

ECOLOGICALLY CONSIDERED DESIGN OF OPERATIONAL SYSTEMS FOR HIGH-  
RISE BUILDINGS IN KOLKATA

by

KALYAN CHAKRABORTY

B.Arch, Jadavpur University, India, 2001

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Major Professor  
Prof. R. Todd Gabbard

## **Abstract**

This thesis presents design possibilities for reducing the ecological impact of the operational systems of high-rise buildings in Kolkata, India. This research is supported by a study of the current urban situation of Kolkata which shows a recent growth in number of high-rise buildings and a need for ecological considerations in their operational systems. To fulfill this need this thesis studied recent developments in alternative operational system design and explored the possibility of developing operational systems in a proposed residential high-rise building.

In the process of developing an alternative operational system for a high-rise building in Kolkata this thesis firstly studied development of operational systems in high-rise buildings and recent sustainable architectural guidelines to understand the primary design necessities for ecological considerations. Secondly a study of alternative design strategies and techniques was done and a research for the development of a building integrated solar thermal updraft façade was carried out. The research into a building integrated solar thermal updraft façade showed the possibility of developing a façade system in high-rise buildings which can generate electricity. Finally on the basis of the studies and the research an analysis was done to check the reduction in carbon footprint and improvement in the design of operational systems in a hypothetical high-rise residential building in Kolkata.

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## **Dedication**

To my parents.

# **CHAPTER 1 - Background Study**

## **Purpose Statement**

The purpose of this research is threefold. First, it is to study the socio-economic, cultural, and climatic context and crises which frame the needs to develop design principles for ecologically considered building operational systems for high-rise buildings in Kolkata. Second, it is to identify the conventional strategies, sustainable precedents and new research which can be used to develop ecologically considered building operational systems. Third, it is to set strategies for ecologically considered building operational systems for high-rise buildings in Kolkata which can make buildings act as an integrated system to solve existing problems of encroachment into wetlands, pollution, energy crisis, flooding and sewage treatment. The significance of this research is to examine and synthesize design strategies for ecologically considered building operational systems for high-rise buildings in Kolkata.

## **Introduction**

“The ancient concept of the earth as nurturing mother was radically transformed in Bacon’s writings, and it disappeared completely as the scientific revolution proceeded to replace the organic view of nature with the metaphor of the world as a machine. This shift, which was to become of overwhelming importance for the further development of western civilization, was initiated and completed by two towering figures of the seventeenth century, Descartes and Newton” (Capra, 1983). Since the development of Cartesian mechanistic philosophy, a view of reductionism evolved, which approached every system as a linear process and viewed the universe as a machine whose working principles can be completely understood by the Cartesian-Newtonian theories and thus can be controlled. This mechanistic world view inspired us to

control the nature and solve problems through the development of new technologies. But humankind failed to realize that infinite growth is not possible in a finite world. Fossil fuel based rapid industrialization reshaped the face of earth. Industrialization developed rich industrialized countries but led the rest of world to an even worse condition. The developed countries, with only twenty percent share of global population, consume eighty percent of the global natural resources (Cassara, 2007). At the same time nearly a billion people in Sub Saharan African and Asian countries are suffering from malnutrition (FAO, 2009). Besides the evident issues of inequity there is a major issue of an ecological crisis which is related to fossil fuel energy. With the use of concentrated energy in the form of cheap fossil fuels modern civilization reshaped the face of earth in the last couple of centuries, but the issues of depleting fossil fuels and increasing global pollution combined with an exponentially increasing global population forced the development to face a global crisis.

In present global context, India, being one of the fastest growing economies, is now a major consumer of natural resources. With this economic development Kolkata, the third largest city in India, is experiencing a rapid growth in the number and size of high-rise buildings. In this context this thesis explores possibilities in the design of building operational systems of high-rise buildings in Kolkata to reduce the natural resource consumption and, thus, reducing the negative ecological impact of such buildings.

***The end of fossil fuel era - the global context:***

Contemporary civilization is a product of cheap oil. It shaped the way we live, build our houses or cities and even grow our food. Baudrillard mentioned “Energy is a sort of fantasy projection which nourishes all modernity’s industrial and technical dreams; energy is also what tends to give our conception of man the sense of a dynamic of the will” (Baudrillard, 1990). But



the future of global fossil fuel scenario is not bright. According to experts we are on the brink of global oil peak. The prediction of oil production peak was introduced in the middle of twentieth century by M. King Hubbert, a scholar of geophysics from the University of Chicago who later joined Shell oil company in its research laboratory. The greatest recognition for Hubbert came from his studies of petroleum and natural reserves. These studies he started in 1926 while a student at University of Chicago. In 1956, on the basis of his reserve estimates and his study of the lifetime production profiles of typical reservoirs, Hubbert predicted that the peak of crude oil production in the United States would occur between 1966 and 1972. Although most economists, oil companies, and government agencies (including USGS) dismissed the prediction at that time, the actual peak of US oil production occurred in 1970 (Heinberg, 2003). After predicting the US oil production peak, Hubbert also tried to predict the global oil production peak. According to the calculation he made on the basis of available data, the global oil production was predicted to peak within 1990 and 2000. This prediction seems too pessimistic, as we have already passed this time frame, but according to contemporary experts it will not take too long to reach the peak oil production. “Irrespective of the insights provided by natural resource and energy economics and the dynamics of technological change, some analysts had from time to time pointed to the risk of the imminent exhaustion of the last oil well. A recent example is the work of the Association for the Study of Peak Oil and Gas (ASPO). The group estimates global oil production to peak in 2008 and proposes an international accord (The Uppsala Protocol) to prevent major economic and supply disruptions in the transition to a post-oil world” (Toth, 2005).

There are some counter arguments to the global oil peak and the existing global oil reserve in different forms like heavy oil in the tar sands in Venezuela and Alberta (Huber, 2005)

but the problem is not with the reserve estimates. Peak oil doesn't mean the end of oil reserves. But it happens at the half of the total production. It is never possible to extract all the oil which is inside a reserve. As Lomborg mentioned, "we use new technology to extract more oil from known oilfields, become better at finding new oilfields, and can start exploiting oil fields that were previously too expensive and /or difficult to exploit. An initial drilling typically exploits only twenty percent of oil in the reservoir. Even with the most advanced techniques using water, steam or chemical flooding to squeeze out extra oil, more than half the resource commonly remains in the ground. It is estimated that the ten largest oilfields in US will still contain sixty three percent of their original oil when production closes down" (Lomborg, 2001). Although with the help of new technology we will try to exploit the maximum of this left over reserve, it will not help us much. With the depletion of reserve, production becomes more and more difficult and the EROEI (energy return on energy invested) decrease. And once the EROEI is negative then production leads to net loss. ERORI is also an important consideration in the substitution of one energy resource for another: if we replace an energy resource of four to one ERORI ratio by another with two to one ERORI ratio, we will have to produce roughly double the amount of gross energy to have equal amount of net energy.

***Coal:***

Along with petroleum coal is the other most important and widely used fossil fuel energy source in the world. It seems that at the end of the cheap petroleum age there will be still sufficient reserve of coal to supply the demand for a few more years. Heinberg mentioned, "demand for coal has increased over past few decades at an average pace of 2.4 percent per year (meaning that at current rates of increase, total usage doubles every 30 Years). The EIA estimates that recoverable reserves in the US amount to about 275 billion short tons (bst),

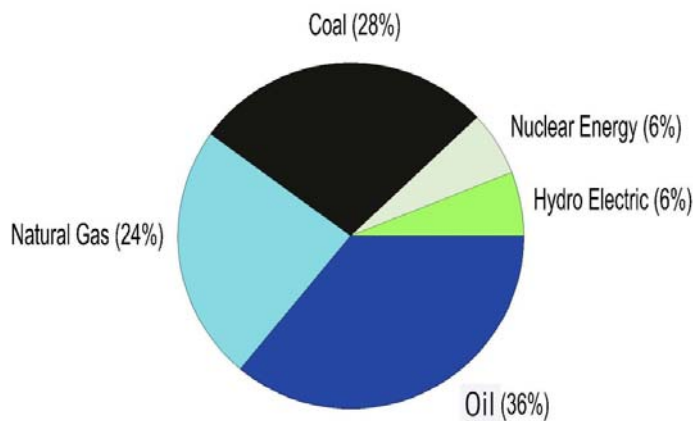
representing roughly twenty percent of total world reserves. Production in 1998 amounted to about 1.1 bst; at that rate of usage current reserve could theoretically last for 250 years” (Heinberg, 2003).

But due to different environmental emission issues coal is not a good choice as an alternative. Coal as a fossil fuel is a major contributor to ‘global warming’, which is another major concern for the world. According to the UN Habitat report: “In the 20th century, sea levels rose by an estimated 17 centimeters, and conservative global mean projections for sea level rise between 1990 and 2080 range from 22 centimeters to 34 centimeters. Oceans, which have been absorbing 80 per cent of the temperature increase attributable to global warming, are expanding as ice sheets in the North and South poles melt. These events have led to a rise in sea levels and increased flooding in coastal cities. The projected rise in sea levels could result in catastrophic flooding of coastal cities. Thirteen of the world’s 20 mega cities are situated along coastlines. Coastal cities that serve as ports are a vital component of the global economy. In fact, the importance of port cities in international trade has grown significantly, particularly in developing countries, as the volume of sea trade has more than doubled in the last 30 years. Port cities have, therefore, not only grown in terms of population, but in terms of asset value, as well. A recent study by the Organization for Economic Cooperation and Development (OECD) found that the populations of Mumbai, Guangzhou, Shanghai, Miami, Ho Chi Minh City, Kolkata, New York City, Osaka-Kobe, Alexandria, and New Orleans will be most exposed to surge induced flooding in the event of sea level rise” (State of the World Cities, 2009).

With the development of new technologies efficient use of coal with fewer emissions may be possible in the future. Heinberg mentioned that, “The most promising proposal in this regard comes from the Zero Emission Coal Alliance (ZECA), a program started at New

Mexico's Los Alamos National Laboratory. ZECA has designed a coal power plant that extracts hydrogen from coal and water and then uses the hydrogen to power a fuel cell. The ZECA plant would attempt to recycle nearly all waste products and heat" (Heinberg, 2003). Considering all these issues if the environmental pollution is taken care of, then it seems that coal can be used for a few more years. But not for long as with the depletion of the resource the EROEI will drop and the profit ratio will become so low that its use will have no point. Moreover as the Figure 1.1 shows that coal presently supplies only 28 percent of our total energy need. Thus supplying our entire need for energy with coal for a long time is only a distant possibility.

**Figure 1.1 World's primary energy consumption by fuel type, 2006 (Canada's Energy Future - Reference Case and Scenarios to 2030, 2010)**



***Context of India:***

The British left India in 1947 after a span of 190 years of colonial rule. During the British period there was no proper evolution of any aspect of Indian culture (Nehru, 1951). In almost all aspects, western culture became a role model for Indians, without the consideration that outcome of modern western development neither fits into economic and climatic conditions nor the socio-cultural heritage of Indian society. Balakrishna.V.Doshi said "The realization that the western model of architecture and urban planning introduced by the colonizing agencies, as well as the

subsequent developments in the west, were not very suitable to their resources and climatic circumstances and socio-cultural well being has led to a healthy questioning. This has also required Indians to look into their own past heritage to understand the architectural and planning practice which evolved over centuries of adaptation and in few cases adoption.” (Doshi, 2007).

### ***Contemporary scenario:***

Recently the economic scenario has changed. India is perhaps experiencing the biggest growth in its recent history. Presently India is considered to be a major developing economy in the world. According to a Goldman Sachs analysis in 2007 India is ranked as the thirteenth major economy by GDP. As per the Sachs prediction, by 2050 India will be the third major economy in the world (Sachs, 2007). With the growing economy, India is also becoming a major consumer of natural resources and making a major ecological footprint. In 2007 India has consumed 2.8 million barrels of oil and 578.6 million short tons of coal. Besides that in the same year the country consumed 1473 billion cubic feet of natural gas and 517 billion kilowatt hours of electricity. The ecological impact of this consumption is great. In 2006 India produced 1300 million metric tons of energy related carbon dioxide (U.S. Energy Information Administration, 2009). With the economic development, recently there has been considerable growth in the building sector and particularly in the construction of high-rise buildings. Building sector is a major contributor in the energy consumption and thus high-rise buildings in India need an ecological consideration.

### ***Context of Kolkata:***

As with most of the major cities of India, Kolkata is also experiencing explosive economic growth. The city is showing marked improvement in every economic sector as well as in its property market. Table 1.2 shows a striking growth in the number of high-rise buildings in

recent years in Kolkata. As it is shown in the Table 1.2 there were only 12 buildings in the city which were taller than 15 stories before 1990 and by the end of 2009 that number has grown to 98.

### 1.1 General formations on Kolkata: (KOLKATA (CALCUTTA) : GEOGRAPHY)

Latitude	22°32'N
Longitude	88°22'E
Annual rainfall	1600mm
Average high temperature	38°C (April, May June ,July, August, September, October)
Average Low temperature	12°C (December, January)
Annual mean Temperature	26.8°C
Average daily solar insolation	4.93 kWh/m <sup>2</sup> /day

At this point of real estate growth there are very few high-rise buildings designed with proper ecological consideration. Perhaps the only example is the ‘City Center’ designed by Charles Correa.

**Table 1.2 Development of high-rise buildings in Kolkata: (Emporis, 2000-2010)**

Time-line	Before 1970	1970- 1990	1990- 2000	2000- 2009	Under Construction
No. of High-rise Buildings (more than 15 stories)	-	12	21	98	36

Recent high-rise and other intensive use buildings of Kolkata consume huge resources and produce huge waste. A recent survey in Kolkata shows scenario of contemporary high-rise buildings and respective energy consumption (refer Table 1.3). Moreover as it is shown in Table

1.3 a major share of the energy consumption in these high-rise buildings is due to the use of HVAC. This lack of concern for the local context led to many problems including power shortage, pollution, flooding that has been discussed further in the following section.

**Table 1.3 A survey of Contemporary scenario of energy consumption in high-rise buildings in Kolkata**

Name of the Project	Building height	Electricity consumption	H.V.A.C. consumption.
Haldia Commercial complex	G+38 stories	4.396 M.V.A.	1200 tons
South city project	G+34 stories	2 M.V.A (in one tower)	1172 tons (in one tower)
Highland Park	G+27 stories	1M.V.A (in one tower)	586 tons (in one tower)
Sunrise point	G+14 stories	A total consumption of 2 M.V.A for entire complex of .63 million sqft.	1242 tons (entire complex)
Globsyn crystal	G+11 stories	6 M.V.A.	2100 tons
Eco Space	G+7 stories	A total consumption of 10.4 M.V.A for entire complex of 2 million sqft.	2000 tons (entire complex)
Development Consultants LTD.	G+7 stories	.8 M.V.A.	

***Recent problems of Kolkata:***

As these case examples shown in Table 1.2, most recent developments are high energy consuming and intense use buildings which do not relate well to the context of recent problems of Kolkata rather they intensify the problems associated with energy use, pollution, encroachment into wetland and flooding as discussed below in more detail.

### ***Energy Crisis:***

Electric power in Kolkata is not dependable and blackouts are a major concern. In recent years the demand has reached such a critical condition that in May, 2008, the governor's Palace observed voluntary power cuts for an hour in the morning and an hour in the evening. Governor Gopalkrishna Gandhi stated that "it need not be an exception to the city's electricity supply situation" (Gupta, 2008). Commercial buildings usually have a hundred percent backup power supply with diesel generators which exacerbate air and noise pollution.

### ***Pollution:***

Pollution is another major issue in Kolkata. Its air quality is one of the worst in the world. Major contributors to air pollution are the automobiles (Foul-air slap from Delhi, 2008). In contrast to the national capital Delhi, where most of the public vehicles run with compressed natural gas (CNG), in Kolkata automobiles run primarily on petrol and diesel. A quick growth in use of automobiles in recent years has worsened the situation. "The carcinogenic benzene levels in Kolkata were found in winter of 2006-2007 to be as high as 36 micrograms per cubic meter, higher than Delhi, which has a larger number of vehicles, said CSE director Sunita Narain" (Hindu, 2009). Some 70 percent of people in the city of Kolkata suffer from respiratory disorders caused by air pollution. Ailments include lung cancer, breathing difficulties and asthma, caused by air pollution.

### ***Encroachment to wetlands:***

The physical and economic growth of Kolkata has been primarily guided by its geographic location. Kolkata is located in eastern India in the Ganges Delta at an elevation of 5.1 meter (17 feet) from sea level (Kolkata : Geography, n.d.). The city is spread linearly along the banks of the River Hooghly in a north-south direction. Much of the city was originally a vast



wetland reclaimed over decades to accommodate the city's burgeoning population. The remaining marsh land, known as East Calcutta Wetlands, has been designated a “wetland of international importance” in the Ramsar Convention (Ramsar List of Wetlands of International Importance, 2002). The restriction in wetland encroachment in Kolkata leads the city to a high density high-rise development in future.

The city of Kolkata derives multiple benefits from the adjoining wetland ecosystem. Kolkata, in spite of being one of the biggest cities in the world with nearly fifteen million citizens, does not have a centralized sewage treatment plant. The human sewer and industry wastes get drained to the East Calcutta Wetland and are treated there via natural process. Thus Kolkata saves a huge amount of money and energy required to run industrial treatment plants. After the sewage treatment the nutrient rich water is channeled to farmland and fisheries where it helps crop production and pisciculture without much use of artificial chemical fertilizer. Roychaudhuri mentions “East Calcutta Wetland (ECW) is an example of wise use of cities solid and liquid waste through integrated resource recovery, mainly for pisciculture, vegetable as well as paddy cultivation and manure production” (Roychaudhuri, 2007).

***Flooding:***

In the monsoon months flooding is a major problem in Kolkata. The city developed on a flat low lying plane, reclaiming a vast wetland over the decades. Instead of developing in harmony with the local geography, the growth process of the city has filled up wetlands and developed on top of these important natural systems. This growth pattern destroyed much of the wetland. Moreover this top down development pattern is in sharp contrast to the local vernacular approach which retains most of these wetlands, generates unique landscape morphology. As most of the area is a low-lying flat plane which can be regularly flooded during monsoon, a

raised platform is required for the building; and traditionally a pond is cut to raise a piece of the land for building construction which develops unique landscape morphology. This process not

**Figure 1.2 Typical landscape morphology by cut and fill (Kolkata, West Bengal)**



only produces some raised platform for residential buildings but also generates some catchment areas for storm water management. This practice has developed an interesting landscape fabric in and around the Kolkata suburban areas. Figure 1.2 (left image) shows a Google satellite image of Khardah, a suburb of Kolkata. Figure 1.2 (central image) shows the ponds by highlighting them and Figure 1.2 (right image) shows the Figure-ground relationship of these ponds to the entire area. This pattern is common in all places near Kolkata. With the growth of urban areas around Kolkata vast areas of wetlands are being filled with sand imported from river bed destroying the fabric of small water bodies (ponds), which used to act as water catchment area during rainy season. Figure 1.3 (left image) and Figure 1.3 (right image) shows typical recent development happening near Khardah. Since most of Kolkata is now composed of low-rise and high-density, the city is becoming mostly covered with impermeable surface which increases flooding during the rainy season. The condition is getting worse as new developments are growing by filling in wetlands indiscriminately.

**Figure 1.3 Typical recent practice of urban growth by filling up wetlands (Kolkata, West Bengal)**



***Prospective Solution:***

The solution can be derived by analyzing the context. India has very few resources for a huge population leading to a poor economy and poor infrastructural base, which cannot support the development patterns of the cities as in rich developed countries like the United States. Duplicating this pattern is even more illogical because the experts have already indicated that the urban growth pattern in the U.S. is not sustainable. The automobile-based urban development of the U.S. was made possible because of availability of cheap fossil fuel. As Farr argues “people making these lifestyle choices are automobile dependent. As a result two-third of all oil consumed in United States is processed into fuel for transportation” (Farr, 2008).

Along with this core issue the automobile-based development pattern of the U.S. is not suitable for India due to the lack of infrastructure. As an example if we compare the demographic and infrastructural pattern of Kolkata with that of Kansas City then we will find that Kolkata has only 6 percent road area for its 12.9 million citizens (Largest Cities of the World - by population, n.d.) whereas Kansas City has 30 percent road areas supporting half a million people (Top 50 Cities in the U.S. by Population and Rank., n.d.). Clearly Kolkata cannot sustain

an individual automobile-based transportation. More automobiles will lead Kolkata to even more traffic congestion (refer Figure 1.4).

The typical commercial buildings in U.S. are large boxes with centralized HVAC systems demanding large supplies of electrical power, which is not viable in a city like Kolkata given its limited power supply and very large population. Traditionally in Kolkata buildings were designed utilizing local vernacular bioclimatic design strategies without HVAC systems. But with the growth of shopping malls and high-rise commercial complexes and the impulse to copy western lifestyle, the use of mechanical cooling systems are increasing. Due to geographic conditions Kolkata has become a linear city and further increase of its size will either push the edge farther from its central business district (CBD) or lead to additional encroachments into wetlands. Neither of these scenario is desirable. In this context the principal question is what should be Kolkata's directions for future development?

Balakrishna V.Doshi, a prominent Indian architect, asserts: “we should search for our cultural catalysts which become the institutions of man and which give life its meaning” (Doshi, 2007). To counter the present crisis and to develop a sustainable architecture in Kolkata architects and ecological designers should develop sustainable design principles based on local vernacular bioclimatic strategies for specific intensive use buildings which can serve the present need without losing relevance to its culture and context.

**Figure 1.4 Automobile density in downtown Kolkata left; and Automobile density in downtown Kansas City right; (source: Author's photograph)**



***Ecologically considered high-rise buildings as a solution:***

Until the late twentieth century Kolkata was a city of high density low-rise and mid-rise buildings. To accommodate the immense growth in population presently there is a tendency in many cities to move forward high-rise construction. High-rise helps to form a high density development and thus limits sprawl. The striking difference of urban footprint between San Francisco bay area and Hong Kong proves this fact. Although both of the cities have similar population but Hong Kong is primarily a high-rise city and thus has a much less urban footprint compared to predominantly low rise San Francisco bay area (Bosselmann, 2008). In ‘The New Landscape’ Charles Correa mentions “as the building height increases twenty fold, gross neighborhood densities increases only about four-fold” (Correa, 1989).

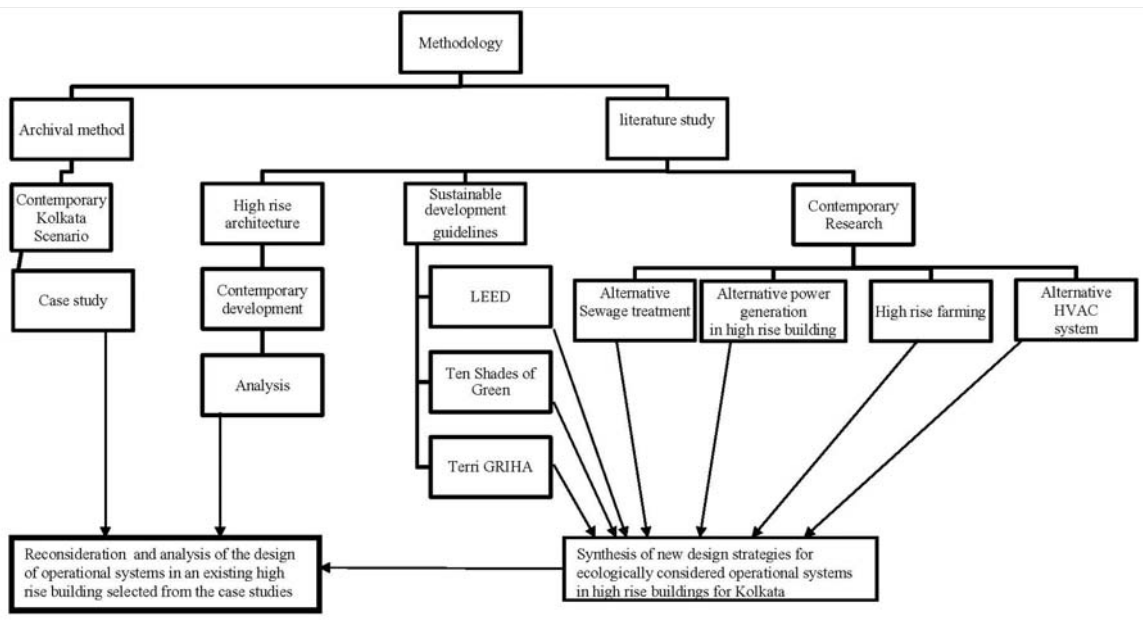
The climate of Kolkata is not suitable for a low-rise high density development which is found in more arid regions. With similar population Karachi achieved more density with primarily low to mid-rise development. Kolkata cannot have Karachi’s pattern because it receives much more rainfall and more ground coverage will intensify its flooding problem. The high-density low to mid-rise development pattern in Kolkata has led to its currently sprawling

size. Geographically the city is bounded on its east and west borders by wet lands and highly fertile farmlands. As previously noted, the tendency was to grow linearly along the banks of river Hoogly (a tributary of Ganges), which supported waterway transportation. Nevertheless it is difficult to support such a long distance from centre to periphery with a poor transportation network. In this context high-rise high-density development is growing in Kolkata which seems logical to increase density near central business district (CBD) without encroaching on remaining wetlands. The building sector is a major consumer of energy and natural resources and in high-rise building the operational systems takes the major share of it. Thus in Kolkata it is important to develop ecologically considered operational systems for high-rise buildings to reduce the consumption of natural resources and thus the negative ecological impact.

### ***Methodology***

The primary goal of this research is to present design of ecologically considered operational systems in high-rise buildings. To fulfill this goal first it was important to understand present context of Kolkata and the trend of new high-rise buildings in it. Second it was important to understand the development of high-rise buildings and sustainability issues associated with this building type. The third important aspect was to understand the major focus areas in the contemporary sustainable architecture movement. After understanding the major focus areas the fourth important part of this research was to study these focus areas in details to understand new researches and contemporary development in these areas. Finally in the fifth stage, it was important to apply ecologically considered operational systems in a contemporary high-rise building in Kolkata, and make a comparative analysis to check the ecological benefits.

**Figure 1.5 Methodology**



***Archival research: Understanding the context of Kolkata:***

An archival research was done to understand the contemporary context of Kolkata. The purpose of this study was to understand the contemporary scenario of newly developed high-rise buildings in Kolkata in resource consumption and their carbon footprint. Nine new projects were studied. Out of these projects three were residential and six projects were commercial. The information were primarily received from the websites of these projects. Besides the websites some information was received from the project consultants and facility management.

