economics is the force that keeps the world as we know it moving and Property developments and Real Estate are important cogs in the wheel of global economics and as the present recession has shown dramatically, supports millions of people around the world. But somewhere, someone has to draw a line between that which is economically viable and that which affects our very lives directly. Many developers are skeptical about the overheads incurred while employing 'Green' practices. But with growing popularity and a renewed awareness of our planets fragile position, a lot more players are entering the market and in the coming years, competitiveness will ensure that environmentally friendly construction will be budget friendly as well. A lot of speakers at the many conferences around the world are keen on driving home the fact that 'Green Designs' may cost marginally more at the moment but it cannot be denied that they have a huge impact on cutting energy bills and ensuring that the payback period for the initial investment is within economically acceptable terms.

However when one considers a market such as Dubai that is hailed as the Architects Playground, where unlike most major cities around the world, bound by strict rules and regulations that limit the creative expression of architecture on general buildings, Dubai offers a fantasy world to the architects, a blank canvas where they are given the license to explore ideas bound only by their imagination. As a professional architect working in Dubai, the opportunity to work on several ‘projects of a life time’ in a single career is blemished by the realization that much of the buildings in the region simply do not belong here. The Global character of architectural expression imitates successful models in less extreme environments without making necessary adjustment to adapt to the site conditions.

The real dilemma, here perhaps, is the conflict in the vision of an architect, one of sleek, glazed and smooth structures which reflects literally the ego and ambitions of the architect and Client alike. How then can one incorporate a more articulated façade that has shading canopies and punctured fenestrations? Is there an alternative to glazing that will offer the same smooth and sleek aesthetics while offering bio-climatic solutions to the weak spot in the building’s defense against the elements?

Ignoring the obvious and ominous warnings from the experts and carrying on building sealed glass boxes pretending that it is a sign of modernization and globalization could be to our own peril. James Wines (2000, Green Architecture, Taschen) wrote of the growing perception of Buildings as “machines to live in” (Le Corbusier, 1887-1965) since the Industrial Revolution. The problem perhaps lies in the misconception of architects and developers of buildings as an extended form of art and a commodity. If we are to have a chance of reviving the health of the planet’s eco-system one has to find a more Bio-Climatic solution to the way we design building facades.

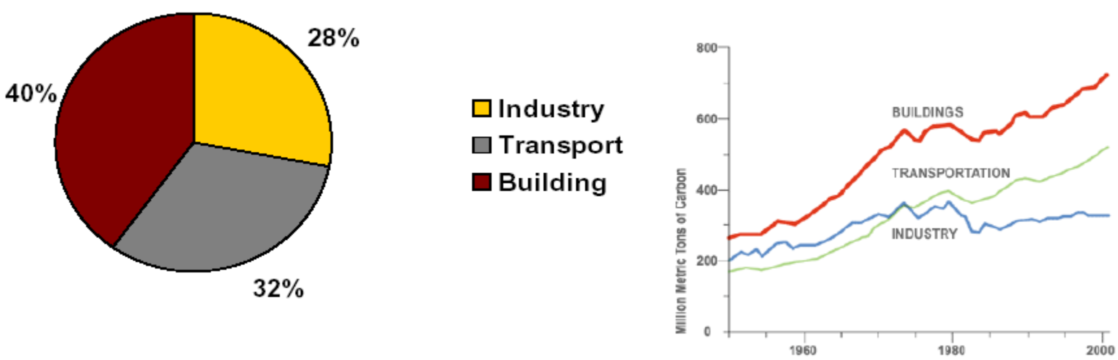


Fig 1.1 Global Energy Consumption by Buildings Charts,
Image Source- IEA, Bio-climatic Facades, Somfy, Living Architecture Conference, Dubai, 19th Jan 2009, www.somfyarchitecture.com

1.2 The Bio-climatic approach –

First introduced by the Olgyay Brothers in 1963, the term Bio-climatic Design can be defined as a climate sensitive approach to design where the design takes into account the climatic conditions of the site and works with nature to create comfortable indoor spaces for human activity. Although the Olgyay brothers established Bio-climatic charts (Design with Climate- Bio-climatic Approach to Architectural Regionalism, 1963), it would be worth noting that any given site will be unique to itself, as it will also be affected by its immediate and neighboring topography. This means that architectural solutions to the site should also be unique in response to the existing conditions. Hence to assume that Buildings built around the world should be similar in design and use as a result of Globalization would mean expecting people living in a desert to wear heavy fur coats like their counterparts in the Arctic all throughout the year.

Before the advent of curtain walls and air-conditioning, for centuries human civilizations around the world have built structures grounded in passive design strategies that responded to their specific climatic conditions and also influenced the rich and diverse growth of culture and regional architecture. Houses built in Europe, the Middle East and the Indian Sub-continent not only looked distinctly different, they also adapted to their respective climatic conditions quite efficiently. A closer look at nature also reveals an infinite source of information and inspiration for climatic adaptation that could help us embrace sustainable development.

The USGBC asserts that 'Green Buildings' helps improve productivity of workers by 16%,which maximizes the return on operation costs in office buildings, which apart from HVAC and Lighting constitutes a large portion of a Building's associated cost over its lifetime. With the help of on-site renewable energy generation technologies, firms like Atkins are targeting even 60% energy savings and more in high rises. It is then a matter of significant priority that buildings are designed and built to respond to the local climate and the use of bio-climatic facades could help achieve better and more energy efficient thermal control in buildings. Firms such as Arup and Somfy are developing thermal control solutions such as operable blinds and dynamic facades that can be adopted into urban architecture and growing interest in such solutions can be seen around the world. In this research, the design and practicality of using bio-climatic facades to help reduce heat gains in buildings in an extreme Hot Climatic region will be studied and analyzed.

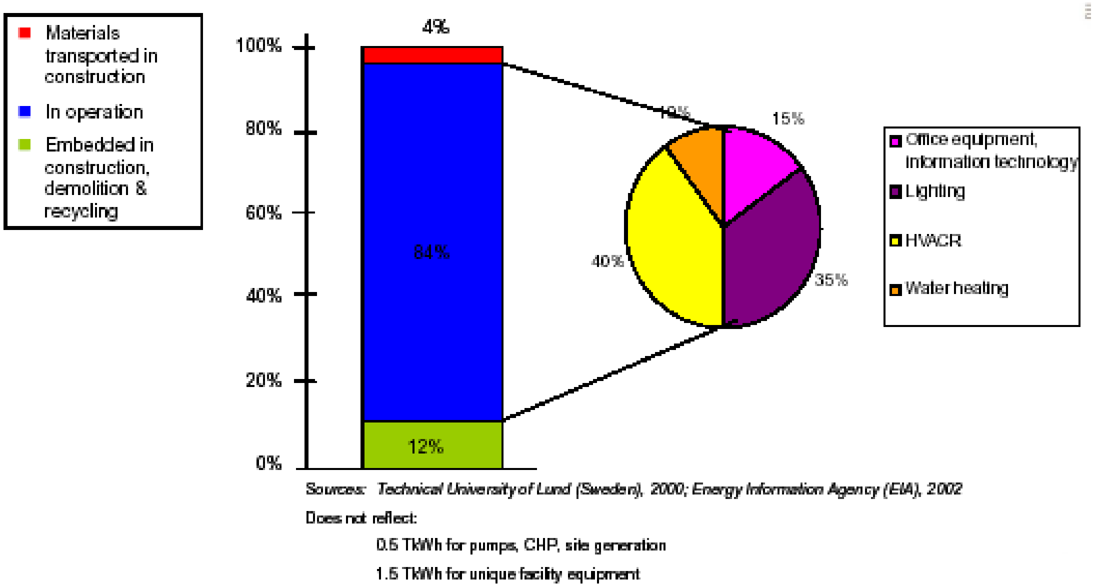


Fig 1.2 Life Cycle Energy Consumption for Buildings Charts,
Image Source-EIA-2002, Bio-climatic facades, Somfy, Living Architecture Conference, Dubai, 19th Jan 2009, www.somfyarchitecture.com

1.3 Dubai- the city of architectural anomalies?

The city of Dubai offers an interesting site for this research as its incredible transformation from a barren desert to a modern global city has raised a lot of uneasy questions. The exponential increase in the number of skyscrapers fighting for attention on the city's ever changing skyline has replaced the traditional architecture of the region and the ensuing debate on the loss of heritage and identity of the city has always evoked a wide array of emotions. But from an architectural point of view the construction of highly glazed towers has completely ignored the lessons from the rather successful passive design strategies that the indigenous craftsmen used to survive the harsh summers without any modern day technology or even electricity.

Industry experts like Mr. Jayasuria V, Senior Associate Mechanical Engineer, RMJM Middle East, claim that almost 75-80% of a buildings energy demand in Dubai is related to HVAC, much more than the 40% (EIA, 2000) in the cooler western nations. This shows the need for a careful introspection in the way that facades are designed in the regional urban context. Although the need for mechanical ventilation and cooling cannot be eliminated completely, sensible design practices could help reduce the dependence on the same. Today highly glazed towers, some with even 100% of their facades glazed are common sights in Dubai and it has to be wondered whether these are sensible designs backed by a research of the local climatic conditions or just gimmicks glorifying the role of aesthetics over common sense.

Dubai can experience extreme summer peak temperatures in the high 40s with the highest recorded at almost 50º C and the average winter temperatures are in the low 20s, the lowest recorded just below 10º C. The average relative humidity level in the city is 60% but can go up to 85% and more. These conditions could be found prevalent in more countries in the future with rising global temperatures. Hence it is quite a source of motivation to try and tackle the problem of proper façade design. With the number of people migrating to cities in search of a better economic prospects increasing, and the fact that the bulk of the planets human population lives in Tropical regions, this research aims to address a key issue in the pursuit of a more sustainable future.

Fig 1.3 View of Sh. Zayed Road, Image Source- Personal Archive, Jidesh Kambil

2.1 Evolution of Facades –

From caves to modern skyscrapers, the human abode has undergone a fascinating journey of transformation. It has evolved from primarily a protective boundary against the wild outdoors to a medium of aesthetics and cultural expression (Christian Schittich, 2006). Today the building skin or façade is the deciding factor that helps an architect sell an idea to the client. In a world obsessed by glamour, the form and beauty of a building takes the spotlight, at times compromising the integrity of the design.

As humans moved out of caves, the first building skins were erected to protect its inhabitants and fenestrations were to a minimum. The construction was simple and civilizations as old as the ones in Harappa (2550 BC) and Mohenjodaro (1700 BC), one of the most well planned cities of its time used bricks to raise its structure. Bricks were the first building blocks of architecture as evidence points out in ancient Mesopotamia. (Jonathan Glancey, 2006). Together, Mud, Earth Blocks, Bricks, Timber and Stones paved the way for durable shelters and settlements that became possible with the advent of agriculture. It was the early Romans who first discovered the potential of concrete, using it to create large spanning structures. Often, local availability of the materials determined the extent of their use.

The facades were heavily decorated with frescoes and carvings and the use of external arcades and galleries further added interest to them. But it was not until the Gothic monumental churches built in the late Medieval age (1400 AD), that the use of large glazed openings first saw light. A complex composition of “ribs, vaults, masonry surfaces, flying buttresses and pillars”(Christian Schittich, 2006), these facades were detached from the need to shoulder structural load, allowing large glazed windows that let in light while the use of colored stained glass created backlit patterns on the inside which were used to portray a message or simply create an attractive façade. (Jonathan Glancey, 2006)

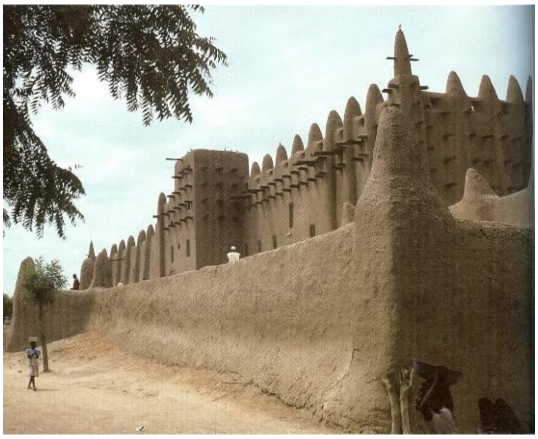


Fig 2.1 Mud Walls of Great Mosque- Mali,
Image Source- Green Architecture, 2000, Taschen

Fig 2.2 Laterite Stone Walls in Rural Kerala,
Image Source- Personal Archive- Jidesh Kambil

Fig 2.3 Stone Walls and Flying Buttresses - UK,
image Source- Personal Archive- Jidesh Kambil

Fig 2.4 Stained Glass Windows in Gothic Church,
Image Source- Architecture, 2006, Dorling Kindersley, Great Britain

Buildings of more domestic functions however still had smaller windows often protected with the use of wooden shutters, blinds, screens, and curtains. Considered an expensive material in the Medieval Period, Glass became a popular material after the onset of the Industrial Revolution in the 19th Century. The emergence of the use of Iron along with the mass production of Glass (Christian Schittich, 2006) soon took the world by storm and the newfound 'transparency' in the structures that followed made it a desirable quality in public spaces.

In the late 19th Century, a flourishing economy and real estate economics in Chicago paved the way for the introduction of the first high rises. Use of ‘steel frames’ and the invention of ‘elevators’ made it possible to scale previously impossible heights, but the use of load bearing technology was a handicap to the progress being made and led to iron and glass dominating larger spans of the façade while most architects remained loyal to the decorative stone facades reminiscent of the past. The Reliance building (1894) designed by Daniel Hudson Burnham and the Schlesinger and Mayer Store (1899) designed by Louis H Sullivan exhibited more transparent facades, clearly divided by horizontal bands co-relating to the floor slabs creating clean visual lines (Christian Schittich, 2006)

Fig 2.5 (From Left) Bauhaus-1919, IBM Plaza-1967, Lake Shore Apartments-1958; Early Eamples of Glazed Facades in Modern Architetcure, Image Source- www.wikipedia.com

Through the installation of a transparent skin absolutely detached from the role of load bearer in Fagus Works (1911-19) at Alfeld-an-der-Laine, Germany, and the exposed glazed corners at Bauhaus (1919), Walter Gropious (1883-1969) gave the first glimpse of the “curtain wall” that would redefine the way that building facades would be designed and built in the future. Post World War I, the need to break free from the regimes of the past lead to clean facades abandoning all forms of decorative elements and architects like Ludwig Mies van der Rohe (1886-1969) came to the fore. In 1951, Mies succeeded in his first high rise with curtain walls in the form of the Lake Shore Drive towers in Chicago and later designed the Seagram Building in New York (1958) with tinted glazing, leaning away from the move towards transparency. The Lever Building

(1952) designed by Skidmore, Owings and Merrill, displayed facades with clean lines of 'polished stainless steel profiles' together with 'semi-reflective glazing with an iridescent blue-green sheen' creating a lightweight and detached appearance from the structural members giving rise to the totally sealed building forcing it to depend unconditionally on mechanical ventilation and cooling. This would be the beginning of an age dominated by sealed glazed boxes that resulted in energy hungry buildings. (Christian Schittich, 2006)

At the same time though architects like Frank Lloyd Wright, Louis I Kahn and Alvar Alto, would experiment with exposed bricks, concrete and natural stone and create styles of their own that maintained the integrity of the design with its function.

Fig 2.6 Brick Walls in IIM Ahmedabad by Louis-I-kahn
Image Source- http://iimahmedabad.batchmates.com

Fig 2.7 Brick Walls in Baker House by Alvar Alto (1948)
Image Source- www.wikipedia.com

Fig 2.8 Organic Architecture in Guggenheim Museum by Frank Lloyd Wright (1959)
Image Source- www.wikipedia.com

Since the late 1980s, architects such as Tadao Ando, Herzog and De Meuron, David Adjaye, Frank Gehry and Rem Koolhaas, have re-introduced a variety of material with a wide array of visual qualities, bringing back interest in the building façade with the intention to use the material in its natural form. Today the façade also serves as a medium for displaying information. The use of new age materials like ETFE, electro-chromic, glazing, steel meshes and ceramic cladding is once again redefining the building façade.

2.2 Bio-climatic Facades in Traditional Architecture-

“The control of nature is a phrase conceived in arrogance, born of the Neanderthal age of biology and the convenience of man” – Rachel Carson, 1962

“To a rational being, it is the same thing to act according to Nature and according to Reason.” –
Marcus Aurelius Antoninus.

Architecture in the past has traditionally been bio-climatic by default as they strived to create internal comfort without the use of advanced technology and simple electricity. All around the world, regional indigenous design elements helped in creating suitable environmental filters that were harmonious with nature. Passive design strategies such as canopies, roof overhangs, screens or jhalis, inner courtyards, building orientation and protected balconies and verandahs have helped in achieving comfortable internal spaces, but the facades themselves have also played an important role in achieving the same. Motivated by need more than a conscious stride towards ‘eco-philosophy’ according to Wines (James Wines, 2000), most early settlements however developed sustainable building technologies based on available resources and existent skill sets. Cultural beliefs in most ancient civilizations were deep rooted in the recognition of the impact and role of nature in our lives and people respected it unlike the materialistic mind-set of the modern individual where the pampered ego of man makes him believe he is in control and that the building is just ‘a machine to live in’ as suggested by Le Corbusier . Below, some of the climate responsive façades that have been developed in various climatic zones are discussed.

2.2.1 Traditional Romanian Houses (Cool Temperate Climate)-

The country of Romania situated at latitude of 45ºN, experiences extremely cold winters and hot summers. It receives predominantly strong and cold winds from the northwest and is prone to snowfalls. With a varied topography consisting of Mountains, Hills and Plains, the climate can vary from region to region.

Petrasincu and Fara (Nicolae Petrasincu and Laurentiu Fara , 2006) in their study observed that a lot of Bio-climatic principles were followed in the conception of rural Romanian Traditional houses. Optimal orientation of the buildings on site to take advantage of the solar gains with most entrances and fenestrations facing the south side, while the North façade is relatively solid and generally devoid of any punctures or fenestration in the masonry. The windows and doors are usually small in size and are designed to reduce heat loss in the winter. Glazed panels with timber frames are generally used and also timber is used for doors and doorframes.

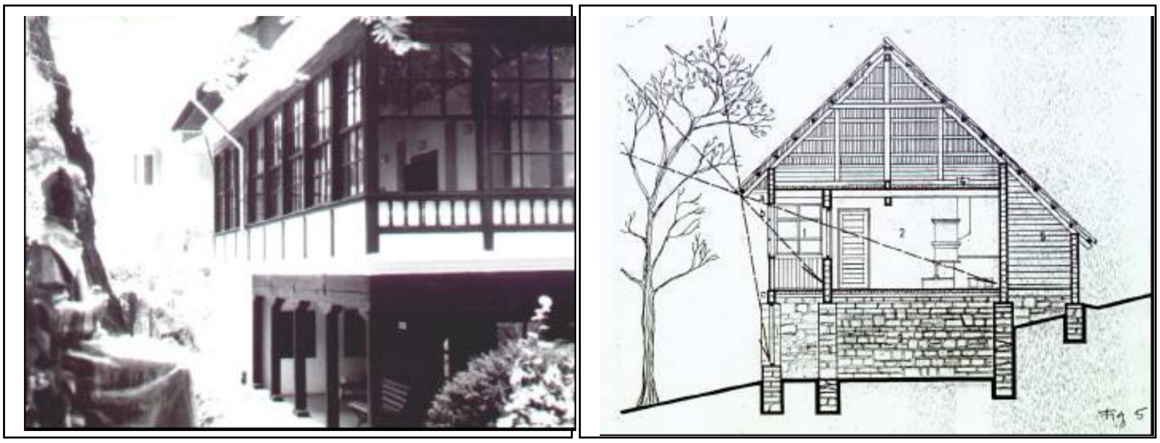


Fig 2.9 and Fig 2.10 Use of Porch in Romanian Houses, Image Source- Bioclimatic Elements for Traditional Romanian Houses, Nicolae Petrasincu and Laurentiu Fara , PLEA2006

The presence of a porch with flexibility in use is also common with detachable glazed panels on the south facing porches in order to exploit the heat gain during the frigid winters. The walls were built with bricks, with the available resources determining the extent to which they are burnt, large trunks of wood and a coating of clay on the internal surface. These have a high co-efficient of 'thermal transfer' and sound 'thermal inertia'. The use of seasonal trees have been used to good effect in the South side.

The façade in the traditional Romanian Houses is a climate sensitive environmental filter that takes advantage of local resources and skills to create a sustainable structure that helps to create comfortable inner spaces. Petrasincu and Fara (Nicolae Petrasincu and Laurentiu Fara , 2006) claim that the goal of reduction in consumption of 'conventional energy' by 40% to 50% is attainable

2.2.2 Traditional Architecture in Kerala (Tropical Climate) –

Kerala is a South Indian state situated on the southwestern tip of the Deccan Peninsula. It enjoys a Tropical climate with hot and humid summers and cool winters with the annual Monsoon from mid-June to the end of October bringing long wet spells that sometimes stretches for days. During a case study of vernacular architecture in Kerala in 2000, it was observed that Bio-climatic principles were followed in construction of buildings. The traditional courtyard houses celebrated a harmonious celebration of nature and not isolation from it.

Protected from the wet weather by sloping roofs with generous overhangs, the walls of the houses were built of locally available Laterite stone or burnt bricks. The wall thickness measured from 350mm to over 600mm creating a massive environmental filter that had a high co-efficient of thermal transfer and thermal inertia. Timber panels were used in order to enhance aesthetics but also it is believed to be a good absorbing agent for atmospheric impurities and water vapor. Masonry was either exposed or plastered with Lime or more recently with paint.

Wood plays a very important role in traditional architecture in the region as it is used to build roof rafters, floors and screens. Wooden screens play a very important role in providing thermal control and at the same time offered privacy as the cultural system made it necessary to have some spaces reserved only for the use of women in the house. In the ground floor the doors and windows were made from solid wooden panels with teak being the preferred wood of choice for the main entrance as this offered strength and security.

Fig 2.11 Traditional Architecture of Kerala
Image Source- http://www.healthyholidayskerala.com

Fig 2.12 Courtyards in houses in Kerala
Image Source- http://s306.photobucket.com

In the upper floors, the walls were generally protected from the external elements by roof overhangs and wooden screens. Wooden screens, in some cases, provided solar shading to the protected inner spaces above where the walls of the rooms were set in by a corridor of around 800mm or more from the face of the wooden screens ensuring that the rooms do not get direct solar gains but at the same time light can filter through and also allows for natural ventilation to circulate within the space. The doors and window shutters were made of wooden panels and louvers. This helped to create a protected area away from the scorching summer heat that is well ventilated naturally. In homes where there are inner courtyards, the same design is sometimes seen on the side overlooking the courtyard as well with screened lounge spaces that offers privacy yet visual connectivity to the courtyard.

Fig 2.13 and Fig 2.14 Use of Wooden Screens in Facades,
Image Source- http://www.rocksea.org/images/kerala; http://binbrain.com

Vernacular architecture has been practiced and perfected in Kerala for centuries and still continue to be an important feature of the local architectural scene. The use of local materials like the Laterite stone, bricks and abundant timber and skill sets helped sustainable construction of climate responsive architecture and the bio-climatic facades serve as an eco-friendly environmental filter that lasts the test of time and creates a cool and comfortable internal environment. The solid wooden fixtures and panels are much sought after even today and have been acquired and reused in a number of projects. The durability of the materials used for facades ensures that they are not wasted and can continue to serve future generations in a constructive manner.

2.2.3 Traditional Architecture in Dubai (Maritime Desert Climate) –

Situated at 25.2697° N 55.3095° E, the coastal city known as a trading hub and for the art of pearl diving, Dubai has over the last decade been transformed from a barren desert land to the most successful global cities. Dubai faces scorching summer temperatures with average range in the higher40's with maximum recorded close to 50ºC. Winter temperatures feature around the low 20s with the lowest recorded temperatures just below 10ºC. A noticeable drop of between 10 to 20ºC can be observed between daytime and nighttime temperatures. The coastal areas experience land/ sea breeze with North-Northwesterly winds during the day, replaced by South-Southeasterly breezes at night. Occasional strong gale force winds called Shamal strikes from the North around the months of May and June. Relative Humidity levels are at around 60% or more during the morning and evening while the midday sees a drop in the same as the air gets heated up. Sandstorms are another feature of this city along the Arabian Gulf. The natural topography consists of mainly deserts, and coastal plains. Further inland, hard, rocky mountains and wadis or stream beds can be found. Owing to its geographical location, the city receives intense solar radiation of about 600 W/m^2. Daylight is available for around eight to eleven hours a day, highlighting the potential to exploit it for lighting purposes and to generate solar energy.

Little of Dubai’s traditional architecture can be seen today but during a case study at the Bastakiya area that houses preserved indigenous buildings of the ancestral inhabitants of the land. These buildings offer an insight to the lifestyle of the earlier locals and their craftsmanship. They offer good examples of bio-climatic solutions to the most extreme climatic conditions around the world. During a case study in October 2006, temperature readings taken both inside and outside showed a drop in almost 4º to 5ºC on the inside.

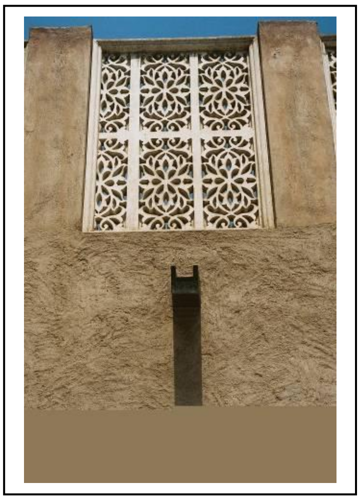
The houses following courtyard planning, had the walls facing the courtyard protected by colonnades or arcades, concealing it from the severe summer sun. The walls were found to be between 550 to 600mm thick. They were made of Coral stones that are porous in nature serving as good insulators. They were coated with mud plaster, which lent a cooling effect to the structure. Once again it is the local availability of resources and its sustainable implementation that comes to the fore. The rough texture of the external plastering helped reduce reflectivity and cut out glare. Timber was also used, which, it is believed to have been imported mainly from India, to build the roofs, windows and door shutters, protective screens and pillars. Untreated timber was used for its good acoustic and thermal insulating properties and as it is believed to absorb moisture from the atmosphere.

Fig 2.15 Courtyards in Traditional Homes in Dubai
Image Source- Personal Archive- Jidesh Kambil

Fig 2.16 Shaded Passages
Image Source- Personal Archive- Jidesh Kambil

The fenestrations on the outside wall are very small and used only where necessary to let in light with the majority of the wall openings facing the protected inner court. This provided security and also kept out the harsh elements of nature. The external façade is mostly plain and devoid of decorative elements in keeping with the teachings of the Islamic culture which preached modesty with only the main entrance doors, crenellated parapets, air-pullers, screened galleries and wind-towers offering outlets for creativity. In places where upper floors are constructed, screened balconies or galleries are provided at heights of 1.5m to 1.6m. These screens were inclined inwards adding to privacy and this helped the upper rooms with low windows closer to the ground to be opened at night, helping wind circulation as most activities like sitting and sleeping were done close to the ground and not on raised couches or beds. The screens ensured that onlookers from the street could not stare into the rooms above.





(From Left) Fig 2.17 Façade Materials-Coral Stone and Mud Plaster, Fig 2.18 Louvred screens protecting fenestrations in facades, Fig 2.19 Crenellated Parapet
Image Source- Personal Archive- Jidesh Kambil

Terraces were used for sleeping in most houses and here too the parapets built at heights of 1.3m to 1.6m had specially designed niches to let breeze flow while providing protection. The external walls enclosing rooms sometimes had special niches built into them with provisions for additional lighting and ventilation facilitated by small openings catering to activities close to the ground while niches higher up were used for storage. The doors opening into the galleries had decorated grills above it enabling filtering in of light and ventilation even when the doors were closed. The entrances to stairs were usually set deep allowing for our eyes to adjust to the changing light levels in a gradual manner.

