FAÇADE-Integrated Sustainable Technologies for Tall Buildings:
A discussion of the extent of adoption of such technologies in the most sustainable fifth generation tall buildings and the trends of the future

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ABSTRACT
CLIMATE change and energy depletion are two of the greatest risks facing humanity in the 21st century. Urbanisation is increasing the rate of energy depletion in many ways - demand for buildings, for transport, for more energy consumption and for higher living standards for a great number of people. Buildings account for about 1/3rd of the global greenhouse gas emissions and it is estimated that they account for 40% of global energy utilization, 25% of global water usage and 40% of global resources utilization. Our buildings need to be more sustainable and energy efficient. In the classification of tall buildings, the term ‘fifth generation’ is used to describe ones with high environmental and energy performance. The building façade is the main visible element of a building, acting as a boundary between the interior and the exterior, working as an interface between the living spaces and the external climate, influencing comfort and energy efficiency. Residential buildings have the advantages of balconies and active residents to operate blinds and windows. The more difficult design task is for the office building where occupants expect the building to be comfortable, but have almost no say in the control systems. If the façade fails to provide a habitable environment, mechanical and electrical systems (MEP) fill the gap. Sustainable environmental performance can be attained only with the smart use of new efficient façade systems that reduce the MEP, and helps us design and build low energy buildings for a low carbon future. A new paradigm of façades has emerged which interact with the external environment by the integration of new technologies, some with intelligent controls. Some make use of long standing passive technologies such as solar shading and thermal mass. New areas of interest are active technologies which can respond to the environmental demands, energy generating surfaces, active shading layers, even the ideas of biomimetic facades that are designed to perform responsively, like natural organisms. A detailed study of these technologies especially analysing the thermal behaviour of different façade systems and materials along with case studies will be carried out to learn how these approaches can be implemented and to what extent it can help in the approach to carbon neutrality. Sustainable futuristic façade technologies such as breathing facades, fabric facades, air filtering facades will also be covered in the study.

CHAPTER -1. INTRODUCTION
CLIMATE change and Energy depletion are two of the greatest risks facing humanity in the 21st century. The world’s population is growing, but there is also urbanisation - polarisation of the population location and lifestyle as people move from country to cities. Urbanisation is increasing the rate of energy depletion in many ways - higher demand for buildings, for transport, for more energy consumption and for higher living standards for a great number of people. According to the UNEP-SBCI1, buildings account for about 1/3rd of the global greenhouse gas emissions.

1 United Nations Environment Program-Sustainable Buildings and Climate Initiatives (UNEP-SBCI)
emissions and it is estimated that they account for 40% of global energy utilization, 25% of global water usage and 40% of global resources utilization. This clearly indicates the growing need to make our buildings more sustainable and energy efficient.

The building façade is the main element of a building, acting as a barrier between the interior and the exterior, working as an interface between the living spaces and the external climate, influencing comfort and energy efficiency. If the façade fails to provide a habitable environment, mechanical and electrical systems (MEP) fill the gap. There is a cost and technology battle between Façade and MEP that designers must always address with the help of engineers and good design. Sustainable environmental performance can be attained only with the smart use of new efficient façade systems that reduce the MEP, and helps us design and build low energy buildings for a low carbon future.

A new paradigm of facades has emerged which interact with the external environment by the integration of new technologies, some with intelligent controls. Some make use of long standing passive technologies such as solar shading and thermal mass.

New areas of interest are active technologies such as control systems which can respond to the environmental demands, energy generating surfaces and active shading layers. Designers are even studying the ideas of biomimetic façades which are designed to perform responsively, like natural organisms.

1.1 Research Question

A detailed study of passive and active technologies especially analysing the thermal behaviour of different façade systems and materials along with case studies will be carried out to learn how these approaches can be implemented and to what extent it can help in the approach to carbon neutrality. Sustainable futuristic façade technologies such as breathing facades, fabric facades, air filtering facades will also be covered in the study.

1.2 Methodology

Different types of sustainable façade technologies, both currently used as well as futuristic approaches will be studied in detail. Analysis of the thermal behaviour of different façade systems and materials along with case studies of façades from varying climatic zones will be carried out.

The number of tall buildings (above 200m) constructed in the last decade alone exceeded the number that was constructed in the entire previous architectural history. So the search for advanced examples is focused on what are called ‘Fifth Generation’ tall buildings. (This taxonomy of ‘Generations’ was defined in CTBUH publications and papers in 2009 by Philip Oldfield and Dario Trabuco.)

1.3 Synopsis

Chapter One: Discusses the general idea about this dissertation, the main research question and the methodology carried out.

Chapter Two: Literature search and known discussion points about sustainability in regions, cities and buildings in general.

Chapter Three: Literature search and details regarding carbon neutrality and the various targets and ways of achieving carbon neutrality.

Chapter Four: Discusses about tall buildings, functional and iconic tall, along with the various energy generations of tall buildings.

Chapter Five: Discusses about the façades in general and the different concepts of low energy façade design such as climate, orientation, day lighting, glare, etc.

Chapter Six: Discusses about the different types of façade systems and materials available.

Chapter Seven: Discusses about the innovative and advanced sustainable façade technologies such as energy generating smart façades to biomimetic façades.

Chapter Eight: Explains about the case studies.

Chapter Nine: Explains the conclusion of this complete study about sustainable integrated façade technologies.

CHAPTER-2. SUSTAINABILITY IN REGIONS, CITIES AND IN BUILDINGS

2.1 Sustainability – Definition

SUSTAINABILITY literally means the ability to be sustained … i.e. To continue to have the same behaviour, quality of life, access to resources. Merriam Webster.com defines ‘sustainable’ as the ability to be used without being completely used up or destroyed. Towards the latter half of the 20th century the word sustainability achieved prominence more in the context of the realisation
about the environmental degradation that had resulted from the economic and social development. Thus the most definitive explanation of sustainability, which is based on the concept of sustainable development, first appeared in the Brundtland Report for the World Commission on Environment and Development (1987). The Report defined Sustainable development as:

![Fig1 - The three spheres of Sustainability](Source: University of Michigan Sustainability Assessment 2002)

"...Development that meets the needs of the present without compromising the ability of the future generations to meet their own needs." The Report stressed that true sustainability requires a successful combination of Social, Economic and Environmental strategies to meet targets in all these influences.

### 2.2 Need for Environmental Sustainability

Solid scientific evidence gathered through most advanced and sophisticated instruments and technologies have proved that the planet earth’s atmosphere is warming up faster than ever. Global temperatures have increased by about 1.33 degrees Fahrenheit (0.74 degrees Celsius) during the last one hundred years. But the alarming fact is that more than half of this increase has happened after 1979. Intergovernmental Panel on Climate Change (IPCC)’s report points out that the ten warmest years since 1880 have all happened since 1998.

Independent analysis by the National Oceanic and Atmospheric Administration (NOAA) of the US and NASA have shown that in 2015 the surface temperatures of the Earth were the warmest since 1880 i.e. the year when modern record keeping on this subject began.

NASA officials reported in July 2016 that from January to June 2016, each month had been setting new temperature records and thus 2016 is on its way to be the hottest year ever on record.

![Fig2 - Carbondioxidelevels](Source: NASA)

The warming of the atmosphere is largely the result of emissions of carbon dioxide and other greenhouse gases from human activities like burning fossil fuels and changes in land use, such as agriculture and deforestation. Greenhouse gases are not harmful in themselves, but their effect is to trap solar thermal energy in the atmosphere, thus raising the temperature. Carbon dioxide concentrations in the atmosphere since pre-industrial times have increased from 280 parts per million to around 400 parts per million. (Fig-2)

IPCC has observed that “Scientific evidence for warming of the climate system is unequivocal”. IPCC’s Fifth Assessment Report (AR5) and NASA’s observations, all point to human influence as the most likely predominant cause for the earth’s warming for the last more than six decades. More than half of the observed increase in temperature in almost sixty years (1951-2010) is likely due to the combined effect of the anthropogenic increase in greenhouse gas concentration and other anthropogenic activities.²

The amount of warming that occurs by the end of this century will invariably depend on human choices now. The lack of progression in curbing emissions could make the temperature of the planet rise between 4.7°F to 8.6°F (2.6°C to 4.8°C) by the end of this century, compared to the average temperature around the end (1986-2005) of the 20th century. Warming in the United States

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² IPCC AR5, Working Group 1, Summary for Policy Makers, p.17
is considered to be generally higher than the global average. Warming across the country averaged between 5°F to 10°F, assuming that emissions rates continue.

Although we have the opportunity to avoid some of this warming, we are still likely to face a number of considerable secondary impacts arising from climate change in the decades ahead.

Reports of the IPCC, NASA and National Oceanic and Atmospheric Administration (NOAA) all clearly documents the effects of climatic change that have started manifesting. Gavin Schmidt, director of NASA's Goddard Institute for Space Studies in New York City in his “Earth in the Balance: 7 Crucial Tipping Points” says: “Sustained above-average temperatures, as the planet has seen so far this century, can affect the ice sheet, global sea levels, ecosystems and more.” These effects influence all the components of the earth from bacteria to volcanoes. The most important among such effects are:

- **Shrinking of Arctic Ice** - The extent of Arctic sea-ice is shrinking due to global warming and according to NASA, now during the peak of summer it covers 40 per cent less area than it did in the late 1970s. During the first half of 2016, arctic sea ice extent had hit record low levels. It is feared that some time in this century during summer months Arctic will be ice-free. It is also observed that with warming climate the frozen tundra landscape has changed into a green, new ecosystem. The rate of melting of ice sheets is increasing in Antarctica and Greenland also.³

- **Rise in Sea Level** - The melting polar ice is resulting in the rise of the sea level. IPCC has reported that the sea level has risen about 8 inches in the last 100 years. This is causing increased levels of coastal erosion and heightening the devastation effects of coastal storms. Sea levels are estimated to rise to a range of 1-4 feet or higher and many cities, even capital cities are under threat from the ill effects of such rise.

- **Frequent Heat Waves** - Increasing frequency and intensity of heat waves experienced by various regions of the planet are resulting in water scarcity, increased energy demands, reduced agricultural production and increasing human health problems.

- **Very heavy rains** and more devastating floods are becoming more frequent in many parts of the globe.

- **Effects on the Ecosystem** - Increasing temperatures and acute droughts are affecting human, animal and plant life and resulting in their migration.

- **Oceans are becoming more acidic** due to the carbon dioxide in the atmosphere and this is threatening the marine ecosystem.

- **Spread of agricultural pests** - Agricultural pests and pathogenic microorganisms are spreading to newer geographical areas due to the milder winters that facilitate their growth. This is causing immense damage and problems to livestock and agriculture.

These impacts pose challenges to infrastructure, businesses, and communities, particularly in countries already struggling to meet the basic need of food, water, shelter, and security of their citizens. If the trends of the earlier decades continue, the impacts will be severe. The Earth will continue without us, but if we want a habitable planet for our descendants, there is an urgent need to reduce greenhouse gas emissions and to equip ourselves to meet the climate impacts. As the timescale for response of the ecosystem is slow, this becomes very important.⁴

The concept of sustainability, or ecological design, is to ensure that our actions and decisions today do not inhibit the opportunities of generations to come. Energy efficiency over the entire life span of a building is of utmost importance. Different passive and active techniques are used by the architects to reduce the energy needs of buildings and increase their ability to capture or generate their own energy. One of the keys to successful sustainable design is to exploit local environmental resources and influence energy-related factors such as daylight, solar heat gains and ventilation in the use of site analysis.

### 2.3 Urban Heat Island Effect

Urban areas usually experience higher temperatures when compared to their rural surroundings. Studies have explained that these urban conditions have

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³ Charles Miller, deputy science lead for the Arctic Boreal Vulnerability Experiment (Above) at NASA’s Jet Propulsion Laboratory in Pasadena, California

⁴ IPCC AR5, Working Group 1, Summary for Policy Makers, p.17
been identified and defined as ‘Urban Heat Island’ (UHI) phenomenon. Numerically it is the maximum difference between urban and surrounding areas’ temperatures, but in actuality it is a more complex malaise for the urban dweller. Buildings, roads, and other constructions in urban areas absorb heat during the day and re-emit it after sunset, creating high temperature differences between urban and rural areas.

Many factors bring higher temperatures in the urbanized environment, such as anthropogenic heat, excess of heat stored by construction materials, decreased long-wave radiation losses from urban areas, lack of vegetation and reduced evapotranspiration processes, reduction of wind speed and consequent reduced convective heat removal from urban surfaces to the atmosphere. The energy performance of buildings located in densely built areas can be affected by urban heat islands. The syndrome is made worse by dust levels from burning of coal and diesel, from concrete and rubber dust and the lack of breeze. 