***Literature study: high-rise architecture:***

To present the design of ecologically considered operational systems for high-rise buildings in Kolkata it was important to understand high-rise building type and its operational systems. A literature study was done to understand the development of modern high-rise buildings their structural and operational systems. The primary focus of this study was to understand the development of operational systems in modern high-rise buildings and ecological

concerns associated with this building type. The study was done on the basis of several previous researches done on this building type and its operational systems.

***Literature study: understanding sustainable architecture:***

After studying the high-rise building type and ecological concerns associated with its different operational systems it was important to understand the most critical areas of ecological concerns. To understand this, studies of three sustainable design guidelines, LEED, GRIHA and Ten shades of green were done. Selection of these guidelines was done on the basis of their importance to the context and present movement of sustainable architecture. LEED is a widely accepted green building rating system which is also being applied in India whereas GRIHA is a new green building rating system, developed in India keeping the Indian context in mind. Although Ten Shades of Green by Peter Buchanan is not a rating system but it is a major discussion of sustainable design guidelines. After the study a matrix analysis of these three design guidelines were done which showed maximum stress on renewable resource use and resource recycling in green buildings.

***Literature study: new researches and contemporary development in ecologically considered operational systems:***

From the understanding developed from the matrix analysis of three sustainable design guidelines, four operational systems namely 1) Alternative HVAC system; 2) Alternative power generation; 3) Water efficiency; and 4) Food production in high-rise building were selected for detailed study. The intention of this study was to understand new developments in these areas and possible integration of some particular techniques in a high-rise building.

The researches on alternative HVAC system, water efficiency, and food production in high-rise buildings were done from the literatures on contemporary developments in these topics.



Besides the literature study an experiment was carried out to understand the possible development in alternative power generation.

The experiment was done to check the possible development of a solar updraft façade system. For this experiment, prototype modules of a solar updraft façade system were built and the temperature and air movement within this prototype were studied with the help of Hobo data logger and velocity stick. Hobo data logger was used to measure temperature, humidity and the intensity of solar illumination. The velocity stick was used to measure the wind speed.

***Comparative analysis:***

Finally one high-rise building was selected from the nine case studies done in Kolkata and redesigned to integrate different ecologically considered operational systems with it. After that a comparative analysis was done between the existing building and the modified design to check the improvement in the carbon footprint.

## **CHAPTER 2 - High-rise as building type**

High-rise or tall buildings have become regular features in big cities. A high-rise building is defined as “a building greater than 75 feet (23 meters) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupied story” (Craighead, 2003). Development of modern high-rise buildings was possible with the development of their structural and operational systems. To develop ecologically considered operational systems for high-rise buildings in Kolkata it is important to understand high-rise building type and its operational systems. This Chapter explores the development of high-rise buildings and their structural and operational systems, and sustainability issues related to this building type.

### **History of tall buildings:**

Since their early history, human beings have built tall buildings across the globe. “The tall building began as an isolated monument, and can be formally considered as a monolith in the visual world having a closed system of values. The symbolic column can be traced historically, beginning with the free standing Egyptian obelisk. The Romans developed their own version with Trajan’s column (A.D.98) which became the prototype for western monuments such as Nelson’s column (A.D.1843). Today the tall building is symbolically devalued and placed in a related system of architectural form” (Prescott, 1962). Some of the early forms of tall buildings were the Ziggurats of Mesopotamia, pyramids and the monolithic obelisks in Egypt, Stupas in India and Mayan temples of Mexico. Later the forms started to change, to develop domes and towers, as we find them in the church domes and spires, mosque towers, pagodas and temple peaks which were attached to some religious significance (Ali, 1995).

In a later period it gradually became independent form of towers and minarets as an example Qutub minar in Delhi and victory tower in Chittor, India. “In the Middle East, the minaret of Muslim architecture, from the square towers of great mosque of Damascus (707A.D.) to the slender spires of Turkey and India (for example, the Qutub Minar in Delhi), exerted significant influence on Gothic and Renaissance architecture of the west” (Ali, 1995).

The earliest instance of tall buildings designed primarily for human habitation is found in the desert city of Shibam in Yemen, mostly built in sixteenth century (1532-1533 CE.), several centuries before the modern era of tall residential building construction. Shibam was declared a World Heritage Site by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2010).

#### ***Contemporary tall buildings and their classification:***

The development of modern day tall buildings started in the late nineteenth century, made possible by several technological developments in Europe and America. This building type was not evolved from their walk-up predecessors but was the product of a conceptual breakthrough (Ali, 1995).

High-rise building is a specific building type where, due to its height, several measures are necessary for structure, fire safety and vertical circulation. According to Beedle (1971) “The multistory building is not generally defined by its overall height or by number of stories, but only by necessary additional operations and technical measures due to the actual height of the building” (Ali, 1995). Beedle also states in the Foreword of the Monograph Structural Design of Tall Concrete and Masonry buildings (Habitat., 1978) that the typology is “a building in which tallness strongly influence planning, design and use,” or “a building whose height creates

different condition in design, construction and use than those that exist in ‘common’ buildings of a certain region and period” (Habitat., 1978).

On the basis of the architectural developments Cesar Pelli and Ada Louise Huxtable identify four ‘skyscraper ages’ (Ali, 1995).

### ***Skyscraper Ages:***

The first skyscraper age started with the then-new structural systems and the invention of safe elevators. The home insurance building of 1884-1885 first used the innovative structural steel frame (Ali, 1995). The skyscrapers of this age are characterized by their functional orientation and their expression of the steel frame in the elevation. The innovative use of the structural steel frame was initiated by the Home Insurance building designed by William Le Baron Jenney.

The second skyscraper age was developed with the influence of the ‘Beaux-Arts’ and the French academy. The character of this era is an eclectic style in which aesthetic considerations were made through the application of historical details. The American surety building of 1894-1896 is considered as the epitome of this style.

The third skyscraper age is one of modernism. This age developed in reaction against the ‘Beaux-Arts’ eclecticism. The new revolutionary approach in this period redefined architecture and tried to make it completely free from the influence of the past by taking a more technological and rational expression in building form.

The fourth age according to Huxtable is the postmodern phase. This phase lacked the stylistic clarity of the modern phase, instead having a pluralistic character which includes many styles including post-modernism and late-modernism. Post-modern high-rise architecture

blended modern design influences with vernacular, historical, regional, metaphorical, and contextual influences (Jenks, 1988).

“The fourth skyscraper age reflects a personal appropriation of eclectically derived historical forms and symbols as well as a return to neo-traditional urban planning principles (Huxtable, 1984). Architects and architectural firms are currently designing multifunctional tall buildings that derive their formal and stylistic vocabularies from the classic skyscrapers of the twenties and thirties. Asymmetrical or stepped towers loom over low-rise and mid-rise volumes and are designed to integrate with the urban context” (Ali, 1995).

***Factors influencing the development of the tall building type, structural and operational systems:***

Among the technological innovations that made tall buildings possible were the development of new structural systems, elevators, fire safety and environmental control systems.

***Tall building structural system:***

The development of tall buildings was made possible by the invention of new structural systems. A major breakthrough was the freestanding, load-bearing iron skeleton, which was later replaced by an even stronger steel frame. The self supporting iron frame which was originally invented in England in the first half of the nineteenth century was further developed in France in 1850, by French engineer Gustav Eiffel. The ground breaking invention of a riveted iron construction developed by Gustav Eiffel reached the United States in 1885 with his design for the internal support structure for the statue of liberty. His plans for a 984-foot tower for 1889 World exhibition in Paris was a direct challenge to the American engineers. The architect Leroy S. Buffington from Minneapolis had patented a skeleton construction, called the cloud creeper, by 1888. This structural system could accommodate up to twenty eight floors (Lepik, 2008).

Since the beginning of the second half of the twentieth century there have been many advances in structural systems for high-rise buildings. These innovations allowed ever taller buildings.

A major development was in the field of economy of structure and one of the major contributors to this development was F.R. Khan of Skidmore, Owens and Merrill (SOM). Lepik mentions, “In the late 1950’s it was realized that a structure placed at the perimeter of the building was an efficient means of resisting lateral loads.

That realization was based on a simple mathematical model of the efficiency of the hollow tube. A framed tube was a logical and practical solution for building construction. The tube action could be created by closely spaced columns, typically in the range of 3 to 4.5m (10 to 15ft), in conjunction with deep spandrel beams, creating a hollow tube perforated for window openings. The first well documented use of this system was by F.R. Khan in 1963 in the reinforced concrete 43-story DeWitt Chestnut Apartment tower, located in Chicago. During this time this system was very popular and was used in many buildings in Chicago, New York, and other cities. The most notable buildings are the John Hancock Centre and Sears Tower in Chicago and the Twin towers of the 110-story World trade center in New York. Another good example is Amoco Building in Chicago. The tube system is still in frequent use today” (Lepik, 2008).

### ***Elevators:***

Another important development was in the field of elevators as it was impossible to find tenants for offices and apartments above the fourth and fifth floor because of the tedious climb up. The invention of elevators was the second factor underpinning the establishment of the skyscraper. Mechanical elevators as such had been known long before the nineteenth century, but safety was an issue. In 1853 Elisa Graves Otis presented a passenger elevator which

guaranteed not to plunge suddenly downwards. After that it becomes possible for people to travel upwards in safety and comfort. The first passenger elevator was built into a five story New York office building in 1857. However the hydraulic system used to power these elevators-still being used in offices for a long time, those could only achieve very slow speeds. In 1880 Warner Von Siemens in Germany developed the first electrically powered elevator. First electric elevator system was installed in an office block in New York in 1889. Improvement of technology soon opened the way to ever faster vertical conquest (Lepik, 2008).

### ***Tall building and fire safety:***

Fire safety is another important criterion for the development of high-rise buildings. Although firefighting has a long history but the development in this field since nineteenth century contributed considerably in the development of tall buildings. Fire safety in high-rise buildings has become so important that the very terminology ‘high-rise’ depends on the firefighting ability of the regional firefighting department.

In contemporary tall buildings fire safety measures are usually integrated within the building systems. There are several fire protection systems applied in contemporary tall buildings as an example water supply systems: a) Fire pumps, b) Fire department connections, c) Sprinkler systems, d) Fire sand-pipe systems, e) Fire extinguisher, f) Halon fire suppression system. Other than that there are Smoke management systems which is done by Stair and vestibule pressurization and Fire detection system. There are three categories of fire detection system a) Heat detectors, b) Smoke detectors and c) Manual fire alarm system

### ***Environmental control systems in high-rise:***

High-rise buildings usually accommodate large number of inhabitants. So it becomes more important for high-rise buildings to maintain a physiological comfort level for the indoor

environment. Without complete air conditioning a limited control can be achieved in a high-rise. It is relatively easier to heat a building interior than cooling. Although cooling a building interior without air-conditioning is possible, it is limited. Moreover it becomes even more difficult in the case of high-rise internally loaded buildings in hot humid climates. In such cases mechanical air conditioning becomes imperative to maintain a certain comfort level.

The basic objective of environmental control in a building is to create an environment that is comfortable for the occupants. Although in most cases the objective goes beyond meeting the physiological necessity of the occupants and includes meeting a greater expectation of rich environmental experience. Moreover, in tall buildings, the objective is further expanded to include the creation of an environment that is most conducive to optimum productivity of the occupants for the intended function.

#### ***Subsystems of Tall Building Environmental Systems:***

Building environmental systems can range from a very simple heating and cooling systems for a small residential building to a very complex fully automated all-air HVAC system for large buildings. In a tall building, for the sake of better environmental control, it is desirable to isolate the indoor environment completely from the outdoor environment. To accomplish its purpose, an HVAC system consists of four subsystems: the heating subsystem; the refrigeration subsystem; the air-conditioning and distribution subsystem; and the regulatory subsystem.

The heating and refrigeration subsystems are used to add and remove heat to and from the system, thus controlling the quality of the thermal environment. The air-conditioning subsystem conditions the air, both thermally and chemically, and the distribution subsystem does the job of distribution and circulation of the conditioned air throughout the building.



Conditioning includes heating, cooling, humidification, dehumidification, replenishment of oxygen and removal of carbon dioxide and other pollutants. All of these are functions done by the air-handling unit.

On one side the system requires continuous monitoring of the environmental state, as well as various operational characteristics of the functional subsystems, and, on the other side, activation of appropriate operational measures that can steer the entire system's performance toward the creation of the optimum environmental state. This is done by the regulatory subsystem.

### ***Heating Subsystem:***

In a large building with a centralized HVAC system the heating subsystem usually has three additional subsystems of its own heating plant, air heating system, and perimeter heating system. However, under certain conditions, despite high energy costs of the electricity itself, the use of decentralized electric heating with heating strips can be far more attractive than the use of a conventional gas or oil-fired centralized hot water heating system. This alternative can provide the benefits of savings in construction and maintenance costs that will result from the elimination of the central heating unit along with the smokestack and the entire hydronic system for perimeter heating. Tall buildings usually fit into this situation. "Because of the preferred depth of 12 to 15 m (40 to 50 ft) for lease on both sides of the building core, as well as for structural reasons, tall buildings tend to be fairly deep, that is, about 34 to 40 m (110 to 130 ft) along the narrow dimension of the plan. This, coupled with their height, makes tall buildings 'core-dominated' or 'cooling-load driven,' with relatively low heating requirements. Furthermore, every square meter literally counts in tall buildings, and the elimination of

hydronic perimeter heating, particularly the baseboard type, will increase the amount of leasable floor areas substantially” (Ali, 1995).

***Refrigeration Subsystem:***

The most widely used refrigeration system in tall buildings is the centrifugal refrigeration machines which operate on a compressive refrigeration cycle. The centrifugal refrigeration machine consists of evaporator and condenser. The condenser can be either water-cooled or air-cooled. Chilled water generated in the evaporator is distributed to various air handling units. The used chilled water is brought back to the chiller. The heat is transferred to the evaporating refrigerant and again chills the used water. Although the cooling load depends on the size and the specifics of the building, “in the absence of any specifics, one may assume about 1kw of cooling load for approximately 8 to 12 m<sup>2</sup> gross” (Ali, 1995).

***Air-conditioning and distribution subsystem:***

The air-conditioning and distribution subsystem has two primary parts, the air handling unit and the duct system. The heart of the air-conditioning and distribution subsystem is the ‘air handling unit’. The air handling unit is the machine which conditions the indoor air thermally and chemically and blows the conditioned air through the ducts. The air handling unit cools or heats the air adds required oxygen and removes the carbon-dioxide. This subsystem requires a significant amount of space, and in the case of high-rise buildings, often an entire service floor is provided for the purpose.

***Regulatory subsystem:***

The spatial and temporal variation of air-conditioning load over time across the same space is taken care of by the air handling unit. But a subsystem is employed to support the job.

Two generically different strategies are there to deal with this kind of variation, either by varying the temperature or by varying the amount of the air that is supplied to different spaces. Various alternative systems developed from these two generic strategies, namely terminal reheat system, VAV system, double duct system, dual conduit system and multi-zone system (Ali, 1995).

***Energy consumption and Ecological impact of H.V.A.C system:***

In contemporary global scenario the conventional building cooling systems are major contributors to the building sector energy end use and green house gas emission. In United States the building sector contributes to the 48 percent of the total energy consumption and 76 percent to the total electricity consumption (The Building Sector:A Hidden Culprit, 2008-2009). One third of the energy used in the building sector in the United States is used by the HVAC system (Residential & Commercial Overview, 2008). The energy requirement for the space cooling is even more in hot-humid countries. As an example, 29 percent of the total electricity of Hong Kong is consumed by space conditioning (Department, 2008). In this scenario the impact of air conditioner usage is an important problem for peak electricity demand, forcing utilities to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning. The refrigerants, as an example Chlorofluorocarbons (CFC) used in conventional HVAC systems, are the prime contributors to the ozone layer depletion. In this scenario an alternative passive cooling system is in demand. Development of an efficient passive cooling system can contribute significantly in the development of a sustainable global environment.

In this context it is important to look into the other possible alternatives to the conventional cooling systems.

### ***High-rise buildings and Sustainability issues:***

By virtue of their enormous size, high-rise buildings or skyscrapers consume energy and other natural resources at a prodigious rate and produce a huge amount of waste but in terms of sustainability there are both advantages and disadvantages to high-rise buildings. In an article on ‘Multi-Unit Residential Buildings Energy and Peak Demand Study’ Paul Myors discussed about the relatively higher energy demand in high-rise multi unit residential apartments (Myors, 2005). Ken Yeang argued that with the normative practice of mechanical and electrical operational systems, “the skyscraper is not an ecological building type. In fact it is one of the most un-ecological of all building types. The tall building over and above other building typologies uses a third more energy and material resources to build, to operate and eventually to demolish” (Yeang K. , 1999). To reduce the surface area and to have a preferred leasable depth of 12 to 15 meters usually skyscrapers are designed as deep buildings, thereby reducing the opportunity of daylight use. As the wind speed increases considerably with the increasing height it is difficult to naturally ventilate these buildings and thus these buildings mostly depend on mechanical ventilation systems. These mechanical ventilation and electrical illumination demands high amount of electricity consumption and thus increases the overall resource consumption in high-rise buildings. But the argument that skyscrapers are un-sustainable just because those need more natural resources and produce more waste often misses the entire lifecycle analysis of a building and the larger web of interrelated human and environmental systems. Ken Yeang mentioned that “it is the case of skyscraper in particular that the eventual recovery of the building’s materials and components at the end of its life is most significant simply because of its scale” (Yeang K. , 1999). So for high-rise buildings the most important aspects are; 1) efficient use of resources, 2) design of resource recovery system and 3) use of renewable resources. Moreover high-rise

buildings play a crucial role in developing urban density which can help to reduce the urban sprawl, use less land area and consequently reduce the use of vehicular transportation. It is quite evident if we compare the density pattern of New York city to the San Francisco bay area. The total urban footprint of San Francisco bay area is almost double to the urban footprint of New York city, although the later has more than double population to the earlier (Bosselmann, 2008).

The advantages of high-rise buildings are several, as an example;

1. These have smaller foot print and higher density
2. They reduce vehicular transportation (if located close to city centre)
3. They help to reduce urban sprawl.
4. They can use alternative power generation as because their height allows them to integrate wind turbines to catch steady flow of high wind at upper level.
5. They can be adaptable for high-rise food production as because these buildings have large surface area with small footprint so these buildings can increase more effective cultivation.

Although there are some ecological and sustainability concerns associated with tall buildings, the present trend of urban population growth makes it evident that the high-rise building type will flourish in the future and until we have an economically viable alternative this building type will continue to be build prolifically. So in this context green designers should develop design strategies which can help to mitigate the negative environmental impacts of skyscrapers. In this context leading architects, such as Ken Yeang, Norman Foster etcetera are working for the development of new sustainable high-rise buildings. Already there are few examples of such developments as an example commerzbank in Berlin by Sir Norman Foster and Menara mesiniaga in Malaysia by Ken Yeang (Ali, 1995).

## **CHAPTER 3 - Understanding Sustainable Architecture**

Sustainable Architecture is a frequently used phrase in contemporary architectural discourse. There are several issues related to sustainable architecture and ecologically considered operational system design is one of that. For the development of Sustainable Architecture since late twentieth century several organizations developed across the globe. These organizations structured several guidelines for sustainable architecture.

This chapter focuses on the analysis of three such guidelines LEED, Ten shades of green, and Teri GRIHA to understand the primary issues in this topic on which these guidelines gave major stress.

### **The Crisis:**

Presently there are number of global problems faced by humanity, from increasing global population to rapid destruction of global finite resources. As estimated by United Nations Population Division the global population is increasing almost at a rate of one billion per twelve years. It reached six billion mark in the year 2000, will cross seven billion mark by 2013 and eight billion mark by 2028. Whereas it took 1800 years to reach first billion from .3 billion, which was at the beginning of Christian era (United Nations Population Division, 1999). The depletion of global natural resources is even more rapid; “over the last 50 years the world’s population has increased by 50 percent; but our resource utilization has increased by 1000 percent for the same period” (Chapman, 2005). According to statistics presented by David Orr in Ecological Literacy (1992) on each average day we are adding fifteen million tons of carbon to the atmosphere, destroying 115 square miles of tropical rainforest, creating seventy two square miles of desert, eliminating forty to hundred species, eroding seventy one million tons of top soil

adding twenty seven hundred tons of CFCs (Chlorofluorocarbons) to atmosphere and increasing the population by 263,000 (Orr, 1992). At this rate we have almost consumed all of our finite natural resources within only two hundred years. Most of the specialists predicted Year 2010 as the time of global oil peak, which means since then there will be constant decrease in oil production although the demand is increasing to maintain the pace of development and population growth. In this context our present development appears to be a cancerous growth rather than a healthy body development. We almost reached a point of no return.

If we look at these issues holistically instead of a part at a time then it will appear to be a total cultural crisis, with the understanding that it is a ‘turning point’, as discussed by Fritjof Capra: “To understand our multifaceted cultural crisis we need to adopt an extremely broad view and see our situation in the context of human cultural evolution. We have to shift our perspective from the end of the twentieth century to a time span encompassing thousands of years; from the notion of static social structure to the perception of dynamic patterns of change. Seen from this perspective, crisis appears as an aspect of transformation. The Chinese, who have always had a thoroughly dynamic world view and a keen sense of history, seem to have been well aware of this profound connection between crisis and change. The term they use for crisis—*wei-ji*—is composed of the character of ‘danger’ and ‘opportunity’” (Capra, 1983).

Since the development of Cartesian mechanistic philosophy a reductionist worldview evolved, which approached every system as a linear process and viewed the universe as a machine whose working principles can be completely understood by the Cartesian-Newtonian theories and thus can be controlled. This mechanistic world view inspires us to control nature & solve problems by developing new technologies. What we failed to realize is that infinite growth is not possible in a finite world. Rapid industrialization based on fossil fuel actually reshaped the

face of earth. Industrialization developed rich industrialized countries but led the rest of the world to an even worse condition. The developed countries, which have only 20 percent share of global population consumes 80 percent of the global natural resources & produces huge wastes. The United States itself consumes 30 percent of the global natural resources with only 5 percent share of global population. Building industry is contributing a major share in this mammoth consumption & production of huge waste (Leonard, Fact Sheet, n.d.). With the trend of urban population growth the issue regarding the intensely used building type like skyscraper has become even more serious.

### ***The Context:***

Wednesday, May 23, 2007, represents a major demographic shift. According to researchers from North Carolina State University and the University of Georgia, for the first time in human history, the earth's population will be more urban than rural. In this context it has become more important for green designers to pay high attention to the sustainable development of high-density urban buildings such as skyscrapers because it is evident that until we have an economically viable alternative this building type will continue to be built prolifically to accommodate this increasing urban population.

The problem is that the conventional skyscraper, with normative practice of mechanical and electrical operational system, is not an ecological building type. In fact, it is considered to be one of the most un-ecological of all building types. Skyscrapers use a third more energy and material resources to build, to operate and eventually to demolish over and above other building typologies (Yeang K. , 2002). Almost sixty percent of this energy and resource is consumed by the maintenance and operational systems (Yeang K. , 1999). This shows that in case of skyscrapers the most important issue is ecological consideration in design of resource recovery



systems and use of renewable resource generation. This argument is supported in the following section by the analysis of three sustainable design guidelines which shows a major stress on resource recycling and renewable resource generation.

### ***Sustainable Design Guidelines***

To address the issue of sustainable architectural development, in many nations a number of organizations have been formed; as an example United States Green Building Council (USGBC) in U.S.A., the Building Research Establishment (BRE) in U.K and The Energy Research Institute (TERI) in India. These organizations have developed different green design rating systems like LEED, BREEAM, and GRIHA respectively. Besides that there were major discussions and suggestions of alternative guideline systems; one such example is 'Ten Shades of Green' by Peter Buchanan. Though not a sustainable design rating system itself; 'Ten Shades of Green' by Peter Buchanan is a major discussion of sustainable design guidelines.

The rating systems attempted to set certain guidelines for sustainable architecture. Judgment of sustainability on the basis of a few set guidelines is a questionable approach. Susan Maxman suggested: "sustainable architecture isn't a prescription. It's an approach, an attitude. It shouldn't really even have a label. It should just be *architecture*" (Guy, 2001). This same argument has been reflected in the articles 'Ten Shades of Green' by Peter Buchanan and 'Reinterpreting Sustainable Architecture: The Place of Technology' by Simon Guy and Graham Farmer. In the 'Ten Shades of Green', Peter Buchanan argues "There can be no single route to sustainability. Just as in nature, biodiversity ensures the vitality and adaptability to cope with change and disruptive incidents, so sustainability cannot be achieved by the homogenizing and universalizing tendencies of the waning industrial era" (Buchanan, 2005).

Sustainable architecture is not a product but a process which is developed by interaction between built form and the ambient forces that impinge upon its surface. The definition of “Sustainable Development” produced by the Brundtland report states; “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). This definition contains within it the key concept of need; the need for ecological, economic, social and physiological well-being for today and tomorrow. In the Brundtland Commission report these four needs was discussed in three sections namely: 1. common concern; 2. common challenge; and 3. common endeavors. Moreover the human need for physiological, economic and social wellbeing was also discussed by A. H. Maslow in the paper ‘A theory of human motivation’. Maslow arranged human needs in a hierarchical form where he mentioned the physiological needs, the safety needs and the love needs as basic needs which must be fulfilled for human self actualization. In the paper the author explains the safety need as the need for economic and social stability and the love need as the need for a social relationship and its stability (Maslow, 1946). The Brundtland commission report clearly discusses the fact that for economic and social stability ecological wellbeing is important and without that a sustainable development is not possible. To achieve the goal an integrated systemic approach rather than a Cartesian reductionist approach is necessary, which keeps all four of the needs as priorities and this systemic approach needs to be reflected in any sustainable design guidelines.

Although the sustainable guidelines try to incorporate all relevant issues and give required priority to all the needs, there is an obvious hierarchy of emphasis according to priorities in the present context. An analysis of these well researched guidelines and rating

systems can show the hierarchy and help to understand most important issues that need major consideration for the development of sustainable architecture.

### *Description and Analysis of sustainable guidelines*

#### *Ten Shades of Green:*

In the article “Ten Shades of Green” Peter Buchanan argued that “green design, though not dauntingly difficult, cannot be achieved by any simplistic or formulaic approach: no single approach is likely to be adequate, let alone appropriate or even applicable, to all situations instead it must attend to a whole range of matters from the technical and ecological, to the economic and social, including even the cultural and spiritual” (Buchanan, 2005). To explain the broad span of the issue and its exact character, in this book Buchanan discusses ten “shades” or aspects, of green. The ten “shades” are; 1) Low energy / high performance; 2) Renewable resources; 3) Recycling; 4) Embodied energy; 5) Long life, loose fit; 6) Total lifecycle costing; 7) Embedded in place; 8) Access and urban context; 9) Health and happiness; 10) Community and connection.