Fig 2.20 Niches in Parapets to direct breeze
Image Source- Personal Archive- Jidesh Kambil

Fig 2.21 Niche for Wind Pullers on external Facade
Image Source- Personal Archive- Jidesh Kambil

Another ingenious design element was the air pullers, built into special niches in the masonry. This provided aesthetic relief to the external façade while on the inside it served as source of indirect lighting and ventilation. In addition to livening up the internal spaces, it brought in daylight without the need for large window openings, and a source of cool drafts of air making the indoor spaces more comfortable. Most of the activities like cooking are usually carried out in the courtyards, with the rooms used mainly for resting.

(From Left) Fig 2.22 Wind Tower, Fig 2.23 Air Vent above doors, Fig 2.24 Openings in Façade to let in light and ventilation.
Image Source- Personal Archive- Jidesh Kambil

Aided by master-planning that enabled maximum distribution of wind through the narrow lanes, with broader lanes along the North-South direction and narrower lanes along the East-West direction that also provided shading during most part of the day, with intermittent open spaces between the clusters, and wind-towers designed to catch wind flowing at a higher altitude and re-directing it inside the building, the traditional buildings in Dubai offered sustainable bio-climatic solutions to counter the extreme climate in the region with limited resources and indigenous skill sets.

2.2.4 Highlights of Traditional Bio-climatic facades –

- Locally available materials and resources like stones, bricks, clay, timber and indigenous skill sets have been used for construction.
- Construction was simple, sustainable and mostly load bearing in nature.
- Deep understanding of climate and forces of nature was common.
- Facade design was characterized by the building orientation with respect to the site
- Thick walls were used to create greater thermal mass to delay the transmittance of heat from the external surface to the internal surface.
- Fenestration in masonry were small and used minimally to reduce heat gain/ loss
- The use of screens, protected galleries and louvers were popular and used to provide shading, privacy and ventilation
- Using limited technology, they came up with innovative solutions to counter the external elements and create comfortable internal spaces that were sustainable and connected to nature.

2.2.5 Drawbacks of Traditional Bio-climatic facades –

- The walls were massive, took a lot of space from the floor area and were heavy in both cost and weight.
- The use of load bearing technologies made it difficult to build high rises.

- The small fenestrations made it difficult for light to enter, creating dark and dim lighting conditions at times.
- The designs were a reminder of the past and the failed regime of previous civilizations.
- The designs were seen as limiting and arresting in terms of artistic expression of the architect and the ambitious human mind.
- The lack of reliable humidity and moisture control led to damp internal conditions in structure built in wet climate zones.
- The use of natural materials made it prone to attack from pests unless treated properly.

2.3 Static Bio-climatic Facades in Modern Architecture –

Post World War I construction saw the rise of a more mechanical and industrial era of architecture as faster, more easily repeatable construction methods were adopted to erase memories of the failed regimes of the past. (James Wines, 2000). With the rise of curtain walls, initiated by Walter Gropious (1919) and sealed glass boxes introduced by Skidmore Owings and Merrill (1952), the general public were treated to an architecture of clean lines and unprecedented levels of transparency in facades, creating bright internal spaces, and soon saw it as the answer to the traditional bio-climatic facades, fast becoming outdated. As this energy hungry model of construction became the dominant symbol of growth and prosperity all around the world opening up to globalization, few architects continued to defy the norms and explore creative solutions to the problems of modern architecture. Some of these architects from a long list of creative geniuses and their works are discussed below. The solutions discussed below are extensions of traditional bio-climatic designs and strategies that have evolved over time and are fixed solutions that remain unchanged throughout the year and are hence referred to as ‘static’ as against ‘dynamic’ solutions as discussed in segment 2.4.

2.3.1 Falling Waters, 1939 - Frank Lloyd Wright (1867-1959) – Organic Architecture –

Built at Bear Run, Pennsylvania, the residential masterpiece is hailed as one of the finest works of the Master architect, claimed to be a voice of reason in a world where architecture was slipping into sealed boxes of many geometric forms. Wines (James Wines, 2006) wrote of Frank Lloyd Wright as “the pioneering force behind Organic Architecture”. Wrights vision of architecture incorporated with its environment, where the functions embodied in a space mimed natures approach to similar objectives.

In Falling Waters, Wright used both Limestone and Concrete to create a structure that made the most of the materials and their properties. While Limestone was used for the vertical walls, the cantilevered terraces were built in Concrete. By understanding the qualities of both the materials
Wright was able to use them in a manner that justified the choice of material while at the same time achieving an aesthetic building.

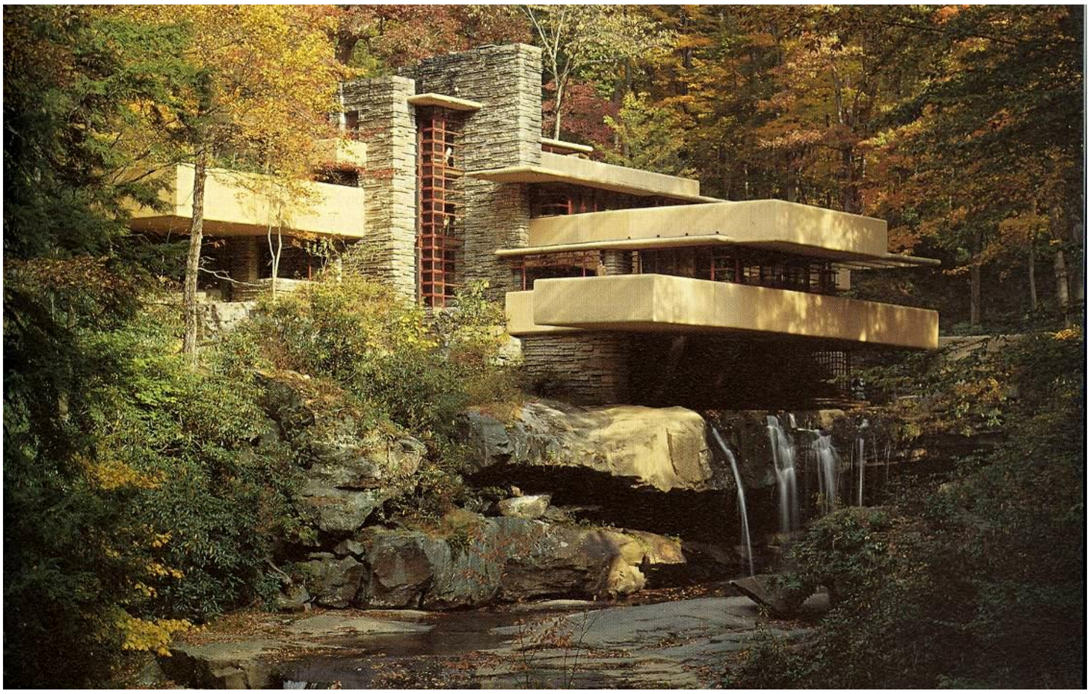


Fig 2.25 Falling Waters by Frank Lloyd Wright, Image Source- Green Architecture, 2000, Taschen

The Lime stone added thermal mass to the façade, which helped in regulating the internal temperature while carefully placed generous glazed openings made use of daylight to create a well lit space that was protected from excess solar radiation by the cantilevered Concrete terraces. This house built in a rocky terrain over a running stream of water took the living spaces as close as possible to nature creating a harmonious convergence of built form and nature.

Falling Waters provides a good example of modern architecture that is sensible and sensitive to the environment around it. The design made use of locally available resources but the design may not appeal to everyone, as the constant noise of the stream could be distracting for some. The basic strategies employed here could be applied anywhere in the world in building an environmentally responsive structure using local resources. But the use of thick walls to improve the thermal mass would not necessarily be applicable in urban high rises.

2.3.2 Centre for Development Studies, 1971 - Laurie Baker (1917- 2007) – Regional Urban Architecture for Tropical Climate–

Laurie Baker, often referred to as the Gandhi of Architecture, took the indigenous craftsmanship and construction principles in Kerala and developed it into a brand of his own, a regional urban architecture that delivered the essentials without fuss and fanfare. His works embodied modesty and down to earth approach. The public appreciated the low cost construction, as it was a style that catered to the common man and his lifestyle.

At the Centre for Development Studies in Thiruvananthapooram (Trivandrum), the capital of the South Indian state of Kerala, Laurie Baker used locally available materials and centuries old building technology to create an example of true regional Urban Architecture, that had an identity of its own in a growing Modern India coming to terms with the effects of Globalization. The campus built over ten acres of land is host to facilities for academic and residential purposes.

The walls are built in exposed Bricks made from the abundant red clay soil present in the region, with lime mortar. Use of Concrete is limited and filler slabs are used with burnt-clay products such as tiles and bricks used as the filler material. The Brick walls range from 230mm to 350mm in thickness and owing to its high thermal mass prevents excess heating up of the internal spaces.

Fig 2.26 Brick Walls of Center for Development Studies
Image Source- www.lauriebaker.net

Fig 2.27 Brick Jhalis of Center for Development Studies
Image Source- www.lauriebaker.net

The sun-path direction in India is predominantly more intense along the Southern side. The South side of the façade is protected by a brick screen or jhali connected to the room walls by a corridor giving extra protection from direct incident solar radiation and the resulting heat gain. This also allows for a protected well-ventilated access to the rooms, which remained cool even during summers. Fenestrations facing the North directions are more generous taking advantage of the diffused daylight available, while the South façade served as mainly a source of natural ventilation but the jhalis ensure that some light does permeate into the spaces behind it. This offers a bio-climatic solution to regional urban architecture, which does not imitate styles from the rest of the world and is not confused about what it represents.

2.3.3 State Mortgage Bank building, 1976 – Geoffrey Bawa (1919-2003) – Bio-climatically Responsive Low Energy High Rise Building For Tropical Climate–

Built in the city of Colombo in 1976, the project was a brave attempt at creating a high-rise office building without any reliable sources of power available. Dr. Tan Beng Kiang and David Robson (2006) analysed this building to gather some insight into the design approach of the great Sri Lankan architect, Geoffrey Bawa. They noted that it was claimed by Ken Yeang as " probably the best example of a bio-climatically responsive tall building to be found anywhere in the world " (Keniger, 1996) and Robson (2002) stated that " the design offered a prototype for office buildings in a Tropical city ". The tropical climate in the island nation of Sri Lanka would be a challenging environment even with the latest technologies on hand, and yet more than three decades before the current outcry for sustainable and energy efficient designs, this Bio-climatic skyscraper made an impact in the city's skyline.

The building was oriented to ensure that the broader facades faced North and south directions as dictated by the Tropical climate while taking maximum advantage of the winds coming from the Northeast and the Southwest (Monsoon) improving ventilation. The façade was developed in an interesting manner. The building was a R.C.C frame structure with glazed windows spanning the distance between every two peripheral columns. 'Pre-cast Ventilation Grills and Slots' placed both above the glazed window openings and at sill level, allowed for unobstructed airflow, even in the scenario where the windows are not opened. These were sheltered from rain by 'overhanging floor slabs' and 'down hung fascia parapet'. The windows were pivoted vertically.

Cross ventilation of the office space was achieved by having 'pre-cast ventilation openings' that exited into the naturally ventilated lobby space and stair case cores which were pushed to the periphery and not centrally located as it is generally practiced. This allowed for provision of natural light and ventilation to the lift lobbies and stair cores reducing need for energy to run artificial lighting and mechanical ventilation.

Fig 2.28 Sate Mortgage Bank Building-Colombo, Image Source Bio-climatic Skyscraper-Learning from Bawa, Dr. Tan Beng Kiang and David Robson, PLEA2006

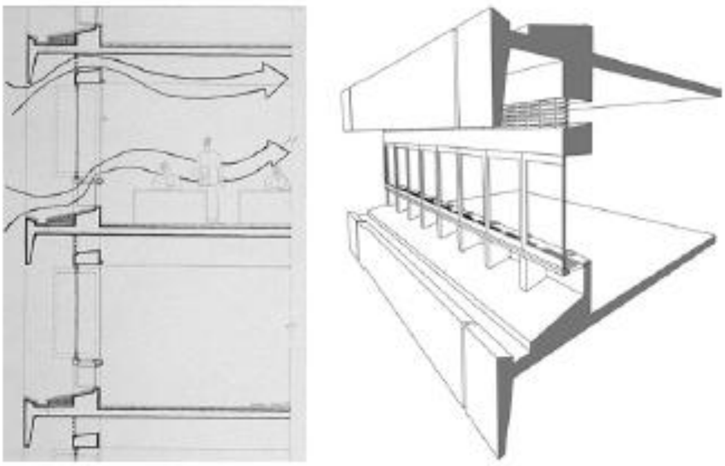


Fig 2.29 Detail of Façade S. M. Bank Building-Colombo, Image Source- Bio-climatic Skyscraper-Learning from Bawa, Dr. Tan Beng Kiang and David Robson, PLEA2006

The building users found the infiltration of dust and noise through the facades to be a problem as was the greater wind velocity in upper floors where handling paperwork became difficult. Much of these problem are a result of the mindset of the end user, and their unwillingness to adapt to the difference in conditions from across the world and the use of air-conditioning window units have

distorted the intended functioning of the building which created comfortable conditions in a tropical climate. Unfortunately though, the lack of effort from the expatriate professionals occupying the building now to adjust with the native climate and looking for home conditions in someone else's plot has led to the disfiguring of this novel design concept.

2.3.4 Jean-Marie Tjibaou Cultural Centre, 1998 - Renzo Piano – Culturally and Ecologically Responsive Structures for Warm Island Climate –

Located in New Caledonia a part of the French Oceania territory this masterpiece is atribute to architecture that celebrates its relationship to its context and environmnet. Integrating the wisdom of the indigenous people of 'Kanak Culture' (James Wines, 2000), Renzo Piano succeeded in collaborating the use of locally available resources, the best of the local construction techniques, contemporary methods and an eco-friendly approach to create structures of immense beauty and intrigue.

Treated Bamboo that can withstand the effects of the weather are used to create operable ventilators to control wind flow into the internal spaces. Bamboo is a rapidly renewable material and a very strong and sustainable alternative to timber and metal louvers. a series of these bamboo louvers and inner glazed louvres can be opened to permit windflow through the internal spaces or closed up in the event of extreme weather and storms.

The complex consisting of spaces for 'exhibitons, conferences, classrooms, lectures and cafeterias' (Jonathan Glancey, 2006) enjoys an image of cultural expression of the island while structurally achieving a fusion of both modern and traditional construction technologies. The success of this project highlights the simplicity of bio-climatic facades and proves that they are not a hindrance to acceptable and progressive aesthetics while being sensitive to the site and its context.

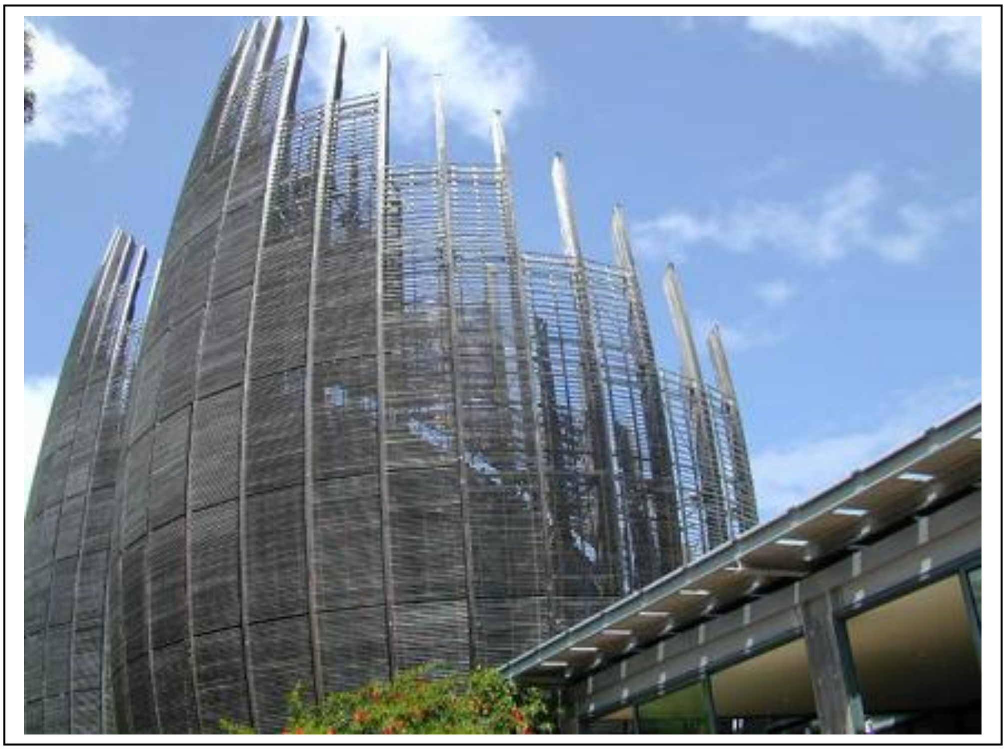


Fig 2.30 Tjibaou Cultural Center, Image Source- http://www.galinsky.com/buildings/tjibaou/cct-exterior.jpg

Fig 2.31 and Fig 2.32 Detail of Louvered Façade, Image Source- http://www.galinsky.com

2.3.5 IBM Plaza, 1987 and Menara UMNO, 1998 - Ken Yeang – Urban Bio-climatic High Rises for Tropical Climate –

Built in Tropical Malayasia, these towers are examples of the theory of Bio-climatic skyscrapers
synonymous with Ken Yeang. An advocate of integrated and inclusive high rises which are designed as vertical urban streetscapes with the addition of green spaces and sky gardens that helps create more humane environments inside traditionally machine like cold structures, Yeang has earned a reputation as the flag-bearer of the 'green skyscraper' campaign. (Ken Yeang, Reinventing the Skyscraper, 2002)

In their study on the performance of Ken Yeangs bio-climatic towers, Puteri Shireen Jahnkassim and Kenneth Ip (2006) analyzed the performance of the buildings with respect to daylight and heat gain using IES VE software to simulate models of the chosen buildings. They found that the performance of the bio-climatic towers were better than those of more 'generic' designs.

The IBM Plaza tower is oriented to have the broader façade facing the North and South sides while narrower facades are exposed to the East and West. The cores are also pushed to the periphery leading to lesser heat gains. The North and South facades are mostly glazed but are heavily shaded by the projected bands of opaque panels, asserting more control over direct incident solar radiation entering the building.

In the Menara UMNO, the Western façade is more exposed and is heavily glazed but once again they are heavily shaded with bands of metal clad projections starting from the floor slab level and extending downward to protect the glazing behind.

Although generously glazed with modern double pane glazed panels, the facades of these buildings succeed in limiting the amount of heat gain received through them by employing simple passive design strategies. These Bio-climatic examples of Ken Yeang show that urban aesthetics and modern and contemporary styling of building facades need not be sacrificed for the sake of sound climate responsive design. The bio-climatic approach helps to reduce the energy consumption of a building for cooling and ventilation by appropriate intervention of the intense solar radiation experienced in the tropics.

Fig 2.33 Menara UMNO building,
Image Source- http://www.thecityreview.com/sky39.gif

Fig 2.34 IBM Plaza building,
Image Source- www.wikipedia.com

2.3.6 Highlights of Static Bio-climatic Facades in Modern Architecture –

- Use of locally available materials, rapidly renewable materials and resources is common.
- Combination of traditional bio-climatic design elements and principles and modern technology is seen.
- There is a tendency to learn from the past and develop and adapt the ideologies to the modern era.
- Fenestration design and placement is governed by building orientation on site and the sun path pattern.
- High rises make up for use of transparent facades by using shading techniques.
- Natural ventilation is encouraged by use of operable glazed panels and ventilation grills.

- Understanding of the local climate and the site context makes the designs unique and sensitive to the environment.
- The bio-climatic designs are eco-friendly solutions and meet the needs and functions of the modern society in a sustainable and energy efficient way.

2.3.7 Drawbacks of Static Bio-climatic Facades in Modern Architecture –

- Allowances for natural ventilation makes it prone to infiltration of noise, moisture, dust and excess wind.
- The solutions employed to control penetration of solar radiation into the building limits the creative expression of the architect aiming for clean and smooth facades.
- They suffer from a perception of being non-progressive and non-futuristic in terms of aesthetics.
- The popularity of high rises means that the use of locally available materials like bricks, tiles and stones is restricted to cladding as maximum lease-able internal space is a priority and they add more weight to the structures.
- Limited use of fenestrations on facades receiving maximum heat gains reduces the opportunity to achieve views to the outside from all sides, which is a huge selling point in the property market.

2.4 Dynamic Bio-climatic Facades –

Since the 70's, voices of concern were raised in favor of a more conservative 'eco-centric' approach to architecture, only to loose way to the politics and economics that governed the thinking of the majority of the population at the time. Several technologies were developed to counter the growing energy crisis, but the application saw little popularity and stood out as isolated attempts for a greener world (James Wines, 2000)

Today the growing awareness of the precariously fragile state of the planet is bringing in a new wave of interest in the development and use of technology that helps to achieve energy efficiency. Experts specializing in solar control technologies are finding renewed encouragement in the market and this will inspire more actors in the market to exploit this new commodity.

Somfy, a collective group of companies and brand names with worldwide presence in over 51 countries, is an industry leader when it comes to automated openings and shading technology. From shutters, awnings, windows and blinds, they offer a wide range of solutions for optimization of user control of these essential elements that determine the performance of the façade in terms of thermal control and daylight control.

The Animeo range of 'control products' that cater to the window openings and 'dynamic shading' of building facades offers a series of sensors, that monitors the climatic conditions, and motor controls that operate the movable blinds and shading solutions. From simple homes to commercial office towers, hospitals and schools, the Animeo range has products that cater to every faced control need. They can be integrated with Building Management Systems with ease, linking the façade control devices to the lighting and HVAC systems in the buildings.

The Variosys range of Dynamic Bio-climatic façade solutions specializes in controlled 'indoor solar protection'. They consist of a series of motorized blinds that enables the user to attain maximum control over their internal environment by manipulating the transparency and shading of transparent building facades.

Alain Liebard and Andre de Herde (2008, Biocliamtic Facades, Somfy) assert that the occupant is at the core of bio-climatic design considerations. Their studies show that shading by blinds work best for thermal control if they are placed outside the glazing. They also discussed the options in dynamic glazing, or glazing that has variable physical properties that can be altered to achieve desired thermal transmittance characteristics. Electro-chromic glazing, is one where the properties of the glazed panel is switched between colored state and a transparent state, obtained by the application of electronic and ionic charges using an electrolyte over thin films within the external pane. Gasochromic glazing, containing a film gasochromic in nature which when in the presence of low concentrations of Hydrogen mixed with carrier gases like Argon and Nitrogen turns blue while it remains transparent in the presence of oxygen and is usually located on the internal side of the external pane in triple-glazed systems is another available dynamic glazing technology.

Mikkel Kragh (2008, ARUP) also spoke of the advantages and challenges of Dynamic Shading Systems. They usually work under the concept where the physical properties of the façade systems are variable and change in response to the conditions all through the year. The glazing is considered as a fixed entity with standard properties while the shading is seen as the variable element whose properties are changed to achieve desired results. Kragh (2008, ARUP) specified the targets of advanced façade systems as –

- The availability of Natural Daylight and light levels offering visual comfort.
- Access to external views.
- Achievement of thermal comfort levels.
- Creating results showing reduced energy demand for heating/ cooling and lighting.

It was also found that while external shading provided maximum benefits in reducing thermal gains through the façade, internal shading tends to increasing thermal gains as it can only absorb heat from incident sunlight after it enters the glazed enclosure. Using thick curtains and blinds in rooms that have heavily glazed facades is also counter-productive as the heat entering the room through the façade is trapped by the curtains and later released during night time. One solution that has been attempted in mostly European nations for facades that are highly glazed is Double Skin Facades.

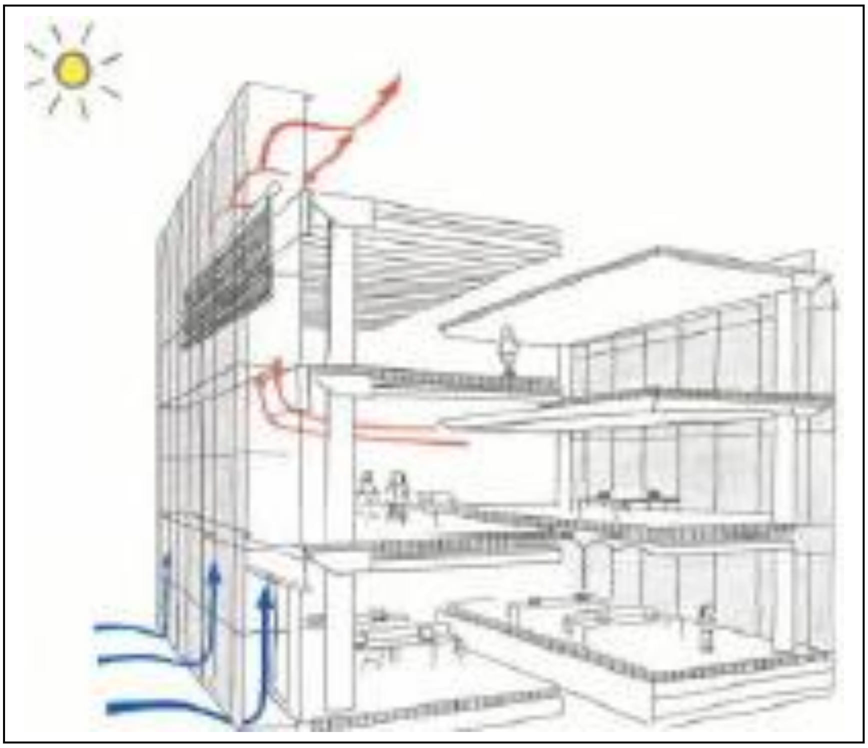


Fig 2.35 Sketch of performance of Double Skin facades,
Image Source- Bio-climatic facades, Somfy, Living Architecture Conference, Dubai, 19th Jan 2009,
www.somfyarchitecture.com

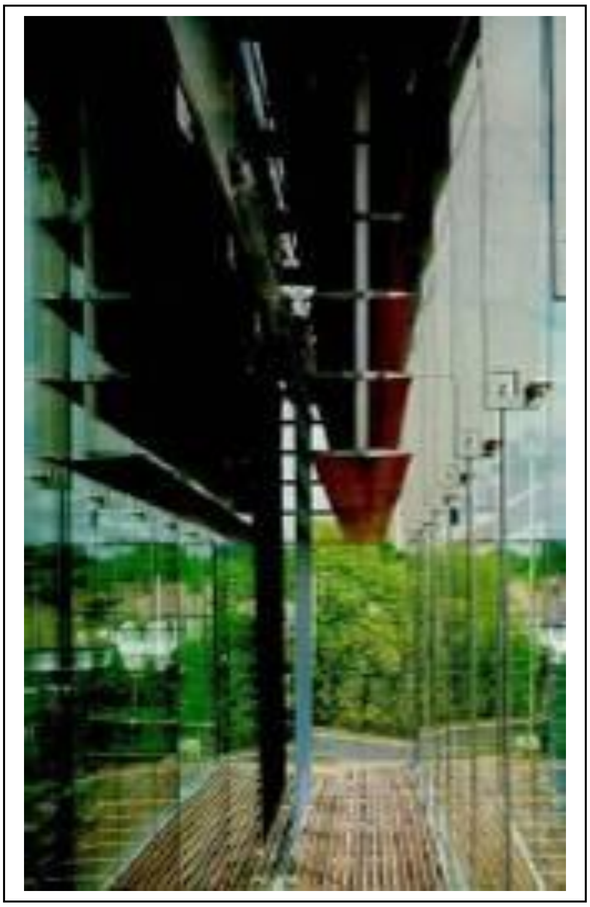


Fig 2.36 Example of Dynamic Shading in Double Skin Facades,
Image Source- Bio-climatic facades, Somfy, Living Architecture Conference, Dubai, 19th Jan 2009,
www.somfyarchitecture.com

Double Skin Facades consist of two glazed skins placed from 0.2m to 2m apart based on the design. There are various types of double skin façade systems such as

- **Naturally ventilated Double Skin Facades –** where the air inlet / outlet can be closed during winter and opened during summer to facilitate movement of air via the stack effect.
- **Mechanically Ventilated Double Skin Facades** – where the air in the cavity can be used to pre-heat the fresh air supplied to the Air Handling Units for cold seasons while in the summer, the heated air in the cavity can be mechanically extracted to prevent over heating of the space.
- **Hybrid Ventilated Double Skin Facades –** is a combination of both the naturally ventilated and mechanically ventilated systems.
- **Airflow Windows –** in this system, the spent air circulated inside the rooms is redirected into the cavity between the two glazed skins as exhaust.