2.4 Sustainability in Cities

Over the last few years, in developing economies such as India, China, Saudi Arabia and Dubai the concept of satellite and networking of cities have emerged as solutions to the rapid population growth. Some of these are still concepts, but there are increasing number of examples. These proposed new communities are planned as city-sized high-density developments where people will live, work, recreate, learn and shop, all within walking distances from each other, occupying only a small area of land. These satellite cities are to be placed on the edge of major cities that have reached their peak at its center. They will be connected by rapid transit systems which connects to the existing city transit systems at some point.

One primary factor of success of these cities are intended to be the hope that they will be more pedestrian friendly with minimum number of parking available leading to minimum ownership of private cars. This will reduce the need for costly parking structures and allows more car-free environments. This in turn helps reduce the carbon footprint of these communities.

Networking of cities is an incentive to upgrade infrastructure and new development in corridors of development connecting existing nodes, such as Britain’s ‘Northern Powerhouse’ (Liverpool, Manchester, Leeds, Sheffield, Newcastle), or China’s Beijing-Tianjin, Guangzhou-Shenzhen-Hong Kong networked city groups.

These new cities and city regions are being designed to be highly sustainable, taking advantage of mass construction techniques, planning principles that take advantages of wind, solar and geothermal energy sources, also minimizing the site specific elements on the buildings. Although there is a danger of these satellites starting life as ‘Ghost Cities’, it takes time for the population to move until other corroborating factors such as transport, shopping, education and employment catch up with the residential building.

2.5 Sustainable Architecture

It could be interpreted as architecture that does not consume large amounts of energy just to be habitable; should not require expensive maintenance, or be subject to massive heat-loss or gain through poor insulation or too much glazing. Such buildings are also called Environmentally Responsible or Green Architecture.

Sustainable architecture could also be defined as architecture which uses materials, energy, development space and the ecosystem at large moderately and seeks to minimize the negative environmental impact of buildings by efficiency.

Concepts of ‘Sustainable Architecture’ or ‘Environmentally Responsible Architecture’ or ‘Green Architecture’ developed in response to mounting worries about ecological and environmental matters from the 1960s, and involved experiments with buildings constructed with natural materials (e.g. timber or earth), which are energy efficient (i.e. are well insulated, and draw on solar and wind-powered sources of energy), and which respect the site.

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6 Article on Design Intelligence “Tall, Global and Sustainable” September 18, 2013 by Adrian Smith

7 SMITH, A. Design Intelligence. Tall, Global and Sustainable WWW page at: <http://www.differenceglobal.comwww/differenceglobal-and-sustainable>?

The International Modernist architecture that has been adopted for tall buildings since 1950 to the turn of the century was anything but environmentally responsible, devoured energy, leaked energy, and was subject to extremes of temperature because of solar-heat gain. The bronze glass monolith (Seagram, New York) spawned uncountable imitators around the World. Architecture struggled to find new expression with Post-Modernism (Sony Tower) and High-Tech Expressionism (HSBC Building) in the 1980s and early 1990s. (See figures below)

There was a paradigm change at the end of the 1990s with three buildings, Commerzbank (Frankfurt, 1997, Norman Foster) and Deutsche Post (Bonn, 2002, Murphy/Jahn Architects), and the unbuilt Editt Tower (Singapore, 1988, Ken Yeang), which showed another way, a bioclimatic way forward for tall buildings.

Unlike the Modern Movement, environmentally responsible architecture considers ways of harnessing natural environmental resources of ventilation, daylight and sunlight, appropriate to the climate of the site, to enable buildings to achieve comfort with reduced dependency on mechanical and electrical systems. It also considers the embodied energy in existing buildings, and the social investment in them.

A scheme in which landscape and architecture coalesce and buildings are designed with energy saving and pollution-reduction intent and buildings in which formal and picturesque gardens form a close part of it are some of the aspects of Green Architecture.

2.6 Sustainable technologies in buildings

For the adaptation to a sustainable green or a carbon-neutral construction, the building should not just be totally energy efficient but it should also be able to produce sufficient energy to meet its own needs. Solar and Wind power along with a large number of other new and innovative technologies help in doing so. City governments are always interested in clean cities and can encourage developers with the bonus of improved FSI for incorporating renewable energy.

New mixed use buildings are coming into trend which incorporates different functions such as residential, hospitality, office, retail, etc. all in a single tower. The advantages of such buildings are that they can reduce the transportation demands and share resources amongst them. For example, the heat generated from the office space can be harnessed to heat the water required for the residential and hospitality sectors.9

2.7 Indoor Working Environments

2.7.1 Sick Building Syndrome

According to Britain’s National Health Service ((NHS), the Sick building syndrome (SBS) is used to describe situations in which the building occupants experience a range of symptoms that appear to be

9 (Sustainability and Energy Considerations by Rick Cook, Bill Bowning and Chris Garwin - CTBUH paper)
linked to time spent in a building, but no specific illness or cause can be identified. Headaches, nausea, fatigue, shortness of breath, skin irritation are some of the symptoms associated with the sick building syndrome. It is generally caused by flaws in the heating, ventilation (HVAC) systems or due to contaminants produced by building materials, volatile organic compounds (VOC), moulds, light industrial chemicals used or the lack of ventilation. 

In workplace buildings, this is a particular disadvantage, as a widespread syndrome affecting many of the workers will reduce the economic productivity of the whole organisation in the building, even leading to demands to find a different building. A good example of one such building designed to avoid Sick Building Syndrome, and reduce energy consumption is the Deutsche Post Tower (Bonn, 2002, Murphy/Jahn Architects), in Germany with its façade no further than 8 meters from the corridor, enabling working in natural daylight and fresh air.

It is notable that the most prominent eco-towers such as Deutsche Post are owner occupied, not speculative. Commerzbank (Frankfurt), HSBC (HK), Bahrain World Trade Centre, the Council House 2 (Melbourne), Hearst (New York) are example of the employer sacrificing floorplate efficiency to achieve improved well being for the employees or to achieve better energy rating for their city.

2.8 Conclusion

Sustainability refers to “the ability to be used without being completely used up or destroyed”. Sustainable development is one “that meets the needs of the present without compromising the ability of the future generations to meet their own needs.” The threat caused to the environment by the unrestrained development practices and the resulting climate change has alerted the global community to think about environmental sustainability. The rise in carbon dioxide and other Green House Gas emissions and the resultant global warming and climate change has compelled them to act.

The built environment used to consume large amounts of energy and emit huge quantities of carbon dioxide and other GHGs. With the stress on environmental sustainability, the need for Sustainable Architecture arose. This has led to evolution of various sustainable technologies and practices, which are finding wide acceptance among architects, planners and builders.

CHAPTER- 3. CARBON NEUTRALITY AND NET-ZERO ENERGY CONSTRUCTION

3.1 Carbon Neutrality - Definition

Concerns about the impact of climate change on the future of life on the planet has been compelling governments and organizations to rush ahead with appropriate actions. In this scenario the term ‘carbon neutrality’ has become a most common attribute which everybody is targeting to achieve. Carbon neutrality in effect refers to measuring, reducing and offsetting carbon energy used by either a building or an organization as a whole.

As per dictionary.com, a building can be said to be Carbon Neutral when it has achieved such a state at which the net amount of carbon dioxide or other carbon compounds emitted into the atmosphere is reduced to zero as a result of the balancing actions to reduce or nullify those emissions. According to Vangie Beal, freelance author on technology and environment, Carbon neutrality can be described as the action of organizations, businesses and individuals taking part in the action of removing as much carbon dioxide from the atmosphere as each puts into it. The overall goal of carbon neutrality is to achieve a zero carbon footprint. She states that carbon neutrality can be widened further to apply to more than just buildings.

According to the Report “Towards Carbon Neutral Buildings in BC: Framework for High-Rise Multi-Unit Residential Buildings” (2012), a carbon neutral building is defined as one with significantly reduced consumption of energy coupled with the increased use of sources with low carbon generation to meet the demand. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) maintain that this must be verifiable through metering of inputs and outputs, and

11 http://www.dictionary.com/browse/carbon-neutral
measurable over at least a year to overcome seasonal variations.

Caruthers H. and Casavant T. (2013) describes the common approach for designing a carbon neutral building as follows:

- Integrating passive design strategies
- Designing a high performance building envelope
- Specifying energy efficient HVAC systems, lighting and appliances
- Installing on-site renewable energy
- Offsetting

3.2 Targeting achievement of Carbon Neutrality

As per IPCC Fourth Assessment Report: Climate Change 2007, the emissions from the buildings sector including through electricity use in 2004 were about 8.6 GtCO₂, 0.1 GtCO₂-eq N₂O, 0.4 GtCO₂-eq CH₄ and 1.5 GtCO₂-eq halocarbons (including CFCs and HCFCs).

As per this Report, the emissions of CO₂ from the building sector in 2020 will be 11.1Gt. and in 2030 it will be 14.3 Gt (including emissions from electricity generation and not reckoning halocarbons as it is planned to be phased out by 2030).

Reduction of GHG emissions from buildings can be achieved by adopting one or more of the following approaches.

- By reducing consumption of energy and embodied energy in buildings.
- By using a higher share of renewable energy and switching to low-carbon fuels.
- By controlling non-CO₂ Green House Gas emissions.

Improvement of energy efficiency is a matter of high priority as it is most cost-effective.

The IPCC Report further observes that the use of mature technologies that already exist and that have been successfully used for energy efficiency, can help substantially reduce CO₂ emissions from energy use in buildings.

3.3 The 2030 Challenge

In 2002, a non-profit initiative, named ‘Architecture 2030’, was established by Architect Edward Mazria, which exhorted the international community of architects and builders to resort to a series of steps to reduce the Green House Gas (GHG) emissions from new and renovation projects. Since the built environment had a major share in the global consumption of energy and at the same time was the leading producer of Green House Gases (GHG), the initiative sought to reduce the emissions in this sector with a view to limiting the future global warming below one degree Celsius. Thus the primary objectives of Architecture 2030 were:

- reduction of global fossil fuel consumption and GHG emissions of the built environment by changing the approach to planning, design and construction of cities, communities, infrastructure, and buildings.
- the regional development of an adaptive, resilient built environment that can manage the impacts of climate change, preserve natural resources, and access low-cost, renewable energy resources.

Built environment is the major consumer of energy and the dominant source of Green House Gas emissions. Reducing the rate of growth of GHG emissions and then reversing it is considered to be the most suitable approach to address the threats posed by climate change. Architecture 2030 aims at making all new buildings, developments, and major renovations carbon-neutral by 2030.

To accomplish this, Architecture 2030 issued ‘The 2030 Challenge’ asking the global architecture and building community to adopt the following targets:

- All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70% below the regional (or country) average/median for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70% of the regional (or country) average/median for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to:
  - 80% in 2020
  - 90% in 2025
• Carbon-neutral in 2030 (using no fossil fuel
GHG emitting energy to operate).

Implementation of innovative sustainable design strategies, generation of on-site renewable power and/or purchasing (20% maximum) renewable energy may help accomplish the set out targets.

3.4 ASHRAE Vision 2020

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) declared their vision that the building community will produce market viable net zero energy buildings by 2030. For achieving this ASHRAE aims to provide, by the year 2020, its members from the building community with the tools necessary to design construct and operate Net Zero Energy Buildings. ASHRAE defines a net zero energy building as one that produces as much energy as it uses when measured at the site. This definition enables easy assessment because it could be achieved through on-site metering. But it has some drawbacks in as much as it is not taking into account fuel types or the inefficiencies of the utility grid. Therefore, a net zero source energy building is defined as one which produces as much energy as it uses compared to the energy content at the energy source on an annual basis. In such a case evaluation can be done by using site-to-source conversions to account for source energy.

The definition has two more variations based on two other metrics. They are Net zero energy cost buildings and Net zero energy emission buildings.  

The European Energy Efficiency Plan 2011 (EEP) envisages all the buildings to be built after 2020 to be effectively carbon-free and 3% of the existing buildings to be renovated every year until 2020. EEP’s projections identifies the construction industry to make the largest energy and emission savings.

Another instance of setting of such tight target is by the City of Melbourne, which is trying to reduce the energy consumption of commercial and office buildings in their city by 50% and achieve zero emissions for the city by 2020. Council House 2 (Design Inc, Melbourne, 2006) is one such building designed as a working example for this initiative.