A sustainable system doesn’t work in a linear pattern, rather it works on the basis of the feedback principle developed by the interaction among its environmental, economic, social and physiological needs. Thus a sustainable system demands flexibility as well as an integral approach to different needs. Table 3.1 shows a matrix which evaluates the priority focus of needs in different shades. For a visual reference in this matrix green represents ecological need, blue represents economic need, yellow represents social need and red represents physiological need.

**Table 3.1 The Matrix- Ten Shades of Green**

Shade	Inherent Priority	Contextual Priority	Intentional Priority	Flexibility	Integrity
1. low energy / high performance	ecological	physiological	economic	Will add flexibility to design	Integrate three needs
2. renewable resources	ecological	physiological	economic	Will add flexibility to design	Integrate two needs
3. recycling	ecological	physiological	economic	Will add flexibility to design	Integrate three needs
4. embodied energy	ecological	social	economic	Will add flexibility to design	Integrate three needs
5. long life, loose fit	economic	ecological	social	Will add flexibility to design	Integrate three needs
6. total lifecycle costing	economic	ecological		Will add flexibility to design	Integrate two needs
7. embedded in place	social	economic	ecological	Will add flexibility to design	Integrate three needs
8. access and urban context	ecological	social	economic	Will add flexibility to design	Integrate three needs
9. health and happiness	physiological	ecological		Will add flexibility to design	Integrate two needs
10. community and connection	social	ecological	economic	Will add flexibility to design	Integrate three needs

**Figure 3.1 Emphasis on different needs in Ten Shades of Green**



This matrix analysis shows that although the ten shades fairly integrate different needs in its priority but compared to social & psychological wellbeing it gives more stress on the environmental & economic wellbeing.

**LEED:**



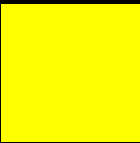








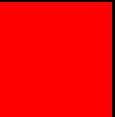


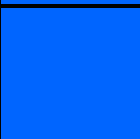













The LEED rating system was first developed by the United States Green building Council (USGBC) in 1998. The first pilot project referred to as LEED Version 1.0, was launched at the USGBC Membership Summit in August 1998. The LEED Version 1.0 was followed by LEED Version 2.0 in 2000, LEED Version 2.1 in 2002, LEED Version 2.2 in 2005 and LEED Version 3.0 in 2009. It is a third party certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED serves as a tool for buildings of all types and sizes. “LEED certification offers third party validation of a project’s green features and verifies that the building is operating exactly the way it was designed to” (USGBC, Project Certification) Now this system has become internationally recognized and is flexible enough to apply to all building types.

The latest version of LEED NC (new construction) rating system published in April 27, 2009 has seven primary sections 1. Sustainable Sites, 2. Water Efficiency, 3. Energy and Atmosphere, 4. Materials and Resources, 5. Indoor Environmental Quality, 6. Innovation in Design, 7. Regional Priority. The rating system aims to improve occupant well-being, environmental performance and economic returns of buildings using established and innovative practices, standards and technologies.

LEED NC-V3 rating system has total 110 points. Which is distributed in seven different categories; Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design and Regional Priority. Table 3.2 shows a matrix which evaluates the priority focus of needs in different categories and emphasis distribution of points. For a visual reference in this matrix green represents ecological need, blue represents economic need, yellow represents social need and red represents physiological need.

This matrix analysis of LEED shows that similar to the ten shades of green, it also gives more emphasis on the environmental and economic wellbeing compared to social and psychological wellbeing.

**Table 3.2 The Matrix- LEED**

No.	LEED Categories	Number of Prerequisites	Number of Credits	Emphasis Maximum possible Points	Inherent Priority	Contextual Priority	Intentional Priority
1.	Sustainable Sites	1	15	26 			
2.	Water Efficiency	1	4	10 			
3.	Energy and Atmosphere	3	9	35 			
4.	Materials and Resources	1	9	14 			
5.	Indoor Environmental Quality	2	17	15 			
6.	Innovation and Design Process	-	2	6 			
7.	Regional Priority	-	1	4 			

**Figure 3.2 Emphasis on different needs in LEED**



## **GRIHA:**

GRIHA is a rating system initially developed by TERI (The Energy & Resource Institute) as TERI-GRIHA which has been modified to GRIHA as National Rating System after incorporating various modifications suggested by a group of architects and experts. “It takes into account the provisions of the National Building Code 2005, the Energy Conservation Building Code 2007 announced by BEE and other IS codes, local bye-laws, other local standards and laws” (TERI). The development of GRIHA is a reaction to the movement of the LEED system. The US based LEED rating system has more on energy efficiency measures in air conditioned buildings. The GRIHA rating system was developed keeping in view of the Indian agro-climatic conditions and in particular the preponderance of non-air-conditioned buildings (TERI). The system focuses on site planning, building envelope design, building system design (heating ventilation and air conditioning, lighting, electrical, and water heating), and integration of renewable energy sources to generate energy onsite, water and waste management, selection of ecologically sustainable materials (with high recycled content, rapidly renewable resources with low emission potential, etc.), Indoor environmental quality (maintain indoor thermal and visual comfort, and air quality). The major aim of GRIHA is to achieve;

- Reduced energy consumption without sacrificing the comfort levels
- Reduced destruction of natural areas, habitats, and biodiversity, and reduced soil loss from erosion, etc.
- Reduced air and water pollution (with direct health benefits)
- Reduced water consumption
- Limited waste generation due to recycling and reuse
- Reduced pollution loads



- Increased user productivity
- Enhanced image and marketability

The GRIHA rating system has 34 different categories with total of 104 possible points but the basic points very similar to the LEED system. The categories are structured under four major sections and their subsections depending upon project stages. The criteria have been categorized as follows:

1. Site planning

Conservation and efficient utilization of resources

Health and well being

2. Building planning and construction stage

*Water*

*Energy: end use*

*Energy: embodied and construction*

*Energy: renewable*

Recycle, recharge, and reuse of water























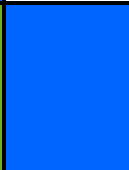










Waste management







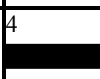



























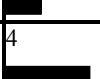















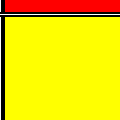
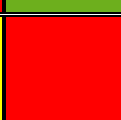












3. Building operation and maintenance

4. Innovation

In Table 3.3 The GRIHA building rating system has been analyzed to find out the stress distribution on different points and the needs of sustainability. For a visual reference in this matrix green represents ecological need, blue represents economic need, yellow represents social need and red represents physiological need.

**Table 3.3 Matrix- GRIHA (TERI)**

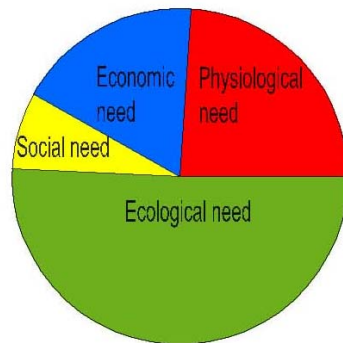
No.	GRIHA Categories	Remarks	Emphasis: Maximum possible Points	Inherent Priority	Contextual Priority	Intentional Priority
1.	Site Selection	Partly mandatory	1 			
2.	Preserve and protect the landscape during construction/compensatory depository forestation	Partly mandatory	5 			
3.	Soil conservation		4 			
4.	Design to include existing site features	Mandatory	2 			
5.	Reduce hard paving on-site and /or provide shaded hard - paved surfaces	Partly mandatory	2 			
6.	Enhance outdoor lighting system efficiency		3 			
7.	Plan utilities efficiently and optimize on-site circulation efficiency		3 			
8.	Provide at least, the minimum level of sanitation/safety facilities for construction workers	Mandatory	2 			
9.	Reduce air pollution during construction	Mandatory	2 			
10.	Reduce landscape water requirement.		3 			
11.	Reduce building water use		2 			
12.	Efficient water use during construction		1 			
13.	Optimize building design to reduce the conventional energy demand	Mandatory	6 			

14.	Optimize the energy performance of the building within specified comfort limits		12				
15.	Utilization of fly ash in the building structure		6				
16.	Reduce volume, weight, and time of construction by adopting an efficient technology		4				
17.	Use low-energy material in the interiors		4				
18.	Renewable energy utilization	Partly mandatory	5				
19.	Renewable energy - based hot- water system		3				
20.	Wastewater treatment		2				
21.	Water recycle and reuse		5				
22.	Reduction in waste during construction		2				
23.	Efficient waste segregation		2				
24.	Storage and disposal of waste		2				
25.	Resource recovery from waste		2				
26.	Use of low-VOC (volatile organic compounds) paints/ adhesives / sealants		4				
27.	Minimize ozone – depleting substances	Mandatory	3				
28.	Ensure water quality	Mandatory	2				
29.	Acceptable outdoor and indoor noise levels		2				
30.	Tobacco and smoke control		1				
31.	Provide the minimum level of accessibility for persons with disabilities		1				
32.	Energy audit and validation	Mandatory					
33.	Building operation and maintenance	Mandatory	2				
34.	Innovation		4				

This matrix analysis of GRIHA shows a clear major emphasis on the environmental and economic wellbeing compared to social and psychological wellbeing.

The analysis of ‘Ten Shades of Green’, ‘LEED’ and ‘GRIHA’ shows a fair amount of bias toward the environmental, physiological and economic wellbeing embedded in them. Moreover The LEED and GRIHA rating systems give priority to energy issues, preservation of site, water conservation and indoor environmental quality.

**Figure 3.3 Emphasis on different needs in GRIHA**



### *Discussion*

The analysis of the LEED and GRIHA rating systems show a strong emphasis on resource recycling and renewable resource use. LEED NC-V3 rating system has total 110 points. These 110 points are distributed in seven different categories; Sustainable Sites (26 Possible Points), Water Efficiency (10 Possible Points), Energy and Atmosphere (35 Possible Points), Materials and Resources (14 Possible Points), Indoor Environmental Quality (15 Possible Points), Innovation in Design (6 Possible Points) and Regional Priority (4 Possible Points). Out of all these categories Water Efficiency, Materials and Resources and Energy and Atmosphere deal with resource recycling and renewable resource generation. Besides that some credits of Sustainable Site category like Development Density and Community Connectivity(5 Possible

Points), Brownfield Redevelopment(1 Possible Points), Alternative Transportation—Public Transportation Access (6 Possible Points), Alternative Transportation—Bicycle Storage and Changing Rooms(1 Possible Points), Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles(3 Possible Points), Alternative Transportation—Parking Capacity(2 Possible Points), Site Development—Protect or Restore Habitat(1 Possible Points) give stress on resource recycling and renewable resource use. Calculation shows that out of total 110 points 78 points (71 percent) depends on the issues related to resource recycling and renewable resource generation. Looking into further detail of LEED NC V3 it shows that issues of water efficiency and energy carries 45 points (41 percent).

The GRIHA rating system doesn't have any specific focus towards high-rise buildings in Indian context. So it cannot be said that this rating system is more relevant to Indian high-rise buildings but it is relevant here to discuss this rating system because it is developed in India keeping the overall Indian context in mind. In GRIHA rating system there is total 104 possible points which are distributed in 34 guidelines. Out of this total 104 points 67 points (64.4 percent) are associated with credits like: preserve and protect the landscape during construction /compensatory depository forestation; reduce landscape water requirement; reduce building water use; efficient water use during construction; optimize building design to reduce the conventional energy demand; optimize the energy performance of the building within specified comfort limits; utilization of fly ash in the building structure; use low-energy material in the interiors; renewable energy utilization; renewable energy-based hot-water system; wastewater treatment; water recycle and reuse; efficient waste segregation; storage and disposal of waste; resource recovery from waste; minimize ozone-depleting substances; energy audit and validation; building operation and maintenance address to resource recycling and renewable

resource generation. This shows a major emphasis on the issues of efficient resource use, resource recycling and renewable resource generation in this rating system.

In Ten Shades of Green 6 out of 10 shades namely; Low energy / high performance, Renewable resources, Recycling, Embodied energy, Long life, loose fit, Total lifecycle costing addresses the issues of resource recycling and renewable resource generation. This also shows a clear emphasis on efficient resource use, resource recycling and renewable resource generation

**Figure 3.4 Distribution of points in LEED, GRIHA and Ten Shades of Green**



in this discussion.

Analysis of LEED, GRIHA and Ten Shades of Green shows a clear emphasis on ecological and economic wellbeing. Moreover the point distribution in LEED and GRIHA shows a clear emphasis on resource recycling, efficient use of resources and renewable resource generation. Resource recycling and efficient use of resources are addressed particularly in issues of alternative cooling systems, water efficiency and waste recycling. Renewable resource generation is addressed in issues of water efficiency and renewable power generation. This analysis clearly shows a major emphasis on water efficiency, alternative cooling systems and renewable power generation among building operational systems. Although this is a general analysis which gives an overall guidance to all types of architecture but these issues are

particularly important in High-rise buildings. Ken Yeang argues that “it is in the case of skyscrapers in particular that the eventual recovery of the buildings materials and components at the end of their life is most significant simply because of its scale” (Yeang, 1999). It is more important for the design of operational systems in high-rise buildings to consider the possible renewable resources and the resource recovery in four major aspects: 1) Alternative HVAC system; 2) alternative power generation; 3) Water efficiency; and 4) food production in high-rise building.

***Alternative HVAC system:***

Development of an alternative HVAC system is important due to two major reasons. First in an intensively used building HVAC systems consume a major share of energy (refer Figure 4.1) and secondly conventional CFC (Chlorofluorocarbon) or HCFC (Hydro chlorofluorocarbons) based cooling systems has a major ecological impact of Ozone depletion and green house effect. LEED NC reference guide 2.2 shows that the available refrigerants like CFC, HCFC and HFC (Hydro fluorocarbons) have either high ozone depletion potential (refer Table 3.4) or global warming potential or both (USGBC, LEED NCV2.2 reference guide, 2005).

Moreover conventional HVAC systems consume almost one third of the energy used by the operational systems in a building (Residential & Commercial Overview, 2008). Obviously this high energy consumption and environmental damage goes against to the major emphasis of ecological and economic wellbeing in sustainable architecture guidelines. Thus both LEED and TERI rating systems gave major stress on issue of HVAC systems. To understand the possible development of alternative HVAC systems next chapter will look into details of contemporary research and development in this issue.

**Table 3.4 Ozone depletion and Global warming potential of different refrigerants (USGBC, LEED NCV2.2 reference guide, 2005)**

Refrigerant	Ozone depletion potential	Global warming potential	Common Building Application
Chlorofluorocarbons			
CFC-11	1.0	4,680	Centrifugal chillers
CFC-12	1.0	10,720	Refrigerator, Chillers
CFC-114	0.605	9,800	Centrifugal chillers
CFC-500	0.221	7,900	Centrifugal chillers, humidifiers
CFC-502		4,600	Low temperature refrigeration
Hydro chlorofluorocarbons			
HCFC-22	0.04	1,780	Air conditioning, chillers
HCFC-123	0.02	76	CFC-11 replacement
Hydro fluorocarbons			
HFC-23	~ 0	12,240	Ultra- Low temperature refrigeration
HFC-134a	~ 0	1,320	CFC-12 or HCFC-22 replacement
HFC-245fa	~ 0	1,020	Insulation agent, centrifugal chillers
HFC-404A	~ 0	3,900	Low temperature refrigeration
HFC-407C	~ 0	1,700	HCFC-22 replacement
HFC-410A	~ 0	1,890	Air conditioning
HFC-507A	~ 0	3,900	Low temperature refrigeration
Natural refrigerant			
Carbon Dioxide (CO <sub>2</sub> )	0	1.0	
Ammonia (NH <sub>3</sub> )	0	0	
Propane	0	0	



### **Renewable power generation:**

Both LEED and TERI rating systems gave maximum stress on energy efficiency and onsite renewable power generation issues. The issue of energy is also associated with environmental pollution and global warming. Alternative renewable power generation can make a major contribution in this regard. Since 1970's there has been a major research focus on renewable power generation which developed several systems like solar photovoltaic, wind turbines and solar thermal power generation systems. During the 1980's solar updraft tower was developed as a possible renewable power generation system. A solar updraft tower's three essential elements are solar collector, chimney/tower, and wind turbines. Haaf (1983, 1984) gives test results and a theoretical description of the solar tower prototype in Manzanares, Spain (Schlaich J. , 1995). Due to their enormous height the high-rise buildings have an opportunity of power generation by using solar updraft towers to generate electricity. To understand the possible development of renewable power generation systems next chapter will look into details of contemporary research and development in this issue.

### ***Water efficiency and waste recycling***

A primary principle of any sustainable design approach is to make non-linear closed loop systems where there is no waste and waste is equal to food. In this regard alternative sewage treatment system can not only eliminate the energy demand but also make a building more sustainable by changing the concept of waste. Moreover water is a precious resource and both LEED and TERI rating systems gave major stress on water efficiency and waste recycling issues. To understand the possible development of alternative water efficiency and waste recycling systems next chapter will look into details of contemporary research and development in this topic.

***High-rise food production:***

Although high-rise food production is a recent consideration and has not been addressed in either the LEED or GRIHA rating systems, it can be an added benefit in resource recycling which can also help to redefine the concept of waste and prove that in a closed loop system waste is equal to food. Every high-rise has a huge vertical surface area which can work as a viable area for intensive farming. Moreover such a system can work as a living organism to purify black water and human waste. To understand the possible development of high-rise food production next chapter will look into details of contemporary research and development in this topic.

## **CHAPTER 4 - Alternative Building Operational systems**

The primary objective of this thesis is to present alternative design possibilities for ecologically sensitive high-rise buildings. Analysis of Ten Shades of Green, LEED and GRIHA sustainable architecture guidelines in previous chapter shows an emphasis on wise resource use, including recycling, and on-site generation of renewable resources in the built environment. This chapter focuses on four major issues that have the potential to be incorporated in high-rise building strategies in Kolkata: alternative cooling systems, alternative sewage recycling systems, urban food production, and renewable power generation. It has already been shown that high-rise buildings are an important component of the growth of Kolkata; the incorporation of these operational strategies should, it is anticipated, make the occupation of such buildings more amenable and less impactful on the environment and available resources.

### **Introduction**

Due to their enormous scale, existing skyscrapers need highly refined materials, consume huge amounts of energy and materials, and produce huge amounts of waste and thus inherently unsustainable but we cannot avoid them. High-rise buildings have become regular features in big cities. In this context, it has become even more important for the designers to rethink the design of high-rise buildings to mitigate their negative impacts. To achieve this we need to make a holistic approach and look into the positive aspects of high-rise buildings.

Several specific drawbacks are attributable to high-rise construction, chiefly the amount of materials and energy needed to produce and operate them. Yeang counters this notion: “Such views often fail to look at the entire life cycle of a building and the larger web of interrelated human and environmental systems. In the case of skyscrapers in particular, the eventual recovery of the buildings' materials and components at the end of their life is most significant simply

because of its scale” (Yeang K. , 1999). High-rise buildings have many advantages. For instance, they have smaller footprints and higher density, they can reduce the need for vehicular transportation (if located close to city centre or multimodal transportation lines), and help to reduce urban sprawl. High-rise buildings usually have a large vertical surface area that can be put to use for rainwater collection, wastewater recycling, food production and power generation.

Sustainable design is not a product but a process that is developed by interactions between built form and the ambient forces that impinge upon building surfaces. Considering all these arguments it seems that for sustainability, the future high-rise buildings should be developed keeping a natural tree as a model, which can generate its own energy, recycle its own waste, grow with the resources available on-site and provide shelter.

### ***Research focus for development of a Sustainable High-rise:***

Besides the advantages associated with high-rise buildings there are some inherent disadvantages. One problematic aspect of a high-rise building is its electrically and mechanically controlled operational systems which take major share of its lifecycle resource consumption. Considering all these arguments it seems that for sustainability, development of ecologically considered operational systems in high-rise is very important.

This chapter will focus on understanding the possible alternative development of ecologically considered operational systems like alternative cooling systems, renewable power generation, alternative waste water recycling, and possible high-rise food production.

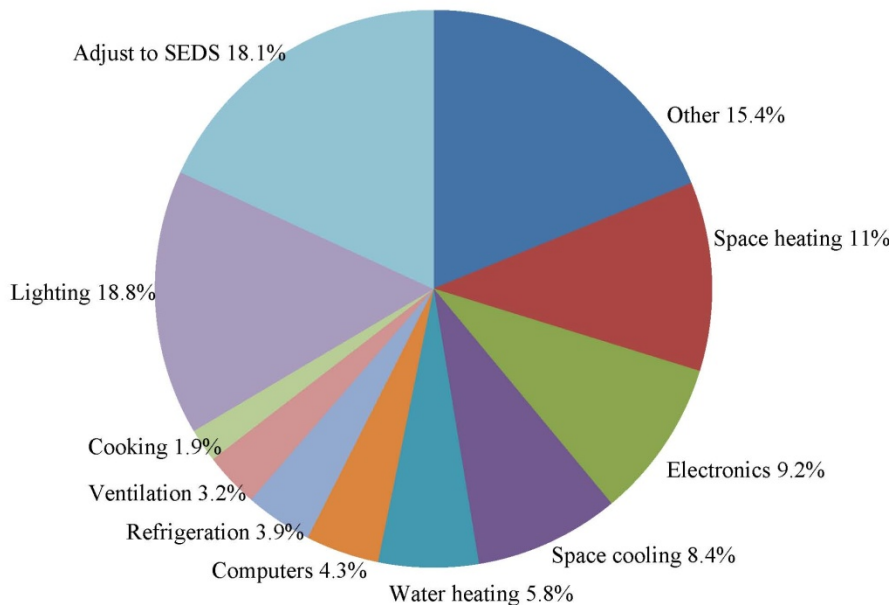
### *Strategies to design a sustainable high-rise building:*

Presently principal threats imposed by continuing unsustainable development are the depletion of non-renewable resources and increasingly negative impacts on the environment. High-rise buildings can be sustainable if they can fulfill its needs while lessening resource use and environmental impact. In the case of high-rise buildings, this includes energy, water, and food.

To reduce demand for water and food supply, it is important to adopt intelligent wastewater recycling and high-rise farming strategies besides the use of water efficient toilet gadgets.

In high-rise buildings energy is primarily used for HVAC and illumination (refer to Figure 4.1) (Buildings and Energy Use, 2003). Beside the use of more efficient systems, intelligent use of daylight and alternative ventilation strategies can reduce the demand.

**Figure 4.1 Energy usage in Office buildings in U.S. 2010 (energy, 2010)**



**Figure 4.2 Comparison of average peak demand for buildings with or without air-conditioning (Myors, 2005)**

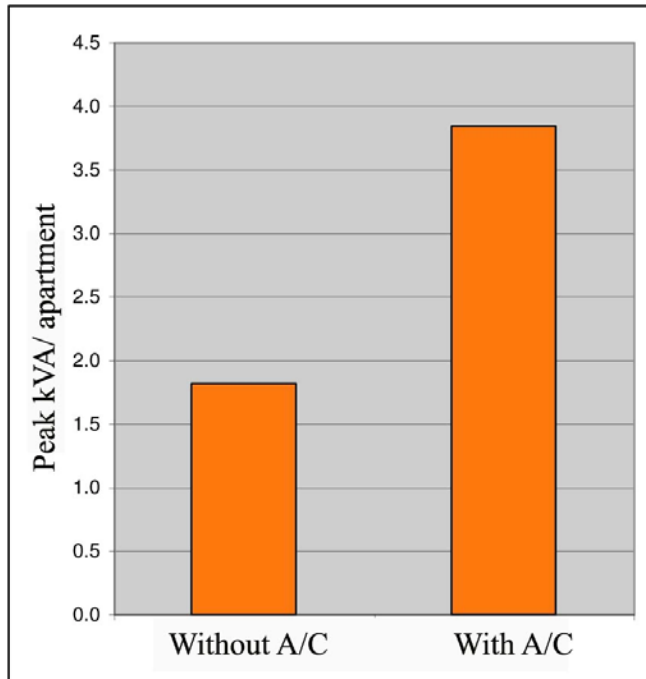


Figure 4.2 shows a study done in Australia, a comparison of average peak demand for buildings with or without air-conditioning (Myors, 2005). The Figure 4.2 shows that the peak demand doubles in case of buildings with air conditioning.

### **Possible alternative HVAC system integration with Sustainable High-rise:**

#### ***The Context:***

In the contemporary global scenario, the building cooling systems are major contributors to the building sector energy end use and greenhouse gas emission. In the United States, the building sector accounts for 48 percent of the total energy consumption and 73 percent to the total electricity consumption (THE BUILDING SECTOR:A Hidden Culprit, 2008-2009). One third of the energy used in the building sector in United States is used by the HVAC system (Residential & Commercial Overview, 2008). In hot-humid countries the energy requirement for the space cooling is even more; as an example in Hog Kong 29percent of the total electricity is

consumed by space conditioning (Department, 2008). In this scenario, the impact of air conditioner usage is an important problem for peak electricity demand (refer Figure 4.2), forcing utilities to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning. The refrigerants used in conventional HVAC systems as an example C.F.C.s, are the prime contributor to the ozone layer depletion. In this scenario, an alternative passive cooling system is in demand. Development of an efficient passive cooling system can thereby contribute significantly in the development of a sustainable global environment.

This chapter firstly aims to present the scenario of available alternative cooling strategies and secondly the possibility of integration of passive cooling techniques in a high-rise building.

### ***Alternative Cooling techniques:***

Alternative cooling strategies are all the strategies available to cool the building interior environment except the conventional mechanical HVAC system, which uses a compressor. Presently available alternative cooling techniques can be divided into two main categories,

1. Passive architectural strategies as an example building orientation, roofing techniques, cross ventilation strategies, solar shading etcetera.
2. Non-architectural alternative cooling techniques as an example absorption and adsorption cooling, geothermal heat pump, desiccant cooling, diffusion cooling etcetera. This chapter aims to focus on three important non-architectural alternative cooling techniques, 1. Absorption and adsorption cooling, 2. Geothermal heat pump and earth tube, 3. Desiccant cooling.