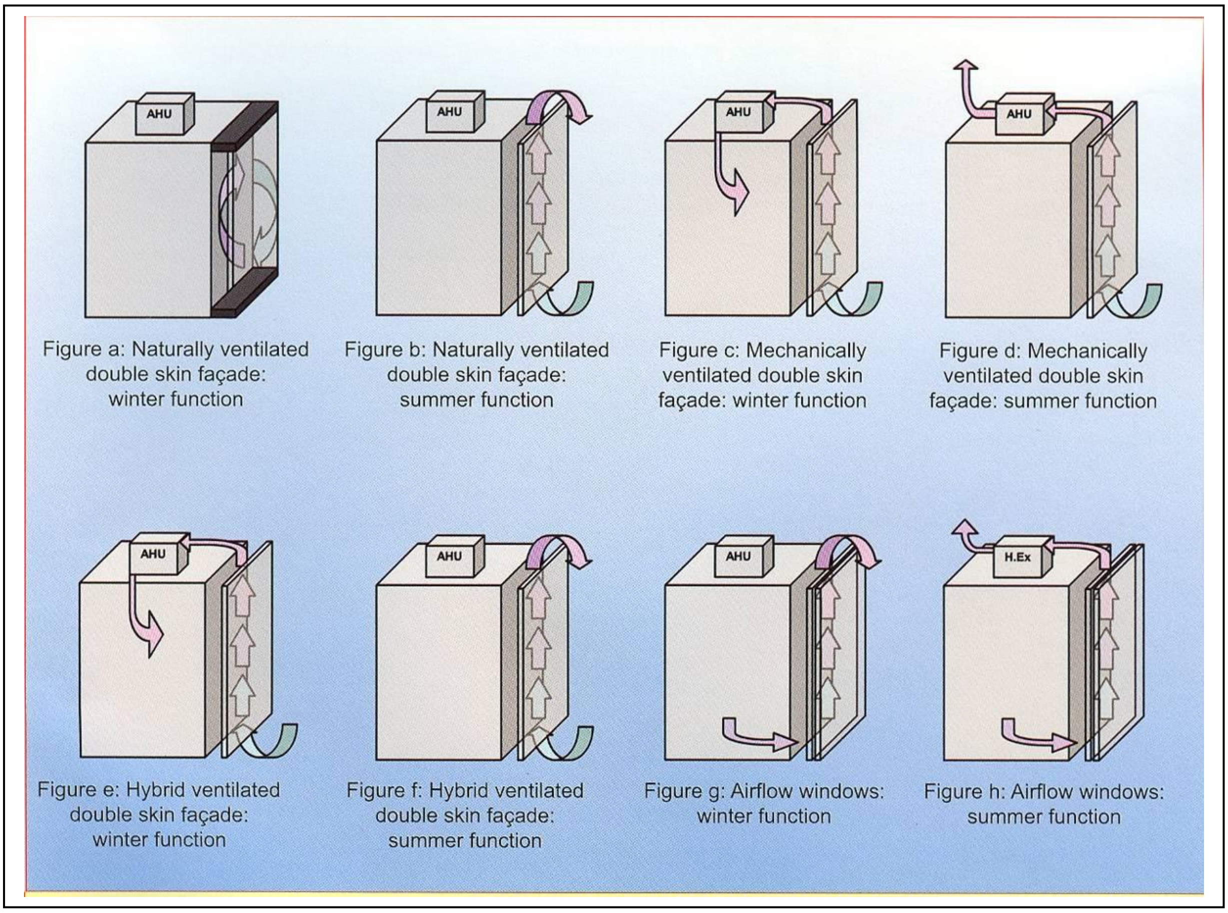


Fig 2.37 Types of Double Skin Façade Systems , Image Source- Bio-climatic facades, Somfy, www.somfyarchitecture.com

The use of shading devices like operable blinds and even the use of plants as shading elements makes the double skin facades more effective. Studies carried out by Hamza and Underwood (Neveen Hamza and Chris Underwood, 2005) reveal that double skin facades with ventilated cavities can help reduce heating of the internal spaces in buildings in Cairo. Double skin facades have undeniable potential but their success in a place like Dubai, which is both hot and humid needs to be studied further.

2.5 Green Facades –

‘Green facades’ are examples of man’s attempt to integrate nature into man-made structures and technology. The cooling effects of plants are well known and experienced by everyone fortunate enough to have had close encounters with vegetative elements of nature. During an earlier case study, it was found that surfaces shaded by plants tend to be up to 4ºC cooler than those exposed to direct sunlight. Plants lose water through pores in their leaves and this transpiration helps to induce a cooling effect by the phenomenon of evaporative cooling.

Researchers W. J. Stec, A. H. C. van Paassen and A.Maziarz (2004)- Modeling the double skin facades with plants, have explored the influence of plants on the performance of double skin facades and the possible creation of better indoor comfort and energy savings. For their study they had used crawling plants such as ivy after a preliminary investigation into the most suitable species of plants for the purpose. Various arrangements of plants within the cavity were discussed and their advantages and disadvantages weighed against each other.

Through laboratory testing, they found that the use of plants in the double skin facades had a 20-35% reduction in heat gain of air in the cavity. Through simulation models by using Simulink, they created thermal models represented by the heat exchange between layers of facades. Absorption coefficients, reflection coefficient and transmission coefficient (the ratio between average values of short wave radiation measured behind and before the plant) were calculated as 0.9, 0.1 and 0.45 respectively. In comparison, absorption coefficient value for front glass was determined as 0.07 and the back wall 0.10.

Further whole building simulation after validation of data from the previous step, led to the conclusion that installing plants in the double skin façade reduced the cooling load by @ 20%. It was also noted that they helped reduce air temperature within the cavity in the double skin facades.

Researchers G.Papadakis, P. Tsamis and S. Kyritsis (2001)- An Experimental Investigation of the Effect of Shading with Plants for Solar Control of Buildings, observed the shading effect of plants on buildings. Using instruments like a pyranometer, net radiometer, anemometer, heat flux meter, air temperature/ humidity meter, and three copper-constantan thermocouples to measure the temperature, wind and humidity factors on the site, they obtained data necessary to quantify the effect of shading by plants on the building. They concluded by noting that plants had a very positive shading effect and their proximity to buildings improves the internal comfort levels by reducing heat gain.

In the book Planting Green Roofs and Living Walls (2004, Timber Press), the authors Nigel Dunnett and Noël Kingsbury describes the concepts of green roofs and its many benefits including good thermal performance. They also explained the concept of Living Walls and their advantages. Examples of houses in Germany and France where plants like the Virginia Creeper and vines are grown directly on walls, a long established tradition in these parts, provide an insight into the feasibility of Living Skins. Alternate methods to have such skins grown detached from the main wall are discussed in the book. The fact that living walls are more effective than green roofs in improving the building environment owing to larger surface area is also mentioned. The scope to increase bio-diversity in the region is also an important factor to be considered.

In a case study report on ‘Bioshader’ by the Centre for Sustainability of the Built Environment, the University of Brighton, the noted that several research carried out on the shading performance of plants as against conventional means of solar shading such as canopies and blinds proved that plant surfaces were generally cooler because of ‘evapo-transpiration’ and that almost 60% of the radiation absorbed by plants can be turned into latent heat. They also suggested that apart from being aesthetically pleasing, they are beneficial in urban environments by helping to reduce the heat island effect. They too tested a screen of climber plants such as ivy as possible ‘climatic modifiers’. They found a temperature difference of between 3.5ºC to 5ºC inside the control room, but also noted an increase in level of humidity.

Studies conducted by E.A. Eumorfopoulou and K.J. Kontoleon (2008) that plant covered walls helps to regulate the internal temperature as well as create aesthetically pleasing facades on the outside. They point out that not only does it help reduce the test buildings energy consumption, but also makes the building design more sustainable.

Rachel Kaplan (2007, Employees’ reactions to nearby nature at their workplace: the wild and the tame) conducted a survey on a group of office employees and found that a large percentage of the surveyed sample of people would be more satisfied and happier with more greenery near their workplace. This would also be able to reduce the Sick Building Syndrome that is a growing ailment surfacing in most modern office buildings.

Several buildings have employed the use of vegetation on facades either as terraces or directly growing on walls. The ACROS building in Japan designed by Emilio Ambasz has a stepped terrace façade with landscaping on each level. This striking building is a good example of integrating meaningful green spaces into an office environment. (James Wines, 2000)

The Musée du quai Branly, 2006, in Paris, built by Jean Nouvel is ana example of a building with a ‘living wall’ where green plants are grown on the façade and becomes the external skin of the building. The Caixa Forum, 2008, in Madrid, designed by the Swiss architects Herzog and de Meuron with help from botanist Patrick Blanc has a 24m high vertical garden covering one of the building’s facades which adds both aesthetic value and a sustainable solution to crate green spaces in tight urban pockets (www.arcspace.com).

Fig 2.38 ACROS Building, Japan
Image Source- Green Architecture, 2000, Taschen

Fig 2.39 Musée du quai Branly
Image Source-
http://deconarch.files.wordpress.com/2008/07/musee-du-quai-branly-4.jpg

2.6 Glazed Facades in Dubai –

Heavily glazed facades have become a norm in Dubai over the last few years. The clean and modern look it is often associated with is hailed as progress of the city from humble beginnings to an international city boasting of skyscrapers that would not look out of place in New York. Some buildings have almost 100% of their facades glazed. Building for aesthetics alone does have its problems and the biggest one is perhaps the easy access for solar heat gain entering the building. This results in energy expensive measures to negate the excess heat and lower internal temperatures. Most offices in Dubai boast of full height glazed facades that promise views of the city and the sea. But in reality blinds are drawn down from dawn to dusk to protect the internal space from the intense glare characteristic of the intense solar radiation in the region.

Observation carried out in office spaces in the Dubai International Convention Centre office tower and the Emirates towers (Office towers) point out that blinds are drawn down through out the day. Other office towers such as the Monarch Office Tower uses heavily tinted Low-E blue colored glazing to cut out the glare and though this provides for glare-free views around the city, it also negates any positive use of natural daylight to brighten up the internal spaces.

Fig 2.40 Use of Heavily Tinted Glass limiting entry of light, Image Source- Personal Archive- Jidesh Kambil

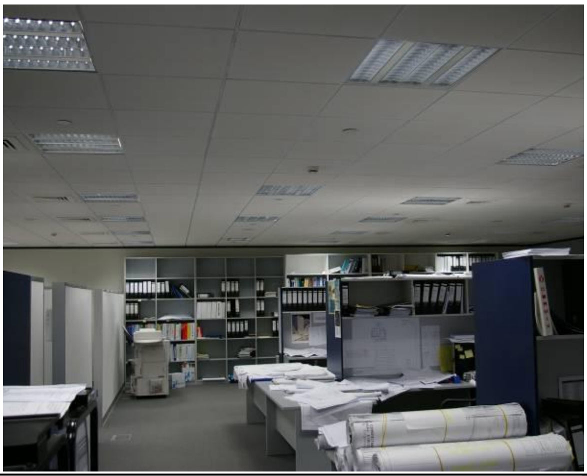


Fig 2.41 Artificial Lighting in Offices during daytime,
Image Source- Personal Archive- Jidesh Kambil

Fig 2.42 Blinds drawn down to reduce glare,
Image Source- Personal Archive- Jidesh Kambil

Mohsen M. Aboulnaga (2006) syudied fifteen highly glazed towers in Dubai to analyze whether the use of glazing in high rises in Dubai is justified. Using the Ecotect software, after running simulations on the buildings, the Daylight Factor was studied against the Daylight Levels. The results showed that in more than 70% of the buildings, which were either 'low performing' or 'intermediate performing' the facades were over glazed and unjustified. It was found there was excessive glare, much higher value for the Daylight Factor than the 10% recommended for offices and indicating that having highly glazed facades in Dubai was indeed counter-productive in terms of building performance.

Fig 2.43 Heavily Glazed Residential Tower in Dubai Marina,
Image Source- Personal Archive- Jidesh Kambil

Fig 2.44 Reflected Glare from Glazing on Residential Tower in Dubai Marina,
Image Source- Personal Archive- Jidesh Kambil

2.7 Alternative to Glazing in Transparent Facades –

Since its discovery, glass has been the one stop solution for transparency. But overuse of the material that redefined modern architecture has led to the rise of towering greenhouses that need massive amounts of energy to counter the overheating of the interiors. Discovered and patented by Dupont in the 1940s, by 1970, ETFE was widely used in cabling and insulation and a wide array of industrial applications. Although, in 1980, a key element in the proposed concept of an enclosed city in the Artic by Buro Happold, ETFE's first tryst with architectre as a surface material came in 1982 when Vector Foiltec were commissioned to repair the failed FEP (Fluorinated Ethylene Propylene) skin of a plant house – the Mangrove Hall at Burger's Zoo, Arnhem, Netherlands. (Ian Liddell, Annette LeCuyer, 2008). Since then ETFE has been used on many projects to create large atriums and skylights and the recent surge in popularity today following the iconic 'Water Cube' project in Beijing has brought ETFE to the fore. Other projects that have used ETFE include the Eden Project (Cornwall, England), Allianz Stadium (Munich, Germany) and National Space Centre (Leicester, England). It is available commercially known as Tefzel (Dupont) and Fluon (Asahi Glass Company). (www.wikipedia.com). Vector Foilec and Makmax offer architectural solutions using ETFE. (Annette LeCuyer, 2008)

ETFE or Ethylene Tetrafluoroethylene is a 'fluorocarbon derived co-polymer' created from Ethylene and Teflon. Hailed as a lightweight, strong and transparent alternative to glass, ETFE has the potential to become the most favored building material of the future. Weighing a hundred times less than glass but strong enough to withstand loads up to 400 times its own weight, this lightweight material could be the most desirable material of the future. The ability to be lit up using LEDs and to be used to screen projected graphics makes it an interesting choice for the urban environment.

ETFE cushions are made up of many layers of the 'ETFE foil', which are between 100-200 μm thick and are set in frames by clamping and 'heat sealing' techniques. An air pressure of between 250 Pa to 400 Pa is maintained inside the cushions with the help of small fans, which needs only around 50W/ 1000m² of energy to operate. ETFE foils are produced in sheets which an be rolled for storage. Sheets are cut into desired shapes and sizes using rotating CNC blades and between two and five foils are welded together with an overlap of between 10-15mm and the welds are around 5mm wide for safety as even a 1mm weld can offer necessary strength and sealing qualities. The external layer of the cushion is usually the most curved one to withstand wind-loads and resulting deformation. Installation of the cushions is carried out by fixing the extrusion at the edges into the designated support structure, after which the inflation system and plenum are fitted and the cushions cleared of unwanted fragments before inflation (Annette LeCuyer, 2008).

S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno (2001) in their research on- ‘ETFE foil cushion for roofs and atria’ observed that ETFE could be considered as an alternative to glazing in certain applications and could also help improve the performance of the building in terms of both the environment and the building procedure as well. The researchers listed several properties that highlighted the performance of the new age material. Use of sensors and monitoring helps to determine which air cushions need more inflation, hence reducing energy costs utilized in keeping the cushions inflated.

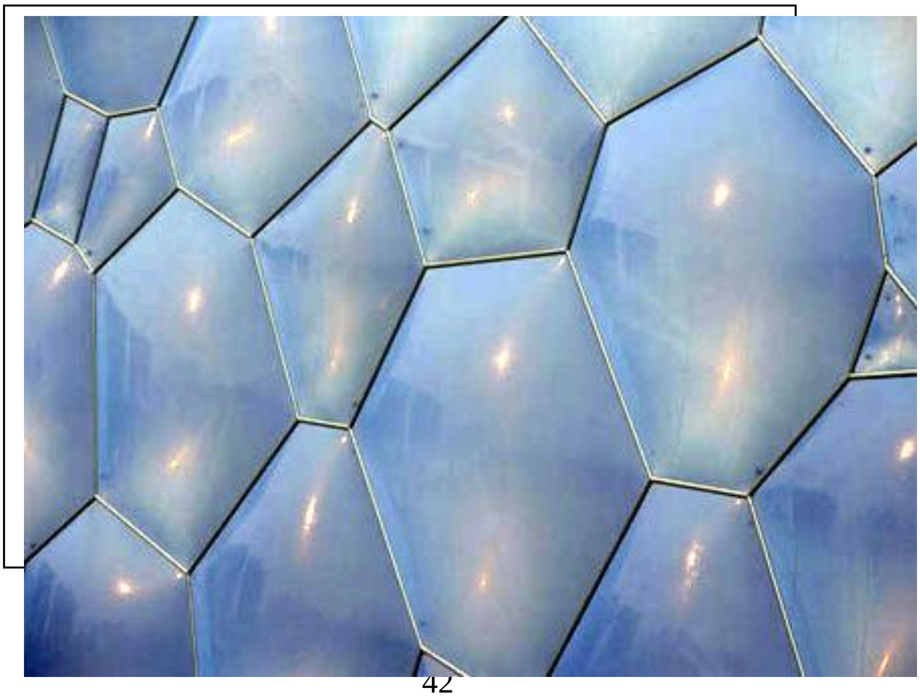


Fig 2.47 National Space Center-England, Image Source- www.wikipedia.com

2.7.1 Transmission of Light –

Allowing the transmittance of almost 95% of the incident visible light, the material outperforms standard 6mm glass panels, which let through only 89% of the light. It was also found to allow the full range of wavelength of the light spectrum, hence aiding in color detection. The curved form of the cushions might however visually distort the image of objects outside the skin. However this very quality could lead to a lot of glare within the internal space and hence should be used in a suitable manner. The ETFE foils can also be used as translucent skins or with printed patterns that can help determine amount of light entering the enclosed space through the building skin and be used to reduce glare entering the building. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

2.7.2 Noise and Vapor Permeability –

Being a foil material, it is very thin and offers very little resistance to sound waves and hence they do not perform well as sound absorbers and will transmit most of the sound through the skin. By being a poor reflector of sound, ETFE skins can help in improving acoustics in places like atriums but can also bring in external noise. Sound absorbing panels and dampers can be used though to reduce noise propagation through the skin. There is a tendency for vapor permeability and the use of dehumidifiers might be necessary in regions with high humidity levels to prevent the moisture from the skin system. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

2.7.3 Thermal Properties –

ETFE has a U-value of 1.9 W/m² K, which, is about the same as that of high performance Low-E Double glazed panels and can further be reduced to 1.18 W/m² K with the use of up to five foils in a cushion. This means that although it lets in more light than normal 6mm glass panels, it keeps out heat as efficiently as the best glazing solutions currently used in the market. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

The solar factor value (G value), which is defined as the amount of solar energy that enters through the glazed surfaces of building facades, is relatively high for clear ETFE foils owing to its high transparency to incident light. The G-value of clear ETFE foils that are 200 µm thick is approximately 0.93, but this can be reduced to 0.48 by using printed opaque graphics on the foils. In comparison, normal 6mm glass has a G-value of 0.88, while treated glass can have values as low as 0.46. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

Although a wide array of pigmentation and printing technologies can influence the heat and energy transmission and shading co-efficient characteristics, the negligible cross-section thickness of the ETFE foil as compared to glazing makes the consideration of the energy absorption and radiation properties unimportant. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

2.7.4 Durability and Maintenance –

Combining the elasticity and impressive mold-able nature of 'Polyethylene' and the low friction surface properties of Teflon, creates a material that is flexible and durable with a claimed lifespan of twenty-five to thirty years. It does not attract dust and is chemically inert. It is not affected by exposure to moisture or UV rays and helps in destroying bacteria. It starts to loose some strength beyond 70ºC but fails only at temperatures higher than 200º. ETFE exhibits elastic properties and can bear strains of up to 400% before failure. In the event of a power failure, the cushions can retain their form and stability for up to four to six hours. ETFE cushion skins have been tested for performance in Hurricane conditions and the results showed it to be a resilient structure. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Ian Liddell, Annette LeCuyer, 2008)

It does not attract dust and hence does not need to be cleaned frequently and uses less water in the process, hence an ideal surface in regions concerned with water conservation and shortage. However, due to its delicate foil like nature, it can be prone to abuse by sharp objects but tears can be repaired in patches on site, making it easy to maintain. Hence use on floors above ground floor is more recommendable or under security and supervision to hinder anti-social and uncivilized behavior. The inner surface of the cushions need to be cleaned only once in five to ten years. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

2.7.5 Manufacturing and Processing –

The raw materials used in manufacturing ETFE are 'Fluorspar' (CaF_2), 'Hydrogen Sulfate (H_2SO_4)', and 'Trichloromethane' ($CHCl_3$). The largest known natural source of Fluorine, Fluorspar is found abundantly all over the world and can be sourced during the acquisition of mined Limestone. Using the raw ingredients, 'Chlorodifluoromethane' which abides by the 'Montreal Treaty' governing 'Ozone Depleting Substances' that are proven to not contribute to further global warming. This material is then transformed into CF_2 – CF_2 (through 'Pyrolysis' process involving high temperatures of over 700ºC), which under the U.S. Patent no. 4016345 can be further polymerized resulting in the formation of by-products like 'Calcium Sulfate' ($CaSO_4$), 'Hydrogen Fluoride' (HF) and 'Hydrogen Chloride' (HCl), of which the former two can be used to create the primary ingredient of Fluorspar, while the remaining waste products are burnt. Carried out at nearly 125ºC, the 'polymerization' process involves the use of water and a 'dispersing agent'. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

The resulting granules of ETFE are then softened by heating it to a temperature' of 170ºC within a 'Hopper' which is part of the apparatus for the processing technique before it is extruded and then 'blow-molded' creating big sheets of films ranging between 50 – 150 µm in thickness. These are then used to create the multi-layered cushions using 'heat welding' technique. The resulting cushions are then supported by the use of either Aluminum or Steel frames. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

In comparison, the raw materials used for glass manufacture are – "sand, dolomite, limestone, soda and feldspar with additional cullets or glass chips". The manufacturing process of glass involves higher heating temperatures and the release of gases such as CO_2, SO_2 and NO_2 are common (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

Physical properties of ETFE foil and glass

	ETFE foil [4]	Glass [5]
Ultimate tensile strength (N/mm^2)	40–46	50–100 (toughened) 10–20 (annealed)
Melting range (°C)		
T_g (glass transition temp.)		600
T_m (melting temp.)	150	1200
Hardness (N/mm^2)	31–33	5500
Yield stress (N/mm^2)	30–35[a]	
Fracture mechanism	Plastic deformation	Brittle fracture

[a] Yield stress is temperature-dependent.

Embodied energy for ETFE foil and glass

Embodied energy	ETFE foil	6-mm float glass
EE (GJ/t)	26.5	20
EE per m^2 (MJ/m^2)	27.0	300

Fig 2.48 Spec Comparison between ETFE and Glass, Image Source- ETFE Foil Cushions in Roof and Atria, S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, Construction and Building Materials 15 (2001), Elsevier

2.7.6 Embodied Energy –

Though the embodied energy accumulated by both glass and ETFE are similar per tonne of the material, the embodied energy calculated for a practical application of the respective materials shows that ETFE has a lower overall value for embodied energy, while glass has values almost ten times that of the ETFE foil. The weight of the ETFE foil is between 2kg to 3.5kg per m^2 while that of glazed panels used in curtain walls are approximately 100 kg to 250 kg depending on the glazing thickness, framing and insulation systems (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

The higher values of glass can be attributed to raw material extraction, depletion of resources and transportation from factory to site. The finished glazed panels are much heavier than the pre-cut foil cushion panels owing to its lower density and hence require more energy to transport them. The area to edge ratio of typical glazed panels is 1:2.5 while that of ETFE cushions is 1:1 and lower as it can span larger distances with less need for support systems. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

The British-German venture that manufactured and supplied nearly 100,000m² of ETFE foil for the 'Water Cube' project in Beijing, Vector Foil claims that to construct a similar project in glass would have required more than two hundred times more energy. (Elizabeth Woyke, Business Week, 2007).

2.7.7 Fire Safety –

ETFE is a non-combustible material and performs well under situations like a fire breakout as the foil melts and recoils and acts to self extinguish by preventing the spread of fire, hence avoiding potentially dangerous situations. The material has passed tests for fire conditions in many countries. Small quantities of harmful gases such as Carbon Monoxide (CO) and Hydrogen Fluoride (HF) are released when in contact with fires. ETFE starts to fail at temperatures above 200ºC and at temperatures higher than 800ºC releases the mentioned toxic gases. Conventionally used open-able vents, vented cushion openings, and vents for release of smoke can be used to exhaust the smoke and fumes of fires, whose temperature do not exceed 200ºC. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

2.7.8 Recycling and Sustainability –

Owing to the absence of any additives to the polymers during the manufacturing process, the cushion foils can be detached from its support frames, cleaned and reused for recycling purposes. Since the required temperature for processing the material is low, less energy is required and the recycled content can be reintroduced to the heating and extruding process with virgin raw material. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

Float glass in comparison is not recycled to manufacture new float glass, as there is minimal tolerance of impurities and deformities in the manufacturing process. Both glass and ETFE are inert and do not contaminate when dumped in landfills but it is highly recommended to recycle the materials instead as they could remain underground for more than a thousand years as they are not bio-degradable. (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008)

Fig 2.49 Building with ETFE Facade, Image Source- www.makmax.com.au

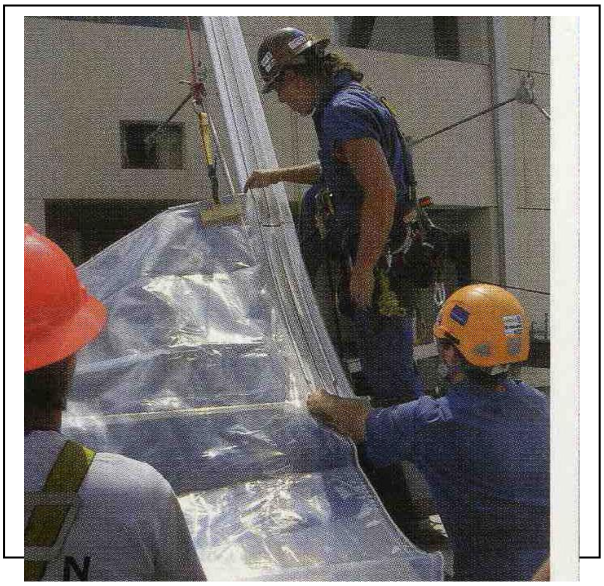


Fig 2.50 Working with ETFE Foil, Image Source- ETFE Technology and Design, 2008, Birkhauser Verlag AG

2.8 Learning from Nature –

Nature is the best example of sustainable and balanced growth. We humans can learn a lot from nature if we observe carefully enough. A part of the planets landscape millions of years before the first recorded evidence of humans, even today, nature and its entire range of bio-diverse entities inhabit our planet and remains sustainable in life and death, co-existing to keep our precious planet alive. We humans have in the last hundred years perhaps done more to upset the delicate balance of nature that is key to survival of all life forms on this planet. A look at how plants and animals survive the extreme desert conditions could perhaps teach us important lessons as to how to live in a sustainable manner.

Desert plants are known to have small thick leaves that limit the loss of water through transpiration. The plants are mostly seasonal and only flourish in the presence of favorable conditions. Xerophytic species such as Cacti have thick succulent stems with no leaves and only thorny bristles, that offers both shading and keeps unwanted creatures at bay and have long roots to tap into available water resources. They are an ultimate example of water conservation in the desert and probably indicates that building skins should also shield the internal spaces from the climatic conditions by creating internal spaces that can be completely sealed from the outside during peak temperatures and have the façade open up for more natural forms of ventilation when the climate permits.