3.5 Conclusion

Though there are varying definitions of carbon neutrality, in simple terms it stands for balancing carbon dioxide emissions from burning fossil fuels with renewable energy that creates a similar amount of useful energy or using only renewable energy that don’t produce any carbon dioxide. The ultimate aim of carbon neutrality is achievement of zero carbon footprint. The concept can be extended to cover other Green House Gases (GHGs) which will be measured by their carbon dioxide equivalence. The impact of 2030 Challenge and the ASHRAE Vision 2020 have slowly started manifesting in the built environment with governments and organizations showing great initiative. Carbon neutrality (with no fossil fuel and GHG emitting energy to operate) and Net Zero Energy Buildings (which will produce as much energy as they use) are the targets for 2030.

CHAPTER- 4. TALL BUILDINGS AND ICONIC/SUPER TALL BUILDINGS

4.1 Tall Buildings

Whenever we see what is obviously a ‘skyscraper’, we know it is tall. However, in the millions of medium tall urban buildings, there is a range of sizes. Therefore, some system of classification is needed. According to the Council of Tall Buildings and Urban Habitat (CTBUH) a tall building is one that exhibits some element of ‘tallness’ in one or more of the following categories:

• **Height relative to Context:** It is not the specific height that matters but the context in which it exists. For example, a 15 storey building is not considered a tall building in a high rise city such as New York or Hong Kong. But in a suburban area or a provincial European city where the majority of the buildings are low rise, this will be considered a tall building.
**Proportion:** There are numerous buildings that are not particularly high, but are slender enough to give the appearance of a tall building, especially against low urban backgrounds. Conversely, there are numerous big/large footprint buildings that are quite tall but do not seem so, for example, the Pompidou Centre, Paris, or the Chicago Mercantile Mart.

**Tall Building Technologies:** A building will be classed as a ‘tall building’ if a building contains technologies, which may be attributed as being a product of ‘tall’ (e.g., specific vertical transport technologies, structural wind bracing as a product of height, etc).

In addition, the CTBUH stipulate additional criteria for judgement, such as whether the prime use of the building is for functional occupation, or whether one is considering the highest occupied floor, as opposed to the height of the spire or mast. Numerical heights are considered ‘tall’ when the height exceeds 100m, and are classified in 100m, 200m, 300m scales up to and beyond the practical limit of 600m. Exceptionally, the Burj Khalifa, Dubai (SOM 2009) has exceeded 800m, and the Jeddah Tower (Smith Gill, TBC) will top 1000m.15

The general view about tall buildings till recently was that they are anti-environmental and that they are mega-scale energy consumers with little regard for sustainability, conspicuous in their energy consumption, high embodied energy and high operation and maintenance costs. But that perception has undergone change because modern high-rise buildings are being designed with varied aims like sustainability, energy conservation, carbon-neutrality, etc. in view. With the rapid increase in population, decreasing availability of land and urbanization at an alarming rate, building tall is the only solution to the growing demand for new buildings.

A new generation of high-rise buildings like Conde Nast Building in New York, Swiss Re Building in London and the Menara Mesiniaga Tower in Malaysia are famous examples of high-rise buildings with sustainable features. These buildings with smart building systems and powerful visual expression disregarded conventional building practices. Very efficient usage of resources and urban space are seen in ‘Vertical garden cities’. They are relatively more habitable and very user-friendly. Sustainability requirements will necessitate future tall buildings to be more energy-efficient and multifunctional.

Any sustainable tall building design should take into account the appurtenant urban infrastructure like water supply, waste management, energy sources, heating and cooling systems and transit systems. Impact of the tall building on the city’s...
physical resources also needs to be considered. All mega-building concepts would have to keep in view the need to conform to the new building systems technology and meet the challenges of sustainable tall buildings of future.

4.2 The Five Energy Generations

Philip Oldfield and Dario Trabucco in their CTBUH Research Paper “Five energy generation of Tall Buildings: An Historical Analysis of Energy Consumption in High Rise Buildings” published in 2009 states that “the environmental history of tall buildings since 1884 can be interpreted as a series of responses to economic, legislative and technological and cost pressures”. The paper categorises high-rise buildings based on energy consumption characteristics. The Fourth and Fifth generation of tall buildings are the ones that reflect the new environmentally conscious principles.

4.2.1 First Energy Generation Birth of Tall Buildings (1885) to the Zoning law (1916)

The first energy generation buildings were bulky, compact forms where floor area was maximized by stacking of large floor plates repetitively. They had a small envelop surface area but were of large volumes with traditional style load bearing masonry construction and big windows occupying 20 - 40% of the façade. (Equitable Building, New York, 1915). Heating and vertical transportation were the main consumers of energy in these buildings.

4.2.2 Second Energy Generation –From the Zoning law (1916) to the development of glazed curtain wall (1951)

The zoning laws were made to increase the airflow and light penetration as well as to avoid big bulky structures overshadowing the surroundings. The ‘Setting back’ required as per this law gave rise to the next generation of tall buildings which dominated the skyline. (The Empire State Building, New York, 1931) These tall buildings had smaller floor plans but bigger envelope surface area compared to the previous generation (See figure below). Facades for tall buildings of this generation typically occupied about 20-40% glazing (Chrysler Building, New York, 1930), often with stone facing and punched hole windows.

4.2.3 Third Energy Generation –From the glazed curtain wall (1951) to the Energy crisis (1973)

The third generation were more prismatic in form, often employing a plaza or forecourt to meet the zoning laws of New York. They had a higher façade surface area to volume ratio of 50-75% (Seagram building and Lake Shore Drive Apartments, Mies van der Rohe, Chicago, 1949). Glass buildings with single glazed curtain walls grew in popularity and
became a new common style especially the black skyscrapers which followed the original design ideals of Mies.

While achieving some perfection of architectural form, with smooth glass surfaces, they believed that solar gain could be met with darkened glass and turning up the air-conditioning. They suffered a reduced façade performance due to high heat losses in winter and excess heat gain during summers. The darkened interiors needed constant artificial lighting, which with the inefficient lighting technology of the 1950s, added to the heat gain problem, and led to high total energy consumption and maintenance costs.

4.2.4 Fourth Energy Generation – From the energy crisis (1973) to the present day

The energy crisis of 1973 resulted in increased awareness about prudent energy usage and this led to the change in single glazed curtain walls to more energy efficient façade systems such as the double glazed façade, use of low e-coated double glazing, argon filled cavities and attempts at solar shading and double skins. Clear glass is used instead of darkened, for improved daylighting, and artificial lighting is more energy efficient. The building of the 4th generation is better insulated and less expensive to maintain as compared to their predecessors, although the prevailing belief is still to have the façade largely of glass. There is resistance to introducing natural ventilation — because air conditioning is expected by tenants, and facades with openings are more costly to build. Elevators have become vastly more energy efficient.

Buildings of this generation have benefitted greatly from improvements in façade performance. However, technological improvements in office work patterns such as large trading floors, computer servers, and 24-hour operations have increased the generation of heat inside the building and this in turn has resulted in higher energy consumption for cooling the interiors. Even in the 21st century majority of urban office buildings are of the ‘Fourth Generation’ category.

4.2.5 Fifth Energy Generation – From 1997 (rise of environment consciousness) to the present day

Fifth Generation buildings are designed with an idea of further reduction of primary energy consumption from those found in the fourth generation. Shallow floor plates or large atriums are provided to achieve a high surface area to volume ratio. The buildings of this generation use natural and mixed mode ventilation systems to avoid excessive dependency on air conditioning. Artificial lighting is reduced by good façade design and use of photo and motion sensors. Another major feature seen in these buildings is on-site energy generation using wind turbines, etc. which are low or zero-carbon sources.
The first of its kind was the Commerzbank by Foster in 1997 which incorporated several energy-reducing strategies such as natural day-lighting and ventilation through its façade design, water based cooling system of chilled ceilings and full height central atrium along with large open sky gardens. There is a succession of exceptional buildings appearing in the current century, but their impact is mainly educational, to show the professions and city governments what is possible with technology and design. The costly investment in them goes beyond their normal economic ‘call of duty’. These exceptional buildings may be classified as ‘6th generation’. It will be a long time before there are enough of them to change a city’s environmental statistic. Encouragement by city governments and enforcement of high standards such as LEED Platinum and BREEAM Excellent are driving the Fifth generation forward.

3 Iconic/Supertall Buildings

According to CTBUH definition a “supertall” building is one which is over 300 meters (984 feet) in height, and a building over 600 meters (1,968 feet) in height is termed as “megatall”. CTBUH data shows that there were 91 supertall and 2 megatall buildings fully completed, as on June 2015.

![Fig-27 Comparison of heights of iconic tall buildings](Source: CTBUH)

In order to provide stability and bracing at higher level, for any building having height over 1 km, two or three support structures, or widened feet are required at the base with links or connections between them. The current tallest building the BurjKhalifa which is 818 m will be eclipsed by Kingdom Tower in Jeddah which will be 1 km tall when completed (Smith Gill, tbf). The purpose of this tower is “to be a symbol of welcoming to the city of Jeddah and to be the centrepiece for a new Kingdom City” (Smith, CTBUH 2015).

Tall buildings require sophisticated methods of getting people up and down, which costs a large amount of money. The requirement of large structural and robust bracing systems for such tall buildings is another reason for the rise in building costs, eg: Petronastowers, Malaysia. Excessive height has a need for multiple levels of mechanical systems seven if there is a bioclimatic design agenda. At some point the cost of infrastructure deflects the cost benefits curve to be very unsatisfactory, either to the developer or the environment.16

As per CTBUH reports, 56 out of 59 supertall buildings built in the last 20 years are situated outside the U.S. This trend is projected to continue in future also. Currently 56 supertall towers are under construction in China. This trend of construction of supertall is driven mainly by city and national pride than economic considerations.17

4.4 Conclusion

A building can be termed as a tall building if it exhibits some element of “tallness” either in its height in relation to the context in which it exists or by its proportion or because of the use of tall building technologies. On numerical height criteria a “tall” building is one that exceeds 100 metres. Unlike the tall buildings of earlier times, new generation high rise buildings are having more and more sustainable features. Based on the energy consumption pattern, the history of high rise buildings are classified (Oldfield and Trabucco) into five Generations. Many of the office buildings of 21st century are still in the Fourth Energy Generation. Modern, environmentally-conscious constructions with various sustainable features come under the Fifth Energy Generation. Many such new buildings with exceptional sustainability features that demonstrates the innovative capabilities of design and technology have come up.

The most advanced of these are likely to be classified as Sixth Generation with passage of time. Presently there are 91 Super-tall buildings (over 300metres) and 2 Mega-tall (over 600 metres) in the world. Most of these with high infrastructure costs have come up not on economic considerations but with the intention to boost the city/national pride.

16 Article on Design Intelligence “Tall, Global and Sustainable” September 18, 2013 by Adrian Smith
CHAPTER - 5. FAÇADE INTEGRATED SUSTAINABLE TECHNOLOGIES

5.1 Importance of Facades in the overall architecture of a building

The function of the external skin/envelope of a building is not only to project an image to the outside world but to also play an important role of an interface between the user, the interior space and the external environment. Facades are becoming more user-friendly and energy-efficient with improved climatic performance.

Environmentally, facades affect the following:
- Solar heat gain, convective heat and long wave radiation heat transfer and the conductive loads
- Penetration of sunlight and daylight into the interior spaces
- Allowing natural ventilation through the building.

Facades can indirectly affect the lighting load while considering day-lighting of a building and directly affect its heating and cooling needs, having effects on the peak electric demand.

The façade design and incorporation is more complex than other building systems due to the fact that they remain the most striking architectural element, are subject to the wear and tear from wind and weather, and because they affect the user’s choice, comfort and fulfilment. Aesthetically, they are the visual identity of the building, and structurally, they may be a significant contributor, interacting structurally with the core through outriggers and belt trusses.

The façade has the largest surface area of the building envelope; it also holds a substantial potential in gain and loss of energy and comfort. Modern facades should not only protect the building from unwanted influences, but also utilize solar energy, provide high thermal and visual comfort, and control daylight and fresh air flow through the building. They should also take the aesthetic, psychological, physiological and social needs of its inhabitants into account.

These complex demands put a great technical challenge on facades, but also show the great potential for saving energy and reducing CO2 emissions. The search of new and robust solutions for truly sustainable facades, which combine maximum energy efficiency and comfort with durability, minimum resource consumption and retention of embodied energy is the leading motif of the basic study.