### ***Passive architectural strategies:***

Not all the passive architectural strategies are equally applicable to conventional high-rise buildings. Although building orientation and solar shading can be applied in high-rise buildings,

it is difficult to use natural cross ventilation as the wind velocity goes up with the increasing height. Due to this reason most of the high-rise buildings are mechanically ventilated and have fixed non-operable glazing on envelope. This leads not only to high-energy demand but also raises health issues like sick building syndrome etcetera. Double skin envelope systems are an important solution to this problem. This chapter will focus in the development and applicability of double skin façade system for natural ventilation in high-rise buildings.

***Double skin façade:***

Though the use of double skin façade is not a new idea, recently this system has gained much popularity among architects and presently is in common use. Besides the purpose of providing controlled natural ventilation, double skin facades are also used for acoustic insulation, thermal insulation, daylight control and aesthetic reasons. Double skin facades are complicated systems, and may be utilized for several different reasons. Harris Poirazis discussed several definitions in the literature review on double skin façades for office buildings. Some of those definitions are stated below.

The Sourcebook of the Belgian Building Research Institute [BBRI], (2002), defines a double skin façade as “An active façade ... covering one or several storeys constructed with multiple glazed skins. The skins can be airtight or not. In this kind of façade, the air cavity situated between the skins can be either naturally or mechanically ventilated. The air cavity ventilation strategy may vary. Devices and systems are generally integrated in order to improve the indoor climate with active or passive techniques. Most of the time such systems are managed in semi-automatic way via control systems” (Poirazis, 2004).

Harrison and Boake (2003) define a double skin facade system as “essentially a pair of glass ‘skins’ separated by an air corridor. The main layer of glass is usually insulating. The air



space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes” (Poirazis, 2004).

Arons (2001) has defined the double skin façade to “consist of two distinct planar elements that allows interior or exterior air to move through the system. This is sometimes referred to as a twin skin” (Poirazis, 2004).

The double skin façade (DSF) is not a new idea. A double envelope system was employed as early as 1903, in the Steiff Factory in Giengen, Germany (Poirazis, 2004). The major development of this strategy however began in 1980s. One of the first examples of DSF in north America was in the Occidental Chemical Building, Niagara Falls, 1981, designed by Cannon Associates. The system used in this building was a buffer façade system. A buffer façade in earlier buildings used to be either a corridor space or a brise soleil which used to work as a buffer to cut down the direct solar glare and heat. The double skin façade in the Occidental Chemical Building was built with a cavity which is 1.5 m wide and 9 m high with open louvers at the top and bottom of the cavity. These louvers were shading devices installed in the cavity (Boake, Case Studies, n.d.).

Since then double skin façade systems has been used in many buildings across the globe. To name a few;

- Helicon, Finsbury Pavement, Sheppard Robson, 1996
- Commerzbank, Frankfurt Germany 1997
- RWE AG, Germany, Ingenhoven Overdiek und Partner, 1997
- Telus Building, Vancouver, Busby Associates, 2001

- Caisse de dépôt et placement du Québec (CDPQ) - Montreal, 2002
- ARAG 2000 Tower, Dusseldorf City-Gate 1998
- Business Tower, Nuremberg 2000
- Debis Building, Potsdamer Platz, Berlin 1998
- Swiss Re Headquarters, London

A double skin façade is a complicated system and not all of its possibilities have been explored completely. Based on the experience from the existing buildings and several researches there are some claims of advantages and disadvantages of a double skin façade.

The primary advantage of the Double Skin Façade systems is that they can allow natural ventilation in high-rise buildings. The selection of the type of double skin façade depends on climates, orientations, locations and building types in order to provide fresh air before and during the working hours. A well-designed double skin façade system can reduce the energy consumption by natural ventilation during the occupation stage and improve the comfort of the occupants.

Another important advantage of double skin façades is sound insulation. Reduction of internal noise levels in an office building can be achieved by reducing both the internal noise pollution and the external noise pollution. For sound insulation, a minimum 100 mm has to be proposed by Jager, (2003) (Poirazis, 2004).

Double Skin Façade System may also provide greater thermal insulation due to the outer skin both in winter and in summer. One main advantage of the Double Skin Facades is that it can provide natural nighttime flush ventilation in the hot summer days, which is both burglar proof and protected against the weather. Double Skin Façades can save energy by reducing the load on

mechanical ventilation as well as by better insulation of the envelope. In case of high-rise buildings, Double Skin Facades can serve to reduce the effects of wind pressure.

Beside the several advantages mentioned above there are some disadvantages, mostly related to the cost aspect of this system. Compared to the single skin type of façade, the double skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance. Evidently, the additional skin increases the weight of the construction, which increases the cost. The width of the intermediate cavity of a double skin façade can vary from 20 cm to several meters, which may reduce the rentable floor area. Mostly in high-rise buildings, increased airflow velocity inside the cavity can cause important pressure differences between offices in case of natural ventilation via the cavity.

Considering all the advantages and disadvantages it can be concluded that double skin façades are an intelligent solution for many issues related to high-rise ventilation, daylight control, acoustic control, and enhanced insulation. This system can become more effective if an effective financial return can be realized.

If the double skin façade of a high-rise building is designed properly then it can act as a solar chimney, which can help to enhance ventilation by working as a suction pump. Such systems are already in use in the head office of Building Research Establishment in U.K. and GSW building in Berlin. Moreover, in a research done in University of Nebraska – Lincoln shows that it is possible to use a solar chimney to pump outside air through an underground cooling tube during summer for building cooling. Such a system can reduce the need of a mechanical HVAC system completely by a passive system, which may generate considerable financial return.

### ***Non-architectural alternative cooling techniques:***

Out of the non-architectural alternative cooling systems, absorption and adsorption cooling techniques are very effective. These two cooling systems are useful and energy efficient if solar insolation is used for the required heat source. Besides absorption and adsorption cooling systems this chapter will focus on desiccant cooling, geothermal heat pump and earth tubes. Although some of these alternative cooling systems, like geothermal heat pumps, work well in small-scale projects but in case of large-scale projects, these are mostly used for pre-cooling and dehumidification purpose. However, in combination with solar powered absorption cooling system these systems can completely replace the conventional mechanical cooling systems. Besides energy savings these systems have another advantage; they usually do not use conventional refrigerant and thus can help to reduce pollution. Moreover, in combination with solar chimneys, earth tube cooling systems can develop a completely passive cooling system.

### ***Absorption Cooling:***

The absorption refrigerator is a refrigerator that uses heat as the energy source to drive the cooling system instead of pumps as used in regular compressor refrigerators. Absorption chiller is a popular alternative in places where electricity is unreliable, costly, or unavailable, and where noise from the compressor is problematic. In case of both absorption and compressor refrigerators a refrigerant is used with a very low boiling point. When this refrigerant evaporates, it takes some heat away as the latent heat, providing the cooling effect. The main difference between the two types is the way the refrigerant is changed from gas back into a liquid so that the cycle can repeat. A compressor refrigerator uses an electrically-powered compressor to increase the pressure on the gas, and then condenses the hot high pressure gas back to a liquid by heat exchange with a coolant. An absorption refrigerator changes the gas back into a liquid using

a different method that needs only heat, and has no moving parts. The other difference between the two types is the refrigerant used. Compressor refrigerators typically use an HCFC, while absorption refrigerators typically use ammonia or lithium bromide mixed.

***History:***

The absorption cooling refrigerator developed in the mid nineteenth century by ‘Ferdinand Carré’ of France, when he made a somewhat more complex system compared to earlier vapor compression coolers in 1859. “Unlike earlier vapor-compression machines, which used air as a coolant, Carré’s equipment contained rapidly expanding ammonia. (Ammonia liquefies at a much lower temperature than water and is thus able to absorb more heat.) Carré’s refrigerators were widely used, and vapor-compression refrigeration became, and still is, the most widely used method of cooling. In spite of the successful use of ammonia, that substance had a severe disadvantage: if it leaked, it was unpleasant as well as toxic.” (Refrigeration, n.d.). In the year 1930 Leo Szilard along with Albert Einstein developed one absorption chiller. This design used only pressurized ammonia, butane and water to keep the things cool. Their invention was used in the early refrigerators, but was dropped after the development of more efficient freon compressors (The green optimistic, 2008). Presently some new researches developed new Lithium bromide refrigerant based absorption cooler which has several advantages over H<sub>2</sub>O-NH<sub>3</sub> absorption units. The LiBr-H<sub>2</sub>O refrigerant has a higher Coefficient of Performance (COP) compared to the NH<sub>3</sub>-H<sub>2</sub>O based refrigerant. NH<sub>3</sub>-H<sub>2</sub>O based refrigerant requires a higher generator inlet temperature. Generally, LiBr-H<sub>2</sub>O absorption units require generator inlet temperatures of 70-88C, while H<sub>2</sub>O-NH<sub>3</sub> absorption units require temperatures of 90-180°C; which results in the H<sub>2</sub>O-NH<sub>3</sub> cooling systems achieving a lower COP when using a plate collectors. NH<sub>3</sub>-H<sub>2</sub>O based refrigerant requires higher pressures and hence higher pumping

power. A more complex system requires a rectifier to separate ammonia and water vapor at the generator outlet is required. There are restrictions on in-building applications of ammonia-water cooling units because of the hazards associated with the use of ammonia (Li, 2000).

***Working principle:***

Absorptive refrigeration uses a source of heat to provide the energy needed to drive the cooling process. The basic thermodynamic process is not a conventional thermodynamic cooling process based on Charles' law. Instead, it is based on evaporation carrying heat, in the form of faster-moving (hotter) molecules, from one material to another material that preferentially absorbs hot molecules. The classic gas absorption refrigerator sends liquid ammonia into a hydrogen gas. The liquid ammonia evaporates in the presence of hydrogen gas, providing the cooling. The now-gaseous ammonia is sent into a container holding water, which absorbs the ammonia. The water-ammonia solution is then directed past a heater, which boils ammonia gas out of the water-ammonia solution. The ammonia gas is then condensed into a liquid. The liquid ammonia is then sent back through the hydrogen gas, completing the cycle. A similar system, absorption chillers that are common in large commercial plants, uses a solution of lithium bromide salt and water. Water under low pressure is evaporated from the coils that are being chilled. The water is absorbed by a lithium bromide/water solution. The water is driven off the lithium bromide solution using heat (Renewable Energy Technologies, 2002).

***Adsorption Cooling:***

There is another variation of similar alternative cooling system which is called the adsorption cooling system. Adsorption chillers are a different approach to achieve air conditioning and process cooling. Adsorption chillers are driven by hot water of 60°-80°C,

instead of large amounts of electricity like conventional air conditioners. There are no Chloro-Floro-carbon (CFC) or freons, no lithium bromide, and no ammonia. By replacing the corrosive salt desiccant with a benign silica gel, adsorption chillers significantly reduce maintenance and upkeep costs. Because of the avoidance of hazardous and corrosive refrigerant and lower working temperature the adsorption cooling systems have several advantages over the absorption cooling system.

### ***Desiccant Cooling:***

Desiccant cooling technology develops a tool to control moisture levels for air-conditioned spaces. Desiccant systems work with conventional air conditioning systems to dehumidify the air. Desiccants are those materials that attract moisture due to differences in vapor pressure as an example silica gel. Desiccants can be solid or liquid. Researchers identified some desiccants that are appropriate as a component of commercial HVAC systems. These desiccants have the ability to hold large quantities of moisture and can be easily reactivated (Torrey, 2010).

To be effective, the desiccant must be able to address the latent cooling load in a continuous process. “In order to accomplish this, commercial desiccant systems consist of a process air path and a reactivation air path. The desiccant that is in the process air path has been prepared to have a lower vapor pressure than the air passing over it. Thus, the moisture in the air is transferred onto the desiccant material. As the desiccant vapor pressure increases due to the presence of the moisture that it has attracted, the desiccant material is transferred to a reactivation process. In the reactivation process, hot air is passed over the desiccant. The vapor pressure of the hot air is lower than the desiccant surface, which forces the moisture to transfer from the desiccant surface into the hot air stream. The moist hot air is then exhausted from the

system into the outdoor air. The desiccant material that has had the trapped moisture removed is now prepared to attract moisture as it is transferred back into the process air path” (Torrey, 2010). Then the dry air is passed over a conventional cooling coil to address the sensible cooling work required to meet the air specification of the conditioned space.

### **Types of Desiccant Systems:**

Types of desiccant system depend on the desiccant material, which attract moisture through the process of either adsorption or absorption. Most adsorbents are solid materials while most absorbents are liquids. Types of materials used as a basis for desiccant systems include the following materials:

- Silica Gel
- Lithium Chloride (Liquid or Dry)
- Lithium Bromide
- Activated Alumina
- Titanium Silicate
- Molecular Sieve

Commercially available desiccant systems are based on five configurations or technologies.

- Liquid Spray Towers
- Solid Packed Tower
- Rotating Horizontal Bed
- Multiple Vertical Beds
- Rotating Desiccant Wheel



### ***Geothermal heat pump and earth tube heat exchanger:***

At a depth of about 10 feet (3m) or more, the soil temperature stays constant throughout the year, and is approximately equal to the average annual ambient air temperature. Thus, the ground can be used as a heat sink for cooling in the summer and as a heat source for heating in the winter (Goswami, 1993). Geothermal heat pumps and Earth tube heat exchanger uses this heat sink of earth for cooling building interior.

### ***Working principle of geothermal heat pump:***

A geothermal heat pump system (GHP) consists of indoor heat pump equipment, a ground loop, and a flow center to connect the indoor and outdoor equipment. The heat pump equipment works like a reversible refrigerator by removing heat from one location and depositing it in another location. The ground loop, which is invisible after installation, allows the exchange of heat between the earth and the heat pump. Depending upon the ground loop type the geothermal heat pump systems can be primarily sub divided in two categories Open loop systems and closed loop systems. The closed loop system can be further subdivided into four different categories: 1) horizontal loops; 2) vertical loops; 3) slinky loops; 4) pond loops (Geothermal: How it Works, 1997).

### ***Open loop system:***

In open-loop GHP systems, a groundwater or surface water supply is used as a direct heat transfer medium, such that the water flows “one-way” through the building heat pump units and then it is discharged.

**Single-well systems:** Single-well systems use a well as a supply well and discharge the used water into a nearby water body or ground drainage field. A variation of the single-well open

loop is the standing-column well, where all or most of the discharge water is re-injected back into the source well. This system minimizes the amount of surface discharge, which may have to be limited for environmental or regulatory reasons (Geothermal Heat Pump Technology, n.d.).

**Double-well systems:** Double-well systems use two separate supply and discharge wells. The distance between the supply and discharge wells is an important design consideration. It is necessary to make sure that any flow between the wells is sufficiently low that discharged water arrives is nearly the same temperature as the aquifer. Spacing between the wells typically will be in the range of 200 to 600 feet, depending on the maximum system cooling or heating load, the typical duration of the maximum load, and the thickness and natural flow rate of the aquifer.

**Surface water systems:** Surface water systems typically use a large water body for water supply, as well as discharge. Thermal stratification in the large water body such as ocean or deep lakes results in keeping stable temperature water at lower level undisturbed throughout the year. The constant temperature water from bottom is used as the supply water and the used water is discharged at top.

### ***Closed Loops***

A closed-loop GHP system uses an underground network of sealed piping, which acts as the earth-coupled heat exchanger. Although there are several materials used but commonly used closed-loop piping material is high-density polyethylene (HDPE). The ground loop piping is filled with a working liquid that is continuously re-circulated without any direct contact with the soil or water in which the loop is buried or immersed. Once filled with liquid and purged of air, nothing enters or leaves the closed loop and this eliminates the problems of water quality and availability associated with open-loop systems.

There are four different closed-loop configurations:

- horizontal,
- spiral,
- vertical, and
- submerged

***Earth tube:***

Another alternative to earth loops is the earth tube. Earth tube heat exchanger is a simple method of using air to pass through an underground air tunnel. The air thus cooled or heated can be used directly for the space conditioning or indirectly with air conditioners or heat pumps. So far there have been several experiments done which shows that an earth tube can reduce the air temperature significantly to condition indoor spaces.

***Description:***

The earth tubes are made of a series of connected pieces of pipes of suitable material and size. A number of studies have shown that the pipe material has very little effect on the overall heat transfer (Goswami, 1993). So the pipes can be made of cast iron, polyethylene or some new materials like Awaduct Thermo pipes from REHAU. The Awaduct thermo has a special advantage as it prevents any kind of microbial formation within the earth tube (Rehau ultimate polymer solution, n.d.). The sections are connected properly to prevent gases in the soil from leaching into the ventilation system. The pipes need to be laid between ten and twelve feet below the ground surface to have a constant year round temperature. The pipes are connected at one end to a larger vertical pipe that will extend above ground and serve as the air intake. In the finished system, it will be covered by a metal roof and the sides will be enclosed with mesh to

prevent entrance of insects or debris. At the other end, the maze of pipes is connected to the basement of the building, where the air will go through a filter and UV lamp to eliminate mold and bacteria before being heated or cooled and circulated throughout the building.

### ***Performance and energy issues***

The earth tube heat-exchange systems have a potential to give very high coefficients of performance (COP), and therefore high-energy savings. Conventionally, heating and air conditioning systems have average year-round COPs of about 2.0. However the COPs of the systems utilizing underground air tunnels for open and closed loop systems can be as high as 10. By doubling the COP over a conventional system, the energy input (energy that one pays for) is reduced by 50 percent (Goswami, 1993).

Moreover, there has been one experiment, which shows that if earth tubes are coupled with a solar chimney then the combined system can work as an electricity energy free cooling system. For the experiment, a cooling tube was buried underground to absorb cooling from low temperature soil. The outside air flowed through the tube to bring cooling from the soil to building and maintain comfort room temperature during summer. A chimney was installed to draw the air through the tube. The room air was heated up in the collector by the solar energy before entering the chimney, then the hot air generated the draft in the chimney, finally the chimney draft formed air ventilation in the cooling tube and solar chimney system. The experiment showed that one solar collector with an absorbing area of 20 m<sup>2</sup> (215ft<sup>2</sup>) and one chimney with diameter of 0.457 meter (18 inch) and height of 10 m (30 feet) can generate the cooling tube airflow of 0.13 m<sup>3</sup>/s (or 270CFM). The integrated system can obtain 2.4kW (8,000Btu/h) peak cooling capacity from underground and supply 1.9 kW (6,500Btu/h) peak

cooling energy to the space in afternoon. The tightened envelope and paralleled tubes can increase the system airflow by 25 percent (Wang, 2004).

**Limitation of study:**

The study done in this thesis on alternative cooling techniques has some inherent limitations. Entire research on this topic is done on the basis of literature study and no specific system has been tested in Kolkata.

Some previous researches and testing have been executed on double skin façade system, absorption cooling system, geothermal heat pump, geothermal earth tubes, and desiccant cooling systems but none of these have been tested in a contemporary Kolkata high-rise building.

A research in the University of Nebraska was carried out to develop a cooling system by the integration of geothermal earth tubes and solar chimney but no such system has been tested in a high-rise building. For the further conclusive development of these systems a thorough on-site testing or through computer generated fluid dynamic analysis is important.

**Barriers to implementation:**

There are some barriers for the implementation of alternative cooling strategies discussed in this section. Cost is a primary barrier to implement a double skin façade. Kolkata being a hot-humid climate region geothermal earth tubes are not suitable as the tubes may have condensation and fungus formation inside.

Good quality earth tubes like Awaduct thermo is not presently manufactured in Kolkata and thus cost and availability is not dependable. Presently in Kolkata Absorption and adsorption chillers are also not readily available technology. So for the pioneering projects there will be an issue of cost effectiveness.

Unless the systems are successfully tested in Kolkata and analyzed for efficiency and cost effectiveness, it will be difficult to implement because of the skepticism of developers.

## **Wastewater treatment:**

### ***Introduction:***

Besides energy, another most important resource is water. Although three fourth of earth's surface is covered with water the actual amount of potable water is very limited. About ninety-seven percent of all water is in the oceans and only three percent is fresh water. Out of that three percent freshwater about 69 percent, is locked up in glaciers and icecaps, mainly in Greenland and Antarctica. In addition, rest of the fresh water is locked in the ground water. Only about 0.3 percent of all the freshwater on Earth is contained in rivers and lakes, and this is the only available water we use in our everyday lives (Survey, 2009). Unfortunately, with the increasing pollution most of these surface water sources have become wasted. In the United States, forty percent of waterways have become undrinkable (Leonard, Fact Sheet, n.d.). Treated and recycled wastewater continues to become a more viable source of potable water.

### ***Sewage and sewage breakdown:***

In general, domestic sewage is a mixture of water and different types of organic matters like feces, urine, food scraps, hair, and toilet paper etcetera. It also contains some domestic chemicals and detergents. The industrial wastewater contains different chemicals and heavy metals as pollutant. Once the sewage is discharged, in different suitable aerobic and anaerobic condition microorganisms breaks it down from the complex organic form to simpler mineral structure. The process of breaking down is called mineralization.

Microorganisms involved in the breakdown process require oxygen for respiration. Compared to bigger and more complex creatures these microorganisms are far more efficient to consume dissolved oxygen in water. So if raw sewage is introduced in a water body then these microorganisms consume the dissolved oxygen and make the condition unsuitable for fishes and other bigger creatures. As the organic matters use oxygen while decomposing, the quantity of organic matter present in a water body can be estimated by the measure of the biochemical oxygen demand (BOD) of the water body. Another measure is the measurement of suspended solid (SS) in a water body (Grant, 2000).

The primary objective of a sewage treatment process is to reduce the BOD and SS through treatment. Other than that, sewage treatment also eliminates the potentially pathogenic materials, bacteria and viruses present in sewage.

### ***Wastewater treatment techniques:***

Several sewage treatment techniques are used, depending on the exact requirement and conditions. The treatment process can be anaerobic, aerobic or both; it can involve physical, biological or chemical processes; and can be either treated close to where it is created, or collected and transported via sewage systems to a central treatment plant. All these conventional sewage treatment techniques are in use in different buildings and complexes of Kolkata.

### ***Sustainable development issues in conventional sewage and waste waters treatment:***

Conventional sewage treatment involves three stages of treatment; primary treatment, secondary treatment and tertiary treatment. Primary treatment removes the solids, secondary treatments dissolved and suspended biological matter and in tertiary treatment treated water is disinfected chemically or physically prior to discharge into natural water body or it can be used

for the landscape irrigation. Conventional waste water treatment can also be divided in physical, chemical and biological processes. The physical process consists of screening, aeration and filtration. Chemical process usually consists of chlorination, ozonation and adsorption. Biological process consists of anaerobic and aerobic treatments in presence of suitable biological organisms.

Presently among several conventional wastewater treatments available most have several drawbacks. According to environmentalists John Todd and Björn Guterstam, conventional water treatment techniques do not provide the level of treatment necessary for industrial societies and they are technologically inadequate (Guterstam, 1990). In the paper, the authors have argued that there are at least four reasons, which makes these techniques inadequate:

1. A byproduct of the process, called sludge, is disposed of by ocean dumping, land filling, spreading on agricultural land, incinerating, or by composting.

2. These wastewater treatment techniques often use environmentally damaging chemicals such as aluminum salts to precipitate out solids, and phosphorus or chlorine for ammonia control and in fecal coliform reduction.

3. These waste water treatments techniques fail to remove metals and synthetic organic chemicals produced and discarded by industrial societies through waste streams.

4. These wastewater treatments techniques are costly.

Other than the abovementioned issues there is another debatable issue of power consumption. Although in cold climate region some of the alternative techniques consumes significant amount of energy, as it is shown in Table 4.1 however, they are mostly passive solar powered.



Table 4.1 shows a comparison of energy requirements and amount of nutrients recycled in produced biomass in case of different types of wastewater treatment plants. Approximate removal efficiencies are indicated for normal strength domestic wastewater (Brix, 1999).

**Table 4.1 Comparison of energy requirements and amount of nutrients recycled in produced biomass in different types of wastewater treatment plants. Approximate removal efficiencies are indicated for normal strength domestic wastewater. (Brix, 1999)**

System	Loading (m <sup>3</sup> day)	Removal Efficiency		Nutrient Recycling		Energy (kWh /m <sup>3</sup> )
		BOD	TN	TP		
Aquaculture Systems:						
The Stensund Facility <sup>(1)</sup>	7	>95perce	ca.	ca. 50percent	ca. 10percent	39
Living Machine (AEES) <sup>(2)</sup>	151	>95perce	>80perc	>50percent	<1perc	2.70
Living Machine (AEES) <sup>(2)</sup>	303	>95perce	>80perc	>50percent	<1perc	2.06
<u>Living Machine (AEES)<sup>(2)</sup></u>	3785	>95perce	>80perc	>50percent	<1perc	<b>1.51</b>
<b>Constructed Wetlands:</b>						
Surface Flow Wetlands (3)		>95perce	c.50per	c.50percent	Variable	<0.1
<u>Subsurface Flow Wetlands (4)</u>		>95perce	c.50per	c.50percent	Low	<0.1
<b>Conventional Systems:</b>						
Extended Aeration (2)	151	>95perce	>80perc	>50percent	0perce	2.39
Sequencing Batch Reactor (2)	303	>95perce	>80perc	>50percent	0perce	1.13
Extended Aeration (2)	3785	>95perce	>80perc	>50percent	0perce	1.06
Carousel Oxidation Ditch (2)	3785	>95perce	>80perc	>50percent	0perce	0.51

**Alternative sewage and waste water treatment systems:**

Parallel to centralized conventional sewage and waste water treatment systems there are several alternatives like constructed wetlands, living machines, septic tank, and settlement tank etcetera.

**Constructed-wetlands:**

Constructed wetland is a process which basically mimics the wetland ecology and treats wastewater in a complex natural biological process by a symbiotic existence of different macro and microorganisms as well as aquatic plants.

**Living machines:**

Living machine is a term originally coined by ecologist Dr. John Todd for a waste water treatment system designed by him which is based on a number of principles intended to maximize a constructed ecology similar to nature. In a living machine system several steps are included namely anaerobic treatment, aerobic treatment, phytoplankton basin, zooplankton basin, poly-culture (Guterstam, 1990).

Living machine was developed to fulfill the need of an alternative environmentally responsible waste water treatment approach. An environmentally responsible technology should produce little or no sludge, use no hazardous chemicals in the process chain, remove synthetic chemicals from the water and be cost effective (Guterstam, 1990). Living machine was developed as complex ecosystems which assemble bacteria, algae, zoo- plankton, crustaceans, fish, and higher plants for nutrient recovery and toxin removal. Internal biotic self regulation is central to the ecological engineering models using only light as the primary energy source (Guterstam, 1990).