Animals too have devised ways to stay protected from the desert conditions. Besides having bodies that are adapted to reduce heat loss by lowered metabolism rates and other anatomical changes from their cousins in the tropics, they tend to seek refuge in caves, under rocks and even burrowing underground. While the first two options are examples of solar shading and passive solar cooling strategies, the option of burrowing indicates the phenomenon of the loose sand having the highest temperatures at the surface while as we go lower in the sand dunes, the temperatures are much lower and even the presence of retained moisture can be seen. This can be explained by the thermal mass properties of sand and the fact that it cannot retain heat for long because of its granulated structure. There is no molecular bonding between the loose grains of sand and since sand as a material is low in density, it cannot retain heat and the air gaps formed helps in the escape of heat. So, the heat received at the surface is not transferred lower down the heap of sand.

Perhaps this indicates that the building skin for high rises too should be one with good insulating properties but at the same time be lightweight and not dense, as this will prevent the retention of heat, which could be transferred by conduction into the internal space later during the day.

Fig 2.51 Leaves-Nature's wonder, Image Source- Personal Archive- Jidesh Kambil

2.9 Aim and Objectives –

2.9.1 The Aim of research –

The main goal of this research is to explore and identify a possible Bio-climatic alternative solution to common glazed facades in Dubai, and to analyze and evaluate it's effectiveness in reducing heat gains in buildings and in turn energy consumption leading to a greener planet. The inspiration for this research is the desire to find a solution that is futuristic, urban and yet bio-climatic, the desire to look away from the conventional solutions. From the data covered in the literature review, it is quite evident that a lot of innovative solutions have been explored in the past and in the present, but a solution that is regionally specific to a city like Dubai that is both urban and futuristic is not very common. It is also intended to learn from nature's adaptive measures in this extreme climate and find ways to implement it in the concept.

2.9.2 Specific Objectives of Research –

- Identifying possible Bio-climatic solution / design to glazed building façade in Dubai using nature as an inspiration and possible solution
- Identifying user needs and requirements of façade design.
- Analyzing effectiveness of Bio-climatic facades in reducing heat gain through facades
- Attempt to calculate the economics associated with the use of Bio-climatic facades.

2.10 Outline of Thesis –

Chapter 1 – Introduction – The need for a re-think on the way we design facades is debated and the topic and research objectives are established.

Chapter 2 – Literature Review – A brief history of facades is explored followed by examples of Bio-climatically designed facades in Traditional Architecture and Modern Architecture. The other topics discussed include Dynamic Facades, Green Walls, the Misuse of Glazing in Dubai, Alternatives to Glazed facades and Natural inspirations.

Chapter 3 – Methodology – The various methodologies used in the study of bio-climatic facades in the past are explored and discussed and their relevance to the research is analyzed. Appropriate methodologies for the current research is identified and described. A hypothesis is set up that justifies the model that will be tested. The research boundary is established and key elements of the model that will be tested are outlined. The external parameters affecting the model are outlined and incidences from past works focusing on similar parameters are discussed.

Chapter 4 – Design and Analysis – Study is done on four different cases which includes the base case of standard glazing system and the Double skin façade system with an outer ETFE skin. Results, values and graphs are shown representing each case scenario. The results and values of each are discussed and analyzed for effective performance of the façade in cutting out direct solar radiation.

Chapter 5 –Conclusion and Recommendations – A conclusion is drawn from the results and calculations are made to identify the economic value of the savings incurred by the implementation of the new façade system. Further recommendations are made for future studies on the subject.

Chapter 3 – Methodology

3.1 Bio-climatic Design Tools –

The study of Bio-climatic designs is a complicated one and involves the analysis of Thermal Gains, Lighting, Humidity Levels, Wind Velocity, Natural Ventilation and Noise Control. Bio-climatic designs reassert the position of the human occupant at the core of design considerations governing the inhabited space. Comfort conditions related to Bio-climatic design can vary constantly owing to the fact that owner preferences change with individual taste and mentality. For example, it is very easy for a person to wear a business suit in a hot climate and turn up the cooling using air-conditioning. But another person could easily wear half sleeve cotton shirts and feel more comfortable in the same space and need less cooling.

Studies have been done identify various elements of bio-climatic designs and explore the benefits and drawbacks of Bio-climatic solutions to building design and a vast foundation of knowledge is available from which one can further develop and explore new possibilities. Studies by researchers like Nicolae Petrasincu and Laurentiu Fara (2006) have helped to identify the bio-climatic elements that have made Traditional Romanian homes comfortable even in extremely cold climnates over the years.

During the study of Bio-climatic Designs, the design tools should be able to take into consideration all of the factors affecting its performance. Several Analysis tools have been developed to assess the Bio-climatic performance of buildings since the introduction of the first Bio-climatic charts (Olgyay, 1963) with relation to thermal comfort. Many softwares are available today to help compute the designs and their performance accurately. These help to study a project regardless of the scale in the convenience of a studio, cutting down the cost of research immensely. Some of the common tools for analysis are discussed below.

3.2 Bio-climatic Charts –

Developed in 1963 by the Olgyay brothers, the Olgyay bio-climatic chart identified the potential comfort zones in a climatic region was plotted on a graph with dry bulb temperature, relative humidity levels and air movement velocity. The Olgyay chart though did not work well in regions that exhibited large differences between internal and external temperatures. (Sopa Visitsak, 2007)

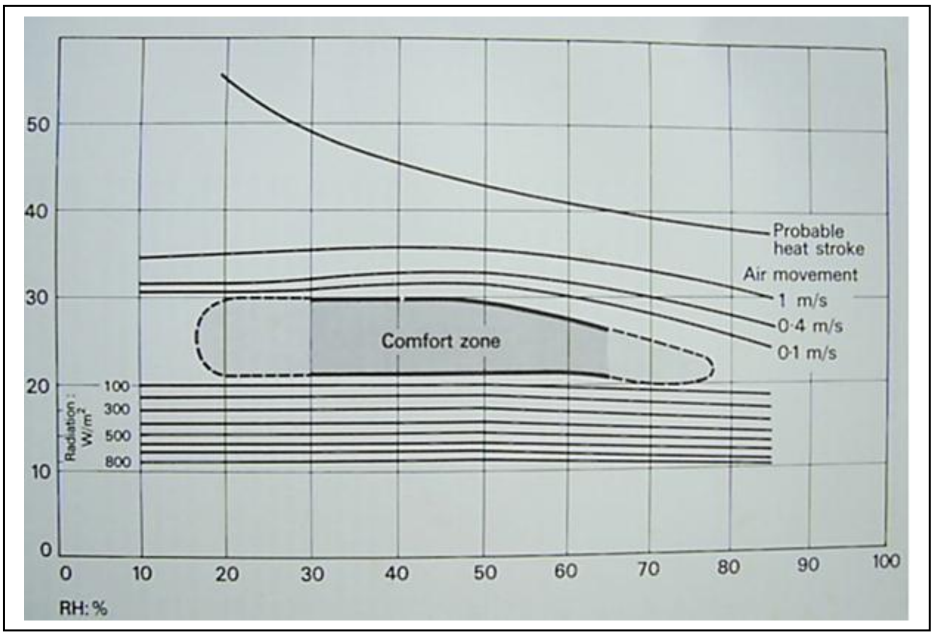


Fig 3.1 Olgyay Bio-climatic Chart,
Image Source- http://www7.ttvnol.com/uploaded2/kts_june/comfort%20chart-fanger.jpg

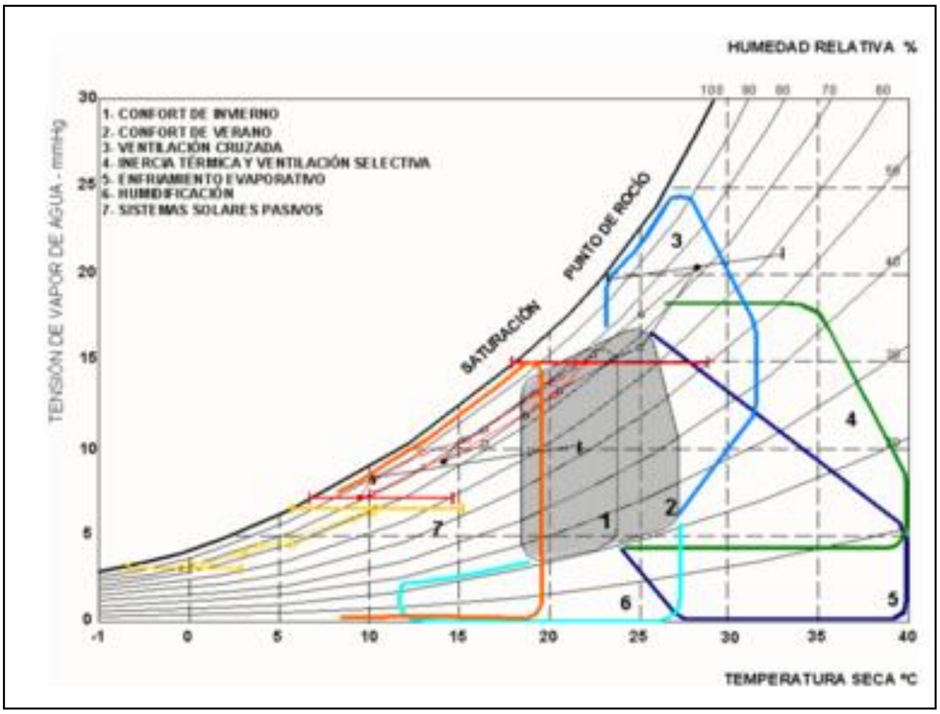


Fig 3.2 Givoni Bio-climatic Chart, Image Source- www.wikipedia.com

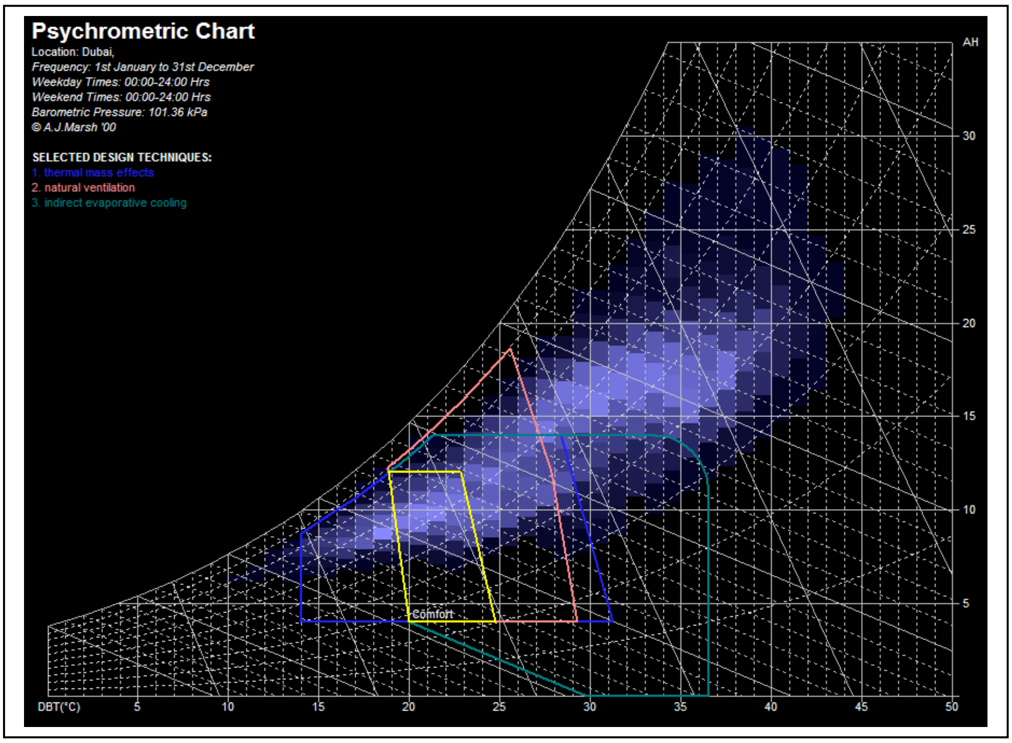


Fig 3.3 Psychrometric Chart, Image Source- Weather tool image (Ecotect5.5)

Another chart developed by Givoni in 1969 was based on the indoor temperatures and took into consideration the building envelope and helped to identify possible strategies to achieve internal space comfort conditions. Further developed with Milne in 1979, they studied the extent of 'effectiveness' of each strategy applied to the design to help counter the external conditions. (Sopa Visitsak, 2007)

Researchers A.Zain Ahmed, A.A.M.Sayigh, P.N. Surendran and M.Y.Othman (1998) in their study on "the Bio-climatic Design Approach to Low-Energy Buildings in the Klang Valley, Malayasia" studied the effectiveness of the bio-climatic charts by Olgyay, Givoni, Szokolay (Control Potential Zone-Psychrometric chart, 1990) and the Mahoney Tables (Szokolay, 1982). They found that while the Olgyay chart helped identify wind velocity necessary to reduce discomfort, Givoni's (Building Bio-climatic) chart identified the proportion of strategies that need to be applied to achieve indoor comfort. But the Psychrometric chart helped identify potential passive and active strategies even outside comfort zones that could be applied to achieve comfort, while the

Mahoney Tables helped by having the pre-design ready design strategies listed down in tables.

These charts proved to be helpful in the study of bio-climatic designs as it took into consideration the temperature, humidity, wind velocity and incident solar radiation. These charts were region specific but the earlier charts were often handicapped because they could not take into account building design and occupancy types as they could only be used to predict suitable pre-design strategies such as the air flow velocity to be maintained or the humidity levels that would help achieve comfort conditions or the temperature at which the lack of control of other factors such as humidity would cease to e a problem. Later charts such as the Psychrometric charts gave added information on possible mechanical interventions such as the use of mechanical ventilation and cooling and direct and indirect evaporative cooling that could help bring down the existing conditions to comfortable levels

These bio-climatic charts though are very general in nature and work well on large developments such as in the study on "Urban Bio-climatic design strategies for a tropical city" by researchers Eleonora Sad de Assis, Anesia Barros Frota (1999) who used the Givoni Bio-climatic chart to study the design strategies applicable to the city of Belo Horizonte in Brazil. They found these charts to be helpful to the extent that it pointed the researchers in the right direction but the chart showed information contradictory to the site conditions and seemed to imply that low rise dense developments as having larger thermal impact than high rises.

In another study on " A Bio-climatic Office environment in Brasilia" by Alexandra A Maciel and Roberto Lamberts (2001) conducted experiments involving on field measurements and questionnaires and later applied the collected information to the Psychrometric chart. They were able to establish the feasibility of "evaporative cooling" as a passive strategy to achieve thermal comfort as also the use of "night ventilation strategies"

These studies show that though the bio-climatic charts have the potential to determine the passive design strategies that could have an impact on the thermal comfort of the designed space, they are too general in nature. In today's urban environment, the micro-climate of any particular site is quite unique to itself as it is governed by so many factors besides the regional climate in general such as surface materials, building form and use of glazing, orientation and height of neighboring buildings and presence or absence of vegetation. Hence these charts can only be used a preliminary pre-design tool.

3.3 Computer Simulation Models –

Computer simulation models are important pre-design tools in the study of a building's environmental performance. They help the researcher understand how both buildings as a whole and specific design elements of the proposed design will perform when subject to a range of environmental parameters without the need for expensive scaled models and strict monitoring of controlled test zones. Various softwares have been used to simulate designs to understand their environmental performance. ECOTECT, a software developed by Andrew Marsh (2000) is a user friendly software that combines 3D modeling and analysis tools for a range of environmental design elements like solar analysis, daylight analysis, shading analysis, thermal analysis, wind-flow analysis, acoustics and life cycle costing in an interactive interface that appeals to architects and designers as it is graphic in nature and not very technical. Add-on applications like Radiance and Win-air help to access several analysis tools from a single package. It is possible to determine the time and location of the intended site during simulation to get accurate results. Material properties are listed in detail and can be modified to create custom materials. Results can be obtained for hourly, weekly, monthly and annual readings. This is a very useful package for studying lighting and thermal performance of buildings for architects.

Mohsen M. Aboulnaga (2006) in his study on the misuse of glazing in Dubai used the Ecotect software to simulate selected building floor-plates and identify the Daylight Factor and Daylight Levels entering each building through its glazed façade. He used it to determine that most buildings were over-glazed and the issue of glare was a serious problem in most glazed buildings studied in Dubai. Observing that most of the Building he had studied had facades with more than 80-100% glazing as compared to recommended 25-40% of façade area, the researcher identified 15 buildings with glazing which were categorized as "high performing" or "low performing". After analyzing the glazing used in terms to its Shading co-efficient and Light Transmission, the researcher overcame the need to calculate the "externally reflected component", "internally reflected component" and "Sky Component" as components of the Daylight Factor by using the Ecotect software. The researcher was successful in studying the Daylight levels and Daylight Factor across the floor-plate of each building and making comparisons to determine the building with the best use of glazing. As an architect, the conclusions of the researcher were eye-opening as it showed that most buildings in Dubai are over glazed and causes excess glare in the enclosed space. However the inability to factor in the effect of natural ventilation and humidity could be a limiting factor.

IES-VE or Integrated Environment Solutions-Virtual Environment is a similar software which has a variety of programs that simulate several factors governing the environmental performance of buildings. Several sub-programs like MODEL-IT (building modeling), SUNCAST (shadow analysis) and APACHE (thermal analysis) are used to run simulations on models of the proposed designs and determine its performance. Here too, it is not easy to factor in the effect of natural ventilation or humidity on the performance of the model.

Puteri Shireen Jahnkassim and Kenneth Ip (2006) in their study on some tropical high rises designed by Ken Yeang used the IES-VE software to simulate heat gain models for the buildings and matched their performance to more 'generic' versions of the selected buildings without bio-climatic features. They used the software to study the impact of Bio-climatic features that are often associated with Ken Yeang's works sch as "core placement, balconies, shading, sky-courts and vegetation" and their response to the cooling effect and energy consumption in a tropical environment such as Malayasia. The Building Skin was simulated to study the performance of the façade in terms of "Solar Heat Gain" and Daylight

Levels to determine whether the Bio-climatic designs of Ken Yeang were successful.They found that two of the three buildings studied exhibiting bio-climatic elements performed better thermally than their more generic versions.

Several other programs used as tools to performance of building designs are DEROB, LTV (Lighting, Thermal and Ventilation) and TRANSSOLAR, which are used in many parts of the world by researchers. The use of softwares for running simulations has been a massive boost to this field of research. Researchers are now able to conduct complicated tests and analysis of even large scale buildings and developments without the need for heavy funding and controlled environments. Softwares in general, along with CFD testing techniques have made it possible to understand to accurate detail how the project would fare in any given condition, even potentially dangerous extreme conditions such as during a storm or extreme rise in temperatures from the safety and convenience of a studio.

These programs are very good pre-design tools and can help an architect make informed decisions about the designs and understand the impact of his design on the energy consumption, cooling loads and resource depletion. Most of these softwares like ECOTECT and IES-VE can also assess the life cycle cost and environmental impact of the designs as also the Carbon emission levels helping to create sustainable solutions for the future.

3.4 Monitoring –

Another method of studying the effectiveness of Bio-climatic concepts is by using a test room or test zone in controlled environments to study the effects of the climate on the scaled model or real time sites and physically taking measurements over a period of time to ascertain the behavior of the material and designs in the test conditions.

Researchers Alexandra A Maciel and Roberto Lamberts (2001) in their study on “Bio-climatic Office Environment in Brasilia” took measurements for temperature and relative humidity for a period of 12 days from two rooms and took user's opinion through questionnaires. They then plotted the data on a psychrometric chart to identify the potential to use strategies such as evaporative cooling. Researchers G.Papadakis, P. Tsamis and S. Kyritsis (2001)- An Experimental Investigation of the Effect of Shading with Plants for Solar Control of Buildings also conducted experiments over a period of time to study the effect of plants as a shading element, taking measurements for light, temperature and humidity in a controlled environment.

While on field monitoring can provide with accurate results which are observed in its natural environment or in a replica of the actual condition as in a laboratory, the whole process could become very expensive with the need for specialized and accurate measurement tools, controlled test environments and a considerably long period of time to do justice to the study. The study of large scale projects will be hard to contain and study making it necessary to make scaled down models. This method is often very laborious, expensive and time consuming making it a less preferred choice for quick studies and research.

Fig 3.4 Artificial Sky Dome-Cardiff University, Image Source- Personal Archive- Jidesh Kambil

3.5 Selected Research Methods –

Due to the time constraints for this research, it is intended to identify a possible Bio-climatic façade that could work in the chosen region and analyze whether it helps reduce heat gains through the building facades to the extent that it reduces the dependence on costly mechanical ventilation and cooling and does not advocate the complete elimination of it. No other factors governing Bio-climatic designs like Ventilation or Humidity Control or Acoustics will be explored.

This research will be conducted through a variety of methods as listed below

- **Literature Review**
- **Simulations**

3.5.1 Literature Review –

A lot of work has been done in the past on Bio-climatic designs and there is a lot that can be learnt. Hence Literature Review will help in identifying the path the research should follow and also examines that advantages and drawbacks for bio-climatic solutions in the past. Nature itself is an infinite bounty of information. One can truly learn a lot jus by observing nature.

In the study on "Bio-climatic Elements for Traditional Romanian Houses", Nicolae Petrasinu and Laurentiu Fara (2006) explored the various elements of Bio-climatic designs in the region. By studying the design elements in use and their response to the climatic conditions they were able to determine the design factors such as " building orientation, use of Porch on South Side and Use of local resources", that could help future designs too achieve comfort conditions even in extreme winters as found in the region through the use of passive strategies and not relying on energy hungry technologies.

As part of the case study of the Bastakhiya area carried out in partial fulfillment of the Masters Program at BUID, it was observed first hand how the ingenious local inhabitants achieved comfort in their shelters even during the extreme summers characteristic of Dubai. Further reading and understanding of the strategies and techniques employed by the past generation was an inspiration and has been helpful in the implementation of sensible strategies that are environmentally responsive in the region both in course work and professional assignments.

Literature Review will be used in this research to understand what Bio-climatically responsive designs are suited to each environment, their advantages and disadvantages and what works locally. Literature Review will help in the identification of what elements made Bio-climatic designs unique and comfortable and how this knowledge can help in the exploration of a new strategy that is bio-climatically responsive to the climate of the region and works to reduce heat gain through the building façade. Chapter 2 covers the Literature Review for this research.

3.5.2 Simulation Models –

For the purpose of this research, ECOTECT 5.5 will be used to simulate the heat gain levels in the sample floor-plate through the façade. ECOTECT 5.5 has been used by many researchers and students in this field of research and has been found to be an accepted analysis tool mostly by architects due to its user-friendly interface and graphical output. It has a range of options and analyses Thermal gains, Daylight level, Wind velocity and heating and cooling loads. It is an available option for researchers and students in Dubai and has been used by several students in the assignment works for course modules at the University (BUID). The ability to export data into excel sheets and various file format options makes it easy to work with. The enclosure that will be studied is split into zones and each zone can be assigned HVAC settings and occupancy levels giving a fairly realistic output that is not very technical in nature and can be easily understood even by people who do not share a background in Mechanical Engineering.

Mohsen M. Aboulnaga (2006) in his study on the misuse of glazing in Dubai used the Ecotect to determine the appropriateness of the over-glazed facades in Dubai by simulating the Daylight Levels and Daylight Factors. The software was compatible with the research need and helped to attain an understanding of the façade performance. The simulation model dealt with lighting level conditions, information for which is available in the weather files. Although other factors such as direct solar radiation and relative humidity can play a role in the study, the software allows one to study a particular aspect that needs inspection without providing unnecessary and conflicting data, allowing the researcher to focus on the one aspect that needs to be studied. Although in reality all environmental factors do play a role in the performance of a building, in studies such as these, it helps when one needs to concentrate on any individual component with clarity.

Since this research is primarily concerned with analyzing the amount of heat gains entering the typical internal space through the building façade, Insolation levels will be simulated in search of information that will decide the result of the research. This will help determine whether the façade is effective in cutting out direct solar radiation from entering the Building. Efforts will also be made to calculate the cooling loads incurred before and after the façade modification.

3.6 Building a Hypothesis –

The purpose of this research is to identify a possible alternative to the current trend of glazed facades in Dubai that will help reduce the heat gains through the façade and in doing so offer itself as a Bio-climatic option for facades in Dubai. Traditionally in the region, Bio-climatic facades were built of coral stones and mud plaster. The walls were thick and fenestrations on the external facades were minimal. The Thick walls acted as a thermal buffer, delaying the crossing over of heat from the external surface to the internal one thus offering substantial thermal insulation. With the advent of glazing, even High performance Low-E glazing with U-values of 1.9 W/m^2 K, do not offer the same thermal insulation and also lets in too much light. Studies conducted on Double Skin facades have shown that they offer some degree of thermal control and the smart use of dynamic shading technology can further help lower heat gains. But the effectiveness of such systems with respect to humidity needs to be researched further. Having full height double skin facades without floor-to-floor separation could also lead to issues related to controlling the spread of smoke through the cavity between the two skins as well as acoustic problems. The weight of the glazed panels currently used makes it difficult for flexibility in the use of the external skin, having to confine it to a fixed condition with no room for mobility.

The concept that is being explored has been influenced by the ability of nature to respond to external stimuli successfully to counter the effect of the elements influencing them. From observing the way that Cacti have succulent stems with a wax like coating that seals the escape of moisture to the way that flowers open and close its petals triggered by the presence of sunlight and our own skin producing extra melanin causing the tanning of our skin in order to protect it from prolonged exposure to the sun, the idea taken forward is to device an interactive skin that responds to the external stimuli in the form of climatic conditions.

To begin with it would be beneficial during the extreme summer daytime conditions to have a double skin façade with the external skin sealed tight locking out excess heat. Technology would be an integral part of every interactive system and here too, a collection of sensors would determine how hot it is and how the skin would respond. Since the façade is not seen as a solution independent of mechanical cooling and ventilation, when the facades are sealed, air vents close to the ground would help in letting the spent air from inside the internal space into the sealed cavity between the internal and external skin, separated at each floor thermally and acoustically. An exhaust vent close to the slab level at the top would vent out the heated air in the cavity thereby refreshing the vacuum with cooler air from the internal spaces in the event of extreme heat build up as a preventive measure if necessary. Ideally though the double skin system should work without mechanical help but it needs to be tested. Also in this case the double skin systems are considered as modular and are floor or room specific, giving the occupants more control over their internal environment.

The same sealed external skin should be able to be operable and mobile permitting the opening up of the façade partially or wholly to aid in natural ventilation during favorable conditions, yet be a good enough insulator to limit heat gains. Considering the urban context of Dubai and the inclination towards transparency in facades, the chosen material for the façade should also transparent or at the most translucent. As a professional architect it is a matter that seeks answers every time we design buildings with floor to floor glazing to enhance views from the building. But do the occupants really need the view through out the day. It is common knowledge that in this generation, both husband and wife in most families do pursue a career which often means that the 'views' which are a much sought after marketing point is not enjoyed by the owners except on maybe a holiday but in which event too, one might consider that in a place like Dubai, there is plenty of things to do in one's free time. So who does really enjoy the view? The children too in a family would be away for most of the day and anyone who knows a child would probably also agree that Television is a much more attractive option to them. Though this is an assumption from personal observation and experience of living in Dubai, it is a point that deserves to be pondered on. So for whom are the floor to floor height glazed openings for? From the assumption made, it could be argued that though good views are a desired selling point for the owners and tenants alike, it does not need to be fully glazed all the time. Perhaps a skin that can be opened and closed when needed to enjoy the views and otherwise would be ideal. This means that the need for permanent glazing is not constant and other forms of skin could be explored without disrupting the potential of a building to exploit views of its surroundings. Hence it would be possible to consider even translucent facades that can be opened up for a clearer view to the outside when desired by the occupant. This brings in an increase in control over ones environment for the tenant of such a building and frees him from his dependence on the architect's vision of what is good for the occupant. In future, sensors and monitoring interactive devices will be more common and would be able to warn the occupant of the potential increase in heat gain if the external skin is left open for a more than permissible duration and inform him of the costs involved in terms of energy consumption. The feasibility to open up the external skin also means that nighttime cooling of the cavity would be facilitated and in the morning when the facades are sealed again, the internal temperature in the cavity would be lower and take longer to heat up.