The tall office buildings require large internal spaces and so achieving better levels of natural lighting and ventilation in the deeper parts of such a building is a very difficult task. In very tall structures, strong winds and lashing rain that hit the higher levels of the building make it difficult or even impossible to keep the windows open all the time and this also complicates the problem.

The façade design strategies which recognize the harmonious link between lighting, façade and mechanical systems will convey high performance over the life time of the building, e.g. ‘Integrated Façade Systems’ help in significant energy reduction, helping us to move towards net zero energy by 2030.

5.1.1 Larger Surface Area to Volume Ratio

Short Buildings have a small surface to volume ratio with their plan and roof being the largest elements. Their facades are therefore small but visible, keeping them restricted to a particular visibility range. Tall buildings have a larger surface-to-volume ratio which makes them visible from all sides, and the overall impact is significantly more than shorter buildings. Tall buildings are more likely to get incidental and solar heat gain through its larger surfaces.

5.1.2 The Structural role of Facades in Tall Buildings

Up to 35 stories (approx.) the tall building could use a rigid frame and the façade is merely applied to it...
as a non-structural environmental and aesthetic envelope. Above that height, the façade takes an increasingly important role as the primary structural strategy. In some cases, the façade is conceived as a structural ‘Tube’ or ‘Tube in Tube’, gaining its stiffness from its rigorously simple form, square or circular (World Trade Centre, NYC 1969).

A more recent idea is ‘core and outrigger’. The façade is acting in concert with the core for stability and protection against wind and seismic movement. This is achieved with the concept of 3 dimensional outriggers projecting from the core, or with belt trusses, connecting core to façade, and mega columns included in the facade. The façade is considered to be in creative tension with the core and must balance out overturning forces. Such systems can be seen in buildings such as Petronas Towers (Cesar Pelli, Malaysia,1996),Jin Mao (SOM, Shanghai,1999),and Taipei 101(C.Y.Lee, Taiwan, 2004).

The architect of the Taipei 101 (C.Y. Lee) said that his façade and outrigger concept has an analogy with bamboo, one of nature’s wonder-materials in its structural configuration. Along the length of bamboo is a structural tubular skin, reinforced at intervals by a structural floor – strong in tension, compression and bending.  

5.1.3 Health and well being

The sick building syndrome can be reduced by natural daylight and natural ventilation (assuming that other local factors like carpet, photocopier, noise levels and other sources are addressed). Good façade systems can help, but only if fundamental factors are addressed, such as floorplate depth, core location and orientation. Double skin facades are characteristic of fourth and fifth generation buildings. If they provide effective ventilation and solar shading, and admit good daylight, then they are a significant way to improve working conditions and thus increase the productivity rate of its occupants.

5.1.4 Refurbishment projects

Refurbishment projects generally require more efforts to make themselves more energy efficient than new projects which can achieve high energy saving standards easily. Energy efficiency on its own does not justify wholesale façade replacement.

The prime pressure for change is functional obsolescence, and thereafter it may be declining physical condition or mounting energy bills. Another is the potential for higher rental income by presenting a smart new rebranding of the building.

If enough pressures for change come together from these causes, then façade renovation or replacement will happen, and energy performance is major bonus of the development. The reduction of greenhouse gases and increasing energy efficiency can be achieved with the help of multi-functional façade systems in refurbishment projects.

5.2 Growing role of Sustainable facades

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18C.Y.Lee’s video about Taipei 101- https://www.youtube.com/watch?v=Holf_So76bs
Facade, the skin that lies between the outside and the inside of buildings has a prominent role in providing protection from the elements that lashes the exterior and in securing optimum internal environments. Designers have moved away from dark glass, the most favoured material of architecture of the International Movement, which in the world of tall buildings, is referred to above as the ‘Third generation’. Dark single-skin glass caused bad experiences of summer overheating and winter heat-loss. The ‘Fourth generation’ was an attempt to make glass more acceptable by developing improved double glazing, having maximum daylight transmission, and avoiding thermal fluctuations with early versions of the double skin. Commerzbank building in Frankfurt, Germany is the first modern skyscraper that has opening windows and natural ventilation. Foster and Partners have combined advanced technology and bioclimatic concepts in its design. The building houses naturally ventilated multi-story gardens and the offices in the building have the luxury of enjoying fresh air during 80% times of a year.

In the book ‘Sustainable façades’, Ajla Aksamija has described the design strategies that can be adopted for high performance building facades as follows:

- Orientation, geometry development and massing of the building to respond to the solar position
- Provide solar shading to control cooling loads and improve thermal comfort.
- Enhance natural ventilation through the building to reduce cooling loads and improve the air quality.
- Optimising natural day-lighting to reduce the energy used for artificial lighting
- Optimise the exterior wall insulation to reduce the energy used for mechanical cooling and heating in the building.

The main function of a façade system is to create a barrier between the interior and exterior environments and provide a comfortable space within. To achieve this there should be a perfect balance between humidity, temperature and...
ventilation. Additionally, facades should provide protection from wind and rain and control of light entry.

5.3.1.1 Facades in summers
With the increasing temperatures over the years, summers make the interior environments uncomfortable for its occupants. There is also an increase in the internal heat loads from electronic equipment especially in case of office buildings. The idea of correcting the design flaws of a building by installing air-conditioning units have long passed. Buildings are now being designed to attain a comfortable room climate naturally or to economically operate an air-conditioned space.  

5.3.1.2 Orientation and Massing to reduce solar gain and maximise day-lighting
Orientation and massing of the building plays an important role in maximising the daylight entry into the building while reducing the solar gain. This can be achieved by extending the building in the east-west axis which makes it easier to manage the solar gain and day-lighting on the north and south faces, while reducing the exposures on the east and the west faces. The orientation of the building determines the altitude and the azimuth of the sun to the façade. The interior spaces must have good thermal comfort within the required supply air limits while controlling the lighting and views. By considering the orientation of the building along with providing good ventilation strategies and solar screening, the interior climate can be improved.

North Oriented – The north façade generally have no solar shading as it receives direct sunlight only during summer solstice allowing it to be extensively glazed.

East Oriented – Solar radiation enters the east facing façade in summers at a very shallow angle, which makes it difficult to provide shading, it will also obstruct the daylight entry and the views inside. The period of use of these shading devices would be 50% of the period of direct sunlight.

South Oriented – Southern façade receives the most abundant and uniform sunlight. Good shading devices such as louvers or projections can be provided while having very little effect on the views and the daylight. The solar gain and the internal loads coincide as the direct sunlight on the surface covers the whole period of use. This side provides the best surface for energy generation such as solar and photovoltaics.

West Oriented – The west side of the building is the most unfavourable one during summers as the heat gain are very high. Optimum shading devices is difficult to design as the lighting is variable on the west side. The no of openings on the western face should be therefore be minimized. Light can be controlled better with the help of vertical screens.

5.3.1.3 Facades in winter
During winters, the need and therefore the stress will be on reduction of heat loss and retention of heat within the building at the same time maximise the light entry into the rooms.

As the climate outside is cold, the room temperatures must be higher to attain thermal comfort indoors. The transmission heat losses and surface temperature on the inside of the façade are influenced by the quality of the glazing and the insulation thickness. In well-ventilated buildings, radiators can be fitted on the internal walls. Good quality insulation can be used to reduce the heat output, which provides better flexibility in the selection of heat generating and heat transferring systems.

Internal heat loads and heat transfer as well as the proportion of window area will help determine the type of glazing required. The window frame is the weakest point in terms of energy, hence it is better to keep them at a smaller proportion at the same time glazing with multiple panes should be avoided. With a larger proportion of window area, the three pane glazing can help save more energy along with providing benefits such as better comfort.

Fig.39 - Thermal and functional effects depending on the facade orientation (Source: Hauser G, Climate Skins, 2006)
environments and less complicated technical building services.

5.3.1.4 Air change and Heat recovery
The ventilation energy demand can be influenced by the rate of air change. Therefore the building should have lesser no of items such as furniture, equipment, materials, etc. which emit pollutants or odour. By limiting the air change to the minimum required level of hygiene and heat recovery, energy can be saved with the use of good insulating facades.

The rate of air change has a very high influence on the heating energy demand and the rate of air flow can be determined by the air-tightness of the building and the adjustability of the ventilation openings. Unintentional air changes or air leaks must be avoided by paying special attention during construction stage.

For heat recovery within the building, the heat from the exhaust air can be collected by a heat exchanger or a heat pump. The heating demand can be reduced by heat recovery methods – up to 25% with low air change rates and up to 40% with high air change rates.

5.3.2 Natural Day-lighting through Façade design
Artificial lighting takes up one of the largest uses of electricity in buildings which can be significantly replaced by natural day-lighting through proper façade design. Distributing sufficient daylight across the interior spaces, manage glare and incorporating lighting control system to maximise energy efficiency are some of the main objectives of natural day-lighting. As the artificial lighting decreases, the cooling load decreases and the indoor comfort level increases.21

Lighting levels in the depths of the rooms can be improved by producing uniform illumination with the use of natural light distribution systems. Examples of light distribution systems are Heliostats, light shelves, prismatic panels, venetian blinds, solar pipes, avoidance of drop-down beams, reflective ceiling surfaces, floor and wall surfaces and even the office worktops.

Glare and reflection can be reduced by good light distribution and reflective louvers can be attached either inside or outside the building façade. Distribution systems direct the light into the upper part of the room which is then washed across the ceiling into the room. Additional reflectors or reflective surface can be incorporated onto the ceilings for better lighting effects and it is better to keep it light coloured so that light does not get absorbed.

The Norddeutsche Landesbank building in Germany uses supplementary day-lighting through the use of Heliostats, but the primary lighting is provided through the prolific glazing and transparent interior partition walls. Automated venetian blinds manage heating and cooling stability of the tower. One Central Park (Jean Nouvel, Sydney, 2014) is another example of a building using heliostats to redirect sunlight into the shaded portion of the building. (Detailed case study done in Chapter 8)

5.3.3 Visual Comfort
Openings for the views should be well positioned at the user’s eye-level. The higher the window position, the better is the daylight entry.

5.3.3.1 Glare
Glare is caused when the luminance levels are very high. Vision is reduced when the light entering one’s eye can no longer be limited. The level of reflective glare has increased inside buildings due to the use of computer screens upon which light gets reflected, creating discomfort to the users. This can be reduced by placing the screens perpendicular to the windows.

Glare protection systems such as louvers, translucent glazing, transparent or semi-transparent films or fabrics create diffused light by scattering the direct light or reflecting light onwards. The best option for glare control is a combination of external solar screening and internal anti-glare roller blinds.

5.3.4 Solar shading/ Solar screening

Solar shading devices help to control heat gain and heat loss and at the same time address the problems of glare, which is a significant problem that affects both the inside and outside of the envelop. Solar shading devices come in different forms and shapes such as sunshades, light shelves, vertical louvers, horizontal louvers, overhangs, blinds, fins, etc. Glare often occurs in areas close to the floor plate edge which receive a large amount of sunlight or bright daylight. This gives occupants of the inner spaces the uncomfortable impression that they are in darkness. Well-designed solar shading devices can perform both functions, those of protecting from sun, and assisting the reflection of light to the interior. Solar screens work on either absorption process, reflection, reduction, selection or transformation process.

In case of absorption process, the light striking the screen is converted into heat, eg.- projections, Blinds and Awnings. Solar screening can work on reflection where it acts like a mirror to reflect light without heating up too much, eg.- Venetian blinds and film roller blinds. The reduction process works by reducing the surface area which in turn reduces the intensity of direct and diffused light, eg.- Screen-prints, perforated plates, metallic fibre, wooden grillage, etc. Selection Process filters out certain wavelength of lights and transformation process is when diffused light penetrates into the room and direct light gets scattered.

If the screens are placed on the interior side of the façade, both the absorbed and the reflected radiation will be released into the room as heat by raising the air temperature. On the other hand, if the screens are placed on the exterior side, only a little amount of the radiation will contribute to heating inside. The A’Beckette Tower (Elenberg Fraser, Melbourne,2010) is a good example of colourful solar shading devices used that is both functional and aesthetically pleasing.

Some of the main features to keep in mind while selecting the right type of screening device are: orientation, transparency of the façade, maintenance costs, wind exposure, daylight requirements and visual comfort. External louvers are the most effective as it blocks the sun from striking the façade but have a high maintenance cost as they are exposed to wind and weather conditions. Internal louvers can be roller blinds or venetian blinds. They can be easily controlled by the users and remains protected from wind and weather conditions.