The process of the system was explained by authors in the paper 'Ecological Engineering for Wastewater Treatment and Its Application in New England and Sweden'. In the system first phase of treatment is anaerobic to promote the production of sulfides by sulfur bacteria in order to precipitate most metal ions as metal sulfides. Then second step involves oxidation of sulfides with aeration. The second step includes microbial detoxification and mineralization. In the third step the process involves the culture of algae for nutrient and food-chain diversification. In this stage as energy source, combination of artificial and natural sunlight needs to be employed for 16-18 hours per day to facilitate growth. In fourth step the process involves the culture of zooplankton which grazes upon bacteria, protozoa and algae cultured in this stage. Water plants

which cover the surface provide habitat for zooplankton, additional nutrient uptake, and algae-growth inhibition. For this purpose temperate and tropical plants are most effective. Fifth step involves the polyculture of fish and crayfish in order to remove detritus, sludge, and plankton from the system prior to discharge. Sixth step involves nutrient polishing with hydroponically grown plants including willows and water-cress. According the authors “The results from the pilot study, upon which the full-scale design was based, are encouraging. Between September 1987 and April 1988, 99.999 percent of the coliform bacteria were removed; 97 percent of the suspended solids, 96percent of the BODs; 85 percent of the total nitrogen; and 62 percent of total phosphorus. With a one- to two-week retention time the pilot study produced good quality waste water” (Guterstam, 1990).

**Anaerobic treatment:**

**Septic Tanks:**

Septic tank is a long practiced anaerobic sewage treatment system. In this process sewage is taken to a two chambered tank, in which the sewage is treated by anaerobic bacteria in absence of air.

**Settlement tank:**

Settlement tanks are similar to septic tank but smaller in scale. The capacity is for holding up to eight hours equivalent flow. The sludge must be cleared at least every two weeks.

Septic tank, settlement tank and living machines are commonly used for small scale domestic treatment, whereas activated sludge, trickling filter and constructed wetlands area commonly used for community scale treatment.

## **High-rise Farming:**

### ***Introduction:***

Total global land area is approximately 13066.9 million hectares and out of that, the total arable land area is 1515.8 million hectares, which is only 11percent of the world's land mass (Agricultural land and Population, 2005). Out of the total arable land approximately eight hundred million hectares is committed to soil-based agriculture, which feeds the nearly seven billion world population (the vertical Farm, 2009). With the present scenario of rapid global population growth, the cultivable land area will eventually become insufficient.

In India, the situation is already grim. Presently malnourishment and hunger are rampant. According to 2008 Global Hunger Index (GHI) index of 23.7 India's rank is 66<sup>th</sup> (Grebmer, 2008), which is worse than many of the third world countries. Moreover, with the present rate of population growth the struggle will increase. The country has utilized almost all of its arable land area, nearly 170 million hectares, to feed its population of 1.1 billion (India, 2007). Cultivation is still the foremost occupation in India but the country cannot further increase its farmland. Urban farming may be one solution to this problem. Moreover, if a hydroponic high-rise farming system is integrated with aquaculture then it can develop a close circuit eco-system where wastewater recycling, fish production and food production can happen in a symbiotic system. This system is also called aquaponics (Diver, 2006). Most aquaculture wastewater treatment systems use plants like cattail and bulrush. Some of these plants have good nutritional value. However, if the high-rise farming is done in a hydroponic process then many other plants can be a part of aquaponic farming system.

### ***Advantages of vertical farming:***

There are several advantages of vertical farming. Firstly, a vertical farm can support a year-round crop production, as it will be done in a controlled indoor environment. A vertical farming also eliminates agricultural runoff and reduces the issue of soil erosion. As it encourages urban crop production, it significantly reduces use of fossil fuels for farm machines and transport of crops from rural to urban areas. As the farming will be done on a high-rise with a controlled climatic condition, there will be no weather related crop failures. Moreover, this urban farming offers the possibility of sustainability for urban centers. If a suitable system like aquaponic is used for harvesting and the system is integrated with a living machine then by the side of food production, it can also treat waste water. The system needs regular maintenance and thus can create new urban employment opportunities. It can also reduce the risk of infection from agents transmitted at the agricultural interface and control vermin by using restaurant waste for methane generation.

### ***High-rise farming techniques:***

Indoor farming is not a new concept, as greenhouse-based agriculture has been in existence for some time. One of the earliest known greenhouses, termed a 'specularium', was constructed around 30 A.D. for the Roman emperor Tiberius. This structure was made for the year-round growth of cucumbers. As the glass was not invented, the glazing for greenhouse-like structure was fabricated from tiny translucent sheets of mica. Few centuries later a French botanist Jules Charles developed first practical greenhouse around 1599 and used to grow primarily medicinal tropical plants (the vertical Farm, 2009). Since then indoor farming has come a long way and numerous commercially viable crops have seen their way to the world's supermarkets in ever-

increasing amounts over the last 15 years. The biggest advantage of indoor farming is the possibility of year-round production in a controlled climate. There are several techniques used for indoor farming:

1. Hydroponic technique
2. Float system
3. Aeroponic technique
4. Drip or container culture
5. Aquaponic technique

***Hydroponic farming:***

The word ‘hydroponics, came from the Greek words ‘hydro’ meaning water and ‘ponos’ meaning labor. It is a method of growing plants using nutrient rich water solutions without soil. In this technique, plants can be grown with their roots in the mineral nutrient solution only or in an inert medium, such as perlite, gravel, or mineral wool (the vertical Farm, 2009). It was discovered in early nineteenth century that plants absorb essential mineral nutrients as inorganic ions in water. In soil based agriculture soil acts as a mineral nutrient reservoir but the soil itself is not essential to plant growth. When the mineral nutrients in the soil dissolve in water, plant roots are able to absorb them. If the required mineral nutrients are introduced artificially into water in which the plant grows, soil is no longer required for the plant to thrive. The technique is also known as ‘tray agriculture’, ‘tank farming’, and ‘water culture’ (Hydroponics - Growing Plants Without Soil, 2006).

***Float System:***

Float system is a type of hydroponic agriculture in which plants are grown in net pots that sit in holes cut into a foam board raft that floats on the surface of long rectangular reservoirs filled with nutrient solution. To ensure the aeration of the roots the nutrient solution should be stirred up every day by hand or by an immersed pump.

***Aeroponic system:***

Aeroponics systems apply hydroponics techniques, without a growing medium, although growing medium are sometimes used to germinate or root cuttings. An aeroponic system suspends the plant within a chamber, such that the roots of the plant are exposed. A nutrient-rich mist is continually pumped into the chamber, so that the chamber is kept at 100percent humidity. The exposed roots absorb the nutrients and oxygen directly from the surrounding air, which purportedly increases the plant's metabolic rate, which can result in a nearly 10-fold increase in growth rate compared to that grown in soil (Nugaliyadde, 2005).

***Drip or container culture:***

Drip or container culture is one method of soil-less indoor growing in which plants are cultivated in media bags, pots or troughs. In soil-based agriculture, plants are cultivated in field soil, a medium that acts as a reservoir for nutrients and water and a scaffold of support for plant growth. The ideal growing medium used for container culture in an indoor farming has to be chemically inert, provide good aeration to the root system, and have good nutrient and water holding capacity. Presently the common materials that meet these prerequisites are perlite, rock wool, expanded clay pebbles and vermiculite.

### ***Aquaponic Farming:***

Aquaponic farming is a bio-integrated system that links recirculation of aquaculture waste with hydroponic plant production. Recent advances in this field have turned aquaponics into a working model of sustainable food production. In aquaponics, the fish waste supplies nutrients for the growing plants and the plants provide a natural filter for the water the fish live in. Fish effluent contains sufficient levels of ammonia, nitrate, nitrite, phosphorus, potassium, and other secondary and micronutrients to produce hydroponic plants. Some plant species are better adapted to this system than others are, but overall, this technique creates a sustainable ecosystem where both plants and fish can thrive. Plants such as lettuce, herbs, spinach, chives, basil, and watercress have low to medium nutritional requirements and are well adapted to aquaponic systems. Other fruit yielding plants as an example tomatoes, bell peppers, cucumbers etcetera. have a higher nutritional demand and perform better in a heavily stocked, well-established aquaponic system. The system establishes beneficial bacteria that convert the ammonia from the fish waste into nitrite and then to nitrate that the plants can easily utilize (Diver, 2006).

### ***Resource recovery by wastewater fed fisheries and agriculture in East Calcutta wet land:***

Kolkata is situated in a hot and humid climatic region. Its tropical climate along with average rainfall of 1650 mm, ninety percent of which happens from June to October, ensures the area to act as a natural incubator for a diverse group of microbes, thus making it a biodiversity rich spot. All these contextual advantages along with the presence of a forty thousand hectare wetland helped Calcutta to develop a unique waste management system. This waste management as well as resource recovery system uses a non-conventional ecological practice for treating both



the solid as well as soluble waste for its fifteen million inhabitants. The system not only detoxifies the waste but also generates resources for the existing society in form of employment as well as edibles vegetable, fish as well as food grains like paddy for consumption. Moreover, some elemental analysis done by department of biotechnology, West Bengal University of Technology of these products showed no metal toxicity due to their cultivation using waste resource (Roychaudhuri, 2007).

The resource recovery system of 'East Calcutta Wetland' usages city sewage for traditional practices of sewage fed fisheries and agriculture is practiced. The four principal resource recovery practices in waste recycling in 'East Calcutta Wetland' are:

1. garbage vegetable farms;
2. wastewater-fed fishponds;
3. paddy fields using fishpond effluent; and
4. sewage-fed brackish water aquaculture.

The Kolkata Municipal Corporation daily produces approximately 600 million liters of wastewater and more than 2,500 tons of garbage. Flowing through underground sewerage system the wastewater comes to into open channels to the sewage fed fisheries. Then it helps the development of sewage fed fisheries, agriculture on solid waste farms for vegetables and paddy.

Locally a sewage fed fishery is called 'bheri'. These 'bheris' are shallow flat bottomed 50 – 150 cm in deep wastewater fed lagoon type ponds, which can be as large as 40–50 ha in size. The shallow basin allows full vertical circulation of water to the surface where algal blooms occur. The shallow depth is also favorable for photosynthesis, as it gives a better surface to

volume ratio compared to a deeper pond. This helps to provide sufficient oxygenation to allow for efficient reduction of biochemical oxygen demand and pathogen or fecal coliform.

The rate of organic loading in these sewage fed fisheries varies between 20 – 70 kg per hectare per day. The cumulative efficiency of reducing the BOD of the sewage water is above 80percent on an average. Each hectare of a shallow water-body can remove about 237 kg of BOD per day. The reduction of BOD in a sewage fed fishery ecosystem happens by a unique algae–bacteria symbiosis, where the algal photosynthesis supplies energy. Some algae are capable of growing commensally in an ecosystem with waste-oxidizing bacteria. The results of the commensal metabolism are the release of oxygen and synthesis of bacterial degradation products into new, protein-rich plant material. The symbiotic system also reduces coliform bacteria prone to be pathogenic. Then the effluents from the fishponds are drained to the cultivable lands for the vegetable and paddy production (Raychaudhuri, 2008).

### ***Role of Aquatic Weeds:***

Although the primary purification happens by the algae–bacteria symbiosis but aquatic plants also play an active role of phyto-remediation, and purification process in this ecosystem. Plants remove toxic materials from the environment through various mechanisms as described below.

1. Phyto-extraction = It is the process which involves pollutant accumulating plants to remove metals or organics from soil ,
2. Phyto-degradation = It is the process which involves plants to degrade organic pollutants,
3. Rhizofiltration = It is the process which uses the plant roots to absorb or adsorb pollutants, mainly metals from water and aqueous waste stream,

4. Phyto-stabilization = It is the process in which the plants reduce bioavailability of pollutants in environment and
5. Phyto-volatilization = It is the process in which the plants are used to volatilize pollutants

Moreover, plants perform in nitrogen fixation as well as accumulate heavy metals. Some of the plant secretions show bacteriostatic properties. The compounds released by plant roots include simple sugars, amino acids, aliphatics, aromatics that stimulate the growth and metabolism of specific microbial communities that accelerate the bioremediation process. Water-hyacinth plays a special role in the functioning of this complex ecosystem. Its roots absorb heavy metal present in sewage water. Water-hyacinth is mainly concerned with rhizofiltration, where plant roots act as 'biocurtains' or 'biofilters' for the passive remediation of wastewater. Thus periodic harvesting of these weeds leads to successful bioremediation (Roychaudhuri, 2007). Moreover, due to rapid growth it can be a good source of biomass.

### ***Fish Cultivation:***

The high productivity of the sewage fed fishponds is due to high content of nutrients in the wastewater, while the high alkalinity stimulates the production of phyto-planktons, a primary product in the fish food chain. There are five major stages in the preparation of a fishpond. The first phase involves the pond preparation, which is done during the coolest months of the year. It involves proper cleaning of the remnants from the pond bottom surface after complete drainage of the pond. The second phase is the primarily involves fertilization. In this process, the ponds are filled with wastewater and the water is allowed to stand to undergoes natural purification through processes mediated by microscopic biota. The water is stirred intensely to remove

anaerobic conditions in the sediments and ensure aerobic digestion. This promotes the development of benthic organisms, which serve as fish feed. The third phase is the fish stocking. Initially the water quality is tested by introducing a small number of fishes in the pond before introducing the actual fish stock. In the fourth phase, wastewater is introduced periodically throughout the growth cycle of fishes. The fifth phase involves harvesting and continues for the rest of the year.

***Vegetable and crop:***

On the eastern fringes of Kolkata, the old solid waste dumping grounds have been converted into cultivable lands. After going through the sewage fed fisheries, the nutrient rich water is channeled through the vegetable farms and paddy fields, which sustain on the garbage and effluent from the wastewater fed fisheries as manure and water for irrigation. These farms yield 150 tons of fresh vegetables daily and the paddy fields produce 16,000 tons of rice annually (Raychaudhuri, 2008).

***Possible contamination of food:***

Although the possibility of resource recovery by sewage fed fishpond and agriculture is established from the existing practice of East Calcutta Wetlands (ECW), the key question of safety, quality and reliability of the method arises at this point. However, several tests done in different institute proves that crops cultivated in sewage water do not get considerable contamination from heavy metals. Some elemental analysis done by department of biotechnology, West Bengal University of Technology of these products showed no metal toxicity due to their cultivation using waste resource. During the analysis different elements in green leafy vegetables and fishes from ECW sites and distant places (non-ECW sites) were

studied. The chosen vegetables were the most commonly consumed vegetables of that region. The concentrations for the elements: P, S, Cl, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr and Pb were determined for both the ECW and the non-ECW vegetables by Department of Biotechnology. The observation shows that although variations do exist in the levels of elements in the vegetables grown at ECW but the net consumption of the aforementioned elements per person per day found to be much below the Recommended Dietary Allowance (RDA) levels in all cases (Roychaudhuri, 2007). More over a field study carried out in University of Agriculture, Faisalabad to observe the effect of heavy metals polluted water on yield, yield components and heavy metal contents in paddy and straw of rice and soil shows that minor accumulation of these heavy metals happens in the harvest, but it remained within permissible limits (Nawaz, 2006). Moreover, as these crops do not need artificial fertilizer or pesticides they have a lesser chance of contamination.

#### ***Possible integration with high-rise:***

High-rise is a building type, which has much taller height compared to its small footprint. Such a building type has huge surface area compared to the roof. So in case of a high-rise vertical farming will be even more effective if it is integrated with the envelop system. Through utilizing the huge surface area, the system can utilize the gravity flow for the wastewater treatment and irrigation of the aquaponic agriculture. That will make the system even more energy efficient and effective.

#### **Limitation of study:**

The entire study of waste water treatment and high-rise food productions is done on the basis of literature study and no specific system has been tested in a contemporary Kolkata high-

rise building. For a conclusive development of a waste water treatment and high-rise food productions system a thorough on-site testing and a thorough computer generated fluid dynamic analysis is important.

### **Barriers to implementation:**

Although Kolkata climate is quite suitable and can make such a system cost effective, the major barrier is a lack of knowledge and skilled labor in Kolkata to manage living machines and high-rise food production systems. Moreover until the systems are tested for a conclusive finding for applicability it will be difficult to implement because of the skepticism of developers.

### **Renewable power sources and possible integration with Sustainable High-rise:**

#### *Introduction:*

Perhaps the biggest threat towards a sustainable development is the end of cheap oil era. Modern civilization has been developed by concentrated fossil fuel energy but it also made us prodigal. “Over the last 200 years industrial civilization has literally reshaped the surface of the earth. Modern America is a creation of cheap, concentrated fossil fuels. But the pattern of the megalopolitan sprawl that has resulted is completely maladapted for our future survival” (Coates, 1981). With the estimated global oil peak by the year 2010, the future of such a development seems grim. In this context, development of technology to harness alternative renewable resources received primary importance.

Recently, research into alternative renewable energy sources is increasing. Many of these sources are suitable to be integrated within the systems of a tall building, reducing their energy demand substantially.

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**Table 4.2 Possible alternative energy resources**

Alternative Energy source	Possible integration in a urban high-rise	
	Presently	Future possibility
Nuclear	Not possible	Not possible
Hydropower	Not possible	Not possible
Ocean Thermal, Tidal and wave	Not possible	Not possible
Geothermal energy	Not possible	Uncertain
Bio-fuel (Bio-mass, Bio-gas, Bio-diesel)	Not in use	<b>Possible</b>
Wind	Possible	<b>Possible</b>
Solar photovoltaic	Possible	<b>Possible</b>
Solar thermal	Not in use	Uncertain
Solar Chimney	Not in use	<b>Possible</b>

This portion of the chapter focuses only on the description of those possible alternative energy sources that are usable in the context of an urban high-rise building. Among all the possibilities Bio-fuel and solar chimney are most important because these have immense possibilities but least explored.

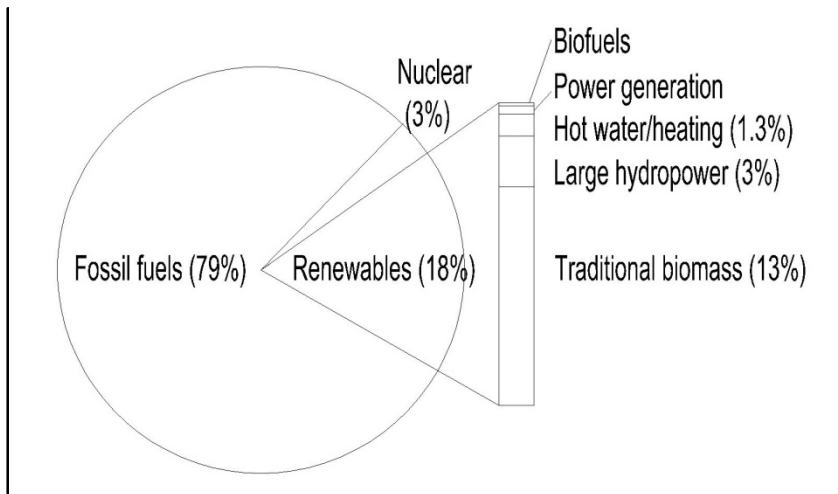
***Bio-fuel:***

Bio-fuel is solid, liquid or gaseous fuel obtained from relatively recently lifeless or living biological material and is different from fossil fuels, which are derived from biological material. In addition, various plants and plant-derived materials are used for bio-fuel manufacturing. There are different types of bio-fuels as an example biogas, biodiesel, alcohols etcetera.

*Biomass:*

In the year 2006, biomass (plant matter) accounts for about 13 percent of world energy use and an even higher percentage of energy use in developing countries. “Traditional applications mean primarily burning wood, agricultural and forestry wastes, dung, and other unprocessed biomass

**Figure 4.3 REN21 2007 global status report on renewable energy resources (GmbH, 2008)**



fuels for home cooking and heating and other process-heating needs. Some biomass is converted to charcoal and sold in commercial markets. Biomass accounts for a large share of total primary energy supply in many developing countries. In 2001, this share was 49 percent in Africa, 25 percent in Asia, and 18 percent in Latin America. In some African countries, the share is much higher, such as 90 percent in Guinea and Niger, and eighty percent in Mali. In 2000, households in sub-Saharan Africa consumed nearly 470 million tons of wood fuels (0.72 tons per capita) in the form of wood and charcoal. In comparison, India and China together consumed 340 million tons. In sub-Saharan Africa, wood or crop residues are the primary source of household energy for 94 percent of rural households and 41 percent of urban households. Charcoal is the primary source of household energy for 4 percent of rural households and 34 percent of urban



households. And kerosene is the primary source of household energy for 2 percent of rural households and 13 percent of urban households” (GmbH, RENEWABLES 2007 GLOBAL STATUS REPORT, 2008). Biomass can also be converted to gaseous and liquid fuel for the use in more affluent societies. Biomass can be generated sustainably as the CO<sub>2</sub> produced in the process can be consumed by plants in the process of photosynthesis.

Other than being used for domestic purposes, biomass is also used for producing electricity. In 2006, globally 44GW electricity was produced from biomass (GmbH, RENEWABLES 2007 GLOBAL STATUS REPORT, 2008).

Possible Building Integration: The council of tall buildings and urban habitat has described the possibility of using biomass for power generation in case of a tall building on an urban site. “When we consider the urban high-rise environment, there seems to be little opportunity to utilize solar and wind energy, for the density of buildings will block access to the sun and create turbulence in wind flow. Substantial amount of biomass are ubiquitous in American city in the form of paper, most of which is used only briefly and then discarded. The vast quantities of waste paper generated by urban life include computer printouts, linerboard, junk mail, tissues, and paper towels to mention only a few examples. Relatively little of this – amount 20percent - ever finds its way back to recycled paper. The rest is disposed of primarily in landfills, where it decomposes. It is feasible to collect and utilize this natural urban conservation of waste paper as an energy source. Moreover, using waste paper as a fuel does not contribute to global warming by greenhouse gases, because the trees grown to provide new paper absorb the CO<sub>2</sub> created by the paper burned as fuel” (Ali, 1995). In the chapter 9.7 of the book ‘Architecture of Tall buildings’ a completed research project has been narrated. The case for this research was a 73-story mixed use building on North Michigan Avenue in Chicago. The research showed that

it is possible to produce as much as 56percent of the system fuel required each week. The research proves that the biomass can contribute substantially to the total energy requirement of a tall mixed-use building.

*Biogas:*

Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of bio-fuel. One type of biogas is produced by anaerobic digestion or fermentation of biodegradable materials such as biomass, manure or sewage, municipal waste, green waste and energy crops. This type of biogas comprises primarily methane and carbon dioxide. The other principal type of biogas is wood gas, which is created by gasification of wood or other biomass. This type of biogas is comprised primarily of nitrogen, hydrogen, and carbon monoxide, with trace amounts of methane.

“Methane constitutes the energy-rich part of biogas. Biogas is composed of 45-85percent methane and 15-45percent carbon dioxide, depending on the conditions during production. Biogas also includes small amounts of hydrogen sulphide, ammonia and nitrogen. Biogas is often saturated with water vapor. The amount of biogas is usually stated in units of normal cubic meters, which is defined as the volume of gas at 0°C and atmospheric pressure.

Methane is also a constituent of natural gas, so that purified biogas can be mixed with natural gas and used in the same way. Natural gas consists of hydrocarbons in gas form, created 50 to 400 million years ago by the anaerobic decomposition of plants, plankton, algae etc. The methane content of natural gas is c. 90percent or more. This gas is extracted from fossil layers in the earth’s crust, together with oil or in separate gas fields” (Held, 2008).

The gases methane, hydrogen and carbon monoxide can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a low-cost fuel in any country for any heating purpose, such as cooking. It can also be used in modern waste management facilities where it can be used to run any type of heat engine, to generate either mechanical or electrical power. Biogas can be compressed, much like natural gas, and used to power motor vehicles.

“The total annual biogas production in Sweden is almost 1.3 terawatt hours (Figures from 2006). Several studies have concluded that the potential production in Sweden is 10 times larger than this, or approximately 14 terawatt hours per year (Held, 2008). These calculations assume that roughly 10percent of the agricultural land can be used to grow crops for digestion in biogas plants. If the possibility of exploiting cellulose-rich woody materials (to produce so-called bio-methane) is also considered (Held, 2008), the potential production of methane from native raw materials increases to as much as 100 terawatt hours per year. Thus, the production of bio-methane appears to be a realistic means of replacing a significant proportion of the total annual consumption of fossil fuels in Sweden (90 terawatt hours)” (Held, 2008).

#### Possible Building Integration:

In case of a tall building biogas has a potential for integration with the sewer system to develop fuel from the anaerobic treatment of the human and kitchen wastes. The biogas can be used as a fuel for the kitchen or for the generation of electricity.

#### *Bio-diesel:*

“Bio-diesel is a diesel replacement fuel for use in CI engines. It is manufactured from plant oils, recycled cooking greases or oils, or animal fats. Because plants produce oils from sunlight and air, and can do so year after year on cropland, these oils are renewable. Animal fats

are produced when the animal consumes plants or animals, and these too are renewable. Used cooking oils are mostly plant based, but may also contain animal fats. Used cooking oils are both recycled and renewable. The bio-diesel manufacturing process converts oils and fats into chemicals called long-chain mono alkyl esters, or bio-diesel. Roughly speaking, 100 pounds of oil or fat are reacted with 10 pounds of a short-chain alcohol (usually methanol) in the presence of a catalyst (usually sodium hydroxide [NaOH] or potassium hydroxide [KOH]) to form 100 pounds of bio-diesel and 10 pounds of glycerin. Glycerin is a sugar, and is a co-product of the bio-diesel process” (Laboratory, 2009).

#### *Alcohols:*

Biologically produced alcohols, most commonly ethanol, and less commonly propanol and butanol, are produced by the action of microorganisms and enzymes through the fermentation of sugars or starches, or cellulose. Biobutanol (also called bio-gasoline) is often claimed to provide a direct replacement for gasoline, because it can be used directly in a gasoline engine.

“Ethanol is by far the most widely used bio-fuel for transportation worldwide – mainly due to large production volumes in the US and Brazil. Fuel ethanol produced from corn has been used as a transport fuel in the United States since the early 1980s, and now provides over 10 billion liters (2.6 billion gallons) of fuel per year, accounting for just over 2percent of the total US consumption of motor gasoline on a volume basis (about 1.4percent on an energy basis). The US production of fuel ethanol is over 20 times greater than production in any other IEA (international energy agency) country and, as shown in, is rising rapidly. In Brazil, production of fuel ethanol from sugar cane began in 1975. Production peaked in 1997 at 15 billion liters, but declined to 11 billion in 2000, because of shifting policy goals and measures. Production of

ethanol is rising again, however, and still exceeds US production. All gasoline sold in Brazil contains between 22percent and 26percent ethanol by volume” (iea, 2004).