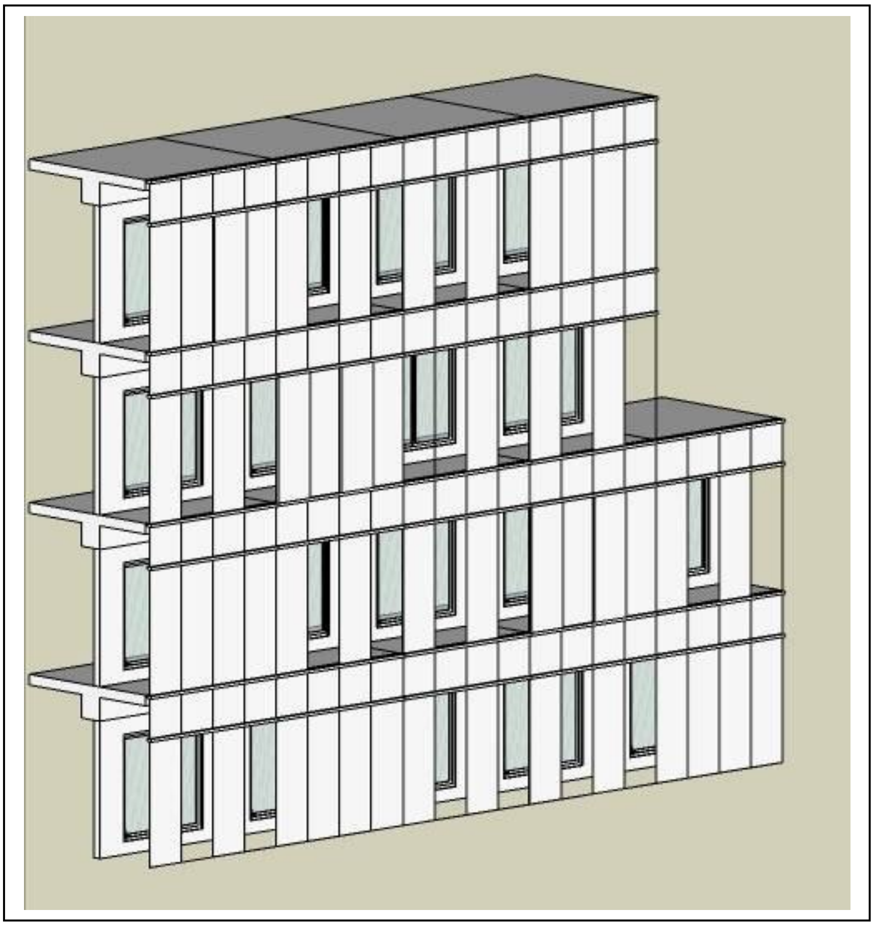


Fig 3.5 Façade Sample, Image Source- Sketch Up Model image

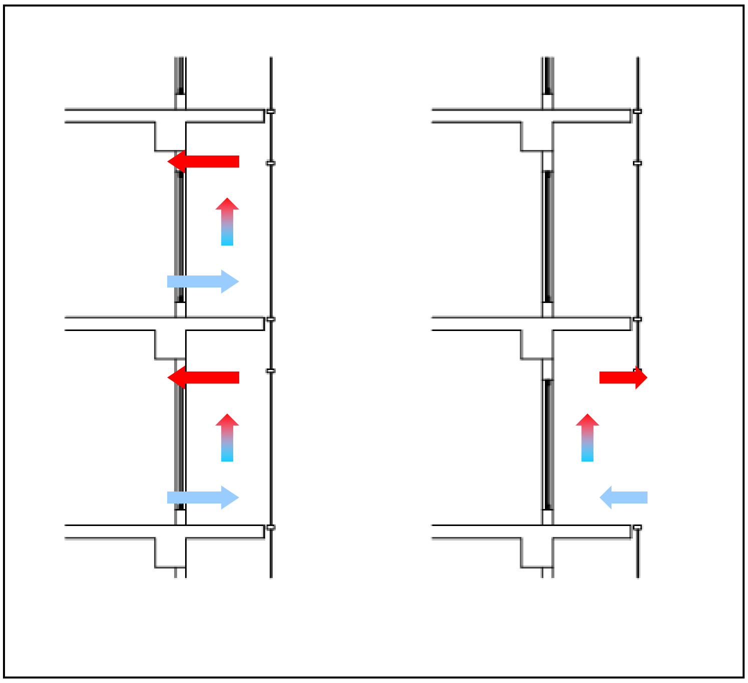


Fig 3.6 Image Showing Ventilation Modes and venting of Heated air in Closed and Open Positions, Image Source- Cad Drawing

Though the future looks promising, for such a hypothesis to work, a flexible, insulating yet transparent/ translucent material needs to be used. ETFE, under today's available choices offers all of these requirements. It is $1/100^{th}$ the weight of glazed panels (S. Robinson-Gayle, M. Kolokotroni, A. Cripps and S. Tanno, 2001); (Annette LeCuyer, 2008), it has good thermal insulation properties with U values of up to 1.19 W/m² K, lets in more light than glass which can though be limited using printed opaque graphics, the material is flexible and can be stretched allowing for folding or collapsible options for the facades, it does not attract dust hence reducing the cost of cleaning the surface regularly. But can ETFE really limit heat gains in buildings? And if so how does it perform when implemented in this Modular Interactive Double Skin Façade system? Can ETFE offer a Bio-climatic solution to Modern Dubai's glazing addiction?

3.7 Defining the research boundaries –

The analysis of the proposed Modular Interactive Double Skin Façade system using ETFE is done using ECOTECT 5.5. A typical case sample floor plate 25m x 25m is considered with a floor to floor height of 3.5m. A Typical and symmetrical floor plate is considered to study the effect the effect of Direct Solar radiation on all faces of a building and hence it is necessary to ensure that neither side has an advantage over the other due to the building form. The model will be split into zones and the zone to be tested is considered to be served by a mixed mode HVAC system with thermostat settings between 18ºC and 26ºC. The number of occupants in the floor space is determined by the thumb rule of 12m² per person for a typical office arrangement involved in a sedentary lifestyle. Total floor area is 625m² and analysis will be done with the analysis grid considered 1m above floor level.

In Case 1, a base case scenario with standard Double pane glazing with a U-value of 2.4 W/m²K is modeled and simulated with three zones, one for each level. Three levels are modeled and the middle zone is analyzed to represent typical case conditions. In Case 2, the skin used in the model in Case 1 will be replaced by ETFE foils in order to study the behavior of ETFE foils in a single skin system and study will be made for a transparent film and a translucent film. In Case 3, the standard façade is replaced with the proposed system with Single pane glazing with a U-value of 6 W/m²K (from Ecotect Material Library) as the internal skin and ETFE with a U-value of 1.9 W/m²K as the external skin. Here, there are three base zones representing the floor space behind the internal skin for three levels with the ETFE zones split into four per level with adjoining surfaces considered as voids in order to improve accuracy in the model. In Case 4, partially open Scenario for the ETFE skin model will also be tested. All of these options will be simulated under the weather conditions in Dubai acquired from the weather file and simulations will be done for heat gain readings resulting from direct solar radiation and the model will be analyzed for its performance in both summer and winter conditions. Annual Heating and cooling loads will also be calculated using the software and used to determine the economic value of the saving if any in energy consumption.

3.8 External Parameters affecting the Model –

Information available in the weather file for Dubai city on temperature, light levels, wind speed, cloud cover and relative humidity all play an important role in governing the outcome of the model simulation. (Refer to Appendix A). But for this study the most important factor will be the Direct Solar Radiation levels received throughout the year as it can change in angle and intensity depending on the position of the sun along the sun path during the course of the day and the seasons.

The Direct Solar Radiation levels in Dubai are very high and reach maximum intensity in the afternoon. Daylight is available for approximately eight to ten hours every day and the sun path follows a pre-dominantly South East to South West pattern for most of the year. During summer the position of the sun is almost overhead during midday. During the winter, the rays of the sun are more penetrating through the building envelope as the angle of incidence of sunrays are more acute during morning and evenings. Hence, the sides that need to be considered for solar shading design strategies in a building in Dubai are the East, West and South facades. The North façade does not receive direct solar radiation, but the use of glazing in an urban environment could result in reflected glare off the glazing on neighboring buildings.

Mohsen M. Aboulnaga (2006) in his study on the misuse of glazing in Dubai focused on the Daylight levels as the main parameters that would influence his study on the glare resulting from the over-glazed facades of most high rises in Dubai. On the other hand, Puteri Shireen Jahnkassim and Kenneth Ip (2006) in their study on some tropical high rises designed by Ken Yeang focused on direct solar radiation and daylight levels as the main parameters affecting the performance of the facades chosen for the study. While each researcher understands the presence and effect of each component of the array of environmental factors that affect the performance of a bio-climatic design, in order to study a specific feature of a design, it becomes necessary to focus on the main component that needs to be analyzed.

Reducing the extent of direct solar radiation infiltrating through the building facades could in turn reduce the heat gain in a building, helping to lower the cooling loads of a building, which would in turn reduce the energy consumption and related Carbon emissions.

Chapter 4 – Results and Analysis

4.1 Case 1 – Standard Double Pane Glazed Panels –

Standard Double glazed panel with a u-value of 2.4 W/m²K was used and it was found that maximum infiltration of heat into the enclosure through the façade came from the East, South and West facades. The heat penetration from the South façade was greater during winter conditions as the angle of incidence of sunrays is more acute in winter. Heat penetration through direct solar radiation can be observed between 2 and 3m into the enclosure from the façade. Effect of the direct solar radiation deeper into the core of the building is negligible.

Total cooling/ heating load for the analyzed zone is 157KWh/m² with maximum cooling loads in the months of June, July, August and September with August the highest. Maximum heating load was found in January, which also had the least Cooling loads. (Refer Appendix B for full tables)

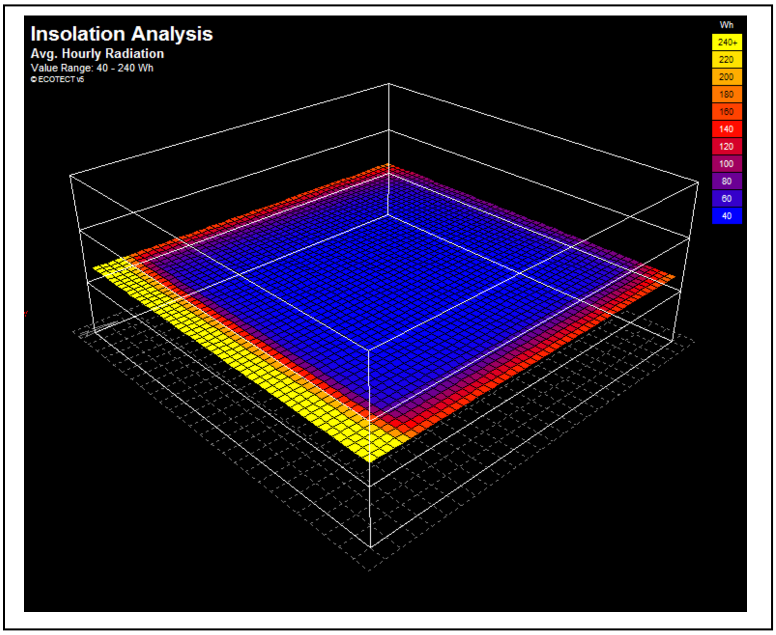


Fig 4.1 Case 1 Model Image,
Image Source- Ecotect 5.5

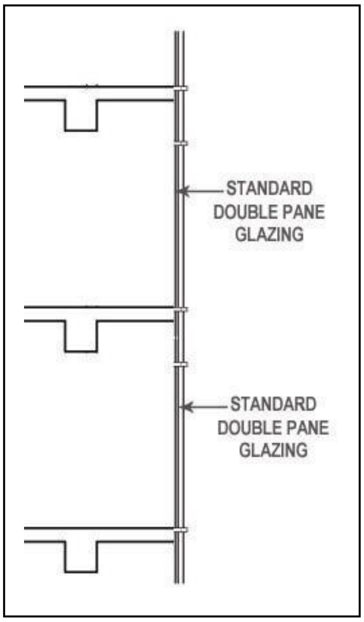


Fig 4.2 Case 1 Typical Section
Image Source- Cad Drawing

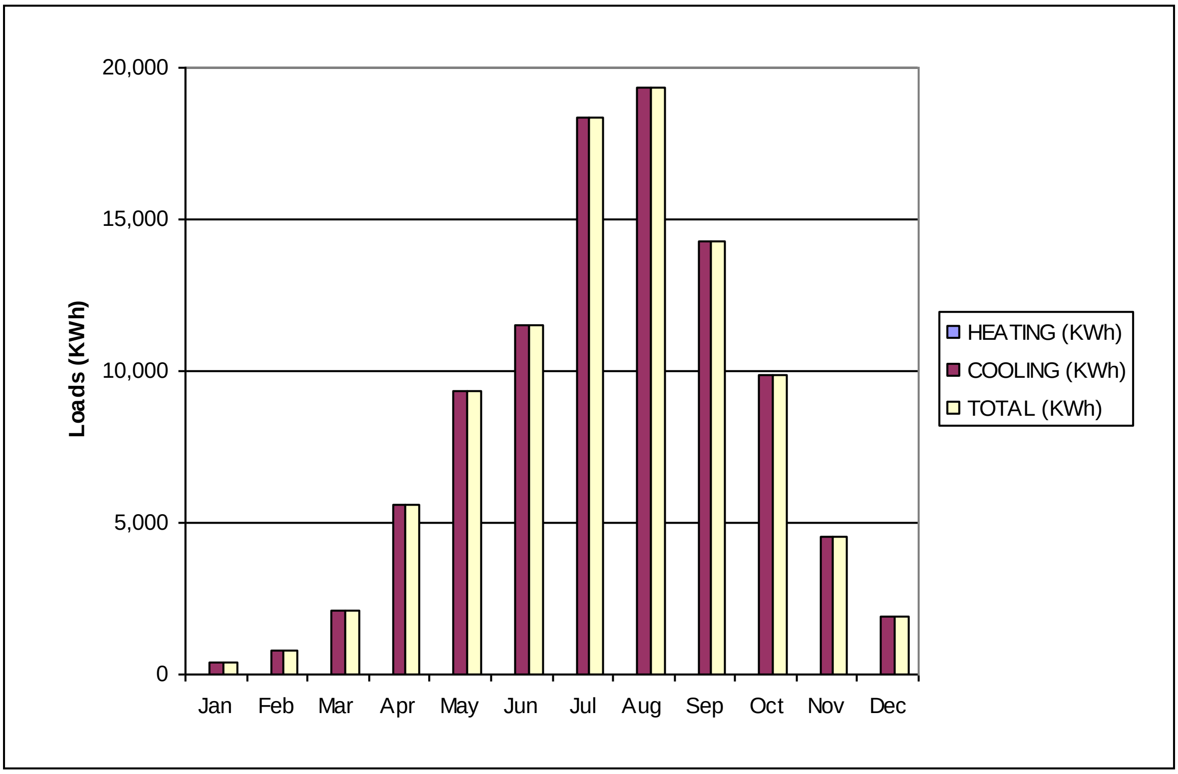
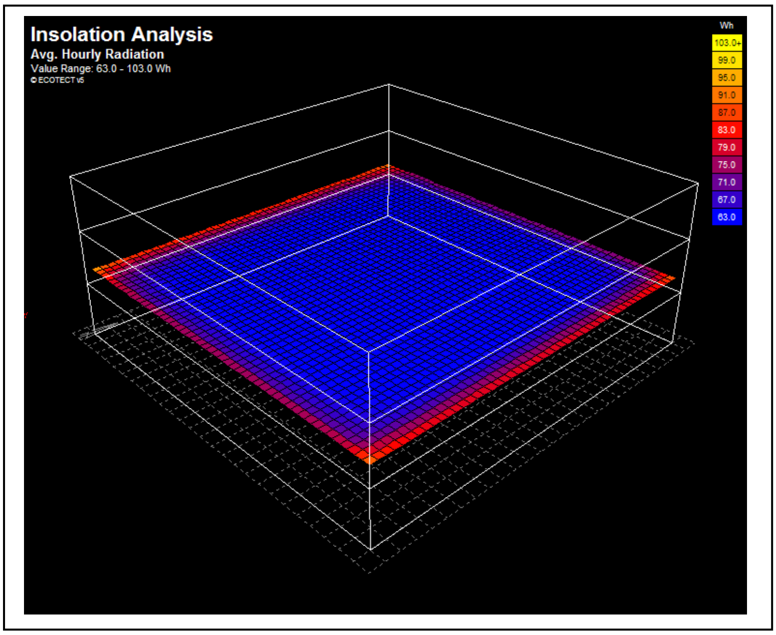


Fig 4.3 Case 1 Cooling Loads, Image Source- Ecotect 5.5

4.2 Case 2 – (Single Skin) ETFE –

In this case, the Single skin in the model is replaced with an ETFE skin U-value of 1.9 W/m²K. A marked decrease in the amount of heat entering the enclosure is found with not much heat penetrating deeper than the cavity that is 1m wide between the two skins. Once again here too the amount of heat penetrating through the South façade is more during the winter. Total annual cooling/ heating loads for the tested zone is 136 KWh/m² with maximum cooling loads in the summer months of June to September with the highest in August. For the model tested with a translucent ETFE foil skin having a U-value of 1.2 W/m²K and 50% transparency, cooling/ heating loads for the tested zone was found to be 130 KWh/m². The difference is too small to warrant a consideration over the transparent ETFE foil skin while testing the Modular Double Skin system. The Cooling loads are reduced by almost 17% over the Glazed panels by just using Single Skin ETFE foils instead of glazing which is encouraging. (Refer Appendix B for full tables)



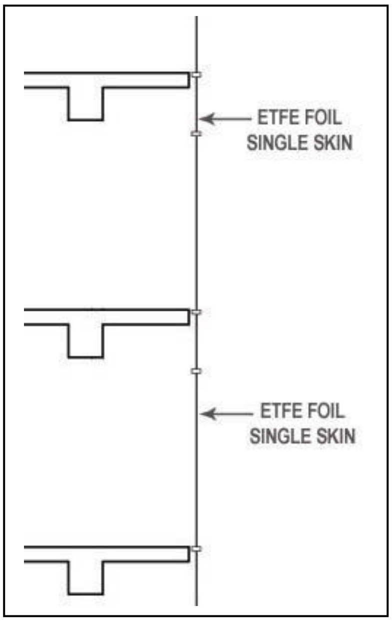


Fig 4.4 Case 2 Model Image,
Image Source- Ecotect 5.5

Fig 4.5 Case 2 Typical Section
Image Source- Cad Drawing

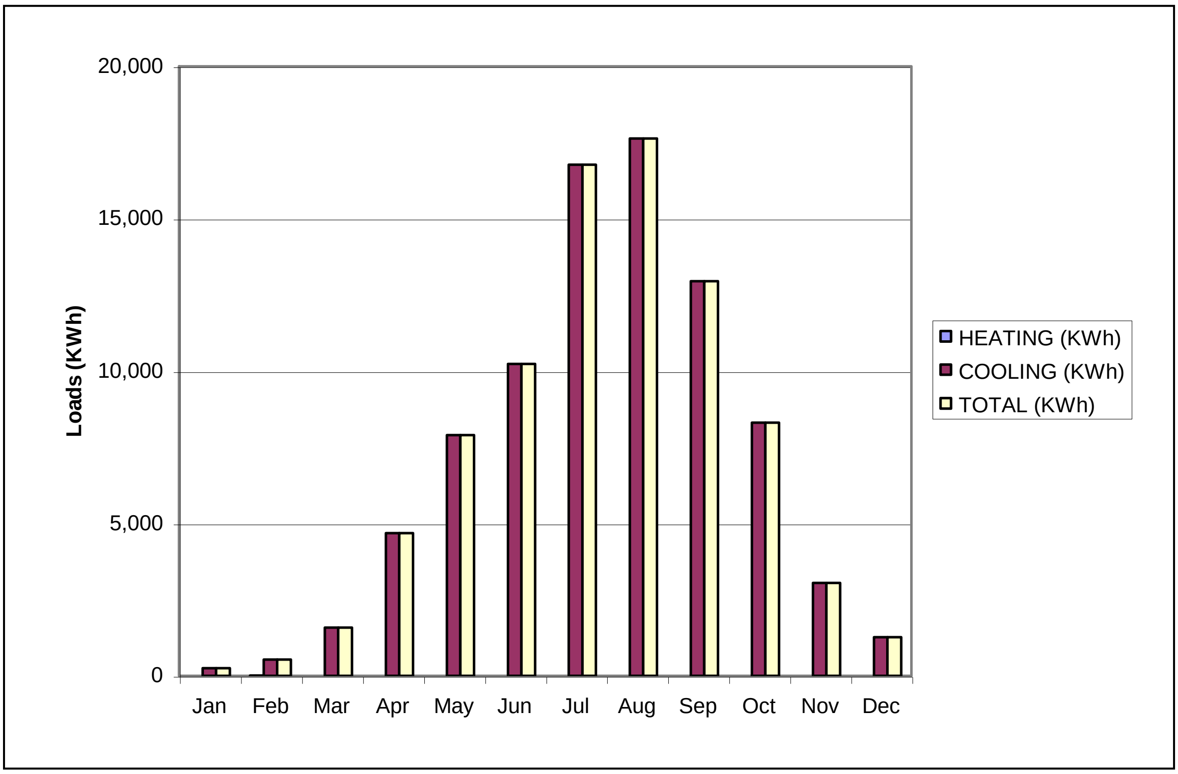


Fig 4.6 Case 2 Cooling Loads, Image Source- Ecotect 5.5

4.3 Case 3 – ETFE Double Skin Façade System –

In this case, the Single skin system is replaced with an ETFE Double skin system with an internal skin made of Single pane glazing with a u-value of 6W/m²K and the outer skin made up of ETFE with a u-value of 1.9 W/m²K. A marked decrease in the amount of heat entering the enclosure is found with not much heat penetrating deeper than the cavity that is 1m wide between the two skins. Once again here too the amount of heat penetrating through the South façade is more during the winter.

Total annual cooling/ heating loads for the tested zone is 126 KWh/m² with maximum cooling loads in the summer months of June to September with the highest in August. (Refer Appendix B for full tables)

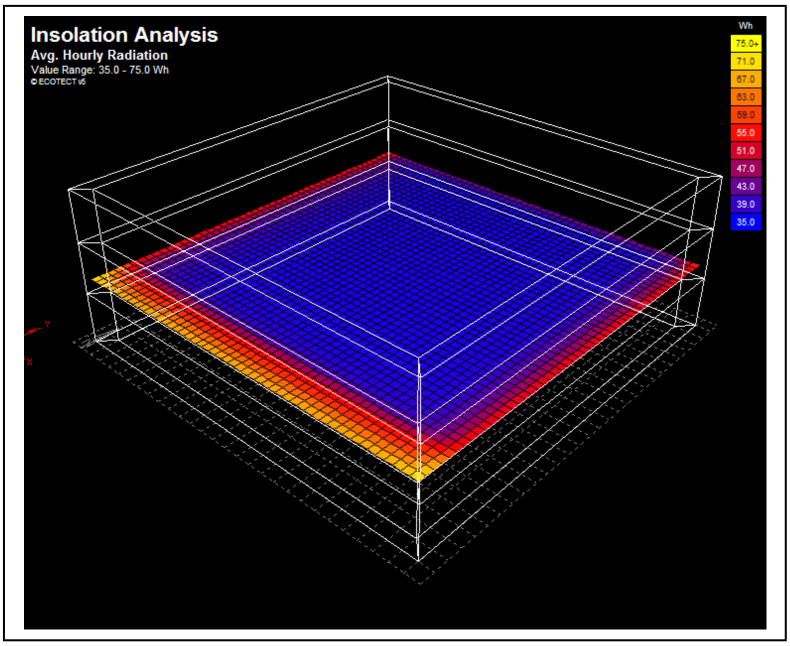


Fig 4.7 Case 3 Model Image,
Image Source- Ecotect 5.5

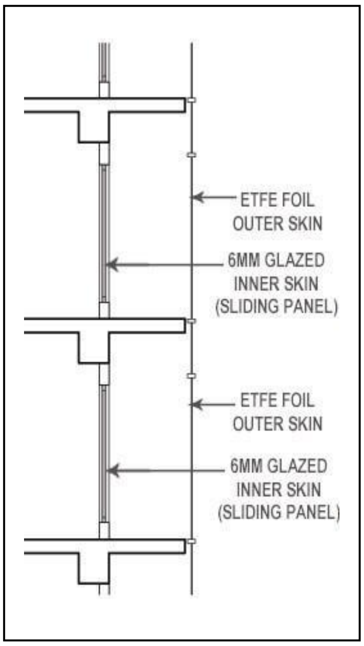


Fig 4.8 Case 3 Typical Section
Image Source- Cad Drawing

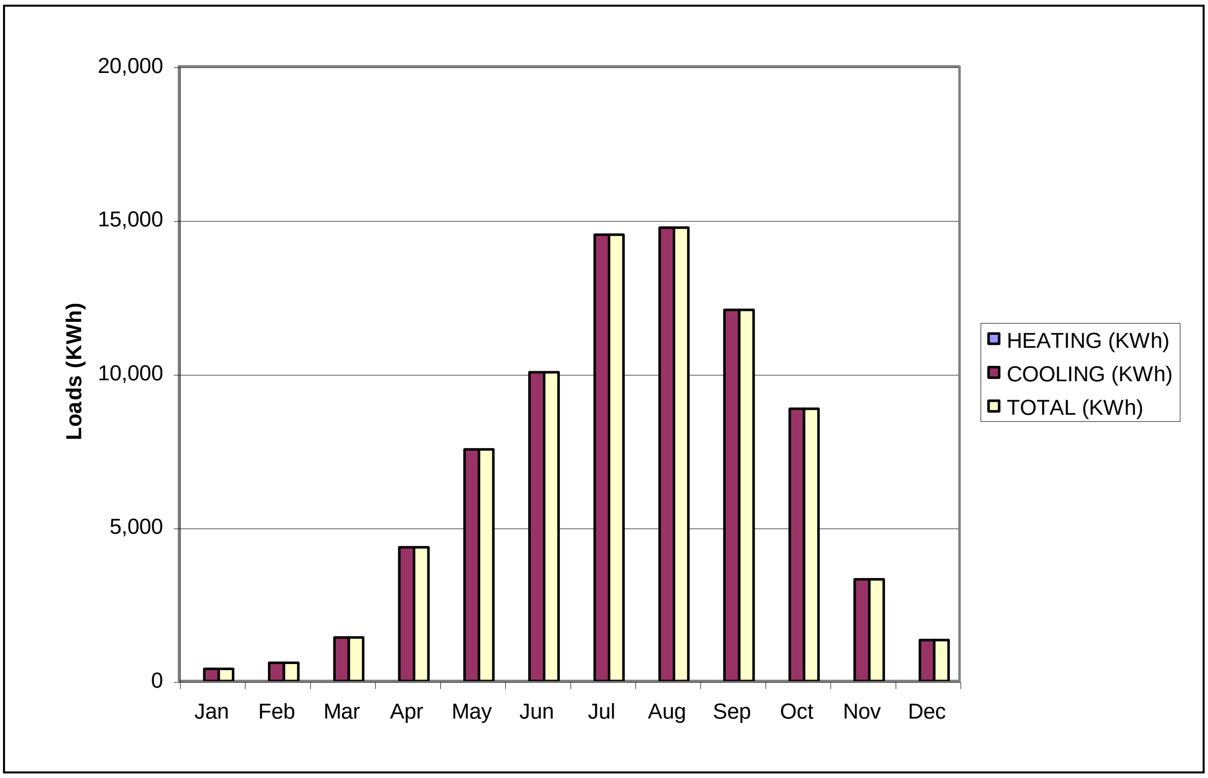
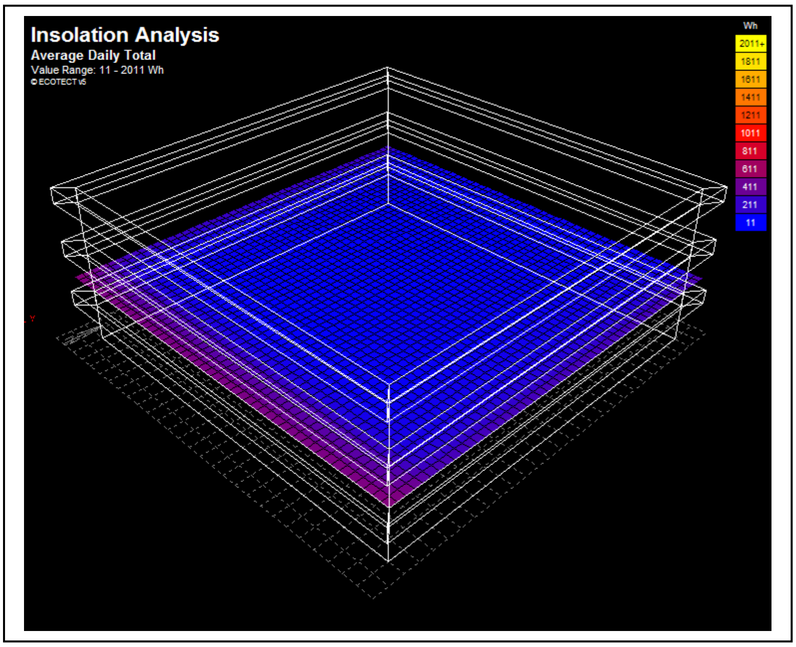


Fig 4.9 Case 3 Cooling Loads, Image Source- Ecotect 5.5

4.4 Case 4 – Partially open (all year round) ETFE Double Skin System –

In this case the same materials as in Case 3 are used but here the ETFE skin is considered to be partially open all year round up to a height of 2.5m from the floor level. There is a much higher penetration of heat from the façade as the inner skin has a very low u-value. There is maximum penetration of heat from the South façade during the winter months. The annual cooling/ heating for the tested zone here is the highest with a value of 162 KWh/m² with a heating load of 0.76 KWh/m².