5.4 Conclusions

The role of facades in the overall scheme of a building is manifold. Apart from contributing to the aesthetic appeal of the building and from being the most striking architectural element, facades may have different functions like structural, protection, ventilation, day-lighting, thermal regulation, etc. They provide protection from the exterior environment especially wind and rains and in some cases from seismic movements. They have a role in regulating solar heat gain, convective heat, conductive loads and long wave radiation heat. Facades which form the major part of the surface area have a crucial role in facilitating thermal and visual comfort in the interior, allowing fresh air flow, utilising solar energy and regulating daylight entry.

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22 New Suburbanism: Sustainable Tall Building Development By Kheir Al-Kodmany.
Modern facades incorporate many sustainable features which enable saving of energy and reduction of carbon dioxide emission. Most façade functions when manipulated prudently can result in great reduction in energy consumption, substantial reduction or even elimination of carbon dioxide emissions and great improvement in internal comfort. Many of the modern sustainable technologies that can manage and manipulate to advantage heat, light and energy gain from sun can be integrated with the facades thereby aiding achievement of carbon neutrality. Many of these modern technologies are active ones like control systems that can respond to environmental demands.

CHAPTER - 6. TYPES OF FACADES AND MATERIALS

6.1 Single Skin Façade

Facades are based on climate, orientation, massing, the building’s function, occupancy patterns, equipment loads, etc. They are mainly of two types:

- **Opaque Facades** – These are facades made up of layers of solid materials. Examples – Brickwork and masonry facades, precast concrete panels, metallic cladding, tiles and stone veneer panels, insulation, cold-formed steel framing, etc.

- **Glazed Facades** - Facades that consist of transparent or translucent materials and metal framing components such as Curtain walling, glazed terracotta, etc.

6.1.1 Perforated Facades

They are the earliest form of facades and mostly consisted of a wall that had openings for allowing passage of air and light. Usually they were also intended to bear loads. These are the traditional method of design and have low maintenance and cleaning costs compared to the other types.

6.1.2 Elemental Facades

These facades are made up of prefabricated elements with functional elements for ventilation, day-lighting and energy generation.

6.1.3 Baffle panel

This is an additional element to the façade where a panel is placed at a short distance away from the windows (perforated or elemental facades) to reduce the disadvantages of ventilation and sound insulation in case of single skin facades. They can provide good solar screening, can be operated in any wind conditions and offer good protection against the weather conditions. It is a cost effective way of optimising a façade. They do obstruct the view out by a limited extend.

6.1.4 Curtain Walls

Curtain walls are lightweight façade systems that are attached to the buildings primary structure using aluminium extrusions. These are the traditional types of systems used in tall buildings which were of different types and methods such as:

- Stick (mullioned) curtain walling
- Unitised curtain walling
- Rain screen cladding
- Windows in walls
- Structural Glass (framed or frameless)

One of the first tall buildings with the mullioned curtain wall façade was the UN Secretariat (Le Corbusier, 1952, New York). Curtain wall systems of this era have high operating energy cost, due to absence of thermal break design, double-glazing or inclusion of insulation. During the more energy-aware late 1970s, this led to a reduction in the use of the bare curtain wall, as in their early formulation.

**Stick Curtain walling**: These are systems where each component i.e., the mullion, spandrel panels and glass are installed on the structure individually.
so as to finally make up the building envelope. They can interior or exterior glazed systems.

**Unitised Curtain wall system:** These are prefabricated units, which generally is a pane wide and about one or two storey high. They are easier and faster to install with less labour required. Unitised systems have a better performance than stick systems.

**6.1.5 Rain-screen cladding**

It is an extra element attached to the wall to keep water from entering in as well as to prevent leakage of air, carry wind load and to offer thermal insulation. The rain-screen concept makes use of the outer layer to act a protective layer against the rain and the weatherproof inner layer blocks moisture and air from penetrating inside. Figure below shows the different forces that lead to penetration of rain into the building. They can be made of different materials such as terracotta, precast concrete, cement composite, stone, glass, metal, etc.

**6.2 Double skin facades**

Over the last 20 years, the most important development in the facade industry has been the introduction of the double skin facade. With the correct configuration, it has become a solution for many of the issues, at height, regarding natural ventilation, need for more natural day-lighting in large spaces and the use of thermal mass for night time cooling. It is not only used for tall buildings. A walk through the City of London, or many cold climate European cities reveals many examples of double skin being used for new buildings of average urban height.

The double-skin façade, as the name suggests, consists of two skins fabricated in a manner that provides enough airspace in the cavity for ventilation routes, shading devices, green planting, engineer access or even leisure spaces. The main insulating façade is the inner skin. The outer façade is the climatic sheath, or wind-breaking skin. Double skins have strategies of air containment, such as the box, corridor, shaft, or uncontained all-over skin.

Ventilation is facilitated by the movement of air through the cavity between the skins. It can be natural, fan supported or mechanical. Various factors like location, climate, time and period of occupation of the building etc. can have a bearing on the origin and movement of air through the cavity. Double skin facades can help in reducing the heat losses in cold climate and at the same time it can aid in passive solar heat gain. During hot days it can reduce solar heat gain. These capabilities together with the facilitation of natural ventilation increases the energy efficiency of this type of façade.\(^{23}\)

Glazing can be done with single or double glazing units and the cavity in between. The width of such cavities can usually be from 20 cm upto 2 meters. Solar shading devices are usually located inside the cavity. This is safe and it helps in heat extraction and ensures protection from corrosive particles in the air.\(^{24}\) Double skin facades are of 4 types: Box window façade, corridor façade, shaft box façade and multi-storey façade.

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\(^{23}\) The Master Builder, Double skin Facades: Solution for energy Efficient Building Operations WWW page at: <http://www.masterbuilder.co.in/double-skin-facadesolution-for-energy-efficient-building-operations/>

\(^{24}\) (Modern Construction Facades by Andrew watts and https://en.wikipedia.org/wiki/Double-skin_facade)
6.2.1 Box Window Façade

A box window has an extra glass panel in front of the window allowing a cavity formation between them. This type of window provides good ventilation, noise reduction and solar screening. They reduce the views outside and the construction costs are high but they provide comfortable ventilation in winters and can be prefabricated making them suitable for renovations.

6.2.2 Corridor Facade

These are double skin facades with the cavity between the facades acting as corridor spaces and are separated storey by storey. The air exchange takes place either at every level vertically or at the corners of the building (horizontally) or by both. The pressure conditions within the building can be controlled using these systems by opening or closing the façade/ window/ panels/ elements. Such type of facades has limited view outside and has high fire-safety requirements.

One Angel square (3DReid, Manchester, 2013) is an ‘Outstanding’ BREEAM building in the UK, with a score of 95.16 out of 100. It has a double skin façade system which consists of two skins connected to each other by struts that create a walkway between them for solar shading, maintenance and ventilation.

6.2.3 Shaft-box type double skin façade

The shaft box type façade is a double skinned one with a mix of both single storey cavity and a multi storey cavity and the benefits of both. It mainly consists of an alternating layout of box façade units. According to the varying climatic conditions outside and inside the building both the facades can be appropriately used when required to attain a comfortable indoor temperature. Though its construction costs are high it can be prefabricated with good ventilation options and can be easily installed.

6.2.4 Unsegmented or Multistorey double skin façade

These facades do not have any horizontal or vertical separations in the cavity which could be as small as 1m to several meters deep. These skins are structurally independent of each other and the interior spaces require mechanical ventilation methods. For noise reduction purposes the number of air inlets can be reduced but for thermal
optimised ventilation the inlets and outlets should be spaced out over the height of the façade to reduce overheating in the cavity. These kind of facades give a homogeneous appearance to the building and can be simply retrofitted. They have high fire-safety requirements and have limited views to the outside.

6.2.5 Controllable Double Skin Façade

The design and construction of this type of façade is very complex. They could be made for an individual opening in the floor to ceiling space of each storey or could be extended to the whole of the outer skin of the building. Control systems adjust the façade to attain good climatic condition and natural ventilation. Its construction and maintenance costs are very high due to the large no of moving parts and control systems. Variable façade settings can be achieved, and by opening the outer skin excess heat in the cavity can be brought down thus facilitating night cooling.

6.3 Fifty percent (50%) Facades

A popular idea is for the return to the use of ‘the wall’, instead of assuming that tall buildings must always be of glass. This is often called the 50% façade concept, whereby one achieves the necessary daylight and ventilation in a workspace with ‘punched-hole windows’ leaving the other 50% of the façade to be high performance insulated wall. (Shuttleworth, CTBUH Dubai conference 2008)

6.5 Multifunctional Façade Systems

These systems are designed with the best level of prefabrication and used in modular construction methods for large scaled residential and office buildings. These unitary systems can avoid thermal bridging, have high air-tightness, attain all thermal requirements as well as integrate large innovative energy sources such as photovoltaics and hybrid technologies, e.g. the TES Energy Façade, enVELOP façade system. Thermal bridging is reduced by quality controlled prefabrication methods, which also reduces the on-site construction time, as well as achieving a very high air-tightness. Integrating cables, ducts and windows, can also avoid thermal bridging, air leaks and future maintenance failures.

PIXEL (Studio505, Melbourne, 2010) is Australia’s first carbon neutral building with colourful panelised façade that control glare, maximise daylighting, provide shade and views and give a unique identity to the building. The façade system consists of perimeter planting, double-glazed windows, solar panels and fixed louvers.

I-module

I-module facades are the best example of multifunctional unitary walling façades. These highly innovative facades integrate heating, ventilation, heat recovery, lighting, sound insulation, etc all in...
its 20cm thick cladding panels. They are made of closed and transparent façade elements acting together as a single unit creating a perfect balance of solar protection and views to the outside, achieving averagely 50% glazing. The façade panel can control the air quality and building’s temperature, and the panels integrated with lighting and acoustic elements.

6.5.1 Solar Active façade system - GAP Solution Façade Systems

In this system, the solar energy is trapped and used, in the passive energy concept. Façade system contains a honeycomb shaped assembly made of natural materials, which increases the temperature when sunlight hits them. This creates a gap between the layers and reduces the thermal bridge. Education Executive Agency +Tax Office (UNstudio, Groningen, 2011) is one of Europe’s greenest building with its façade designed to cause minimal environmental impact. It has incorporated concepts such as wind control, shading, daylight entry through façade elements that are shaped as airfoil fins which help in by keeping the heat outside reducing the requirement for cooling.

6.6 Hybrid Façade Systems

These are new technology façade systems, which are still under development and uses smart materials like aerogel, nano-particles and vacuum insulated panels. Hybrid systems can also be a combination of two different materials or technologies such as timber and aluminium systems. Such a system consists of aluminium on the exterior for durability, long life and low maintenance with the interiors made of engineered timber giving it a natural look and feel inside.

6.7 Green Façade systems

Green Façade systems are made up of living plants or trees. These facades help in increasing the project’s green space with a minimum-sized footprint. They are not a low-cost option. Further the maintenance costs also are high because it requires regular watering and replanting. However, the embodied energy costs are very low and they render considerable pleasure to the users and the public in comparison to other mineral based façade options.

Green facades which are architecturally designed are very attractive and helps in making the project conspicuous. They have the ability to improve the local environment, and increase the appeal of the building.

While the high installation and maintenance costs of green facades are a dampener on the designer’s enthusiasm, they have many advantages like:

- It reduces overheating through shading and transpiration
- Helps in dust filtration
- Reduces perceived noise levels
- Facilitates carbon dioxide storage and oxygen emission
- Helps in increasing Biodiversity – insects, bees, butterflies, birds
6.9 Sustainable Wall Materials

All buildings have an embodied energy cost. The façade, which must face the attacks of nature for many decades is a high proportion of the cost of a tall building. Material selection is very important for sustainable façade design as every material has different physical and thermal properties. The question is if sustainable building materials can be used on the façade instead of costly materials like stainless steel, aluminium or titanium?

Normal urban buildings are designed for a lifetime of 30 years before requiring renovation, but historically, tall buildings have had lifetimes of well beyond 50 years, with periodic expensive refurbishment programmes, but not demolition. Tall buildings suffer more severe conditions of thermal expansion, oscillating wind pressure/suction and UV exposure, resulting in loss of panels or degradation of seals. Various new materials and technologies are discussed below.

6.9.1 Timber

Timber is considered sustainable because it locks up carbon, and is grown through responsible forestry practices. Use of external timber cladding is not discussed in this study because the context of the study is mostly tall buildings. On these, exposed timber is too risky due to the risk of fire spreading easily upwards over the surface of the building beyond the reach of fire-fighting teams, and spread of flame to adjoining buildings. There is also the very high cost of general maintenance of organic material at a great height over the much longer lifetime that tall buildings are designed for.