#### *Wind:*

Wind power is a form of renewable energy that has been harvested by man for thousands of years. Perhaps Egyptians used it for the first time to sail boats in Nile. The first true windmill was developed in Babylon as early as in 2000 BC (Tiwari, 2005). Vertical windmills were developed in China and wind power was used mainly to pump water. Later in 6<sup>th</sup> century AD, the wind power technology was in use in Europe. In the nineteenth century, the windmill technology spread into United States. However, it was not until 1888 that Charles F. Brush built the first large windmill to generate electricity in Cleveland, Ohio. The Brush machine was a multiple-bladed "picket-fence" rotor 17 meters in diameter, featuring a large tail hinged to turn the rotor out of the wind. It was the first windmill to incorporate a step-up gearbox (with a ratio of 50:1) in order to turn a direct current generator at its required operational speed. In 1891, the Dane Poul La Cour developed the first electrical output wind machine and By the close of World War I, the use of 25 kilowatt electrical output machines had spread throughout Denmark. In the twentieth century, the cheaper and larger fossil-fuel steam plants soon put the operators of these mills out of business. (Dodge, 2006). After the fuel crisis of 1970s, research on the wind turbines resumed and since then huge development has happened in this field. “Wind energy has continued the worldwide success story as the most dynamically growing energy source again in the year 2008. Since 2005, global wind installations more than doubled. They reached 121’188 MW in 2008, after 59’024 MW in 2005, 74’151 MW in 2006, and 93’927 MW in 2007. The turnover of the wind sector worldwide reached 40 billion in the year 2008” (WWEA, 2009). At present USA

and Germany is leading the globe in the production of wind energy, closely followed by Spain, China and India.

Technically, there are two types of wind turbines, i) horizontal axis turbines and ii) vertical axis turbines. Horizontal axis turbines are more commonly used and in this case of turbines, the axis of rotation is horizontal and the blades are perpendicular to the ground. On the other hand, the axis and the blades of vertical axis turbines are vertical to the ground. The advantage of vertical axis turbine is that their rotation does not depend on the direction of the wind flow. However, if the direction of wind flow is steady, then horizontal axis turbines are more advantageous as they are generally installed on a high post and can get greater flow of wind.

Recently, wind power has developed as a major alternative source of energy. “Renewable energy markets grew robustly in 2008. Among new renewable (excluding large hydropower), wind power was the largest addition to renewable energy capacity. Existing wind power capacity grew by 29 percent in 2008 to reach 121 giga watts (GW), more than double the 48 GW that existed in 2004. The 2008 increase was led by high growth in the strongest markets of the United States (8.4 GW added), China (6.3 GW), India (1.8 GW), and Germany (1.7 GW)” (GmbH, Renewables Global status report, 2009).

### **Possible Building Integration:**

As the wind flow increases and becomes steady with a greater height so wind turbines are now sometimes being integrated with the tall buildings. Aerodynamically designed building geometry can enhance wind turbine performance. Several manufacturers of building-integrated wind turbines are taking advantage of the increased wind velocities at building parapets—where the wind rises up the façade of a large building and curls over the edge. Some architects are

designing wind scoops right into the structures of buildings or situating building towers to funnel wind into turbines. There is already a major example of such building integrated wind turbine in Bahrain. The first commercial-scale, building-integrated wind-energy system features in the 50 story, sail-shaped twin towers of the Bahrain World Trade Center (BWTC) in Manama, Bahrain, designed by the U.K.-based Atkins Design Studio. Three modified, 225 kW turbines made by the Danish company Norwin A/S are mounted on bridges spanning the two towers. In this configuration, the turbines are stationary, oriented to capture the prevailing winds coming off the Arabian Gulf. There is also another major proposal of building integrated wind turbine in the 71-story, 2.3 million square-foot (210,000 m<sup>2</sup>) Pearl River Tower in Guangzhou, China, designed by Skidmore, Owings and Merrill (SOM). The building, currently under construction and will have four openings that extend through the broad face of the building, two about one-third of the way up and the other two about two-thirds of the way up. At these openings, prevailing winds will be funneled into vertical-axis wind turbines, generating electricity (Wilson, 2009).

However, there are some counter arguments against the building integrated wind turbines as their performance is questionable. “The best wind-turbine performance happens with strong *laminar* wind, in which all of the air flows in a single direction. However, on top of even very tall buildings, wind flow is highly turbulent. Bob Thresher, director of the National Wind Technology Center at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, explains that as wind flow comes over the edge of a roof or around a corner, it separates into streams. ‘Separating the flow creates a lot of turbulence,’ he told *EBN*” (Wilson, 2009).

According to the small wind technology expert at the American Wind Energy Association (AWEA), Ron Stimmel, turbulent flow confuses a wind turbine, affecting its performance. According to him even if it is really windy on top of a building, it’s more turbulent

than steady wind. “A common rule of thumb, according to Stimmel, is to elevate a wind turbine at least 30 feet (9 m) above anything within a 500-foot (150 m) radius, including the building itself.

What about the increased wind velocity at building parapets that manufacturers like AeroVironment use? Although AeroVironment’s turbines harvest this band of higher-velocity wind, they do so only in a fairly narrow band, which limits the potential size and output of wind turbines. Because the turbines are small, the economics are not as attractive as with larger wind turbines” (Wilson, 2009).

Beside few problems there are huge potential in the development of building integrated wind turbines particularly in case of tall aerodynamically designed buildings with large generation capacity. “ The potential energy production and consequent carbon dioxide emissions reductions that can be expected from Building-Mounted/Integrated Wind Turbines (BUWTs) is dependent on the distribution of suitable building structures with respect to wind regime, the possible enhancement of energy capture due to optimal siting of the installation on the building, and the uptake of devices within the building stock.

It is clear that while BUWTs are, perhaps, most easily adopted in new building configurations (an estimated 66 MW per annum capacity at 5percent penetration level); the technology could have a substantially bigger impact from retro-fitting to existing buildings, particularly in the non-domestic sector.” (Dutton, 2005).

### ***Solar photovoltaic:***

Photovoltaic is best known as a method for generating electric power by using solar cells to converting energy from the sunrays into electricity. The photovoltaic effect refers to the knocking of electrons into a higher energy state by photons of light to create electricity. The term



photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the light energy. Virtually all photovoltaic devices are some type of photodiode (Goetzberger, 2003).

Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. The first practical application of photovoltaic was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for grid connected power generation. In this case an inverter is required to convert the DC to AC. There is a smaller market for off grid power for remote dwellings, roadside emergency telephones, remote sensing, and cathodic protection of pipelines.

Although the photovoltaic is the most popular and most commonly known technology for converting solar energy to electricity there are some arguments against its efficiency. Net energy calculations for current photovoltaic technologies are controversial. Although promoters of the technology staunchly claim a favorable figure, so far conventional silicon crystal cells had a relatively low return for the energy invested in their manufacture. Typically promoters exclude from their analysis the energy expended in transportation as well as that embodied in production facilities. In this instance at least, net energy payback is highly sensitive to the volume of production. PV modules are still manufactured on a very small scale; if demand increases, the energy returned on invested would likely rise very noticeably. "It is likely that, even if the most pessimistic assessments of silicon-crystal cells – which suggest a current net return of less than 1:1 – are correct, the newer thin-film and DSC technologies may be able to achieve a substantially more favorable EROEI (The more optimistic assessments of silicon crystal cells suggest a current net return of roughly 10). At some point the net energy available from PV

electricity will overtake the EROEI that can be derived from petroleum, as the latter is depleted” (Heinberg, 2003).

Recently there are many new developments happening in this field. One attractive strategy is the development of solar cells that are based on the sensitization of mesoscopic oxide films by dyes or quantum dots. “These systems have already reached conversion efficiencies exceeding 11 percent. The underlying fundamental processes of light harvesting by the sensitizer, heterogeneous electron transfer from the electronically excited chromophore into the conduction band of the semiconductor oxide, and percolative migration of the injected electrons through the mesoporous film to the collector electrode will be described below in detail. A number of research topics will also be discussed, and the examples for the first outdoor application of such solar cells will be provided” (Grätzel, 2005).

Other than a few negative aspects solar photovoltaic technology has many major advantages. As it is a direct mode of converting solar power to electricity and as it can be produced and used in small modules it has immense flexibility of use in different scale and in remotest areas. Presently solar photovoltaic technology is developing at the fastest rate. “Grid-connected solar photovoltaic (PV) continued to be the fastest growing power generation technology, with a 70-percent increase in existing capacity to 13 GW in 2008. This represents a six-fold increase in global capacity since 2004. Annual installations of grid-tied solar PV reached an estimated 5.4 GW in 2008. Spain became the clear market leader, with 2.6 GW of new capacity installed, representing half of global installations and a fivefold increase over the 550 MW added in Spain in 2007. Spain’s unprecedented surge surpassed former PV leader Germany, which installed 1.5 GW in 2008. Other leading markets in 2008 were the United States (310 MW added), South Korea (200–270 MW), Japan (240 MW), and Italy (200–300 MW). Markets in

Australia, Canada, China, France, and India also continued to grow. The beginnings of growing grid-tied solar PV markets emerged in several countries in 2007/2008, notably China. Including off-grid applications, total PV existing worldwide in 2008 increased to more than 16 GW” (Residential & Commercial Overview, 2008).

### **Possible Building Integration:**

Due the great flexibility of its use the solar PV cells are frequently used as integrated with buildings. Initially it was integrated as individual panels placed on the roof or on sun facing surface, but with the development of the thin film technology the use of building integrated PV cells has now immense possibilities. One major development is PV integration within glass panels. A recent such development is solar glass. Solar glass is one kind of solar installation which is called Building Integrated Photo-Voltaic (BIPV). It is a kind of solar cell that can be incorporated into a house or building in a virtually seamless way. Besides the fact that Solar glass generates electricity, it is aesthetically pleasing. Moreover it occupies building surfaces that would otherwise require reflective glass and window shades to avoid the sun's heat. Besides all advantages solar glass has a disadvantage of cost effectiveness. According to Thomas “The only drawback to solar glass is that doesn't produce much electricity, and it's fairly expensive (about five times as much as regular glass, not counting components such as wiring and inverters).

On a strict analysis of energy cost savings, integrated solar glass rarely pays for itself. Nevertheless, that does not deter architects and owners around the world from installing it. Solar glass generates electricity at a predictable cost, qualifies for financial incentives and often has Park publicity value. Not to mention the uniqueness of a building with custom glazing that generates electricity” (Thomas, Solar Glass at Hong Kong Science Park, 2006). Other than the

solar glass there are many similar development as an example P.V. laminates, P.V. louvers etc. that can be easily integrated with the buildings.

### ***Solar Chimneys:***

The solar updraft tower is a proposed type of renewable-energy power plant. Although the theoretical concept is nearly a century old, the technology has not yet been commercially used. In 1903, Isidoro Cabanyes published the idea of solar updraft tower in the magazine 'Electrical Energy'. In 1982, the German Ministry of Investigation and Technology collaborated with Spanish Power Company Union Fenosa, to promote and finance the construction of a solar tower prototype. This project was based on Isidoro Cabanyes principle and was built 150 km south of Madrid. This medium-scale working model which had a 195 meters tall chimney with a diameter of 10 meters, with a collection area (greenhouse) of 46,000 m<sup>2</sup> (about 244 meter diameter) obtained a maximum power output of about 50 kW. During operation, optimization data was collected on a second-by-second basis. Approximately for eight years this power plant operated. But later it encountered severe structural instability close to the tower due to induced vortices, and was decommissioned in 1989 (Szczygielski, 2009).

The 'Solar Tower' combines three old and proven technologies: the chimney effect, the greenhouse effect, and the wind turbine. "The solar chimney's three essential elements - glass roof collector, chimney, and wind turbines - have thus been familiar from time immemorial. A solar-thermal chimney simply combines them in a new way. Air is heated by solar radiation under a low circular glass roof open at the periphery; this and the natural ground below it form a hot air collector. Continuous 24-hour operation is guaranteed by placing tight water-filled tubes under the roof. The water heats up during the daytime and emits its heat at night. These tubes are filled only once, no further water is needed. In the middle of the roof is a vertical chimney with

large air inlets at its base. The joint between the roof and the chimney base is airtight. As hot air is lighter than cold air it rises up the chimney. Suction from the chimney then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Thus solar radiation causes a constant updraft in the chimney. The energy this contains is converted into mechanical energy by pressure-staged wind turbines at the base of the chimney, and into electrical energy by conventional generators” (Schlaich J. , 1995).

After a successful practical implementation of a prototype plant at Manzanares, Spain now there are several proposals for construction of new solar towers across the globe. In Australia a 200 MW solar tower is currently projected by the company Enviromission Ltd. This proposed plant’s collector will be a glass structure of 5 km diameter and its tower will be 1 km high (Enviromission, 2010).

Solar updraft towers can use all available solar light and do not need direct sunlight only, which is an advantage over concentrating solar power (CSP) technologies that allow them to be installed in a greater variety of climates. Solar updraft towers may have various advantages over CSP technologies. They use all available solar light, which allow them to be installed in a greater variety of climates. In a typical solar chimney power plant thermal storage is offered by the ground itself and can be enhanced by simple water-filled bags in the collector for base-load electricity production. Low efficiency is a disadvantage. Usually the efficiency is close to 1percent, thus requiring much larger land areas for similar capacities. The power output is a function of the size of the collector multiplied by the tower’s height so economies of scale are important for this technology. As such, they may find their way in tropical areas where insufficient direct sunlight does allow for effective CSP technologies (Philibert, 2005).

Financially solar updraft tower is also a practical theory. “Net energy payback is estimated to be 2-3 years, which can be considered short. A 200 MW solar tower would cost over a billion dollars to build, or EUR 5 million per MW. According to a 2005 industry report, this would imply power generation costs of about USD 0.10 per kWh, which is near grid-parity and represents roughly a third of the cost of electricity from current solar cells” (Szczygielski, 2009).

### **Possible Building Integration:**

The solar chimney is a good technology with a possibility to be used as an integrated with a high-rise building. At present there is one major negative aspect regarding the financial viability of a solar chimney. For the power generation the system needs a tall chimney, which requires a huge financial involvement. However, if a chimney is integrated within a double skin façade of a high-rise building then the cost can be reduced substantially. Moreover as the system has no green house gas emission, envelop can supply a considerable amount of energy without considerable environmental effect.

## **Development of Design, And Preliminary Testing of Building Integrated Solar Thermal Updraft Façade**

This chapter attempts to investigate the possibility of using the technique of solar chimney within a double skin envelop system of a tall building façade. Solar chimney and double skin facades are two already established technologies. Solar chimney power plants have huge solar collector surface at ground plane leading to a high cost. This research presents the possibility of integration of solar chimney collector surface and the vertical chimney within a double skin façade of a high-rise. A module of such a double skin envelop system was designed,

built and tested. This chapter presents the experimental facilities, theoretical design principles, results of the experiment and analysis of such a building integrated envelop system.

### **Introduction:**

Often buildings have a large façade exposed to sun that provides a great amount of insolation (the intrusion of solar heat into the building envelope), which is not always desired. This situation exacerbated by buildings that are large in scale with extensive use of glazed surfaces (windows), as is the case with many residential and commercial high-rise buildings. In intensive use high-rise buildings energy is primarily used for HVAC and illumination systems. Natural ventilation can save the power need of HVAC, but as the air velocity increases drastically with the increased height it is difficult to naturally ventilate a high-rise building. Using daylight for illumination can save the energy requirement considerably but it increases cooling load. It is difficult to balance the use of glazed surface for daylight and use of HVAC for cooling. A double skin facade is a potential solution to this problem.

A double-skin façade is a system of two layers of glazing offset by a large air gap. Solar heat is trapped in the area between the two layers, and so does not adversely affect the conditioned space of the building. Hot air is usually directly exhausted to the atmosphere. In high-rise buildings beside natural ventilation a double skin envelop-system can work as a solar chimney to produce power using the solar insolation.

### ***Solar Chimney:***

A solar chimney uses solar thermal energy and pressure difference between the top and bottom ends of a tall chimney to generate an updraft air movement which is further utilized to generate power. This idea was originally proposed by Professor J. Schlaich of Stuttgart in 1968. The successful experimental project of Manzanares produced an updraft up to 12 m/s. Operating

costs of this chimney were minimal. This proved the feasibility and reliability of this novel technology.

A solar chimney usually consists of three principal components: (1) solar collector, (2) chimney, and (3) turbine. The collector is a large sloped surface covered by a transparent glazing and supported a few meters above the ground. It is used to heat up the air inside it by solar insolation. Along the sloped surface buoyancy drives the warmer air into the chimney, placed at the centre of the collector. A turbine placed in the path of the airflow converts the kinetic energy air to electricity. A water-storage system is used as thermal mass within collector to increase the power production at night.

The efficiency of a solar tower can be increased with the increase of tower height and collector area. However the primary problem with solar chimney is the high initial investment cost to construct a tall chimney and a huge ground area for the solar collector. According to the estimate by Haaf et.al made in 1983(Table4.3), the initial investment for a 100MW plant was \$663million which is much higher than the initial investment cost required for a thermal power plant of similar size. Some other recent estimates also suggest similar findings (Table4.4).



**Table 4.3 Power generating costs analyzed by Haaf et al., 1983 (Pasumarthi, Experimental and theoretical performance of a demonstration solar chimney model—part ii: experimental and theoretical results and economic analysis, 1998)**

Annual mean solar radiation	274W/sqm
Mean daily output	36MW
Annual energy production	280 GWh
Chimney height	1000 m
Chimney radius	88 m
Collector radius	2182 m
Peak daily output (approx.)	100 MW
Investment	
Chimney structure	\$126 million
Wind turbine/Generator	\$71.5 million
Collector (glass)	\$350 million
Collector (plastic film)	\$214 million
Total (with glass canopy)	\$547 million
Total (with plastic film canopy)	\$663 million
Average power cost over 20 yr	\$0.19 kWh~1

**Assumptions:**

Amortization period: 20 year; Life of plastic film: 7 year; Life of glass canopy: 20 year; Maintenance cost: 2)5percent (in relation to investment); Rate of inflation: 5percent.

**Table 4.4 Investment cost and LEC (Schlaich J. B., Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flows for Power Generation)**

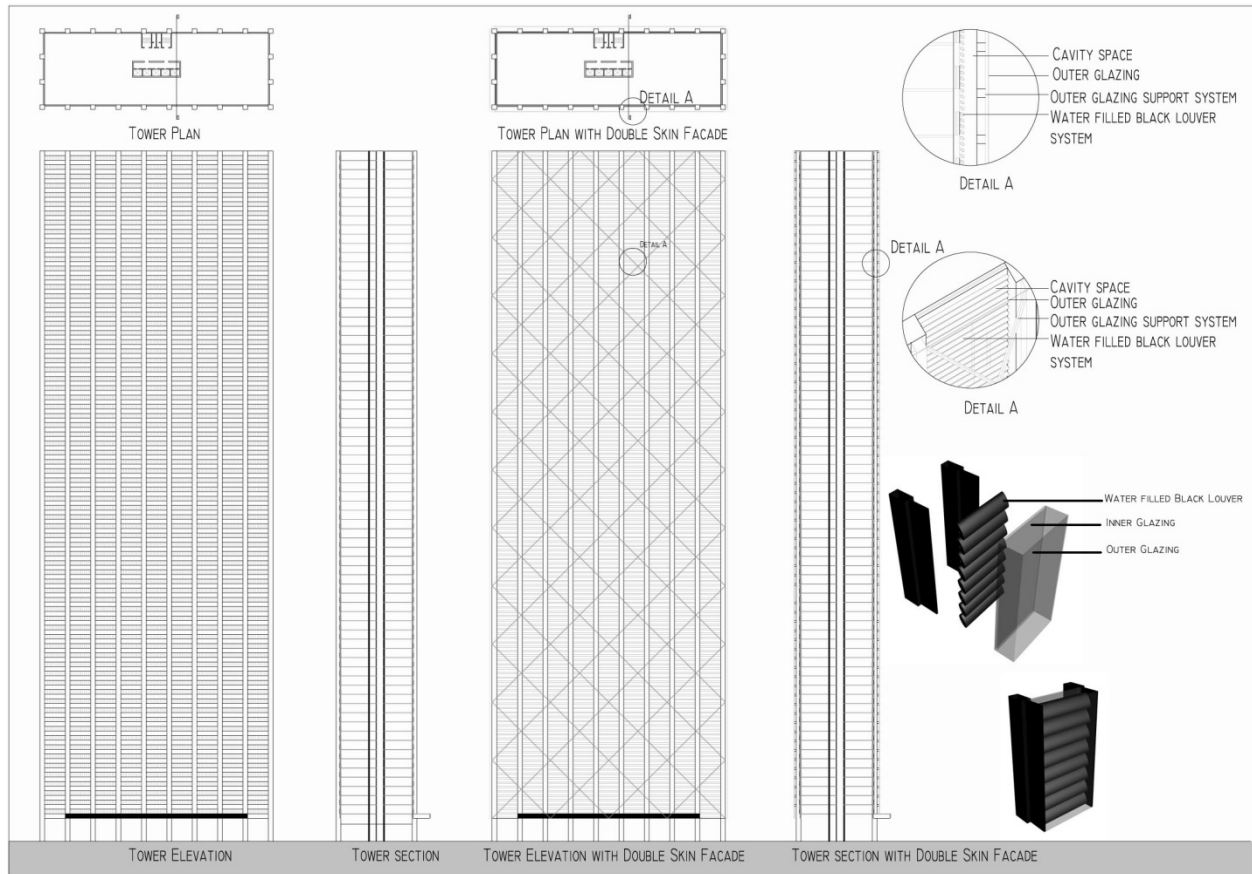
Capacity	MW	5	30	100	200
tower cost	Mio. €	19	49	156	170
collector cost(A)	Mio. €	10	48	107	261
turbine cost	Mio. €	8	32	75	133
engineering, tests, misc.	Mio. €	5	16	40	42
total	Mio. €	42	145	378	606
annuity on investment	Mio. €/a	2.7	10.2	27.1	43.7
annual operation & maintenance cost	Mio. €/a	0.2	0.6	1.7	2.8
levelized electricity cost (LEC) (B)	€/kWh	0.21	0.11	0.09	0.07
A cost for unskilled labor assumed to be 5 €/h					
B at an interest rate of 6 percent and a depreciation time of 30 years					

***The solar chimney envelops system:***

An analysis of the estimates shows the reason behind high cost. The estimates of Table 4.3 and Table 4.4 shows that the principle investment is required for the construction of tower and the collector surface, moreover above estimates doesn't consider the land cost. This problem of initial investment can be solved if the solar chimney is integrated within a double skin envelop system of a high-rise building. Due to the low temperature rise solar chimney is a safe technique compared to other solar thermal renewable energy systems and it can be easily integrated with any high-rise building only if the height is considerable. High-rise buildings can provide the required height and the building envelop can provide the required surface area for solar collector. In such a case the façade can be conceived as composed by a series of parallel vertical solar chimneys. Manzanares prototype plant had a collector area of nearly 45000 m<sup>2</sup> with a tower 195m tall. Many New York skyscrapers have a south façade nearly of that area, as an example the central tower of Rockefeller centre has nearly 25000 m<sup>2</sup> south façade with a height of 259 m

and Met life building has nearly 25000 m<sup>2</sup> south façade with a height of 246 m. With a solar chimney envelop system any of these buildings can generate power. The principal difference in such an envelope system is the orientation of solar collector. In Manzanares the collector was in

**Figure 4.4 Double skin updraft system can be applied on an existing façade**

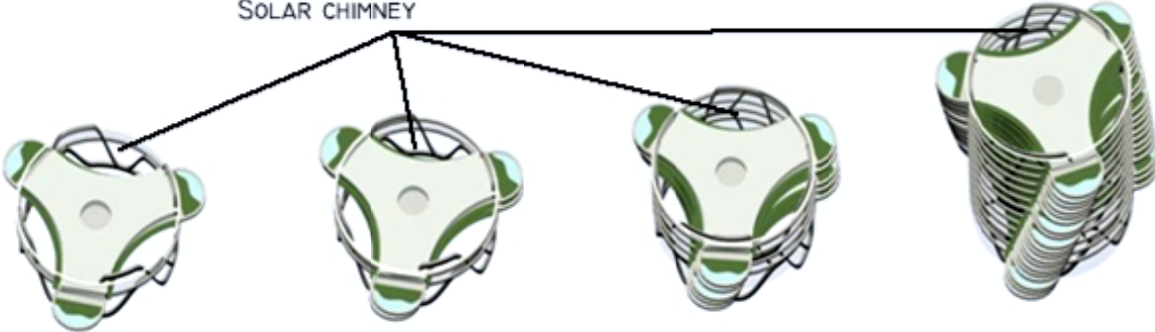


the horizontal plane whereas a solar chimney facade system proposes it on a vertical plane which also reduces the requirement of huge land area. An experiment with a solar chimney model has been carried out in Kansas State University to check the effectiveness of such a vertical solar collector. The model was made as a prototype module of such an envelope system. This chapter tries to find out the possibility of this idea by design, preliminary testing and analysis of the performance of a double skin chimney in isolation.