The maximum cooling loads are in the summer months with the highest in August, while the maximum heating loads are in December. (Refer to Appendix B for full tables)



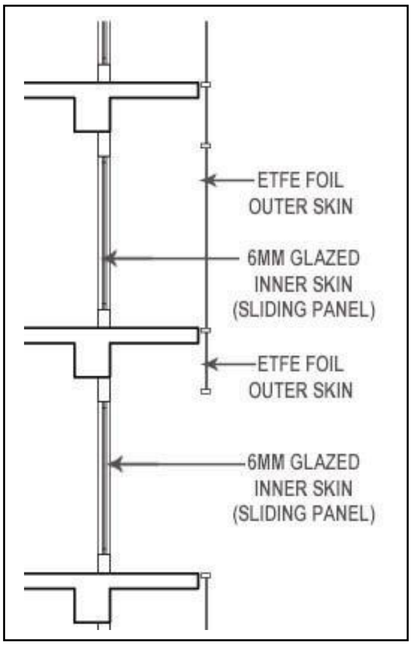


Fig 4.10 Case 4 Model Image,
Image Source- Ecotect 5.5

Fig 4.11 Case 4 Typical Section
Image Source- Cad Drawing

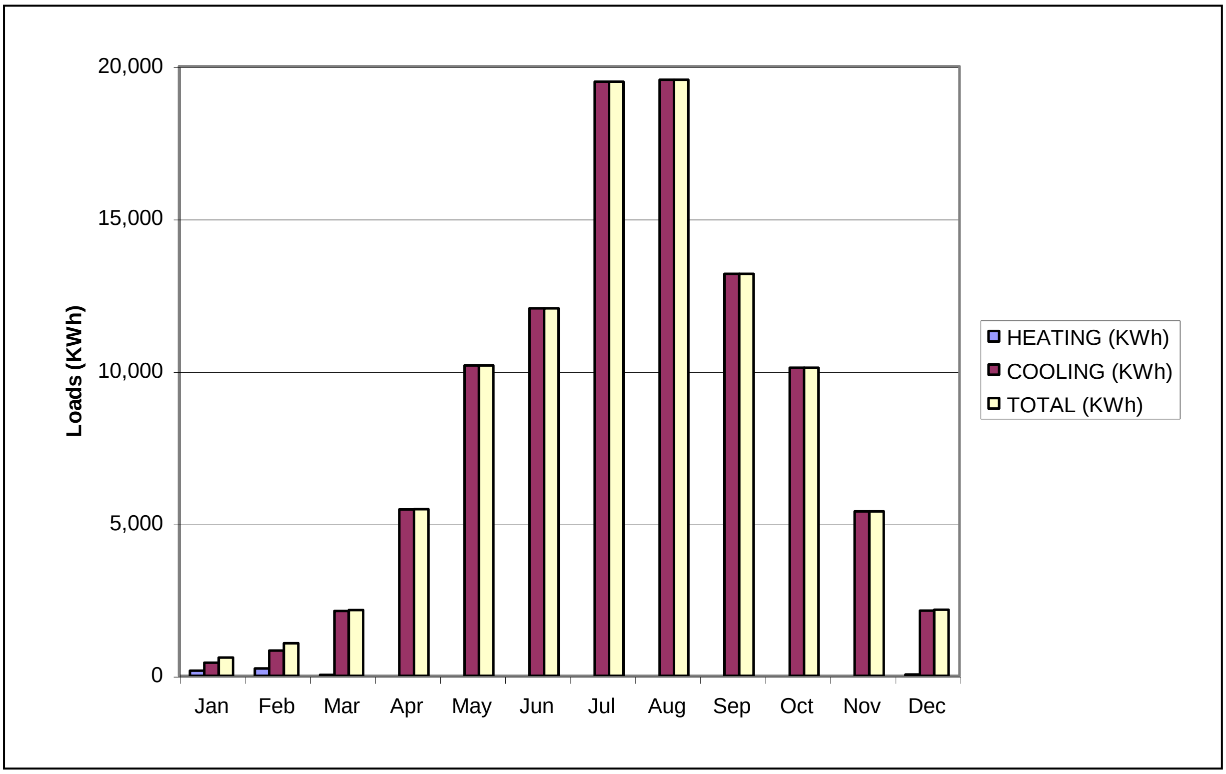


Fig 4.12 Case 4 Cooling Loads, Image Source- Ecotect 5.5

4.5 Case 5 – Selectively Open ETFE Double Skin System –

When the partially open mode is used in combination with the closed mode operation, the results are much more favorable. The cooling/ heating load value is 133 KWh/m². This is almost as good as the Case 3 where the ETFE skin was considered closed through out the year. Hence it has potential to be used in the Selectively open mode where the ETFE skin is kept closed through the months from April to October, while it can be kept opened from November to March. During the summer days too, the ETFE skin can be opened during the night facilitating in nighttime ventilation and cooling. Being able to open up the façade during favorable conditions is a boost psychologically as it helps one connect with the outside environment and though the cooling load reductions are not as good as in Case 3, this options provides a compromise between the best performance and humane built environment.

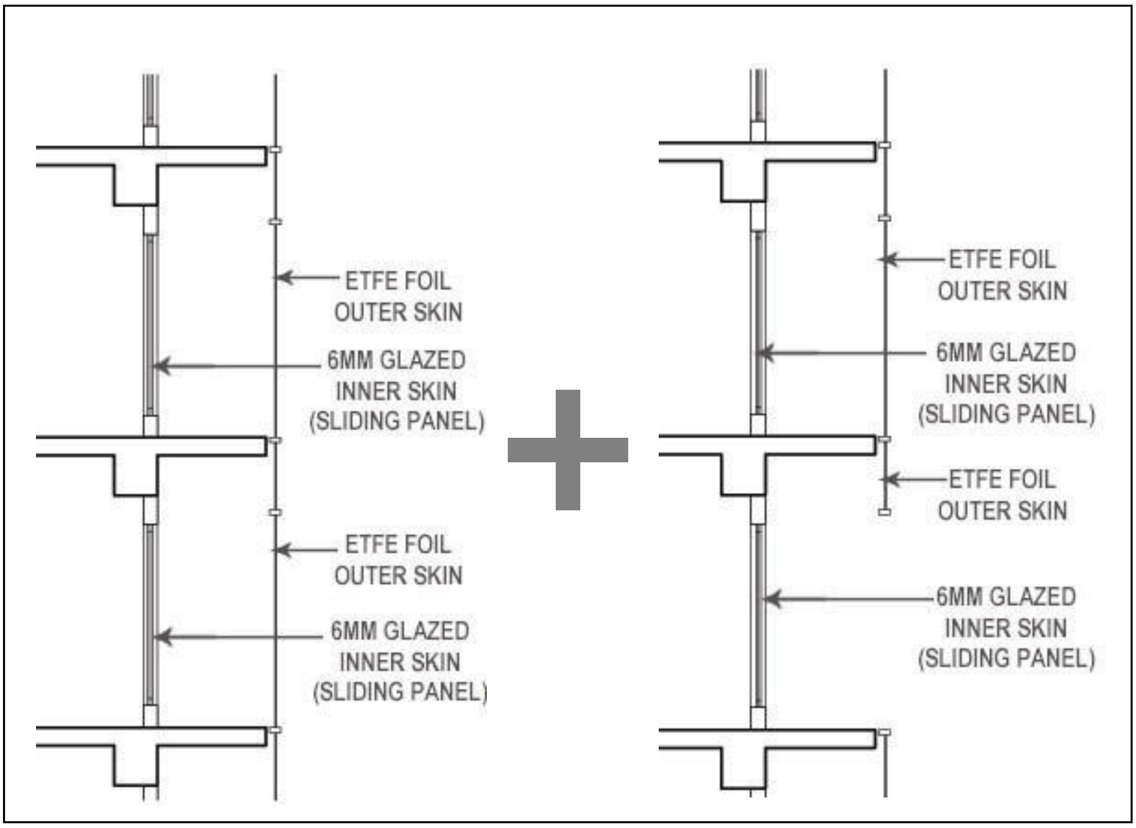


Fig 4.13 Case 5 Typical Section, Image Source- Cad Drawing

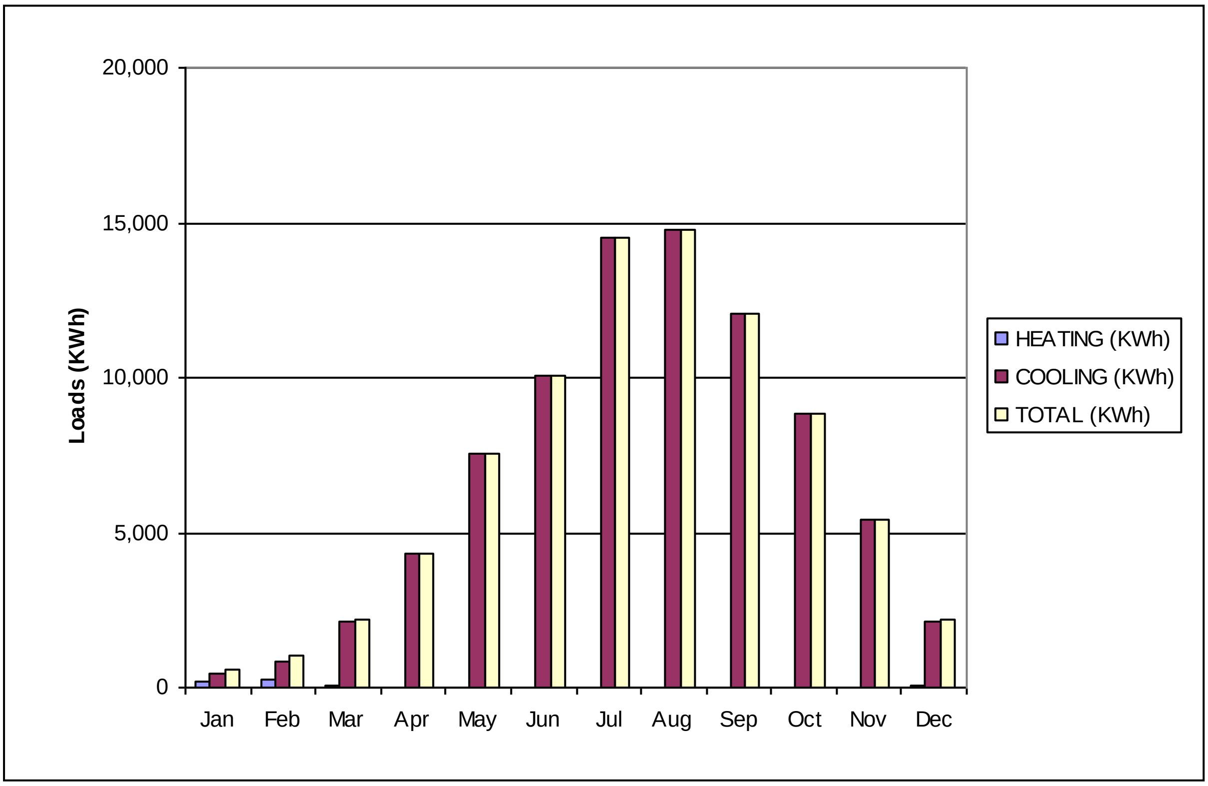


Fig 4.14 Case 5 – Cooling Loads, Image Source- Ecotect 5.5

4.6 Cooling Load Summary –

The Modular Interactive Double Skin Facade System with an external ETFE skin helps to reduce the Direct Solar Gain through the Façade by limiting it within the cavity between the two skins and incidentally helping to reduce the cooling/ heating loads by up to 25% for a fully closed system.

The total cooling/ heating load for Case I or the glazed option is 98.11MWh per floor or 157 KWh/m² while that of the option in Case 3 or the ETFE Double Skin system is 79.2 MWh per floor or 126 KWh/m². When used in a mixed mode where the outer ETFE skin is partially open between the months of November to March, the cooling/heating loads are not much higher than the fully closed mode at 83.5MWh per floor or 133 KWh/m². However, for calculating the value of maximum savings, the fully closed mode is considered which requires 126 KWh/m² as compared to 157 KWh/m² for the standard glazing in Case 1. This leads to an annual savings

of AED 160,000 for a 25 storey building (assuming the unit charge by DEWA to be 0.33aed/KWh and for a floor plate of 625m²).

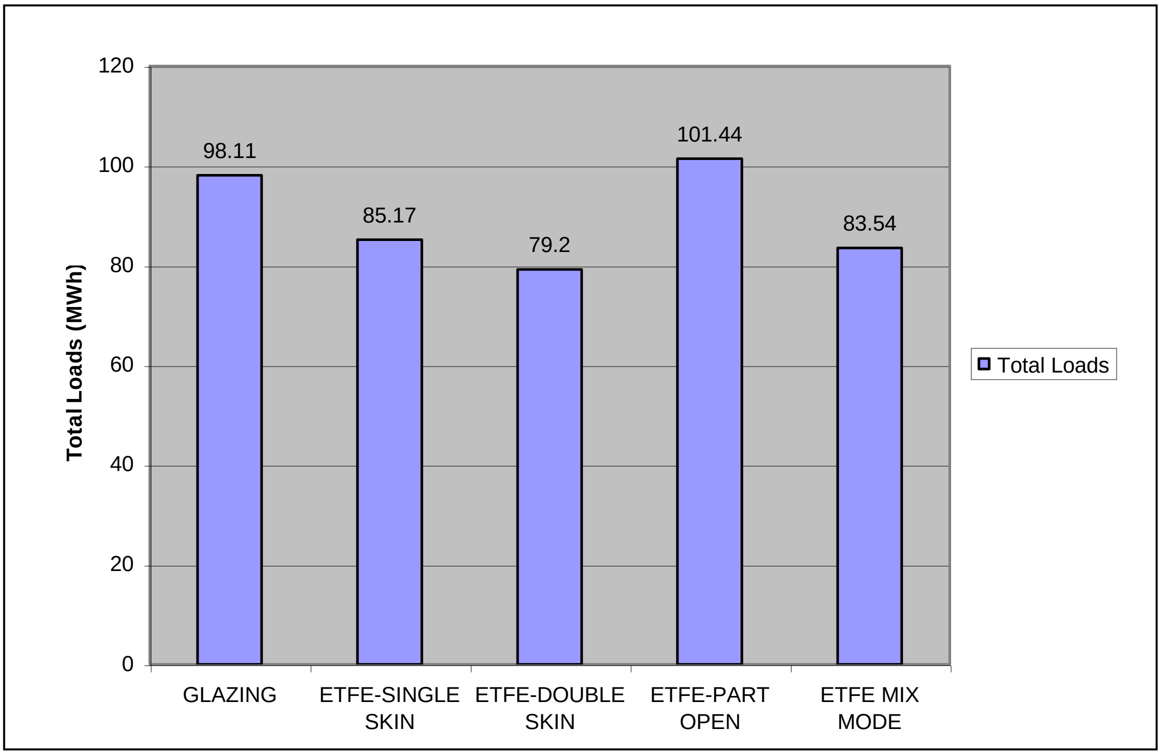


Fig 4.15 Total Load Comparison per floor, Image Source- Ecotect 5.5

4.7 Economic Analysis of Savings –

Economics plays an important role in determining the success of any solution, as to be widely accepted, it has to be economically viable. Hence it is important to determine the present worth of the savings and tally it against the initial cost to understand whether it is a profitable solution. The economic value of the savings in terms of its present worth can be calculated through the formula below

$$PW_A = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

Where

- PW_A is the Present Worth of the savings

- i is the interest rate,
- n is the number of years for which installments will be paid

Considering an interest rate of 10%pa and for a period of 20 years, the present worth of the savings is ~ Aed 1.362 Million.

The initial cost of the ETFE would be higher. From the local suppliers Taiyyo for ETFE manufacturers MAKMAX, the price sourced for the material was Aed 3500/m^2 as compared to price of double pane glazing panels costing Aed 600/m^2. The total difference in initial cost for the materials would be 26.1 million for a 25 storey building with a floor plate of 25x25m.

This makes the investment economically unviable, but it has to be taken into consideration that the price sourced for ETFE was from a single supplier and considering that the material is new to the market, it might be overpriced. The cost though does include fabrication, transportation and installation on site. From a sustainability point of view, ETFE does score more points as it can be recycled and used as a raw material for a new batch of ETFE. This helps cut down energy and carbon costs greatly. Translucent ETFE foil was also tested in Case 2, but the reductions in cooling/ heating loads was not substantial enough to warrant consideration as a possible option.

Chapter 5 – Conclusion and Recommendations

5.1 Conclusions –

The use of ETFE foils and cushions in a Modular Interactive Dynamic Façade system can help reduce the direct solar heat gain through the building envelope by 25% and promises to be a Bio-climatic solution for the region. Using a mixed system where the ETFE skin is opened partially from November to March, the performance of the façade system remains still better than standard glazing and offers cooling load reductions of 15% but its greatest potential is that it can be used as an option where the tenants in the occupied space will have greater say over how they want their façade to be, whether open or closed. The interactive nature of the skin that would be controlled by sensors allowing it to adapt to the external conditions would provide a new age and urban bio-climatically responsive skin that holds potential to transform the way we look at building skins. However initial cost at current rates is much higher than that of standard glazing options available in the market.

5.2 Recommendations –

Although the use of ETFE skin can be an expensive option in the current market, one should not overlook the wide array of benefits and advantages it brings over standard glazing as a façade choice. Although initial investment for ETFE is currently more expensive, it would prove economical for large projects with complex designs that would be a limitation in glass. It would open up a new world of creative expression, as it also looks aesthetically appealing when lit by LED lighting at night. Probably, when there is a competitive market for ETFE, the cost of the material too would come down. ETFE as a material is completely recyclable and can be reintroduced as raw material into manufacturing without expensive treatments for impurities or additives making it a very sustainable choice as a building material.

Another factor is the weight. Weighing a little over 1.5 to 2.5kg/m², it is almost a hundred times lighter than double pane glazing panels, which weigh nearly 150kg/m². This would cut down the need for heavy support members and reduce the number of supports as larger spans can be covered through ETFE foils, hence recovering some of the extra investment by saving on expensive support framing. It also cuts down the number of trips to the site from the factory, cutting transportation costs by a strong margin and reducing earth threatening carbon emissions.

Maintenance is another area where ETFE outscores Glazing as it has a non-stick surface, which does not allow dust to settle, unlike glazing, hence it does not need to be cleaned as often as glazing and the internal side of the cushions are only cleaned once every two or three years. Window cleaning is one of the contributors to the operating costs involved with Building Maintenance. By using ETFE foils instead of glazing, this expense could be minimized besides saving on energy spent in operating the window cleaning systems, also bearing in mind that ETFE does not fade over time or get affected by UV exposure.

Although it has been found through this research that the Modular Interactive Double Skin Façade system with an ETFE outer skin can help reduce the cooling/heating loads by 25%, it still is a fairly new concept and there are many more aspects of this system that needs to be explored which could not be fulfilled due to the time constraints of this dissertation. Some of the potential aspects that could be explored in future include –

- Light Transmission and Glare issues
- Humidity control and condensation issues
- Acoustic control
- Impact of light weight of the material on structural design
- Maintenance cost of ETFE facades over standard glazed facades
- Embodied energy and carbon footprint
- Life cycle cost of the ETFE

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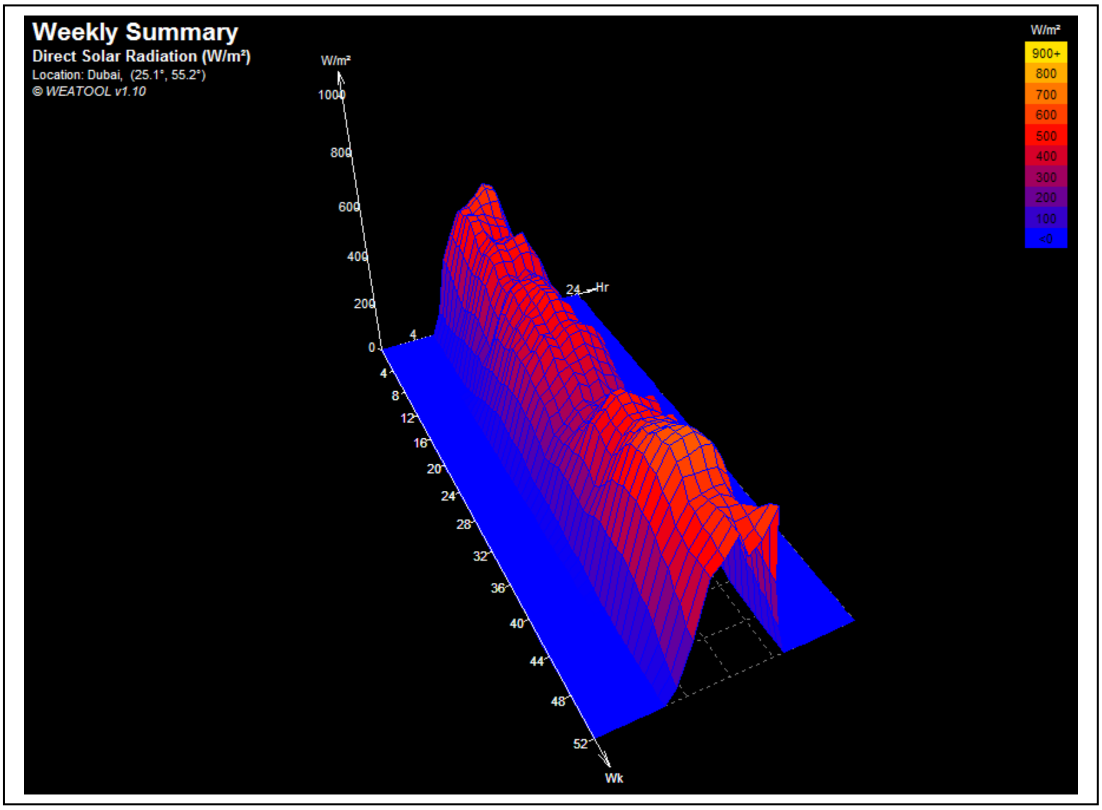
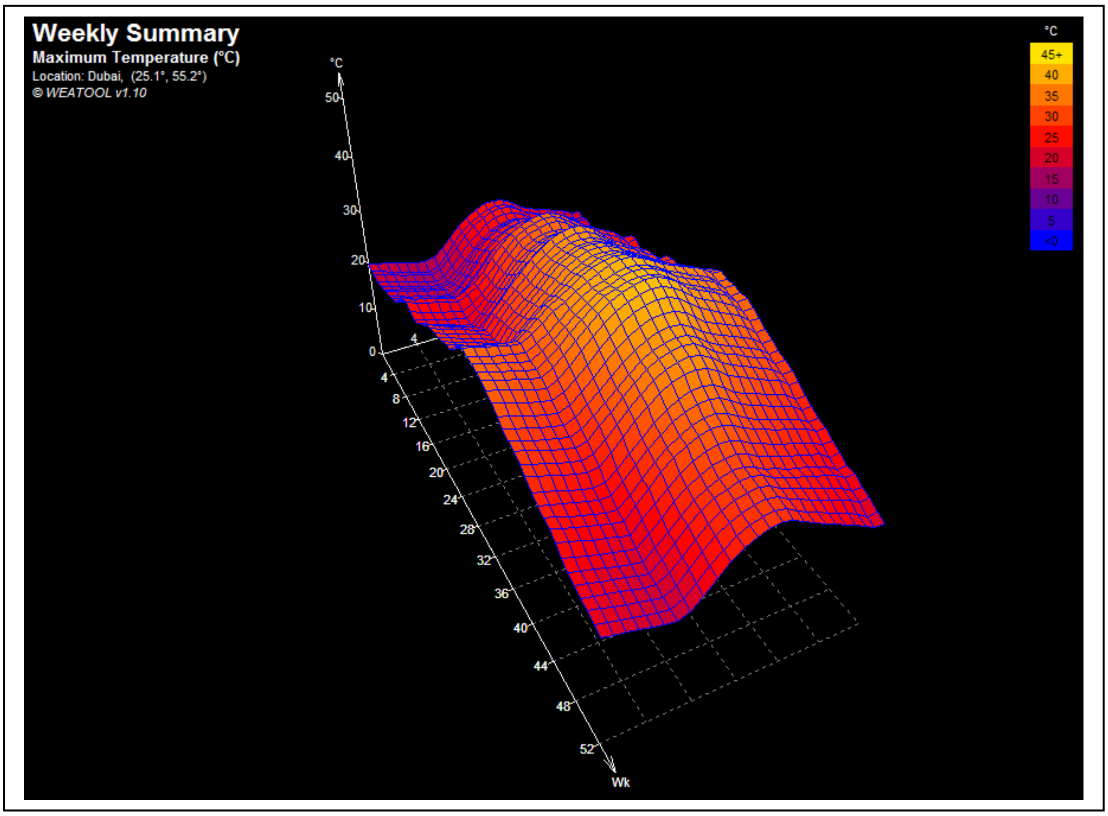
APPENDIX A