Timber in solid form (CLT/KLH) may be used as a wall substrate within the concrete frame, but it is wholly fireproofed, never exposed.

6.9.2 Glass

Glass has become the symbol of modern facades. It is seen and used on the majority of the tall buildings around us and a huge advancement has been made in glass technology in the last few decades. Since the early glazed tall buildings of the 1950s, there have been major advances in the coatings and performance of glass. Furthermore, a wide variety of techniques can be used on glass such as printing, etching, coating, use of metal sheets with perforations over glass, louver variations, etc.

6.9.3 Prefabricated panels

Prefabricated wall panels typically include a structural framing system, sheathing, weatherproofing, insulation and exterior wall cladding. Prefabricated panels are delivered to the project and connected to structure providing the complete building envelope. Prefabrication provides added quality assurance with fabrication under controlled conditions, reduced on site labor and reduced construction schedule. Prefabricated panels can be provided with a wide range of exterior materials including; Aluminium composite materials, thin brick, terracotta, ornamental metals, etc.

6.9.4 Composite Metal

Aluminum Composite Material (ACM) – ACM is widely known as the exterior cladding of choice on multi storey buildings because of its ability to provide complex architectural features and superior weatherproofing. It is also used for column covers, entrances, canopies and other critical design elements. ACM panels are used widely for both new and retrofit construction, and can be field installed or as a component in prefabricated panels to provide a clean high tech look.

6.9.5 Terracotta (‘burnt earth’)

For centuries, terracotta has been used in building construction, mostly as roof and floor tiles. Terracotta now provides a premier architectural option used in Rain screen and ventilated exterior wall construction. Terracotta is available in varied profile shapes and earth tone colours, glazed or unglazed, to provide an architecturally appealing, energy-efficient building. Terracotta is a

**Fig 74** - Jubilee campus buildings with terracotta facades by Ken Shuttleworth and Make architects
(Source: Author)

**Fig 75** - Terracotta Panel Facade System detail
(Source: LOPO Terracotta products)
100% natural material, made from clay and sand, is non-combustible and provides LEED certification value as a sustainable material. Terracotta, with its colours stabilized under a glazed finish, has an eternal durability, and is a prime walling solution for the new buildings of University of Nottingham’s Jubilee Campus, designed by Make.

6.9.6 Fiber Cement
Fiber Cement Panels (FCP) offer an architecturally uniform, non-combustible, durable exterior that is designed for use in Rainscreen and ventilated wall systems. FCP’s are available in a wide range of aspects and colors. FCP’s have been successfully used in Europe for over 35 years as a ‘No’ maintenance exterior, requiring no caulking or painting.

6.10 Fritted Glass
Fritted glass has computer controlled patterns printed on the surface. Fritted glass has application ranging from reducing solar gain; avoid glare; or simply creating a pattern, also, giving better safety and privacy.

The Leatop plaza by JAHN in Guangzhou, China is a light, transparent tower designed to be energy-efficient and is an excellent example for its use of fritted glass making it resemble an ice crystal. It has a high performance façade which is triple glazed, low e-coated, fritted, and shingled.

6.11 Advanced Facade Materials

6.11.1 Self-cleaning glass
Self-cleaning glass consist of a thin layer of photocatalysts on its surface, which are compounds that accelerate a chemical reaction using the UV-bands of sunlight. The commonly used photo-catalyst is titanium dioxide. The self-cleaning process of glass happens in two stages: The photo-catalyst stage when the glass is exposed to light, it breaks down the organic dirt particles and the hydrophilic stage when the rain washes the loose particles from the glass. This reduces the maintenance costs of the building and helps keep the glass clean. Research also proves that self-cleaning glass which uses natural rainwater and gravity can reduce pollutants, such as human-applied detergents which cause major problems in rivers and treatment plants.

6.11.2 Electro-chromatic glass
They consist of an extra layer of film, which changes its opacity when applied with an electrical voltage. The transparent electro-chromatic glass can change into a tinted glass when applied with electricity and vice versa, with the ability to remain in that state unless applied with electricity again. The solar heat gain reduces when the glass is tinted and it increases when it becomes clear. Therefore, it can be used according to the changing climate. It provides good shading to the building and can reduce the overall energy consumption of the building. (Aksamija, A. 2013)

6.11.3 Nanomaterials
Coating the façades of tall buildings with Nanopaint could reduce pollution by acting as air purifiers. Titanium dioxide (TiO2) nanoparticles in paint on exposure to ultraviolet light break down organic and...
inorganic pollutants that wash off in the rain. It also decomposes particles like formaldehyde that causes air pollution.

6.11.4 Solar Nanotechnology

Amorphous silicon, organic and inorganic solar cells derived from nano-crystals has high solar conversion rates and so can produce electricity at a very low cost than the common silicon-based solar cells. These cells also have the additional characteristic that they are ultra-thin.

Nanotechnology has made it possible to print tiny solar cells on very thin and flexible light retaining materials thus obviating the need to meet the cost of silicon.

6.11.5 Phase Change materials (PCM)

The first reported application of PCM was back in 1940s. The main attractive feature of the PCM is that they have a greater storage capacity than that of conventional materials as they can store heat energy in a latent form. When the temperature rises, the chemical bonds break as there is a change in phase from solid to liquid. The PCM absorbs heat as the phase change process is endothermic and when the atmosphere cools down it return back to its solid phase releasing the stored heat.

GlassX is an example of such PCM facades and it consists of a PCM in its core which is made up of Calcium chloride hexahydrate (CaCl2 6H2O) which is a non-toxic salt, with a melting point at room temperature. It can provide a thermal mass equivalent to that of 16” of concrete.

Facade made of this material does both the function of absorbing the solar energy and protecting it as well. A layer of salt crystals on the surface will help absorb the heat and the prismatic glass allows the radiation to pass only at the lowest angle of radiation.

During summers, the solar radiation is reflected by a prismatic outer layer when the sun is at an angle higher than 40 degree. During winters, when the sun is at a lower angle lesser than 35 degrees the prismatic layer allows more solar gain.

ETFE does not have a tensile structure and so cannot support itself. The multi-ply sheets when filled with air forms into pillows which can adjust to the varying loads exerted by the winds. The air pressure in the pillows are maintained constant in relation to the wind force with the help of pumps. The pillows are kept supported by structures made of aluminium or steel. ETFE is fire resistant and can be easily repaired when damaged.

ETFE is 100% recyclable with self-cleaning properties. It is a very sustainable material with low levels of CO2 emissions due to its lightweight at the same time its carbon footprint is believed to be 80 times lesser than other transparent building materials such as glass. ETFE can admit more light than glass, thereby reducing the energy costs by 30%.
6.11.8 Vacuum Insulated layers

Vacuum Insulated layers are 5-10 times thermally more effective than layers of conventionally available insulation. They make use of new technology and have room for further developments, for example, incorporating them into unitary curtain walling systems. Vacuum insulated layers have good insulating properties and can be made very thin, hence they can be easily used in small tight spaces such as below the window sill or floor connections to prevent heat bridges, or by enabling thinner panels, to improve the net lettable space in the gross floorplate area of a framed building. They are used mainly in refurbishment projects as they require smaller space as compared to conventional materials. Vacuum insulated layers can be used in prefabricated components such as precast concrete. In addition, the low self weight makes them attractive for use in tall building walling systems.

6.11.9 Aerogel

Aerogels are synthetic solids that are made up of air having the lowest densities among all solids. Due to the low density, they have low thermal conductivity making them ideal for use in areas where high thermal insulation is needed. When integrated with polycarbonate sheets, they form transparent cladding materials. Aerogels have good acoustic properties with good resistance to moisture and are non-combustible. Diffused lighting into the interiors can be made possible by using silica aerogel due to its translucent nature.

6.11.10 Suspended Particle Device (SPD)

SPD consists of a transparent conductive material with suspended liquid crystals laminated between layers of glass. The amount of light entering the glass can be controlled by applying a voltage. In the normal state, the liquid crystals are arranged randomly and scatters light to give it the translucent appearance.When electricity is passed through, these crystals rearrange themselves, allowing light to pass through it making them appear transparent. They are generally used indoors for privacy control and used less as building envelopes.

6.11.11 Coating agent for reducing the soiling process of facades

US has patented a coating agent for reducing the soiling process of facades. The transparent coating agent comprises of a layered silicate capable of forming a colloidal gel in the presence of water. Soiling of the facades manifests in greying and this happens due to the deposits from the air onto the surface. Researches have revealed that the soiling consists mainly of inorganic particles with a size of up to 10 μm along with small fractions of soot. The transparent, readily processable, colour-neutral coating agent has thixotropic properties. Its composition is suitable for an even application to facades and helps in reducing their soiling tendency and the attenuation of gloss. Moreover, it does not show any colour changes of the substance.

6.11.12 Thermotropic Materials for Adaptive Solar Control

Thermotropic materials which have high stability against solar radiation and heat and also possess optical properties like absorbance and reflection have great utility in adaptive solar control. They also possess technology compatible processing
characteristics. Thus they are among the best energy efficient materials. Such intrinsic solar energy reflecting, phase change materials are now being used for smart window systems. Summarizing their paper (Thermotropic Materials for Adaptive Solar Control) describing the details of this technology, Ruhmann, Seeboth, Muehling and Loetzsch states that “it is amazing that the solar energy itself is used as a promoter against solar heat.”

6.11.13 Coloured Glazed thermal solar collectors
Research has shown that by depositing thin films of silicon oxide and silicon titanium mixed oxides on solar collector glazing in a sol–gel dip-coating process based on alcoxide precursors higher values of energy efficiency can be obtained. The produced coatings combine a bright coloured reflection with an acceptable solar transmittance, and are thus well suited for the application in coloured glazed thermal solar collectors. This innovative method of colour glazing can facilitate architectural integration of thermal solar collectors as in solar active glass facades.

6.12 Conclusion
Façade types vary depending on structure, function and extent of utility. The most common and widely used type is the double skin façade, which with suitable variations and adaptations, helps in solving issues regarding natural ventilation, natural daylighting and the use of thermal mass for night time cooling. Thus, they are most suitable for integrating sustainable features.

Multifunctional façade systems and green façade systems are also desirable from sustainability angles. Controllable double skin facades are complex systems that are capable of adjusting the façade to gain best climatic condition and natural ventilation. Materials useful for imparting sustainable qualities for facades are many. Composite metal, Fibre Cement and Terracotta are materials being used widely. Phase Change Materials, ETFE, Special Nano-paints, etc. are advanced façade materials presently being tried in many buildings.

CHAPTER- 7. INNOVATIVE AND ADVANCED SUSTAINABLE FAÇADE TECHNOLOGIES

7.1 Energy Generating Smart Facades
Smart façades are building envelopes that adapt to environmental conditions. Recent advances in material and chemical sciences have helped in the development of various types of smart facades. Some of the interesting smart facades developed and tried out by architects and designers are listed below:

7.1.1 Energy-Producing Algae Facade
A group of designers from Splitterwerk Architects and Arup in Germany have recently unveiled a 2,150 square foot micro algae bio-facade where countless microscopic algae flourish using the oxygen and nutrients provided to them. It has a vibrant green colour which is due to millions of microscopic algae plants tinted on the louvers covering the building. Under direct sunlight these microscopic algae multiply rapidly increasing the biomass and resulting in heating up the water. This heat is harvested and used in the building. This can be a new source of sustainable energy production, which can transform the urban environment. (International Building Exhibition IBA Hamburg)

According to Jan Wurm, Research Leader for Europe for Arup, “If we can demonstrate that microalgae bio-facades can become a viable new source of sustainable energy production, we can transform the urban environment.”

7.1.2 Building Integrated Photovoltaics (BIPV)
Building Integrated Photovoltaics are photovoltaic materials used on the building envelop such as the roofs, skylights and facades of tall buildings to generate energy. Photovoltaics consists of 20-40 solar cells which are joined together and embedded...
in a 1 x 0.5m module. The voltage obtained from each of the cells are about 0.6 volt and the energy produced depends upon the area of the cells and the solar irradiance. PV panels can be easily integrated onto the facades or placed on the roofs. The two main facades systems which can incorporate Photovoltaics are the curtain walling and rainscreen cladding.

These systems can work autonomously or can be connected to the public supply grid in which case the excess electricity generated will be fed into the public grid. CIS Tower (Gordon Tait, Manchester,1962) renovated the three exposed façades of its service core with blue PV panels. This installation generates an average of 20Kw electricity per year and feeds its excess into the national grid.