Figure 4.5 A solar updraft double skin façade system can be designed as an integrated part of a new high-rise building (Design entry by Author to Evolo Skyscraper Competition 2010)



SOLAR CHIMNEY



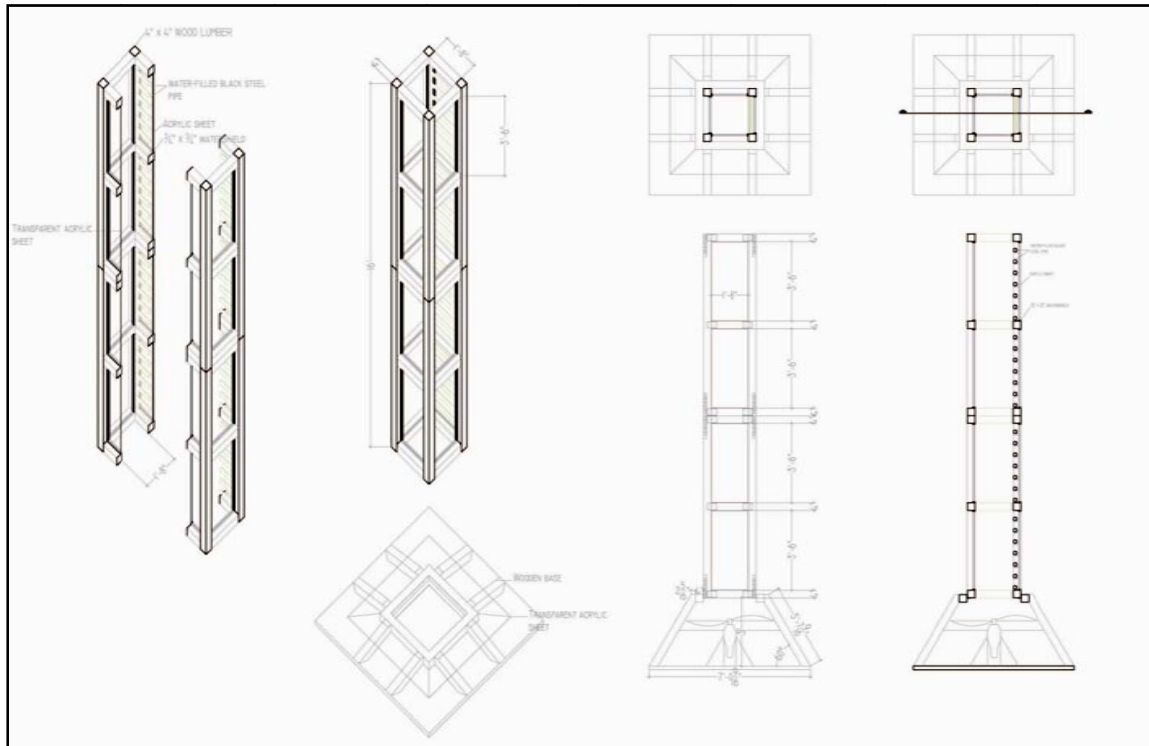
**Figure 4.6 Interior view of the solar chimney showing the wind turbines (Design : Author)**



***Description of the model system:***

For this experiment the prototype was designed as a small segment of a solar updraft double skin façade system. A prototype of the double skin envelop system integrated with a louver system that can work as a thermal mass was designed, constructed and tested for the air flow performance. Figure 4.7 illustrates the prototype double skin envelop solar chimney. The 2.4m (eight feet) and 4.8 m (sixteen feet) tall square base towers were built with weather shield .1 m x .1 m x .2 m(4 In. x 4 In. x 8 Ft) pressure treated lumber joined with metal crown bolt .056 m x .0262 m x .018 m(2-1/4 In. x 1-1/2 In. x .72 in) angle slotted Off set zinc plated and TP35-R Tie Plates. Acrylic sheets (Optix 36 x 72 x .220 ) were used as glazing and .6 m (2') long .05 m (2")  $\phi$  polyethylene tube filled with water were used as thermal mass on collector surface.

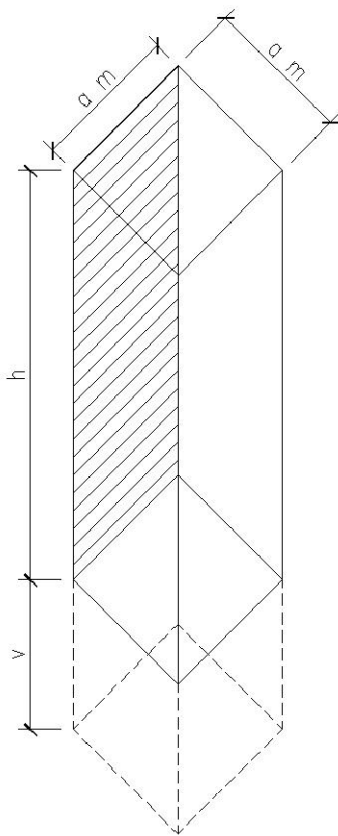
Figure 4.7 Solar chimney model 2.4m top left and 4.8m top right; Drawings at bottom



Water has a high thermal capacity so it can work as a good thermal mass and stores the heat received from sun. This thermal mass could radiate heat and make the system work during the night when the sun was not available. The chimney tower was tied with metal wires to give stability. The top and bottom of the chimney was kept open to allow wind to flow through the chimney freely without any obstacle. An experiment by the Angui Li, Phillip Jones, Pingge Zao and Liping Wang in Cardiff university shows that the chimney performs best when the cross sectional ratio of width to the height is 1:10 (Li A. J., 2004). Therefore in this experiment the width to the height ratio of the tower has been kept as 1:9.6.

***System Airflow analytical model:***

**Figure 4.8 Theoretical model**



Let us consider a solar chimney with cross sectional area ‘A’ $m^2$  and height ‘h’ $m$ . Let us consider three sides as glazed surface with a collector area of  $(1 \times h)m^2$ . The collector will heat up by solar insolation and it will heat up the adjacent air within the chimney which will develop an updraft within the chimney. Gradually a steady state will develop when there will be no increase in temperature and the updraft will reach to its maximum. Some previous researches (Pasumarthi & Sherif, 1998) have developed detail analytical models. Without going to much complexity and to find out an approximate maximum temperature and approximate maximum air velocity within the chimney at a

‘steady state’ (when the temperature of the collector surface is not increasing and the total

insolation energy is being used in the temperature and velocity rise of the air inside the chimney).

Assumptions:

1. 2-D steady flow
2. Constant property condition in which gravity acts in the negative y-direction
3. Incompressible flow
4. Assume boundary layer approximations are valid
5. Fully developed – Narrow channel (chimney) long enough so U-scale becomes negligible

Nomenclature;

$C_p$	air constant pressure specific heat, J/kg·°K;
$A$	Cross sectional area of chimney, m;
$g$	gravitational acceleration, 9.8 m/s <sup>2</sup> ;
$h$	chimney height above collector inlet, m;
$\rho$	chimney air density, kg/m <sup>3</sup> ;
$T_\infty$	outside air temperature, °K;
$\Delta t$	temperature rise, °K;
$v$	Air velocity, m/sec;
$j$	Heat outflow, joules/m <sup>2</sup> /sec;
$h$	Height of chimney, m;
$A$	Chimney cross sectional area, m <sup>2</sup> ;
$V$	Maximum air velocity inside chimney, m/sec;
$\Delta T$	Maximum temperature rise inside chimney, °K;
$\eta_{coll}$	Collector efficiency



- $\alpha$  Effective absorption coefficient of collector,  $w/m^2K$ ;
- $\beta$  Loss correction value allowing for emission and convection losses,  $w/m^2K$ ;
- $G$  Available radiation on collector surface,  $w/m^2$ ;
- $a$  Collector width, m;

Collector efficiency is given in equation 7 (Schlaich J. , 1995)

$$\eta_{coll} = \alpha - \beta * \frac{\Delta t}{G}$$

$$j = \eta_{coll} * h * a * G \text{-----} (1)$$

$$\Delta t = j * h * a \frac{1}{C_p * \rho * A * (v + h)} \text{-----} (2)$$

Now from the equation for the wind velocity inside the chimney given in (Schlaich J. ,

1995) we get,  $v = \sqrt{2gh \frac{\Delta t}{T_{\infty}}}$

$$\Delta t = v^2 * \frac{T_{\infty}}{2gh} \text{-----} (3)$$

Equating (2) and (3),

$$\frac{jha}{C_p * \rho * A * (v + h)} = \frac{v^2 T_{\infty}}{2gh} \text{-----} (4)$$

$$\frac{jh * 2gh}{C_p * \rho * A * T_{\infty}} = v^2 (v + h) \text{-----} (5)$$

$$\frac{2jgh^2}{C_p * \rho * A * T_{\infty}} = v^2 (v + h) \text{-----} (6)$$

Let us consider the maximum temperature of air at steady state is  $\Delta T$ . At the steady state  $\Delta T$  will be approximately equal to arithmetic mean of  $\Delta t$  and  $h * \Delta t/v$ .

$$\Delta T = \frac{\Delta t + h * \frac{\Delta t}{v}}{2} \text{-----} (7)$$

Let us consider the maximum air velocity within the chimney is  $V$ .

Now,  $V = \sqrt{\frac{2gh * \Delta T}{T_{\infty}}} \text{-----} (8)$

Using the value of  $\Delta T$  from eq. (7)

$$V = \sqrt{2gh * \frac{\Delta t + h * \frac{\Delta t}{v}}{2T_{\infty}}} \text{----- (9)}$$

$$V = \sqrt{2gh * \Delta t \frac{(1 + \frac{h}{v})}{2T_{\infty}}} \text{----- (10)}$$

$$V = \sqrt{v^2 \frac{(1 + \frac{h}{v})}{2}} \text{----- (11)}$$

$$V_{appx} = \sqrt{v \frac{(v + h)}{2}} \text{----- (12)}$$

### ***Results:***

The solar chimney was evaluated using the theoretical model and a practical experiment. The practical test was done in three stages. In the first stage the chimney height was 2.4 m which was later increased to 4.8 m then the height was again reduced to 3m. The wind velocity was measured using a velocity stick and the temperature was measured using data loggers and velocity stick. Tables 4.5 and Table 4.6 present experimental temperature and wind speed were recorded inside and outside the chimney for the two types of chimney studied. The speed of wind was not constant. So the two set of wind speed were recorded representing the maximum and minimum wind speed recorded over a period of one minute of observation. Another set of experimental observation were recorded using data logger. These data are presented in the Figures 4.9-4.13. These data logger reports also show the experimental conditions of humidity and illumination. The theoretically computed values based on the mathematical model of the paper are shown in Figures 4.14-4.18.

**Table 4.5 The 2.4m Chimney with open ends**

2.4m tall chimney							
Date	Time	chimney wind speed max(m/s)	chimney wind speed min(m/s)	Outside wind speed (m/s)	outside wind direction	Chimney wind temperatur e (°C)	outside wind temperature (°C)
12/4/2009	11:00AM	0.79	0.09	0.625	N->S	5	4.66
12/4/2009	11:45AM	0.71	0.07	2.785	N->S	1.11	0.246
12/4/2009	12:45PM	0.775	0.14	1.125	N->S	7.77	5.74
12/4/2009	1:45PM	0.7	0.075	0.875	N->S	8.4	5
12/4/2009	2:45PM	0.75	0.16	0.7	N->S	7.27	4.79
12/4/2009	4:45PM	0.3	0.025	0.625	N->S	-0.2	-2.1
12/5/2009	12:45PM	0.67	0.33	1.335	N<->S	6.67	5.12
12/5/2009	1:45PM	0.66	0.31	0.94	N<->S	9.61	7.49
12/5/2009	2:45PM	0.725	0.19	1.025	N<->S	13.33	10
12/5/2009	3:45PM	0.75	0.22	1.075	N<->S	9.55	5.4
12/5/2009	4:45PM	0.45	0.16	0.605	N<->S	5	4

**Table 4.6 The 4.8m tall and the 3m tall Chimney with open ends**

4.8 m tall chimney							
Date	Time	chimney wind speed max (m/s)	chimney wind speed min (m/s)	Outside wind speed (m/s)	outside wind direction	Chimney wind temperature (°C)	Outside wind temperature (°C)
1/22/2010	01:00PM	0.685	0.435	1.26	N<>S	11.49	9.7
1/22/2010	01:30PM	1.335	0.425	2.26	N<>S	15.65	12.5
1/22/2010	02:00PM	1.26	0.665	2.785	N<>S	19.98	15.27
1/22/2010	02:30PM	1.025	0.535	2.62	N<>S	20.62	15.3
1/22/2010	03:00PM	0.635	0.335	2.28	N<>S	15.29	10.19
1/22/2010	03:30PM	0.435	0.255	1.755	N<>S	11.88	8.99
1/22/2010	04:00PM	0.335	0.035	2.115	N<>S	11.19	9
1/22/2010	05:00PM	0.26	0	2.34	N<>S	9	7.69
3m tall							
1/30/2010	12:47PM	0.675	0.45	0.875	N<>S	15.8	14.57
1/30/2010	01:17PM	0.52	0.425	2.31	E<>W	20.74	16.48
1/30/2010	01:47PM	0.685	0.37	0.69	NE<>SW	17.96	16.36
1/30/2010	02:17PM	0.835	0.54	0.89	N<>S	23.5	16.65
1/30/2010	02:47PM	0.925	0.615	0.96	N<>S	26	17.2
1/30/2010	03:17PM	1.01	0.665	1.835	N<>S	23.47	3.5
1/30/2010	03:47PM	0.535	0.255	1.755	N<>S	5.97	1.45
1/30/2010	04:17PM	0.435	0.035	2.115	N<>S	2.77	0.96
3 m tall chimney							
2/2/2010	012:48PM	0.84	0.44	3.05	E>W	15.34	10.39
2/2/2010	01:18PM	0.96	0.635	1.69	SE>NW	19.79	12.38
2/2/2010	01:48PM	0.685	0.4	3	NE<>SW	20.9	14.6
2/2/2010	02:18PM	1.025	0.835	0.63	N>S	23	17.67
2/2/2010	02:48PM	0.72	0.385	3.06	NE>SW	22.29	16.77
2/2/2010	03:18PM					18.67	6.33

	2/2/2010	03:48PM	0.495	0.135	0.615	N>S	8.39	5.07
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**Figure 4.9 Temperature rise and wind velocity inside solar chimney envelop system 12/04/2009**

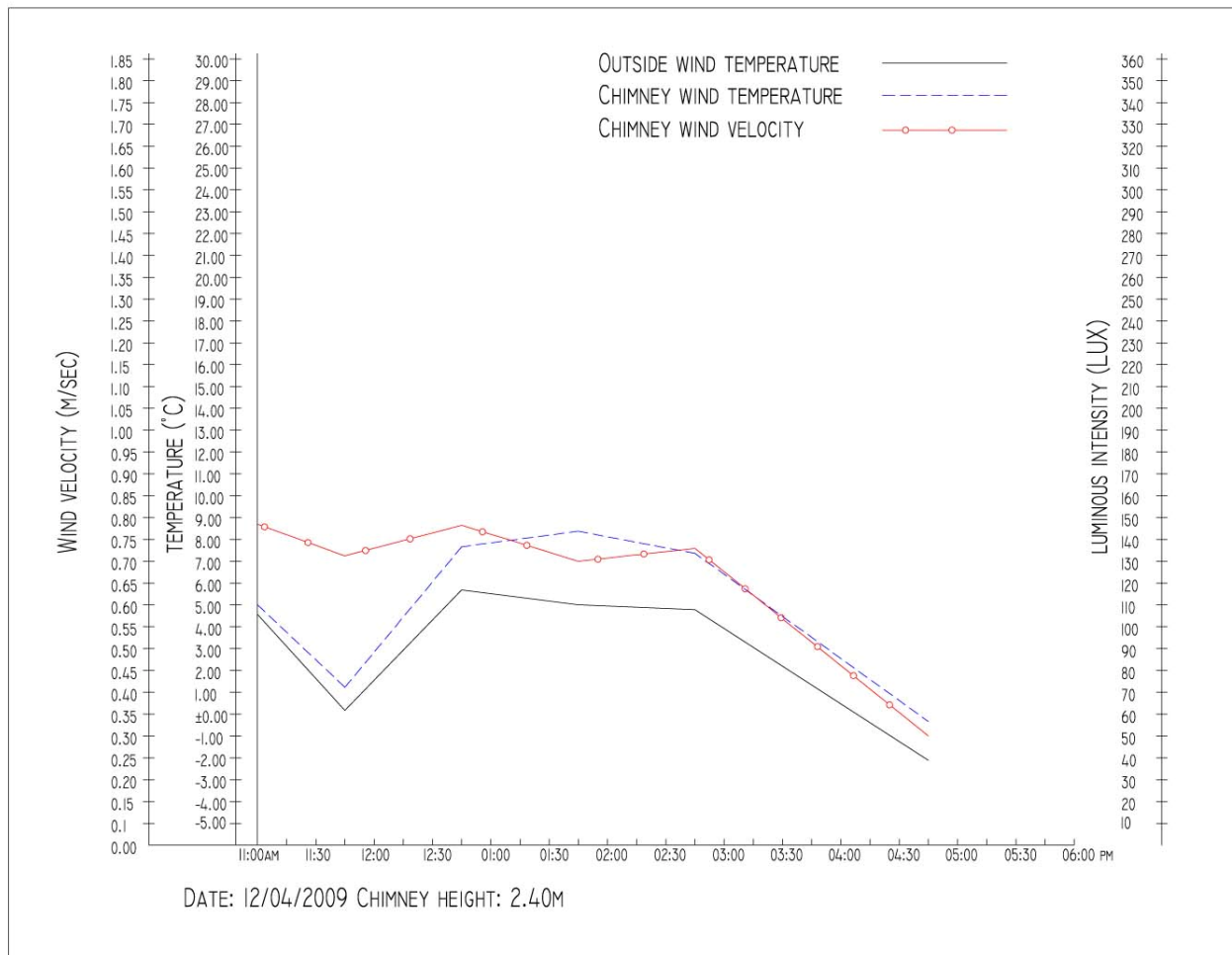


Figure 4.9 shows the temperature rise and wind velocity inside the chimney of 2.4 m height on 4th December. The chain-link line shows wind velocity within chimney, the dotted line shows the wind temperature variation inside chimney and the firm line shows outside wind temperature. The graphs clearly show a steady temperature rise inside the chimney as the day progressed. At 1.45pm the temperature inside chimney reached a maximum of 8.4°C when the outside temperature was 5°C. The graphs also show a clear relation between the temperature rise

and wind velocity. Although there was one anomalous result at 2 pm when the temperature inside chimney was maximum but the wind velocity slightly dipped.

**Figure 4.10 Temperature rise and wind velocity inside solar chimney envelop system  
12/05/2009**

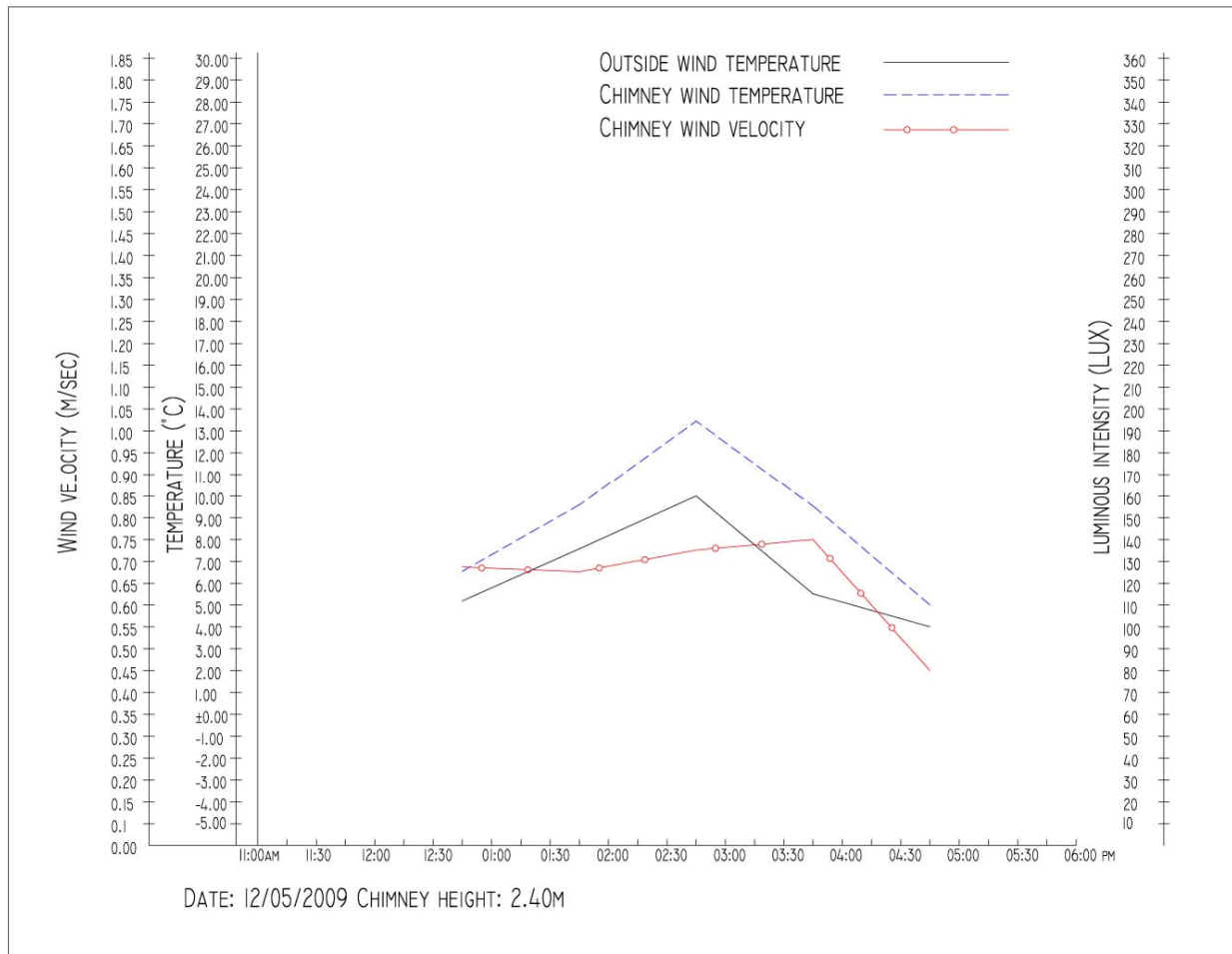


Figure 4.10 shows the information recorded on 5th December for the chimney of 2.4m height. Here also the chain-link line shows wind velocity within chimney, the dotted line shows the wind temperature variation inside chimney and the firm line shows outside wind temperature. These graphs show a clear relation between temperature rise and wind velocity inside the chimney without any anomaly. Temperature air inside the chimney and the wind velocity peaked at 2.30 pm. At peak temperature inside chimney was 14°C and the respective wind velocity was

.85 m/sec. At that time outside wind temperature was 10°C. These graphs also show that although outside temperature peaked at about 4 pm, temperature inside chimney dropped. It happened because the chimney came under the shadow of adjoining building since 3 pm.

**Figure 4.11 Temperature rise and wind velocity inside solar chimney envelop system01/22/2010**

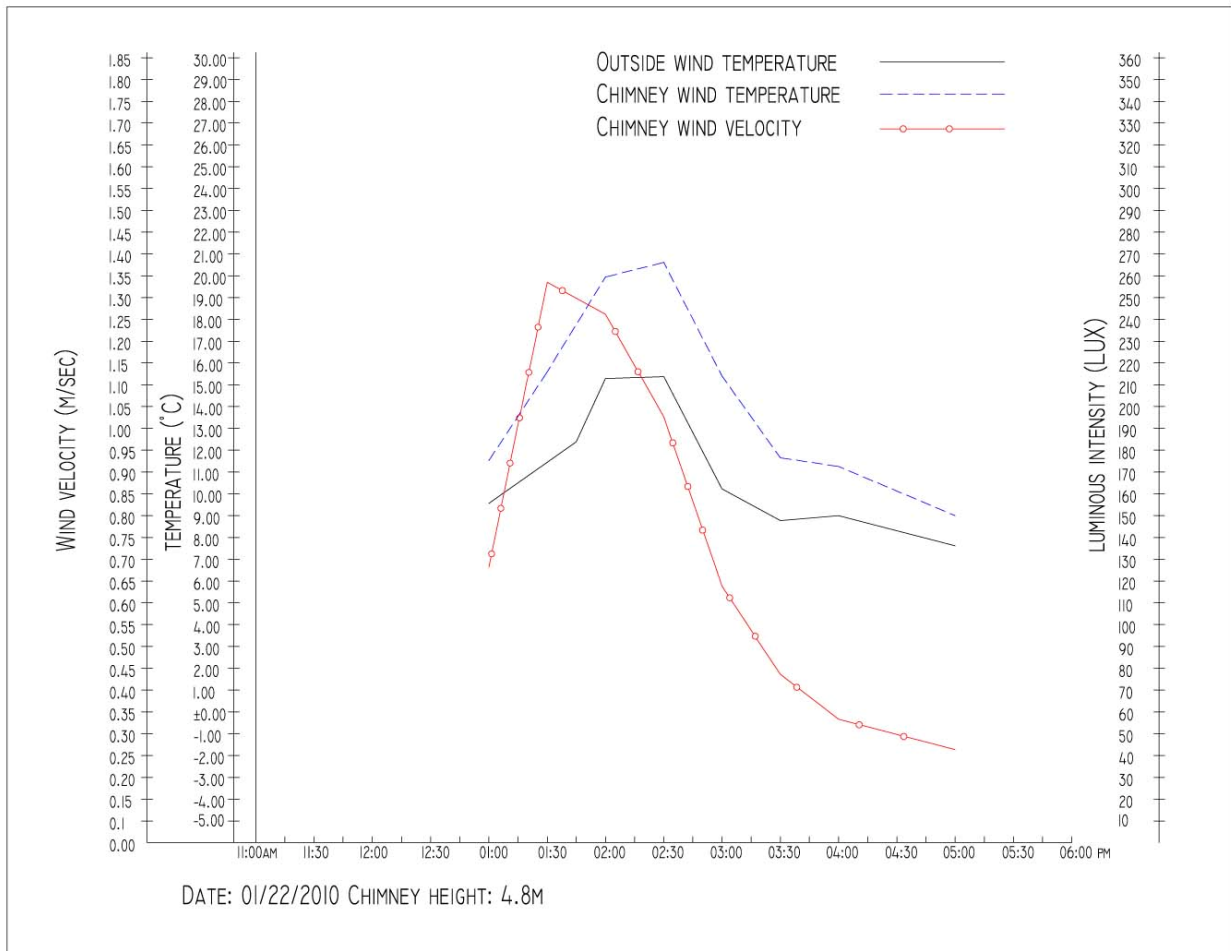


Figure 4.11 shows the information recorded on 22nd January for the chimney of 4.8 m height. These graphs show a clear relation between temperature rise inside the chimney.

Temperature air inside the chimney and the wind velocity peaked at 2.45 pm. At peak temperature inside chimney was 20.62°C. At that time outside wind temperature was 15.3°C.