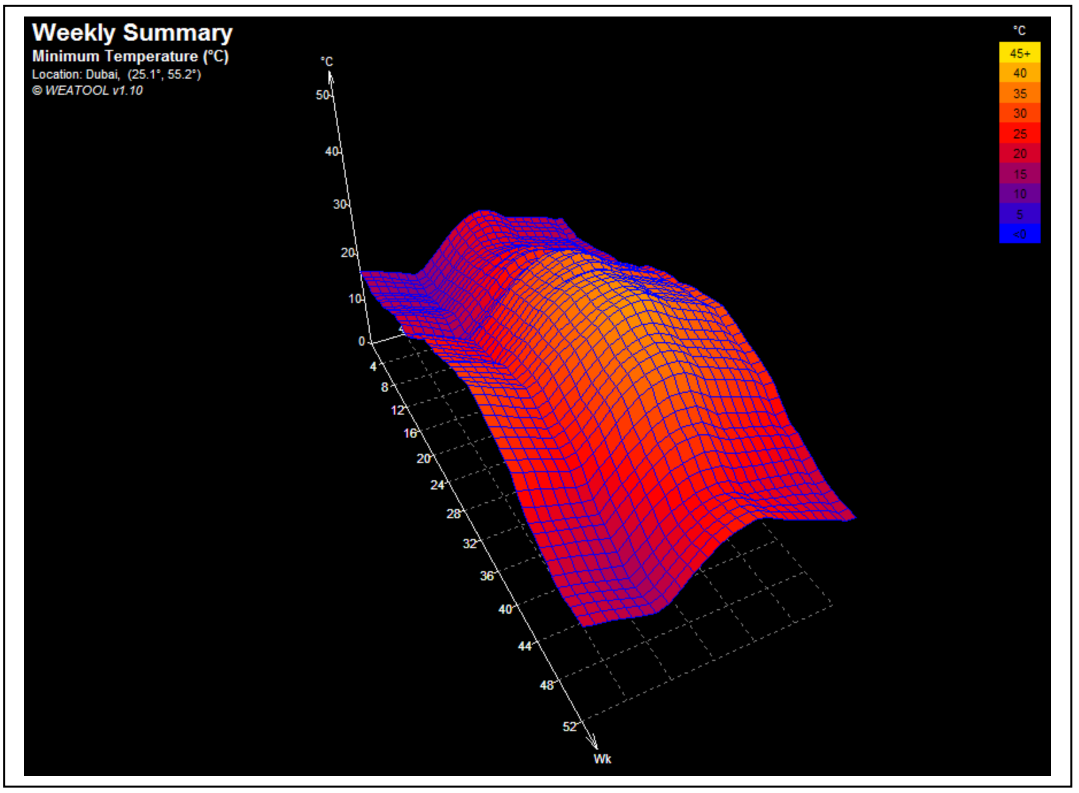
WEATHER CHARTS FOR DUBAI FROM ECOTECT



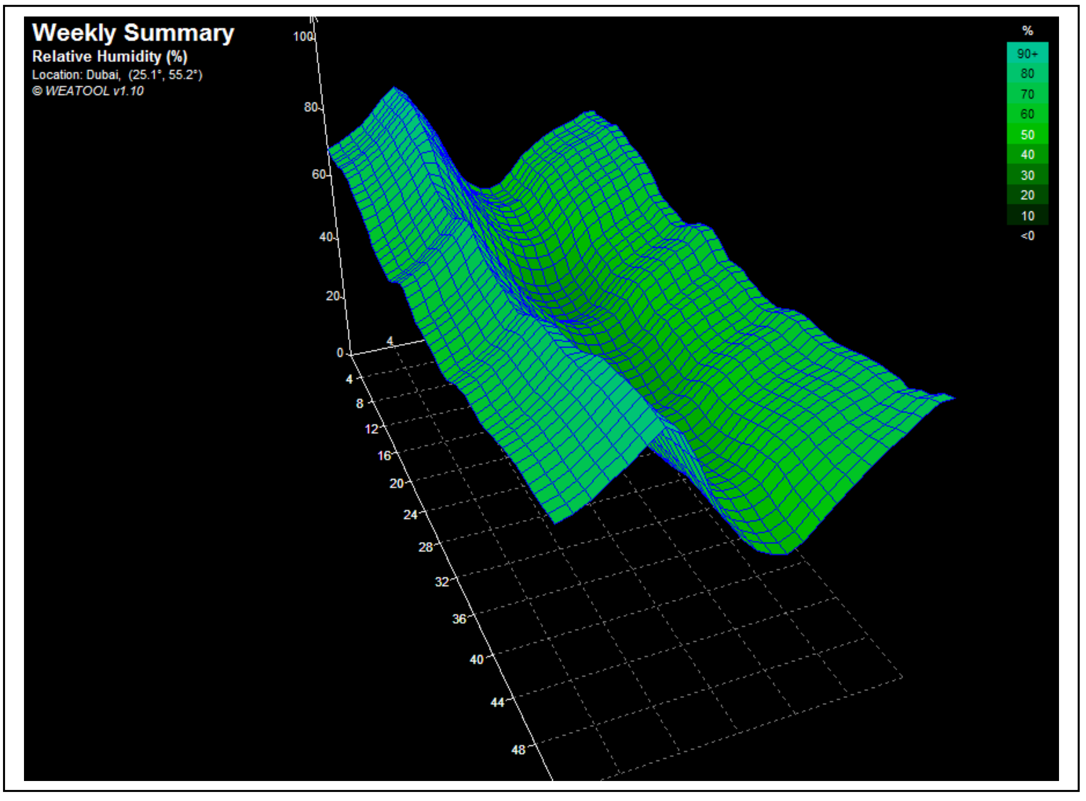
Direct Solar Radiation Chart for Dubai, Image Source –



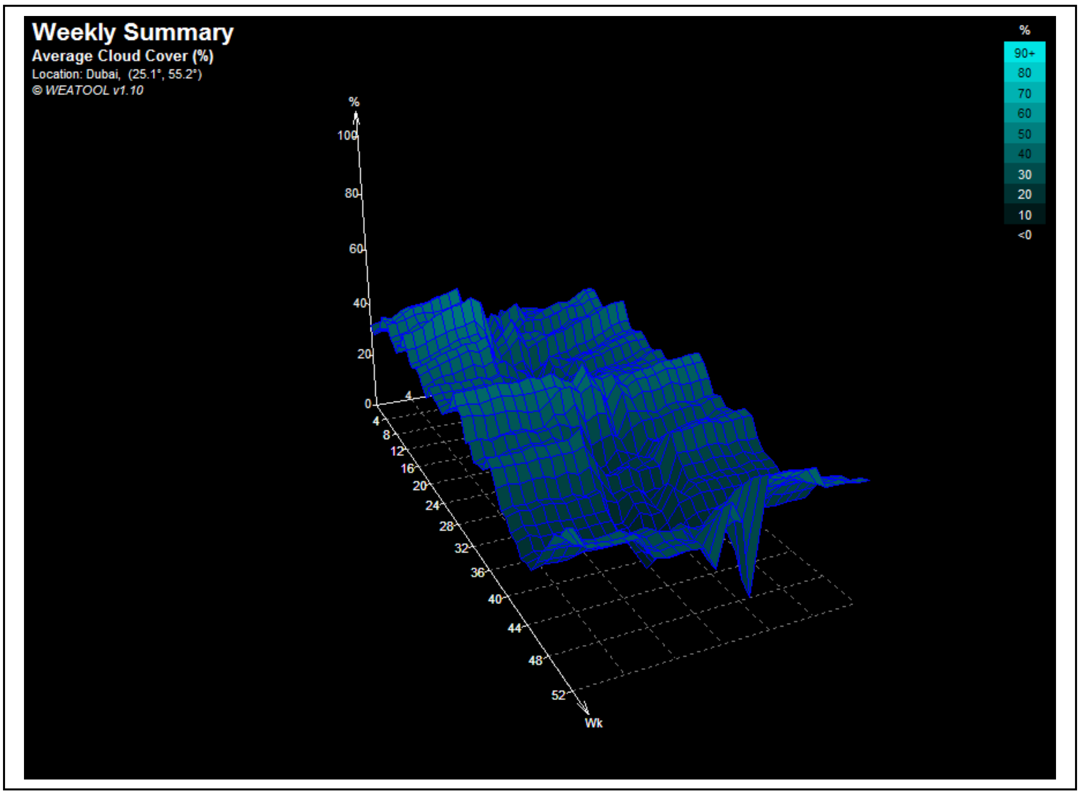
Maximum Temperature Chart for Dubai, Image Source –



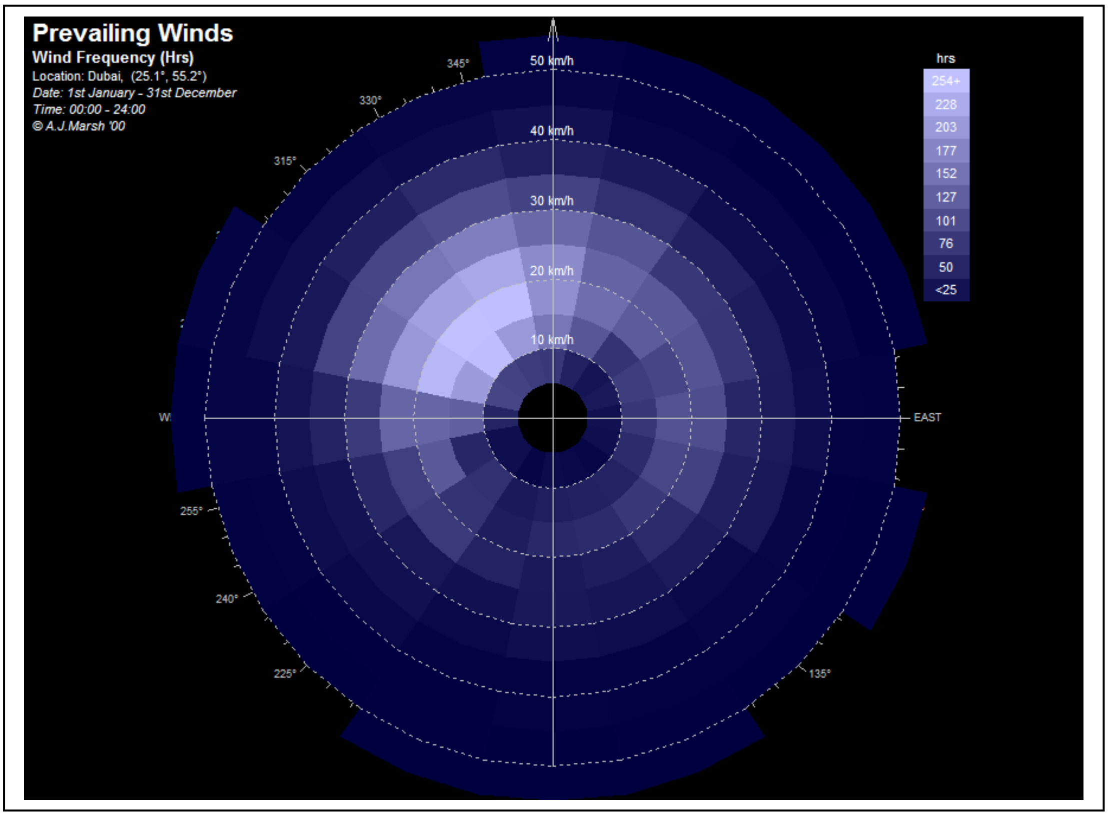
Minimum Temperature Chart for Dubai, Image Source –



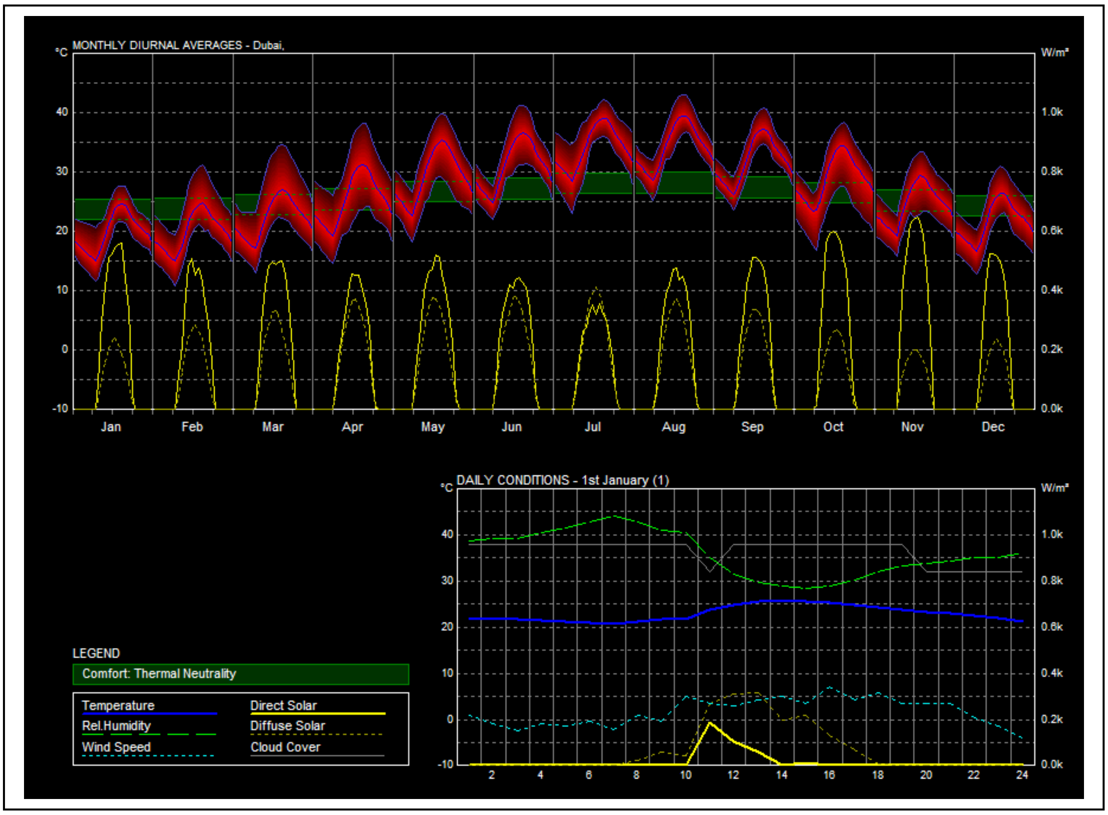
Relative Humidity Chart for Dubai, Image Source – Weather



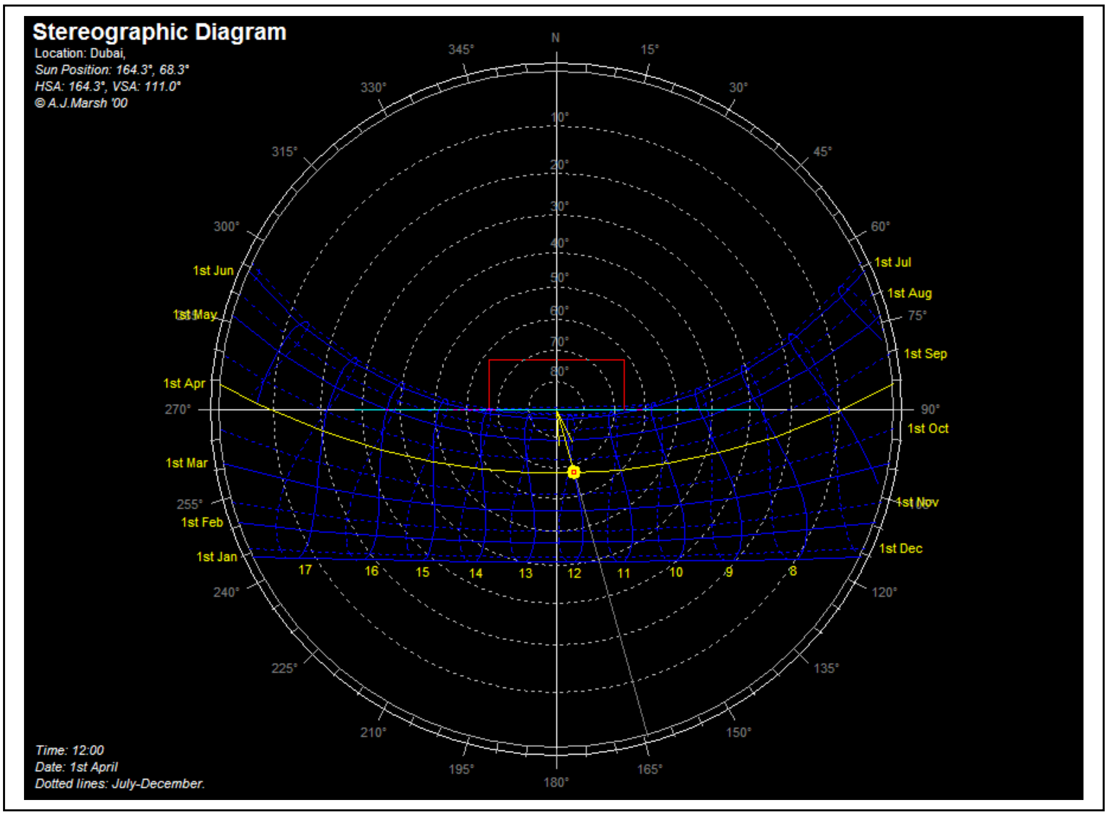
Average Cloud Cover Chart for Dubai, Image Source –



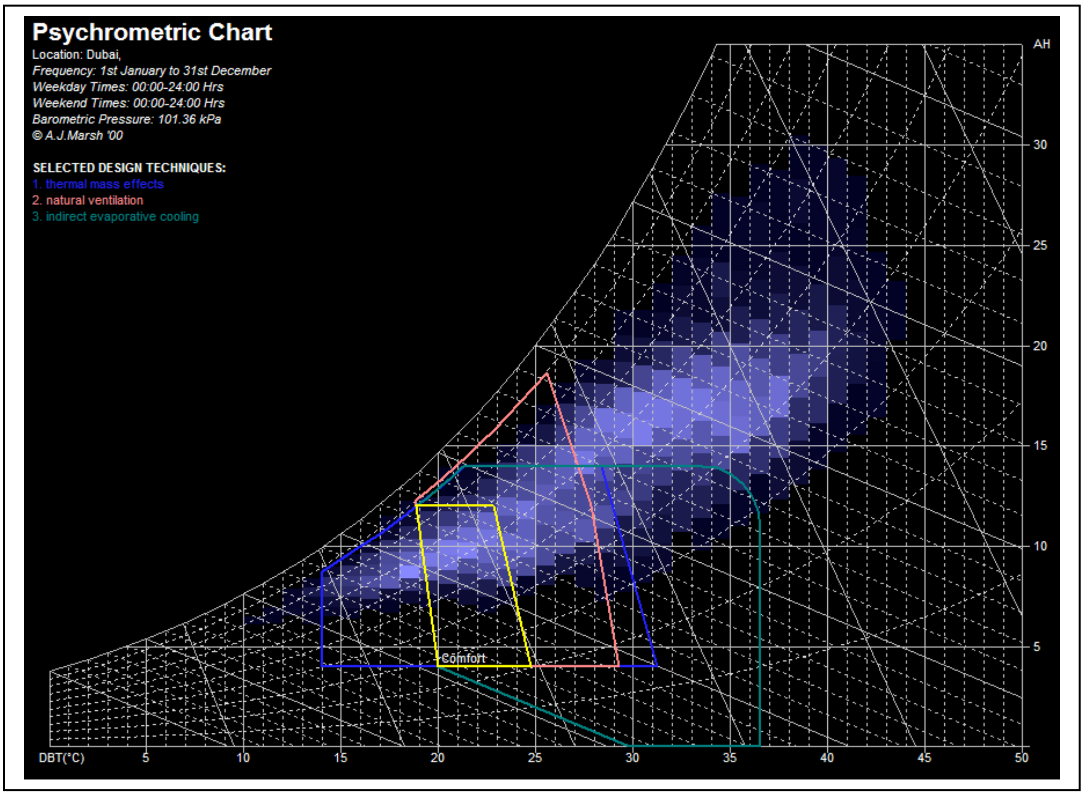
Wind Rose Chart for Dubai, Image Source –



Thermal Comfort Band Charts for Dubai, Image Source –



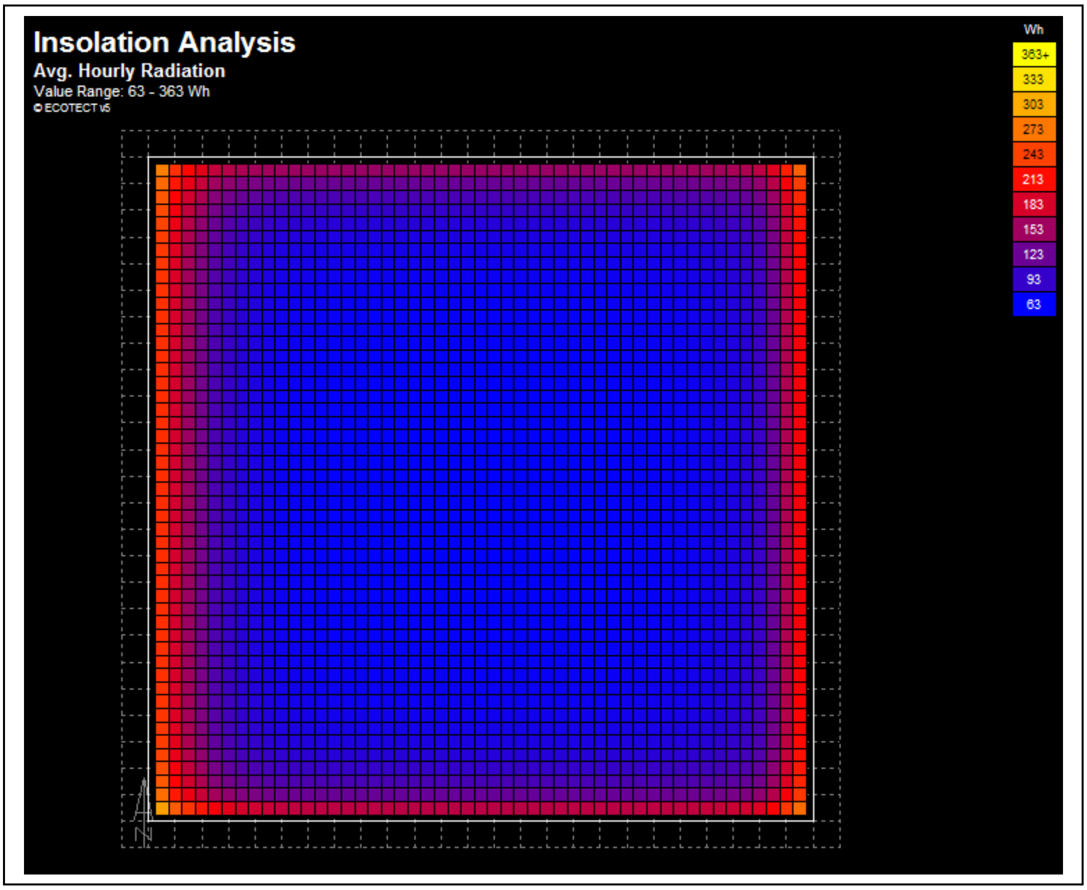
Sun Path Chart for Dubai, Image Source – Weather Tool



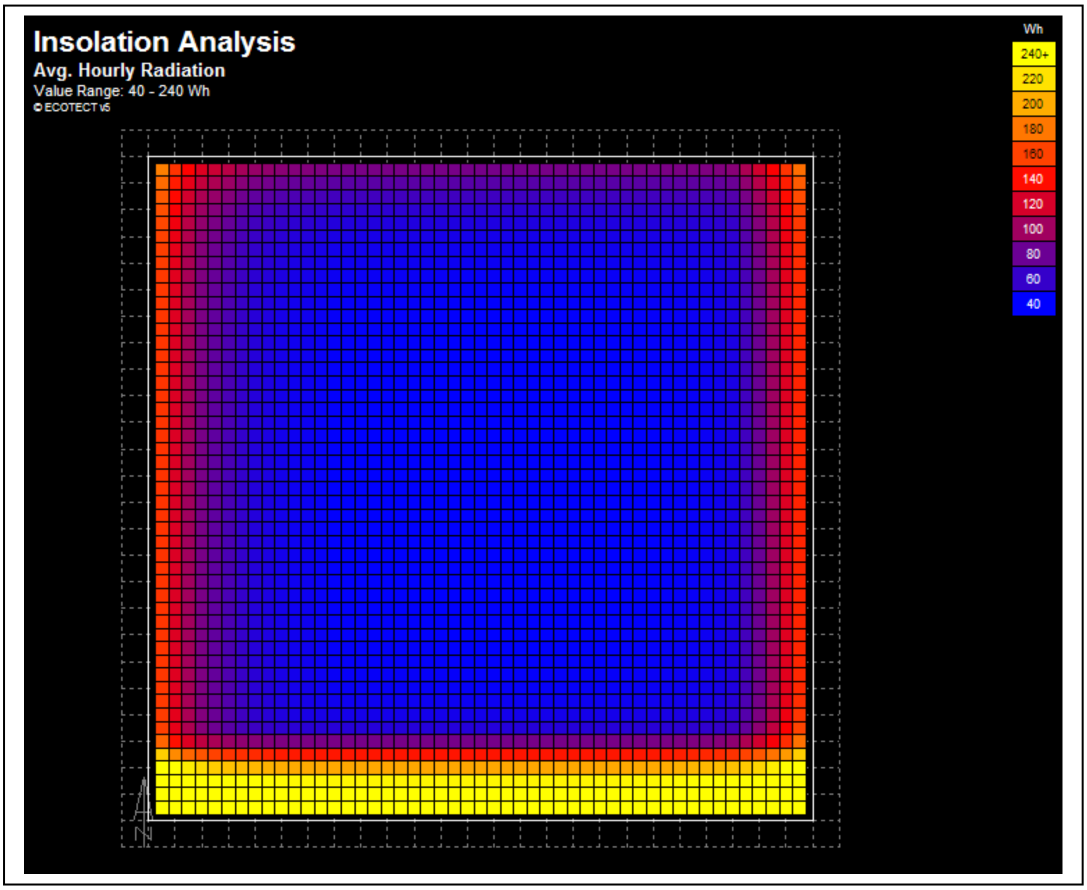
Psychrometric Chart for Dubai, Image Source – Weather