Photovoltaic modules will capture energy, but the bonus is that they can be placed on the façade to provide better sound and thermal insulation, weather resistance as well as effective solar protection. They can be fixed systems or active systems. Active systems may have motorised frames or concentrators which adjust to the changing solar angles to obtain maximum output. Old buildings can be retrofitted with PV panels to give them a more appealing look. In the case of the CIS, it was a ‘Listed’ building, but the PV installation was considered acceptable by Manchester city and English Heritage.

**Transparent solar panels** are also called translucent photovoltaics. These transmit only 50% of the light that is falling on them. They can be installed over glass, or as a replacement for conventional elements that are made of glass such as skylights and windows. Unlike the conventional solar cells which use infrared rays these transparent photovoltaics generates electricity by using the ultraviolet radiation and the current is conducted by the tin oxide coating on their inner surface. London’s Heron Tower and the Jubilee Campus atrium roofing are good example of this.

### 7.1.3 LED Facades

LED facades help create a vibrant and beautiful visual quality to both the building as well as the city. LED’s are becoming famous as media facades, where hundreds of LED’s can be linked together to form large screens but yet can be all controlled individually, letting images and messages come to life making shopping malls and corporate office buildings crowd pullers. LED’s are perfect for outdoor application as they are weather resistant. With a life of 50,000 hours or more they can reduce energy and maintenance costs. The compact design allows them to be installed very close to the façade, saving energy and light emissions.

The Agbar Tower by Jean Nouvel in Barcelona has 4,500 LED’S that can be operated as computer controlled pixels, that creates moving images on the tower envelope, with as much control as the LED screen on the laptop. With RGB (Red Green Blue) management, the LED’s can generate 16 million colours.

Iconic buildings such as Burj Khalifa in Dubai broke the world record for the largest LED-illuminated façade, turning the skyscraper into one of the world's brightest visual display. The LED display has 70,000 LED bulbs held in place by 100,000 brackets and linked using 55,000 metres of cabling.

### 7.1.4 Mashrabiya Facades

Mashrabiya, a perforated screen based on Islamic geometric patterns have long been used in building especially in the Gulf countries to provide solar shading and privacy. This traditional window element with characteristic lattice works are being widely used in new buildings for both aesthetic and functional purposes. Many new buildings in the Middle East have incorporated mashrabiya screens into double skin facades to reduce cooling loads in
the interiors, such as Doha Tower (Jean Nouvel, Qatar, 2012) and Masdar Institute (Foster and Partners, Abu Dhabi, 2010).

Doha Tower has a very rich ornamented multi-layer façade making it stand out amidst all the neighboring towers. The façade is made up of four aluminium layers that are arranged in patterns with varying sizes of perforation.

7.1.4 Active Mashrabiya

Abu Dhabi’s 25-story Al Bahr Towers by Aedas Architects has created an innovative active mashrabiya façade which pays homage to traditional Arabian architecture and design. It is a secondary sun-screen for the two towers that are originally sheathed in a thick skin of glass. This secondary sun-screen deflects a large portion of the glare resulting from the hot desert sunlight without blocking the views permanently. This is made possible by a series of faceted fibreglass rosettes which open and close in response to the temperature of the facade. The geometric patterns that comprise this gigantic screen include over 1,000 moving elements that contract and expand during the day depending on the sun’s position.27

7.1.5 Air-Filtering Façades

7.1.5.1 Smog-eating Facade

A 300-foot-long skin of Torre de Especialidades, a new hospital building in Mexico City, is made up of Prosolve 370e tiles developed by a German firm. They function as air filters around the sponge shaped structures where ultraviolet light-activated free radicals destroy the pollutants thereby making the air inside the building cleaner. The method is based on a technology developed by Alcoa, a chemical company, in which a material containing titanium dioxide destroyed the toxins in the air by releasing spongy free radicals.28

7.1.5.2 Air-filtering Concrete

Italcementi-Lab designed by Richard Meier and partners is one of the first LEED Platinum rated project in Italy. They have sustainable features like rainwater harvesting and solar panels but what stands out more is its high-performance pollution-busting white concrete façade. Solar heat gain is minimized by the low-e glasses on the concrete louvered curtain wall that lets daylight into the building. The heating and cooling needs are met by the geothermal systems and the solar panels.


The white TX Active® concrete is Italcementi’s own innovative product which can reduce pollution by reacting with ultraviolet rays and breaking down the harmful pollutants such as nitrogen oxide and sulphur in the air. The pollutants are converted into inert salts and this helps in overall reduction of smog levels in the environment. It also has self-cleaning properties which will help it to remain white in colour. This innovative concrete was first used as a biodynamic skin in the Palazzo Italia, Italy’s spectacular pavilion at the Milan Expo 2015.

7.6 Kinetic Facades

Kinetics can be exhibited in multiple ways—folding, sliding, expanding, shrinking and transforming. In some cases, Kinetic elements are incorporated into buildings just for aesthetic or experimental purposes such as the John Hancock Centre (SOM, Chicago, 1969). It has a new renovated observatory called 360 Chicago with a tourist attractive feature called ‘Tilt’, which is a platform that tips 30 degree to give visitors the sensation of being suspended in the air. The university building at Kolding, Denmark by Henning Larsen Architects has a triangular form kinetic façade that is climate responsive. The façade consists of 1,600 panels of metal perforated sunshade with heat and light detecting sensors that allow the panels to open and close. Even when the panels are completely closed, a considerable amount of light enters through the perforations.

The Kiefer Technic Showroom designed by Ernst Giselbrecht + Partner is an office building and exhibition space with a façade that optimizes the building’s internal climate. The envelope is made up of several layers—aluminum posts and transoms encased with an EIFS-façade in white plaster. Perforated aluminum panels are operated with computers and it can transform the building appearance from solid monolithic volume to a playful combination of transparent and closed surfaces.

The One Ocean Thematic Pavilion in South Korea is another example which has kinetic façade systems. The Pavilion has fish-like characteristics with a GRP façade system which integrates moving lamellas in to the building skin. It has a kinetic media façade that moves by deforming its louvers. There are a total of 108 fins, each measuring 10 and 42 feet high with 0.35 inch thickness. These fins depict the movement of the gills of a fish. It is compressed at the top and bottom by activators that are attached to the structure of the pavilion. When the fins are compressed, it begins to buckle longitudinally along its side creating an opening in the building skin. The lower opening is widened and narrowed as the other edge pivots on a bearing. When opened, the fins let in natural light into the...
...interior spaces and at night they turn into a LED display.31

7.1.7 Other High-performance Facades

7.1.7.1 Low-Tech, Operable Skin

Sean Godsell Architects covered Melbourne RMIT’s design school building with thousands of small, sandblasted glass circles—each affixed to a central rod. These rods pivot automatically based on the temperature and humidity inside the building thereby facilitating or blocking, as the case may be, the flow of air through the facade.

7.1.7.2 Cooling Facades - BioSkin

The Bio-skin is an elegant cooling system which has been designed not just to reduce the energy use but when used on multiple buildings can impact on the microclimate of that area.

The CTBUH2014 Tall Building Innovation Award winner, the Sony City Osaki Building, designed by Nikken Sekkei, features the Bio-skin system which is a skin of water-filled ceramic pipes. Bio-Skin reduces the surface temperature of a building up to 12°C, and can even lower the micro-climate surrounding the building 2°C.

The system is based on the phenomenon of transpiration, whereby water moves through a plant and is evaporated from the leaves, stem and flowers, as well as the Japanese concept of ‘Uchimizu’ — the sprinkling of water on gardens and streets to lower ambient temperatures and keep dust at bay. Bio-Skin tubes are made of extruded aluminium cores, with a highly water-retentive terracotta shell attached to the aluminium core using an elastic adhesive. When rainwater collects on the rooftop, it is then drained to a subsurface storage tank, where it is filtered and sterilized. This water is then pumped up and circulated through the pipes, which act as the balcony railings for this office tower. Rainwater penetrates outward through the porous ceramic, evaporating from the pipe’s surface, cooling the surrounding air. Excess water is drained down to the soil of the premises to the extent possible, normalizing the water cycle and reducing the load on sewage infrastructure.


32WHITEvoid is an interactive art, design and technology group of specialists who creates spaces, installations and products for museums, exhibitions, events, concerts, etc.
7.1.7.4 Perforated Facades

Perforated facades have been used for centuries as a way of adding a distinctive character to the building along with controlling the airflow and light entry. This is similar to the ‘mashrabiya’ concept widely used in traditional Middle East architecture. The difference is in the computer generation of the perforations, ranging from entire window size down to fine pixel sized pinholes.

They can be used both internally and externally and can help create an interaction between the two environments by inviting views as desired, simultaneously creating a sense of privacy within. Perforated Facades can be in the form of walls, panels or screens. With the use of new technologies, highly detailed patterns and shapes can be easily etched unlike the traditional method of hand carving.

Perforated facades can be used with new as well as refurbishment projects, thereby help create a new identity to an old building. These facades allow a perfect interaction with natural and artificial lighting, from providing solar shading during daytime to media walls and night time lighting. The overall aesthetic delight of the building can be increased by introducing different patterns and shapes with the perforations.

7.1.7.5 Helio-trace Façade systems

Skidmore, Owings and Merrill (SOM) along with Permasteelisa group and Adaptive Building Initiative (ABI) are working together to develop THE Helio-trace façade system, which is an advanced building enclosure concept. The façade system is designed to increase the daylight entry and reduce the solar gain by 81% annually. The prototype is still under testing and further research is required before it can be fully employed on buildings.

It consists of three systems: The first system is the exterior kinetic shading devices which are opaque panels that are placed perpendicular and parallel to the façade. The second is a thermally efficient high performance curtain wall and the third is the MEP and building service such as the chilled ceiling panels.

When the kinetic curtain wall system panels are fully opened they can control the heat gain and glare in the building. When the shades remain partly open, they control the glare without reducing the light entry into the building. During winters, when the shades are completely closed, the system maximises the daylight entry into the room and allows for passive heating.

7.2 Biomimicry in Architecture

Low energy usage, easy to recycle, durability and versatility are some of the basic characteristics of biological systems and the main aim of biomimetic design is to achieve these attributes through engineering. According to Julian Vincent patterns can be translated or adapted from nature in three different ways: The lowest level of direct copying from biological objects (shells, leaves, bones, trees, etc.). The second level is engineering to solve problems by recognizing patterns in the way nature uses them to solve problems. Major part of the design is recognition, solution and elimination of problems. The third level is more closely related to the current practice in engineering and design. It is
founded on the TRIZ system, which was developed specifically for solving engineering problems. Some of the examples that we can learn from nature are:

1. Human skin that is self-repairing, waterproof and heat sensitive.
2. Feathers and Fur – Thermal and water protection
3. Structures of plants which can be applicable to buildings, such as self-cleaning lotus leaf, or leaf bone structures.

7.2.1 Biomimetic facades

These new façade concepts are mostly modular multifunctional units, which aim at being more sustainable, energy active, climate adaptive and energy efficient. A few different types of such facades are described below:

7.2.1.1 Biomimicry - Esplanade

The esplanade in Singapore designed by DP Architects appears like a durian or a bee’s eye. It has a unique geometry for its facades, which consist of a number of diamond shaped panels on the exterior. This façade systems maximises daylight entry into the building at the same time reduce glare and block excessive heat gain. They allow good view to the surroundings through the doubly curved glazed roof.

7.2.1.2 Heat Reacting Metal

Doris Kim Sung, professor of architecture, USC’s research in biomimetic studies how architecture can mimic the human body. His temporary installation named “Bloom” is a sunshade made of thermobi-metal which is a lamination of two metals with different thermal expansion coefficient. When the surface of the shade heats up under sunlight the thin panels on it curl up and permits air to pass through to the space below. When it cools down it closes on its own.

7.2.1.3 Breathing Skin Project

Based on the concept of Biomimicry, Tobia Becker’s ‘Breathing Skins Project’ is inspired by organic skins, which can adjust its permeability to control the required light entry, matter and temperature between the interior and the exterior. This façade works by expanding or diminishing the span of the openings that are scattered over the surface—just like the skin's pores would open up or tighten. There are 140 air channels on each sq. meter, which are depicted by Becker as ‘pneumatic muscles’. These roundabout mechanical assemblies swell, and the aggregate expansion or emptying is the controlling component behind the façade’s porosity. As a type of responsive engineering, the regularly changing pneumatic muscles permit a particular measure of air, light, and visibility. It not only gives a performative benefit but an aesthetic one as well with the ever-changing surfaces. The innovation principally comprises of two glass surfaces sandwiching these pneumatic muscles.

7.3 Conclusion

In times when sustainability is the most sought after quality in the built environment, the face of the building, i.e. the façade, with sustainable features is very much in demand. Research and innovation in the material and chemical sciences have brought out many types of smart facades like, Energy-producing algae façade, Bio-skins, Bio-mimetic facades,
Kinetic facades, Building integrated photovoltaics, etc. Building integrated photovoltaics have great acceptance because of their capacity to generate large amounts of electricity. In the facades, the photovoltaics also replace the cost of non-glazed panels in curtain walling and the rain screen cladding. In the energy-producing algae façade, under direct sunlight, microscopicalgae multiply rapidly in the heated up water, generating vast amount of biomass which can be harvested and converted to oil or gas, or in some cases, directly generating hydrogen. This biomass product is exported or may be used in the building. Other modern façade technologies include Air filtering facades, Low-tech operable skin facades, Pneumatic facades, Helio-trace façade systems, Breathing skin Project, etc.

CHAPTER- 8. CASE STUDIES

8.1 GSW Headquarters, Berlin, 1999

Location: Berlin, Germany
Climate: Maritime influenced Climate
Date: 1999
Architect: Sauerbruch Hutton Architekten
Building Type: Office
Area: 54,000 Sqm
Height: 82m
No of stories: 22
Facade System: Dynamic Façade – Double skin

GSW headquarters building in Berlin is the new extension of the existing 17 storey tower that was built in the 1950s. It has a striking adaptive building façade system and is oriented in the east-west direction according to the prevailing wind. The building consists of a tall and narrow body, which is curving asymmetrically towards the south end. It has a very small floor plate depth of maximum 11.5m to maximise the daylight entry and enable good cross ventilation into the office spaces. Due to this shape, there is good light entry from both the sides of the building. According to B.Cody from Arup, the concept of the building design was to close the west façade with a second skin as it is facing the streets where there is noise, traffic and air pollution. The air inlets are placed on the east facade which will cross ventilate the offices in the double façade.

The south façade is the smallest to minimise heat gain. The east and west facades are designed as double skin facades with different properties i.e., the east façade has two glass skins 20 cm apart, ventilated on every floor and the west has one meter continuous cavity between the glass layers, acting as a solar chimney.

East Façade Treatment
The east façade consists of triple glazed windows with blinds in between the panes and all the module elements can be operated both manually as well as automatically by the central building management system. All the air inlets are provided in the east façade for cross ventilation. Stack effect through the building aids in good ventilation.

West façade treatment
The west façade is deep and triple layered providing stack effect and consists of a double skin with interior double panes that can also be operated both
manually and automatically. The double glass layers acts like a solar chimney creating a natural air conditioned space indoors. This system has helped in reducing the energy by 40% as compared to the German energy standards. (Russel, 2000) The outer single glazed façade is made of laminated glass which is supported by cantilevered bracket with metal-mesh decking. The west façade also contains various colourful vertical perforated aluminium louvers for solar shading purposes. Colours range from pink and orange to bright ruby red giving an aesthetic appeal to the west façade. (GSW, 2000)

The automated building operation system controls the artificial lighting systems by switching off when there is adequate day lighting present. Cross ventilation through the building is made possible by providing large air-inlets with open spaces and by ventilation panels integrated on the doors. Stack effect means that when the air outside the building is warmer than that inside, the hotter air flows out through the solar flue and gets replaced by the cooler air below.

8.2 One Central Park, Sydney, 2014

Location: Sydney, Australia
Climate: Temperate
Completion Date: 2013
Architect: Jean Nouvel
Building Type: Residential
Area: 255,500sq.m
Height: 116
No of storeys: 34
Façade System: Green Facades

One Central Park by Jean Nouvel in Sydney is a residential complex with two towers placed above a 6 storey central shopping center. It has been awarded a five star green star rating by the Green Building Council, Australia. It has followed a carbon conscious design by adopting two technologies into its design – Hydroponics and Heliostats.

The vertical gardens were designed with the help of the botanist Patrick Blanc. These green walls are curtain walls, which were installed as the construction progressed. The planter boxes are made up of rotor-moulded polyethylene, which is very strong, water tight and lightweight, making them easy to be installed and maintained. The vertical gardens can act as an air purification system as the plants can absorb the pollutants present in the air and convert them into fertilizer by slow decomposition.

The heliostats

One of the main features of One Central Park is the large cantilever with heliostats that redirect sunlight. The heliostat systems consists of mirrors and panels that can track sunlight and reflect it to the shaded portions of the building. The heliostat mirrors are placed on the roof of the 16 storey West tower which reflects sunlight onto the reflective panels, that are placed on the cantilevered structure on the East Tower which further reflects it down onto the southern corridor. The cantilever is suspended horizontally 40m from the edge with a structural steel frame on the 28th floor of the East tower and reflects light 120 m down.

The heliostat system consists of 40 motorised heliostats on the west tower and 320 reflective mirror panels on the East tower. At night the system gets converted to an LED screen with 2,100 LED lights displaying videos by renowned artist Yann Kersale on various interpretations of Sydney’s landscapes.
The East tower has majority of the apartments facing the east and west with only one apartment facing north on each floor. Therefore, each apartment gets ample natural daylighting. The heliostats are placed on the west façade of the East tower which also helps provide shading from the harsh west evening sun especially during summers. 

### 8.3 Swiss Re /Gherkin, London

**Location:** London, UK  
**Climate:** Temperate  
**Completion Date:** 2004  
**Architect:** Foster and Partners  
**Building Type:** Office  
**Area:** 64,469 sq.m  
**Height:** 180m  
**No of storeys:** 41  
**Facade System:** Double skin Façade

The façade consists of a double skin façade, which is designed in such a way that the air extracted from the offices cools it and this helps reduce the overall heat load of the building. All the internal and external glazing is easily accessible for cleaning purposes.

The façade is made up of a double-wall system with a double-glazed glass wall for its outer layer. It is composed of triangular shaped windows panes and Mullions. The inner layer is made up of sliding doors. Horizental shading devices make up the space between the two layers. The smooth glass façade consists of thousands of flat triangular panes of glass with a single piece of curved glass at the very top of the building.

![Fig 128-Details of the building form showing the spiralling light well (Source: Foster and Partners)](source)

![Fig 129- Triangular window panes and mullions (Source: Foster and Partners)](source)

![Fig 130- The principle of double skin façade in gherkin (Source: Foster and Partners)](source)

Gherkin has a fully glazed double skin façade, which is designed in such a way that the air extracted from the offices cools it and this helps reduce the overall heat load of the building. All the internal and external glazing is easily accessible for cleaning purposes.

The façade is made up of a double-wall system with a double-glazed glass wall for its outer layer. It is composed of triangular shaped windows panes and Mullions. The inner layer is made up of sliding doors. Horizontal shading devices make up the space between the two layers. The smooth glass façade consists of thousands of flat triangular panes of glass with a single piece of curved glass at the very top of the building.

![Fig 130- The principle of double skin façade in gherkin (Source: Foster and Partners)](source)

Each floor is rotated by 5 degrees from its adjacent floors and the light wells connecting up to six floors. The triangular façade contains venting flaps, which allows the hot air to flow out of the building.

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34 Foster+Partners. Projects: 30 St Mary Axe WWW page at: <http://www.fosterandpartners.com/projects/30-st-mary-axe/>
The ceiling on each floor has a built-in heat exchange system, which cools the interior spaces.

8.4 Council House 2, Melbourne, Australia (2006)

Location: Little Collins Street, Melbourne
Climate: Warm Temperate
Completion Date: 2006
Architect: DesignInc
Building Type: Office
Area: 12,536 m²
No of storeys: 10
Facade System: Louvers, Green walls

Council House 2 (CH2) is a sustainable office building designed by DesignInc in collaboration with the City of Melbourne. CH2 has helped change the idea of sustainability in buildings by being Australia’s first building to achieve a maximum six star green star design rating by the Green Building Council of Australia.

The total building cost was $51.045 million, of which $12 million was spent on sustainable design mechanisms, which has increased the worker productivity/efficiency by 10%. CH2 saves enough energy to equal $5,479.45 every day, about $2 million a year equating to the total cost of the building over a period of 25.5 years.

Biomimicry is a large design component for this building and the design of the HVAC systems are based on the strategies taken from the termite mound. CH2 boasts a number of environmental strategies such as wind turbines, chilled ceilings, phase change material, co-generation plant, shower towers, photovoltaics, night purging, green walls, etc.

Black water from public sewers are collected and recycled for building requirements such as flushing, irrigation, etc., through its water mining plants. The building also has excellent indoor air quality, by providing 100% fresh air to all occupants with one complete air change every half an hour. The chilled ceiling panels help keep the building cool during summers. The chilled water for this is supplied by 3 large tanks. In each of them, there are 100,000 small stainless steel balls filled with phase change material (PCM) that freezes at 16 degrees and acts as a thermal storage device.

**FAÇADE SYSTEMS**

The north, east and west facades are extensively shaded to protect from glare and solar gain. Balconies and light shelves redirect light into the interior spaces to maximise the natural lighting. Task lighting and daylight sensors help reduce energy consumption. The southern face is made up of small louvers made out of recycled timber, which automatically adjust according to the sun. These shower towers take in air as well as water from the storage tanks. The water through this shower towers evaporate and cool the remaining water droplets which is then collected.

**GREEN WALLS**

The north facing balconies from 1st to 9th floor have vertical green wall supported by metal mesh on either sides which protects them from glare and screens the sunlight at low angles. The plant species selected were based on the following aspects: Glare reduction and Solar screening, life cycle and growth rate, climbing habits, less water consuming, aesthetic properties, longevity and maintenance (Hopkins, Goodwin 2011). planet Earth it can also be an economically viable, sociologically beneficial and individually satisfying one.

CHAPTER - 9. CONCLUSION
Concerns about the future of life on planet earth is compelling governments, organisations, architects and designers to become stakeholders and facilitators of sustainability. Concerted efforts to achieve carbon neutrality in the built environment by 2030 are on. 195 countries in the world negotiated the Paris Climate agreement of 2015, and the majority have signed it during 2016. Facades have an important role to play in making a building energy responsible. Provision of natural ventilation, solar control and photovoltaic energy conversion are the most common features of sustainability that are being sought from facades. Research, especially by devoted Façade Research Groups have evolved various technologies and methods in this direction and efforts are on through programmes of publications and conferences to promote the sustainability potentialities of facades. Types and varieties of façade technologies and their sustainability features that have been looked into show that its range is wide. The new and futuristic façade technologies studied prove that they have promising potentialities that will help in achieving carbon neutrality.

Strides in research in the field of chemical sciences, nano-technology, aeronautics, mechatronics, etc. have brought out many new products which are able to provide augmented sustainability capabilities and innovative features to facades. Some of the most sustainable tall buildings studied proves that the cost incurred for incorporating sustainable technologies in buildings is a prudent investment not only in terms of sustaining life on planet Earth through achieving carbon neutrality but also in bringing better returns in terms of economic, social and personal well-being.

Energy efficiency standards of each building calls for appropriately designed solution keeping in view site-specific features of microclimate, orientation and form factor. The wide range and availability of innovative technologies and materials when integrated into the façade designs will definitely aid in the quest to achieve carbon neutrality.

We live in an era of unparalleled technical innovation. At the same time we face an existential

CASE STUDY CONCLUSIONS
The case studies carried out are in respect of four tall buildings renowned for their sustainable features and adoption of most modern technologies. These buildings are best examples of integration of sustainable technologies in their facades. They manifest the practical possibilities of many innovative sustainable technologies. These sustainable features while aiding the efforts to reduce carbon footprint also contributes to physiological and psychological well-being of the occupants. It is important to note that in CH2, Melbourne by spending just $12 million on sustainable design mechanisms the worker productivity/efficiency has increased by 10% and the annual gain on account of energy savings amounts to $2 million. This means that the cost of installing sustainable mechanisms will be recouped in just six years and the cost of the whole building in 25.5 years. The benefits from worker productivity/efficiency over the years will be enormous. This goes to prove that while sustainability efforts are primarily aiming at ensuring the continued existence of homo sapiens

problem greater than all of us, the combination of extreme rates of Urbanization, the end of fossil fuel energy, with advancing Climate Change. Is it too much to ask that the future generations of architects, engineers, governments and citizens should all use their best ingenuity to face up to this challenge?

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