APPENDIX B

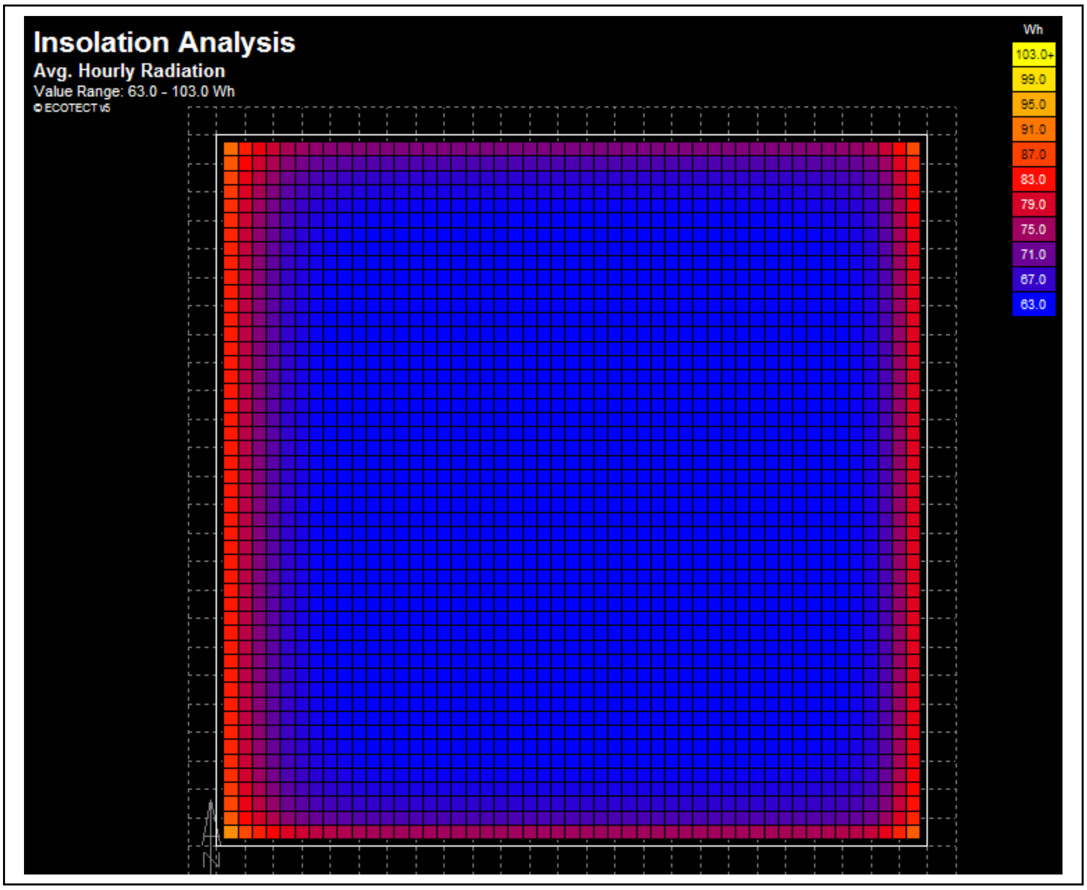
MODEL SIMULATION RESULTS FROM ECOTECT



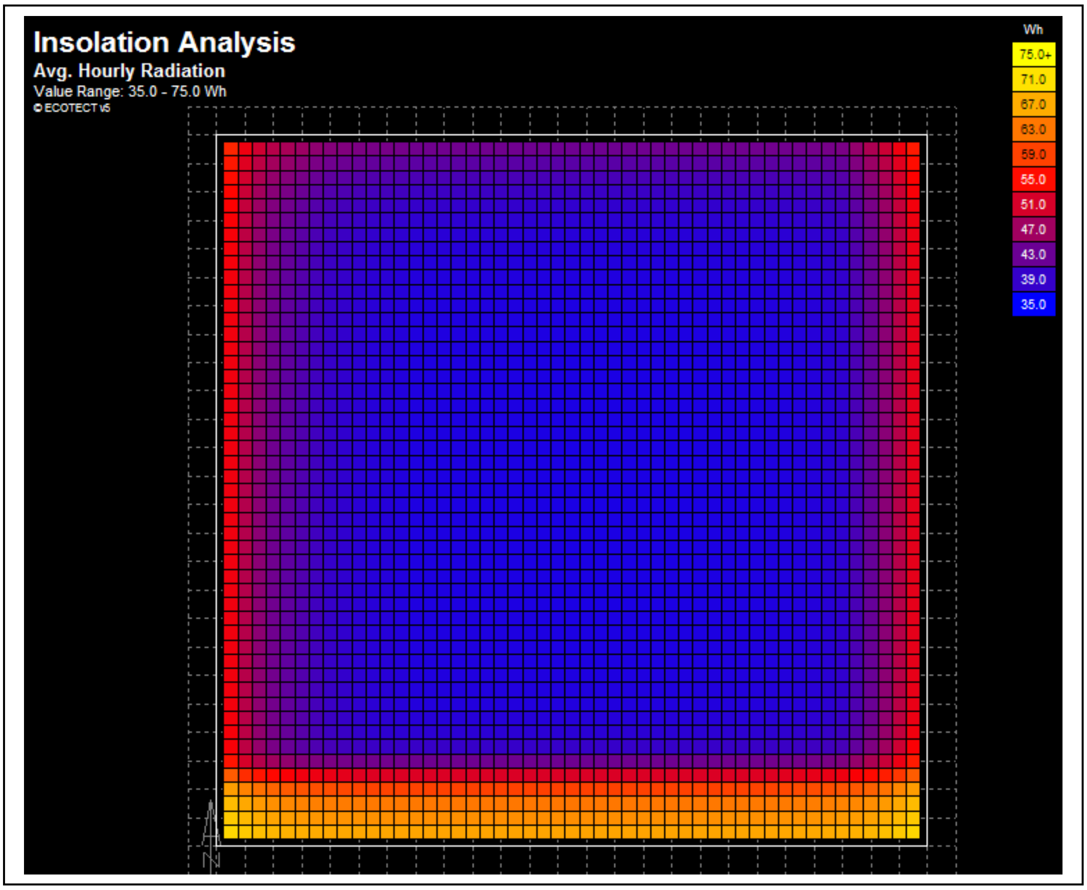
CASE 1 SOLAR GAIN ANALYSIS – SUMMER



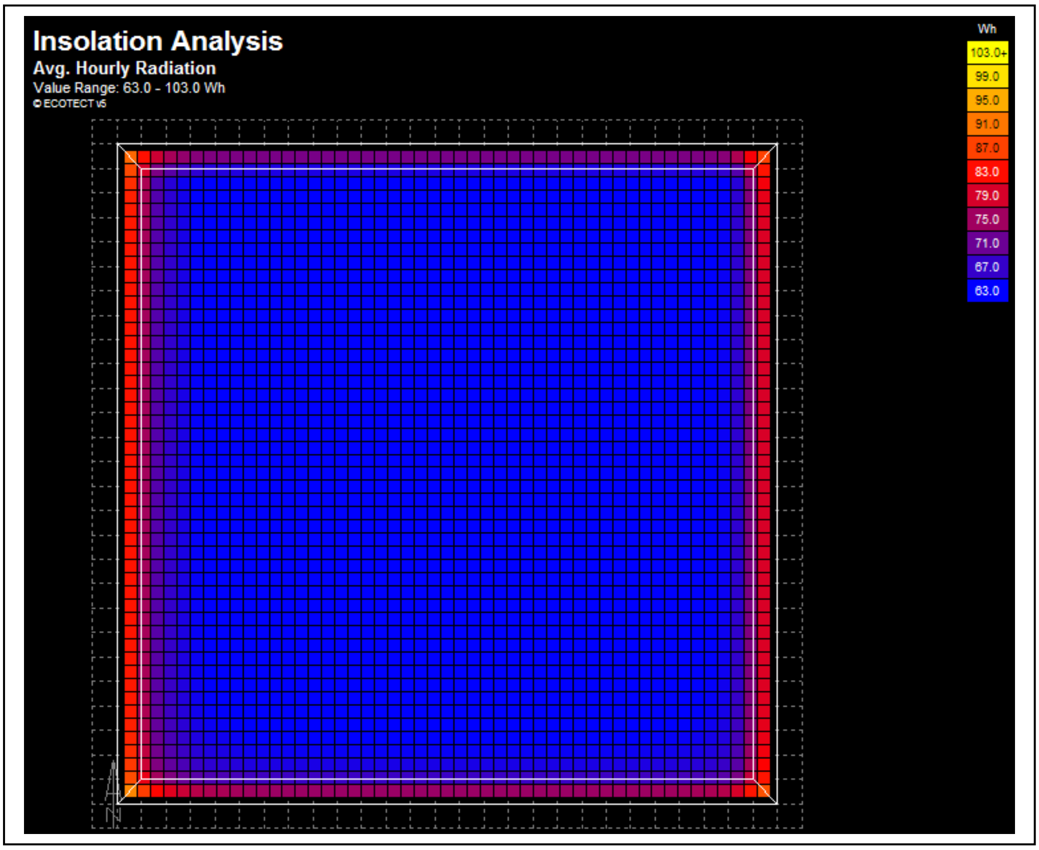
CASE 1 SOLAR GAIN ANALYSIS – WINTER



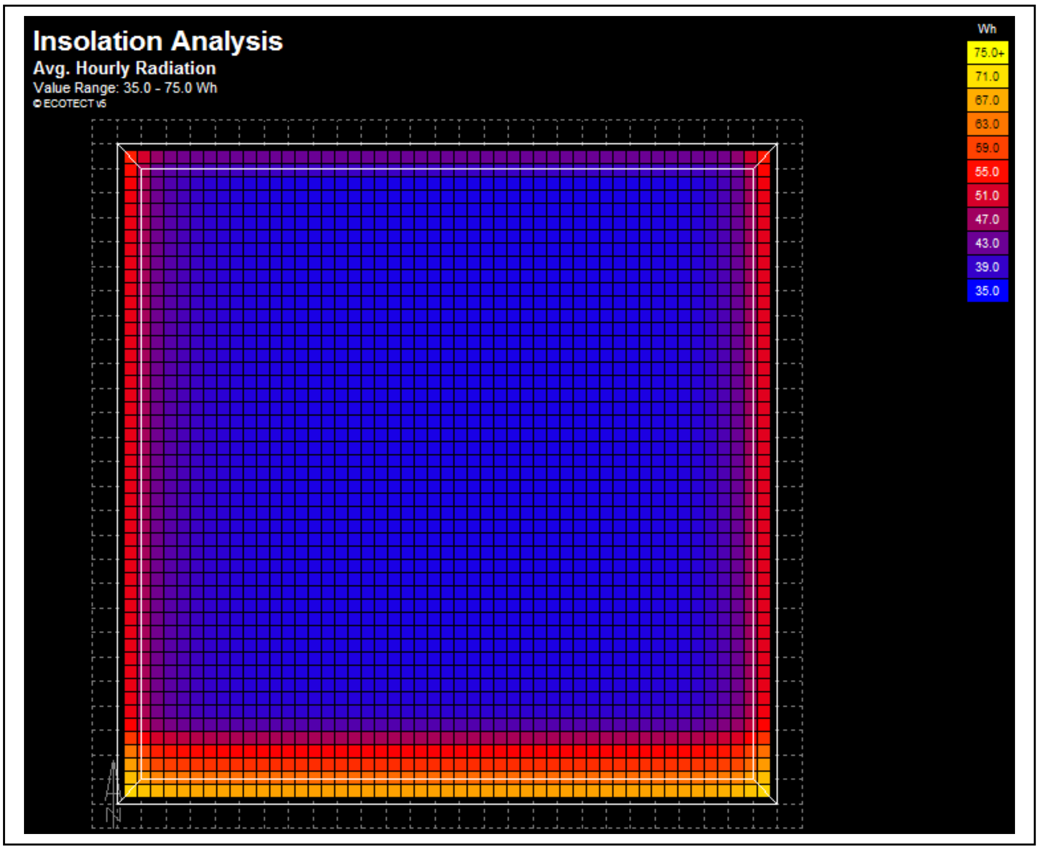
CASE 2 SOLAR GAIN ANALYSIS – SUMMER



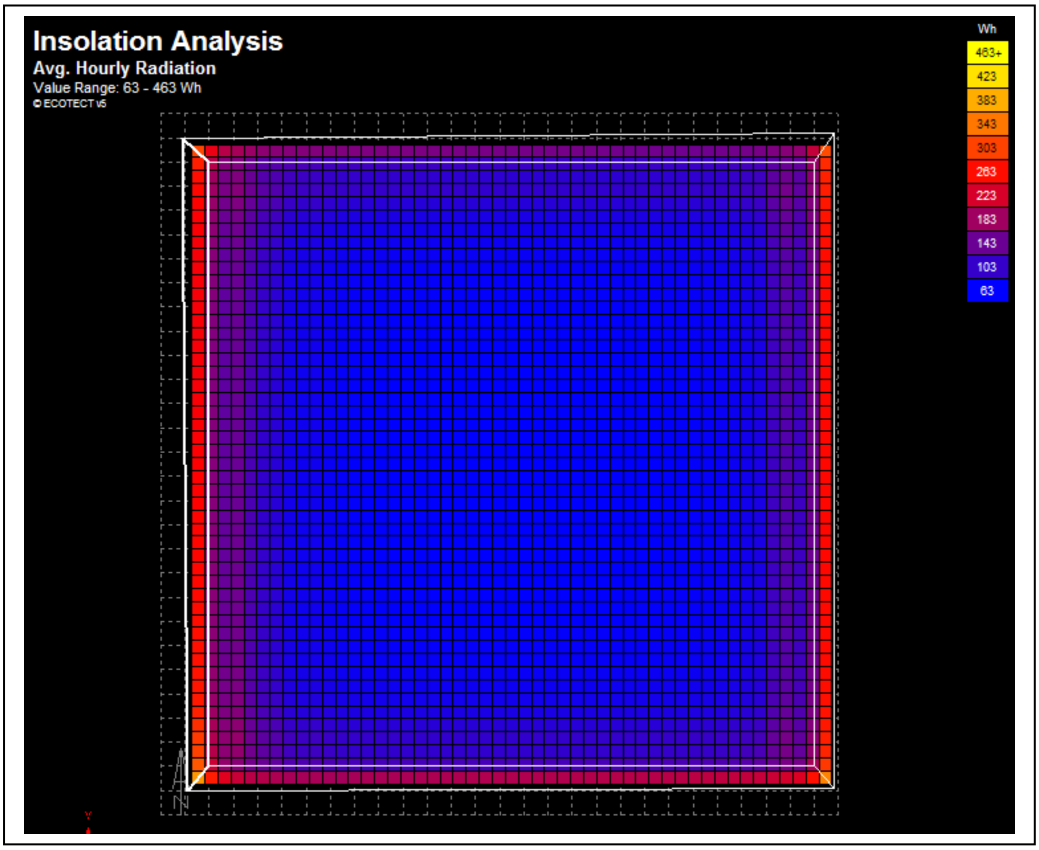
CASE 2 SOLAR GAIN ANALYSIS – WINTER



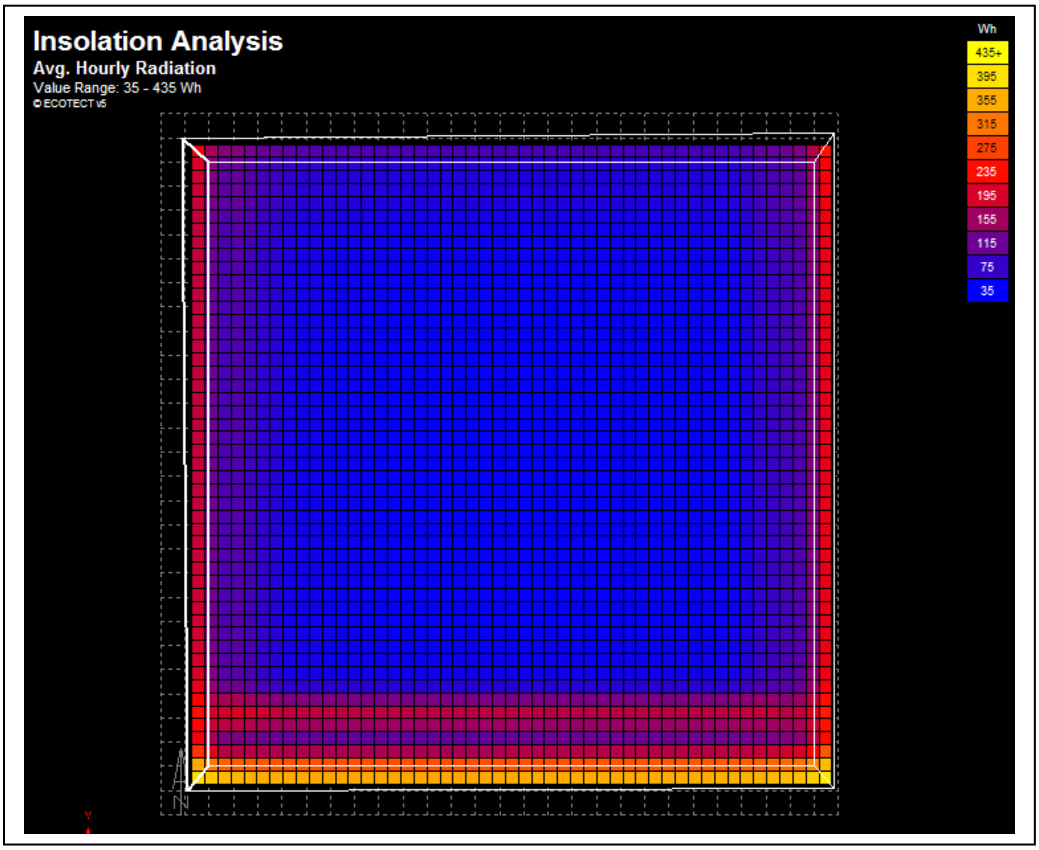
CASE 3 SOLAR GAIN ANALYSIS – SUMMER



CASE 3 SOLAR GAIN ANALYSIS – WINTER



CASE 4 SOLAR GAIN ANALYSIS – SUMMER



CASE 4 SOLAR GAIN ANALYSIS – WINTER

CASE 1 TABLES

MONTHLY HEATING/COOLING LOADS

Zone: mid level-base
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 3752 W at 06:00 on 14th February
Max Cooling: 51615 W at 15:00 on 31st August

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	6.17	413.92	420.09
Feb	12.91	771.49	784.4
Mar	0	2121.68	2121.68
Apr	0	5618.48	5618.48
May	0	9322.76	9322.76
Jun	0	11529.28	11529.28
Jul	0	18386.5	18386.5
Aug	0	19373.7	19373.7
Sep	0	14271.96	14271.96
Oct	0	9844.62	9844.62
Nov	0	4544.19	4544.19
Dec	0.1	1898.9	1899
TOTAL	**19.18**	**98097.48**	**98116.66**
PER M²	**0.031**	**156.95**	**156.98**
Floor Area:	**625.000 m2**		

HOURLY GAINS - Saturday 21st July (202)
Zone: mid level-base

HOUR	HVAC (Wh)	FABRIC (Wh)	SOLAR (Wh)	VENT. (Wh)	INTERN (Wh)
0	26377	6912	0	9341	10125
1	26972	7165	0	9682	10125
2	26807	7165	0	9517	10125
3	27200	7333	0	9741	10125
4	26618	7333	0	9160	10125
5	26997	7502	0	9371	10125
6	28274	7923	111	10114	10125
7	29979	8598	517	10739	10125
8	32326	9272	1000	11929	10125
9	36737	10536	2376	13700	10125
10	37936	11295	1829	14687	10125
11	39386	11801	2116	15344	10125
12	39784	12222	1836	15602	10125
13	40421	12559	1887	15850	10125

14	38702	12391	1133	15053	10125
15	40324	12643	2195	15361	10125
16	38858	12391	1058	15284	10125
17	35522	11801	177	13419	10125
18	34841	11295	188	13234	10125
19	33363	10873	0	12365	10125
20	32769	10536	0	12107	10125
21	32278	10115	0	12038	10125
22	31176	9693	0	11357	10125
23	29229	9019	0	10085	10125
TOTAL	**792876**	**238372**	**16423**	**295082**	**243000**

HOURLY GAINS - Monday 15th January (15)

Zone: mid level-base

HOUR	**HVAC (Wh)**	**FABRIC (Wh)**	**SOLAR (Wh)**	**VENT. (Wh)**	**INTERN (Wh)**
0	0	-1854	0	-2207	10125
1	0	-2444	0	-2946	10125
2	0	-3119	0	-4055	10125
3	0	-3709	0	-5012	10125
4	0	-4214	0	-5422	10125
5	-927	-4805	0	-6247	10125
6	-2346	-5395	0	-7076	10125
7	-963	-4973	606	-6721	10125
8	0	-3119	5961	-4143	10125
9	11091	-1854	5283	-2463	10125
10	16141	-253	6598	-329	10125
11	0	0	7292	0	10125
12	0	0	7988	0	10125
13	0	0	5330	0	10125
14	0	0	5455	0	10125
15	0	0	7908	0	10125
16	0	0	4246	0	10125
17	0	0	96	0	10125
18	0	0	0	0	10125
19	0	0	0	0	10125
20	0	-253	0	-383	10125
21	0	-590	0	-878	10125
22	0	-843	0	-1248	10125
23	0	-1602	0	-2205	10125
TOTAL	**22997**	**-39026**	**56764**	**-51335**	**243000**

CASE 2 TABLES – ETFE TRANSPARENT

MONTHLY HEATING/COOLING LOADS

Zone: mid level-base
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 2468 W at 06:00 on 14th February
Max Cooling: 43374 W at 14:00 on 19th August

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	2.38	247.66	250.04
Feb	6.6	532.35	538.95
Mar	0	1583.95	1583.95
Apr	0	4683.61	4683.61
May	0	7899.02	7899.02
Jun	0	10233.8	10233.8
Jul	0	16777.42	16777.42
Aug	0	17635.87	17635.87
Sep	0	12945.98	12945.98
Oct	0	8304.29	8304.29
Nov	0	3051.44	3051.44
Dec	0	1271.74	1271.74
TOTAL	**8.99**	**85167.13**	**85176.11**
PER M²	**0.014**	**136.26**	**136.28**
Floor Area:	**625.000 m2**		

CASE 2 TABLES - ETFE TRANSLUCENT

MONTHLY HEATING/COOLING LOADS

Zone: mid level-base
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 705 W at 06:00 on 14th February
Max Cooling: 38795 W at 14:00 on 19th August

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	0	250.31	250.31
Feb	1.295	504.95	506.245
Mar	0	1490.2	1490.2
Apr	0	4442.34	4442.34
May	0	7408.84	7408.84
Jun	0	9815.33	9815.33
Jul	0	15870.87	15870.87

Aug	0	16573.38	16573.38
Sep	0	12758.93	12758.93
Oct	0	8264.06	8264.06
Nov	0	2941.02	2941.02
Dec	0	1210.76	1210.76
TOTAL	**1.295**	**81530.99**	**81532.285**
PER M²	**0.002**	**130.45**	**130.45**
Floor Area:	**625.000 m2**		

CASE 3 TABLES

MONTHLY HEATING/COOLING LOADS

Zone: mid level-base
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 0.0 C - No Heating.
Max Cooling: 31923 W at 14:00 on 31st August

MONTH	**HEATING (KWh)**	**COOLING (KWh)**	**TOTAL (KWh)**
Jan	0	395.19	395.19
Feb	0	596.86	596.86
Mar	0	1418.75	1418.75
Apr	0	4352.28	4352.28
May	0	7534.69	7534.69
Jun	0	10051.95	10051.95
Jul	0	14526.82	14526.82
Aug	0	14754.34	14754.34
Sep	0	12076.65	12076.65
Oct	0	8856.07	8856.07
Nov	0	3311.72	3311.72
Dec	0	1330.49	1330.49
TOTAL	**0**	**79205.81**	**79205.81**
PER M²	**0**	**126.72**	**126.72**
Floor Area:	**625.000 m2**		

HOURLY GAINS - Saturday 21st July (202)
Zone: mid level-base

HOUR	**HVAC (Wh)**	**FABRIC (Wh)**	**SOLAR (Wh)**	**VENT. (Wh)**	**INTERN (Wh)**
0	19466	0	0	9341	10125
1	19807	0	0	9682	10125
2	19642	0	0	9517	10125

3	19866	0	0	9741	10125
4	19285	0	0	9160	10125
5	19496	0	0	9371	10125
6	20239	0	0	10114	10125
7	20864	0	0	10739	10125
8	22054	0	0	11929	10125
9	23825	0	0	13700	10125
10	24812	0	0	14687	10125
11	25469	0	0	15344	10125
12	25727	0	0	15602	10125
13	25975	0	0	15850	10125
14	25178	0	0	15053	10125
15	25486	0	0	15361	10125
16	25409	0	0	15284	10125
17	23544	0	0	13419	10125
18	23359	0	0	13234	10125
19	22490	0	0	12365	10125
20	22232	0	0	12107	10125
21	22163	0	0	12038	10125
22	21482	0	0	11357	10125
23	20210	0	0	10085	10125
TOTAL	**538082**	**0**	**0**	**295082**	**243000**

HOURLY GAINS - Monday 15th January (15)

Zone: mid level-base

HOUR	HVAC (Wh)	FABRIC (Wh)	SOLAR (Wh)	VENT. (Wh)	INTERN (Wh)
0	0	0	0	-2207	10125
1	0	0	0	-2946	10125
2	0	0	0	-4055	10125
3	0	0	0	-5012	10125
4	0	0	0	-5422	10125
5	0	0	0	-6247	10125
6	0	0	0	-7076	10125
7	0	0	0	-6721	10125
8	0	0	0	-4143	10125
9	7662	0	0	-2463	10125
10	9796	0	0	-329	10125
11	0	0	0	0	10125
12	0	0	0	0	10125
13	0	0	0	0	10125
14	0	0	0	0	10125
15	0	0	0	0	10125
16	0	0	0	0	10125
17	0	0	0	0	10125
18	0	0	0	0	10125
19	0	0	0	0	10125
20	0	0	0	-383	10125

21	0	0	0	-878	10125
22	0	0	0	-1248	10125
23	0	0	0	-2205	10125
TOTAL	**17458**	**0**	**0**	**-51335**	**243000**

CASE 4 TABLES

MONTHLY HEATING/COOLING LOADS

Zone: base-mid
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 11901 W at 06:00 on 14th February
Max Cooling: 64106 W at 15:00 on 31st August

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	165.59	432.66	598.25
Feb	238.57	825.67	1064.24
Mar	34.08	2128.8	2162.88
Apr	4.33	5460.25	5464.58
May	0	10181.74	10181.74
Jun	0	12055.25	12055.25
Jul	0	19499.59	19499.59
Aug	0	19556.55	19556.55
Sep	0	13187.22	13187.22
Oct	0	10107.53	10107.53
Nov	0	5392.74	5392.74
Dec	37.31	2136.2	2173.51
TOTAL	**479.88**	**100964.2**	**101444.08**
PER M²	**0.768**	**161.54**	**162.31**
Floor Area:	**625.000 m2**		

HOURLY GAINS - Saturday 21st July (202)
Zone: base-mid

HOUR	HVAC (Wh)	FABRIC (Wh)	SOLAR (Wh)	VENT. (Wh)	INTERN (Wh)
0	28471	12366	0	9341	6765
1	29266	12818	0	9682	6765
2	29101	12818	0	9517	6765
3	29626	13120	0	9741	6765
4	29045	13120	0	9160	6765
5	29557	13421	0	9371	6765
6	31279	14175	225	10114	6765
7	33928	15382	1042	10739	6765
8	37248	16588	1966	11929	6765

9	44104	18850	4788	13700	6765
10	45276	20207	3617	14687	6765
11	47356	21112	4134	15344	6765
12	47911	21866	3678	15602	6765
13	48823	22469	3739	15850	6765
14	46219	22168	2233	15053	6765
15	48812	22620	4067	15361	6765
16	46350	22168	2133	15284	6765
17	41654	21112	358	13419	6765
18	40584	20207	378	13234	6765
19	38583	19453	0	12365	6765
20	37723	18850	0	12107	6765
21	36899	18096	0	12038	6765
22	35465	17342	0	11357	6765
23	32986	16136	0	10085	6765
TOTAL	**916265**	**426468**	**32356**	**295082**	**162360**

HOURLY GAINS - Monday 15th January (15)
Zone: base-mid

HOUR	**HVAC (Wh)**	**FABRIC (Wh)**	**SOLAR (Wh)**	**VENT. (Wh)**	**INTERN (Wh)**
0	0	-3318	0	-2207	6765
1	-554	-4373	0	-2946	6765
2	-2870	-5580	0	-4055	6765
3	-4882	-6635	0	-5012	6765
4	-6197	-7540	0	-5422	6765
5	-8078	-8596	0	-6247	6765
6	-9963	-9651	0	-7076	6765
7	-7947	-8897	906	-6721	6765
8	0	-5580	8371	-4143	6765
9	0	-3318	9004	-2463	6765
10	19278	-452	13294	-329	6765
11	0	0	13465	0	6765
12	0	0	15404	0	6765
13	0	0	10293	0	6765
14	0	0	10106	0	6765
15	0	0	15940	0	6765
16	0	0	7134	0	6765
17	0	0	194	0	6765
18	0	0	0	0	6765
19	0	0	0	0	6765
20	0	-452	0	-383	6765
21	0	-1056	0	-878	6765
22	0	-1508	0	-1248	6765
23	0	-2865	0	-2205	6765
TOTAL	**-21213**	**-69821**	**104112**	**-51335**	**162360**

CASE 5 TABLES (MIX MODE)

MONTHLY HEATING/COOLING LOADS

Zone: base-mid
Operation: Weekdays 00-24, Weekends 00-24.
Thermostat Settings: 18.0 - 26.0 C

Max Heating: 11901 W at 06:00 on 14th February
Max Cooling: 64106 W at 15:00 on 31st August

MONTH	HEATING (KWh)	COOLING (KWh)	TOTAL (KWh)
Jan	165.59	432.66	598.25
Feb	238.57	825.67	1064.24
Mar	34.08	2128.8	2162.88
Apr	0	4352.28	4352.28
May	0	7534.69	7534.69
Jun	0	10051.95	10051.95
Jul	0	14526.82	14526.82
Aug	0	14754.35	14754.35
Sep	0	12076.65	12076.65
Oct	0	8856.07	8856.07
Nov	0	5392.74	5392.74
Dec	37.31	2136.2	2173.51
TOTAL	**475.55**	**83068.88**	**83544.43**
PER M²	**0.761**	**132.91**	**133.67**
Floor Area:	**625.000 m2**		

APPENDIX C

ETFE BROCHURE