**Figure 4.12 Temperature rise and wind velocity inside solar chimney envelop system 01/30/2010**

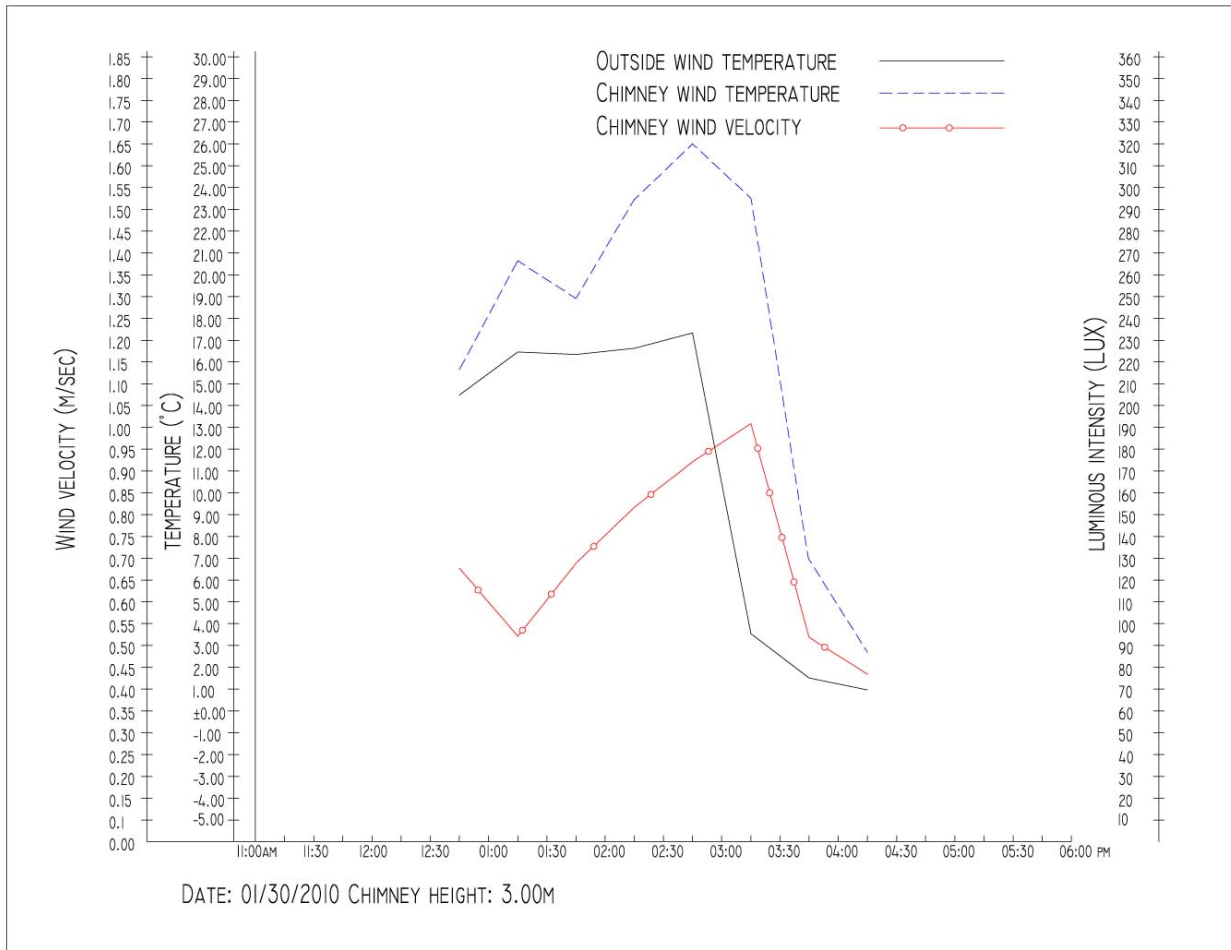


Figure 4.12 shows the information recorded on 30th January for the chimney of 3 m height. These graphs show a clear relation between temperature rise and wind velocity inside the chimney. Temperature air inside the chimney and the wind velocity peaked at 2.47 pm. At peak temperature inside chimney was 26°C. Outside wind temperature also peaked simultaneously



and it was 17.2°C. Wind velocity inside chimney peaked at 3.17pm and the respective wind velocity was 1.01 m/sec.

**Figure 4.13 Temperature rise and wind velocity inside solar chimney envelop system 02/02/2010**

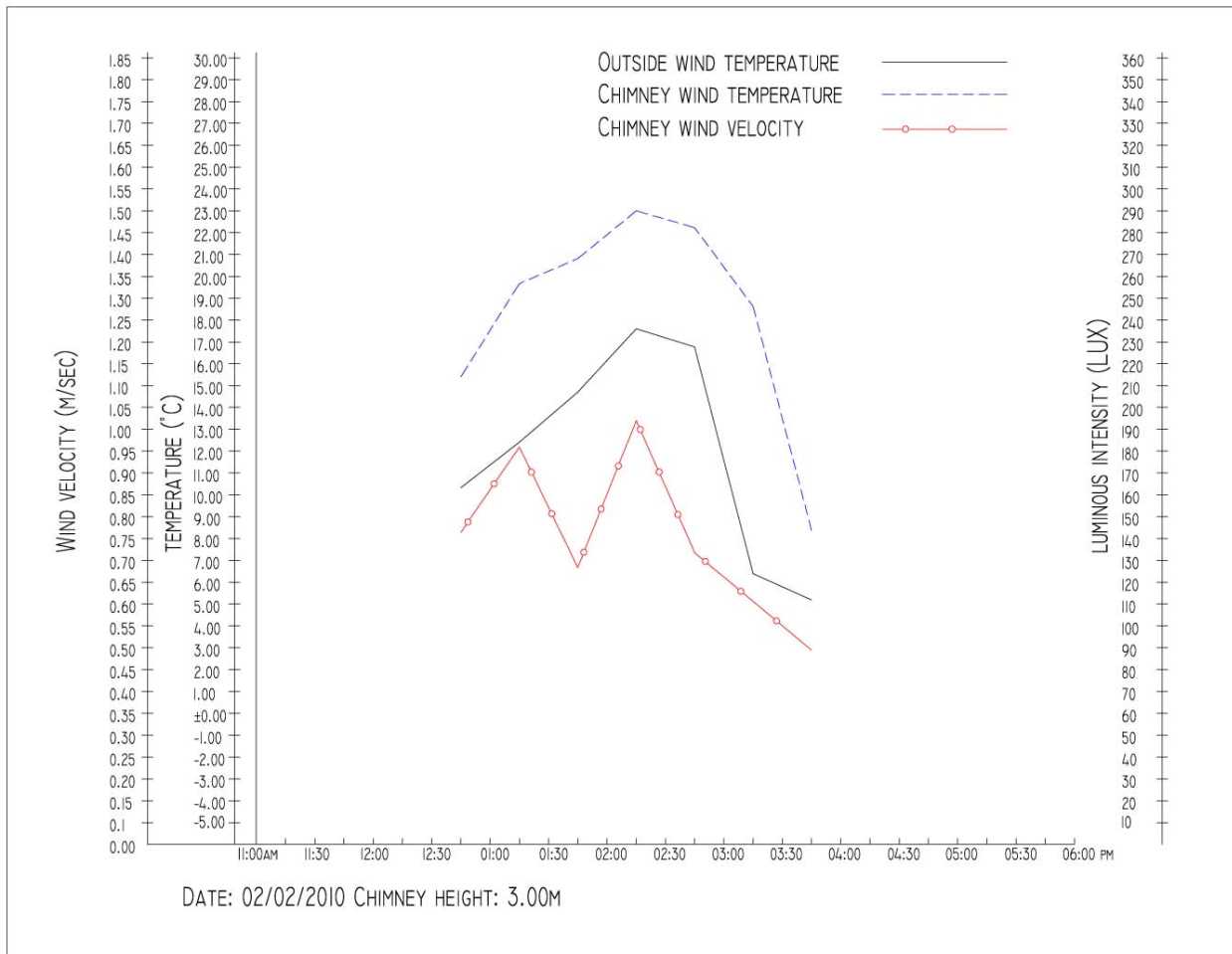


Figure 4.13 shows the information recorded on 2nd February for the chimney of 3 m height. These graphs show a steady temperature rise but wind velocity inside the chimney was anomalous. Temperature air inside the chimney and the wind velocity peaked at 2.18 pm. At peak temperature inside chimney was 23°C. Outside wind temperature also peaked

simultaneously and it was 17.67°C. Wind velocity inside chimney peaked at 2.18pm and the respective wind velocity was 1.025 m/sec.

### ***Discussion:***

The experiment finding shows that in a clear day a significant rise in the temperature inside the chimney is possible. On January 22<sup>nd</sup> the maximum temperature rise was 6.3°C, on January 30<sup>th</sup> the maximum temperature rise was 8.8°C (moreover the temperature inside envelop system remained steady while the outside temperature dropped abruptly and for a brief period the temperature difference was nearly 20°C) and on February 2<sup>nd</sup> the maximum temperature rise was 6.3°C. This is a positive result as with such temperature rise significant updraft can be generated inside the double skin envelop system of a high-rise building.

The equation for wind velocity inside a solar chimney is  $v = \sqrt{2gh \frac{\Delta t}{T_{\infty}}}$  (Schlaich J. , 1995). According to this equation on an average day with 27°C (300K) outside air temperature 8°C air temperature rise inside the solar updraft façade of a 250 m tall high-rise can generate 11.4 m/s wind velocity. In Manzanares plant maximum 12 m/s wind velocity was achieved (Schlaich J. , 1995). This shows that 11.4m/s wind velocity is significantly high to generate electricity. Moreover with a taller chimney height the temperature rise can be significantly more than what has been achieved in this research.

With the temperature rise there was a rise in wind velocity inside the chimney. The maximum velocity achieved in 2.4 m tall chimney was approximately 0.775 m/sec and the maximum temperature rise was approximately 7.78°C. When the 2.4 m tall chimney temperature reached maximum at that point of time the ambient air temperature was 5.55°C. The maximum velocity achieved in 4.8m tall chimney was approximately 1.335m/sec and the maximum

temperature rise was approximately 8.33°C. When the 4.8m tall chimney temperature reached maximum at that point of time the ambient air temperature was 11.11°C. Although wind velocity inside the chimney increased but sometimes the rise didn't confirm the theoretical prediction which was predicted using the equation  $v = \sqrt{2gh \frac{\Delta t}{T_{\infty}}}$  (Schlaich J. , 1995).

**Figure 4.14 The theoretical and practical wind velocity on 12/04/2009**

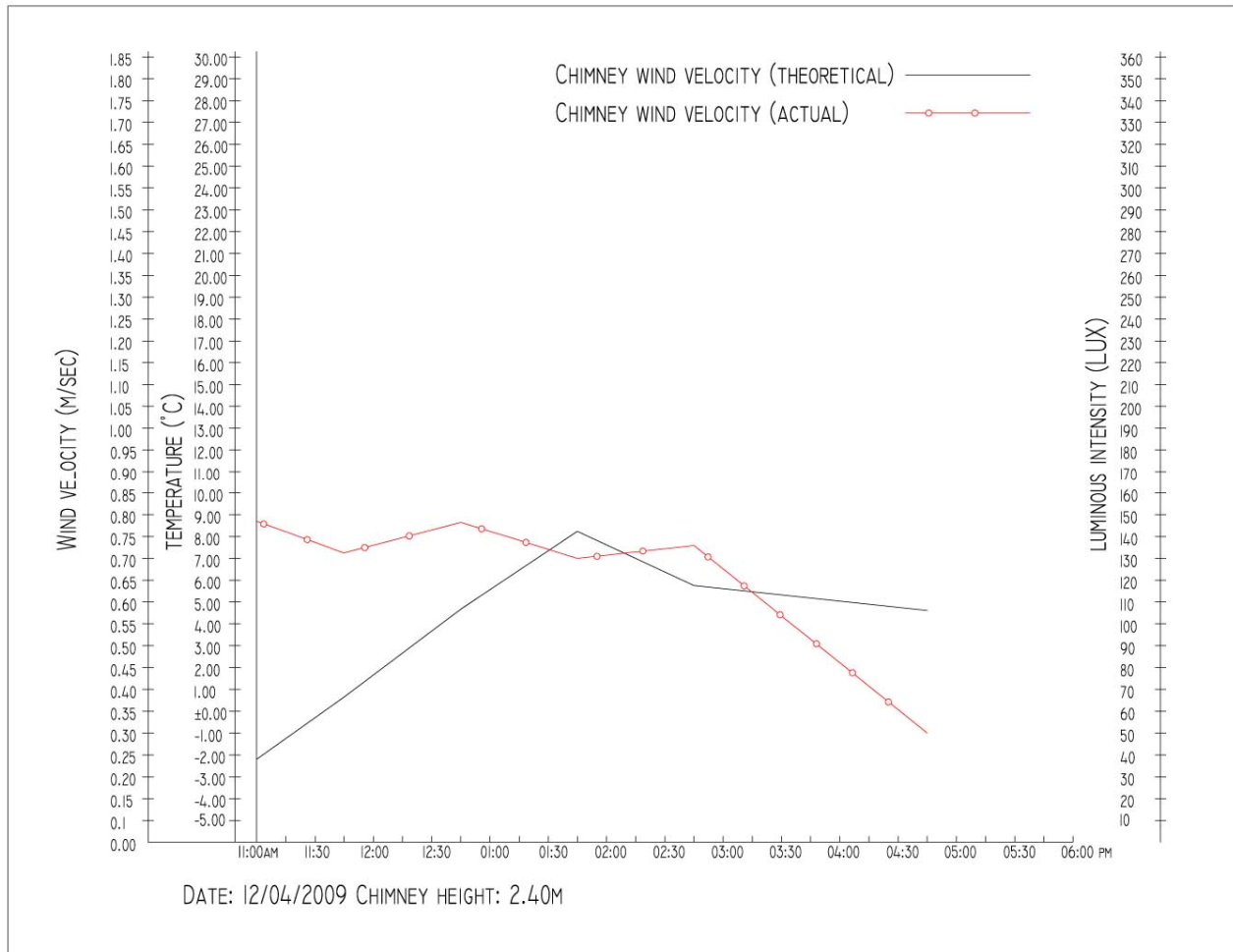


Figure 4.14 shows the information recorded on 4th December for the chimney of 2.4 m height. These graphs show a comparison between theoretical wind velocity inside the chimney and the data recorded. The chain-link line shows the wind velocity inside chimney according to

the recorded data whereas the firm line shows the theoretical prediction. Wind velocity inside chimney peaked at 12.45 pm and the respective wind velocity was .775 m/sec. Theoretical peak wind velocity happened at 1.45 pm and the predicted maximum velocity was .75m/sec.

**Figure 4.15 The theoretical and practical wind velocity on 12/05/2009**

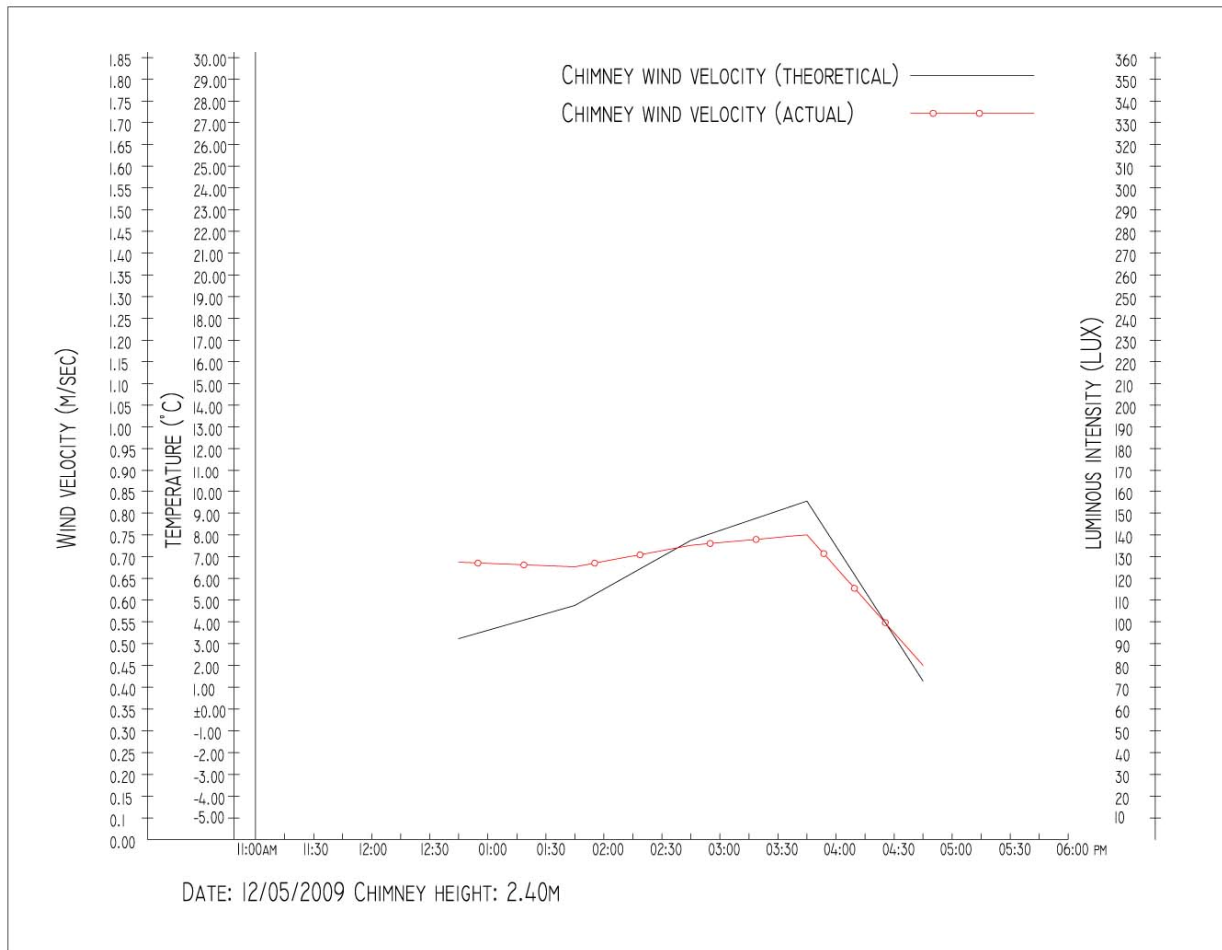


Figure 4.15 shows the information recorded on 5th December for the chimney of 2.4 m height. These graphs show a comparison between theoretical wind velocity inside the chimney and the data recorded. The chain-link line shows the wind velocity inside chimney according to

the recorded data whereas the firm line shows the theoretical prediction. The graphs show a clear relation between theoretical prediction and recorded data. Wind velocity inside chimney peaked at 3.45 pm and the respective wind velocity was .75 m/sec. Theoretical peak wind velocity happened at 3.45 pm and the predicted maximum velocity was .85m/sec.

**Figure 4.16 The theoretical and practical wind velocity on 01/22/2010**

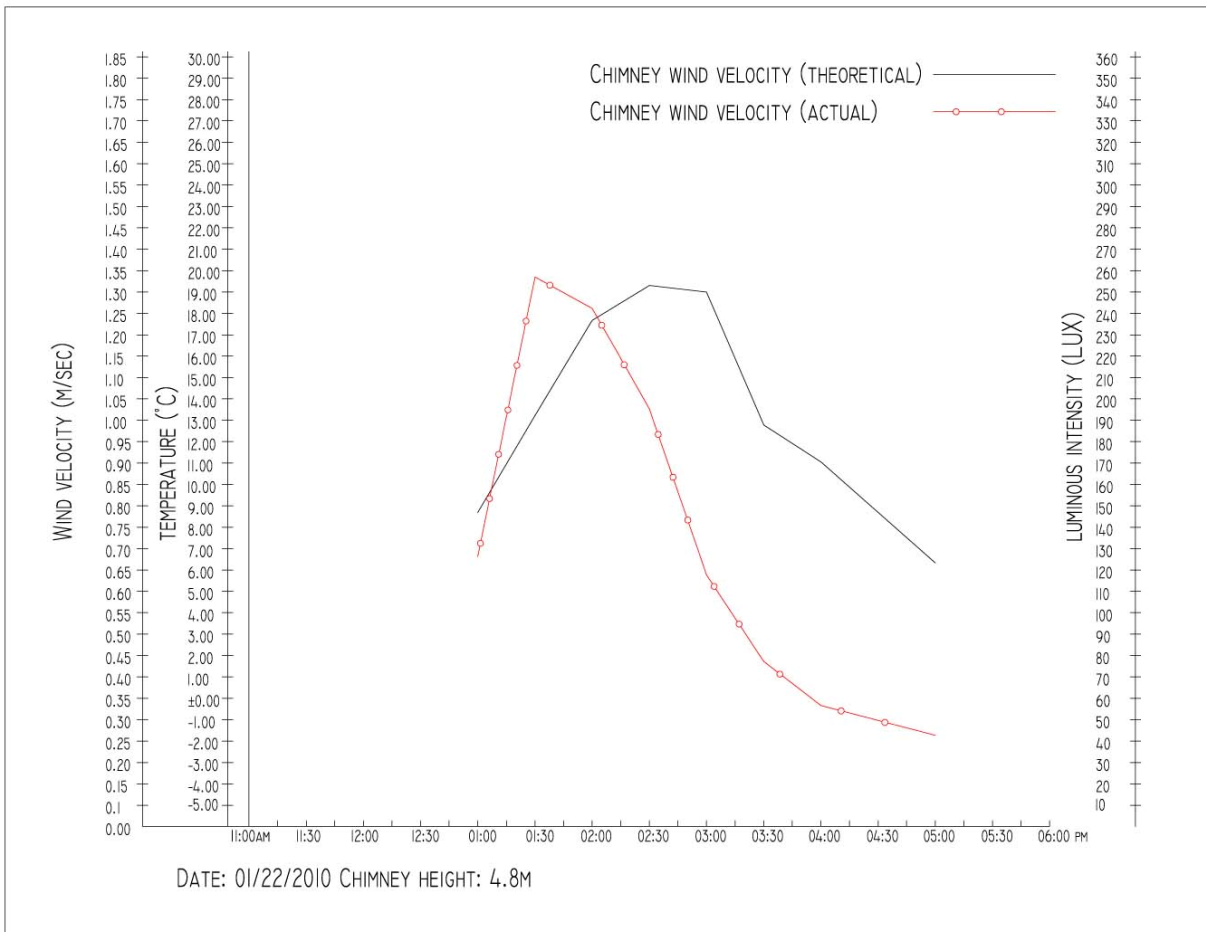


Figure 4.16 shows the information recorded on 22nd January for the chimney of 4.8 m height. These graphs show a comparison between theoretical wind velocity inside the chimney and the data recorded. The chain-link line shows the wind velocity inside chimney according to the recorded data whereas the firm line shows the theoretical prediction. The graphs show a clear

relation between theoretical prediction and recorded data. Wind velocity inside chimney peaked at 1.30 pm and the respective wind velocity was 1.335 m/sec. Theoretical peak wind velocity happened at 2.30 pm and the predicted maximum velocity was 1.3 m/sec.

**Figure 4.17 The theoretical and practical wind velocity on 01/30/2010**

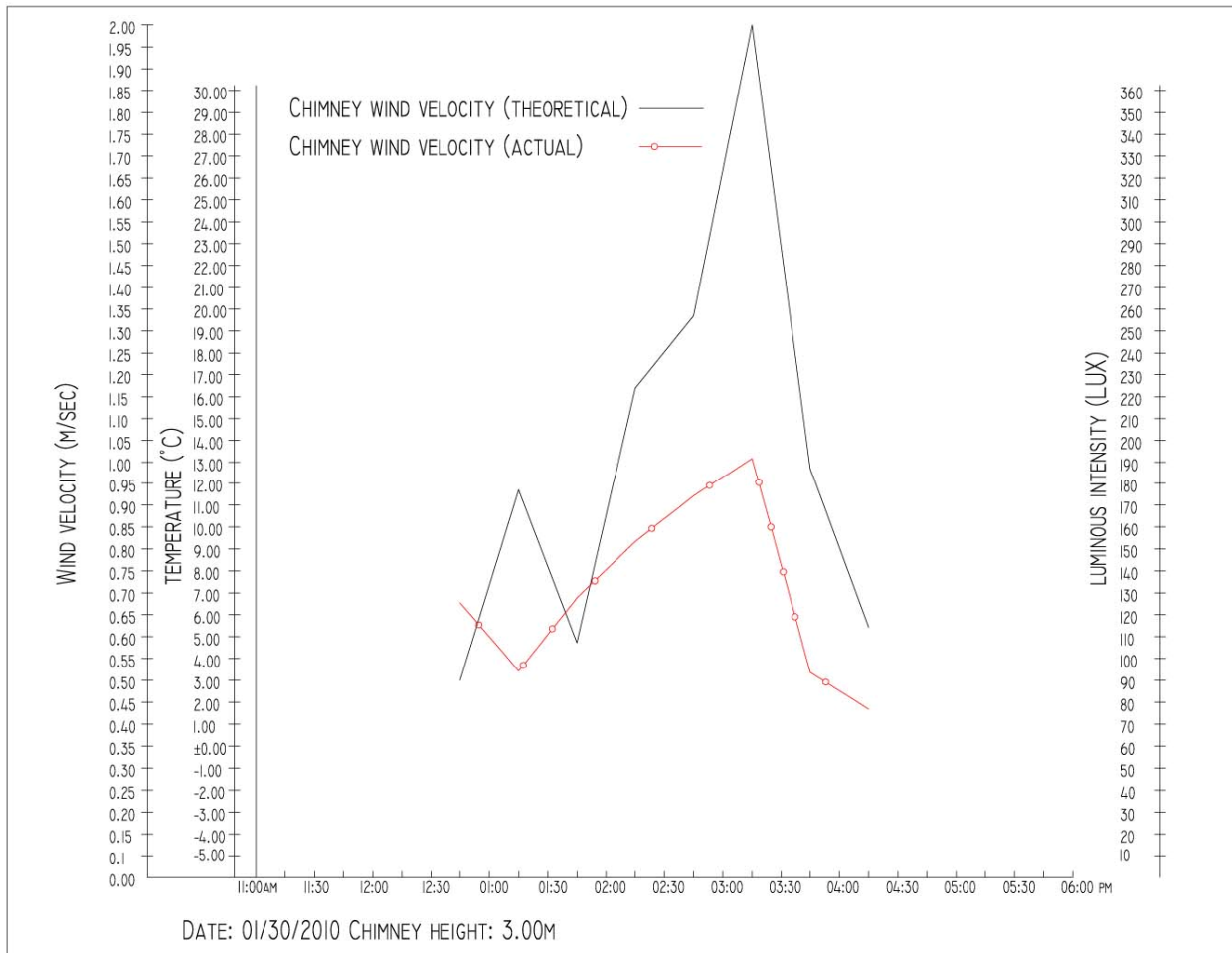


Figure 4.17 shows the information recorded on 30th January for the chimney of 3 m height. These graphs show a comparison between theoretical wind velocity inside the chimney and the data recorded. Wind velocity inside chimney peaked at 3.17 pm and the respective wind velocity was 1.01 m/sec. Theoretical peak wind velocity happened at 3.17 pm and the predicted maximum velocity was 2 m/sec.

**Figure 4.18 The theoretical and practical wind velocity on 02/02/2010**

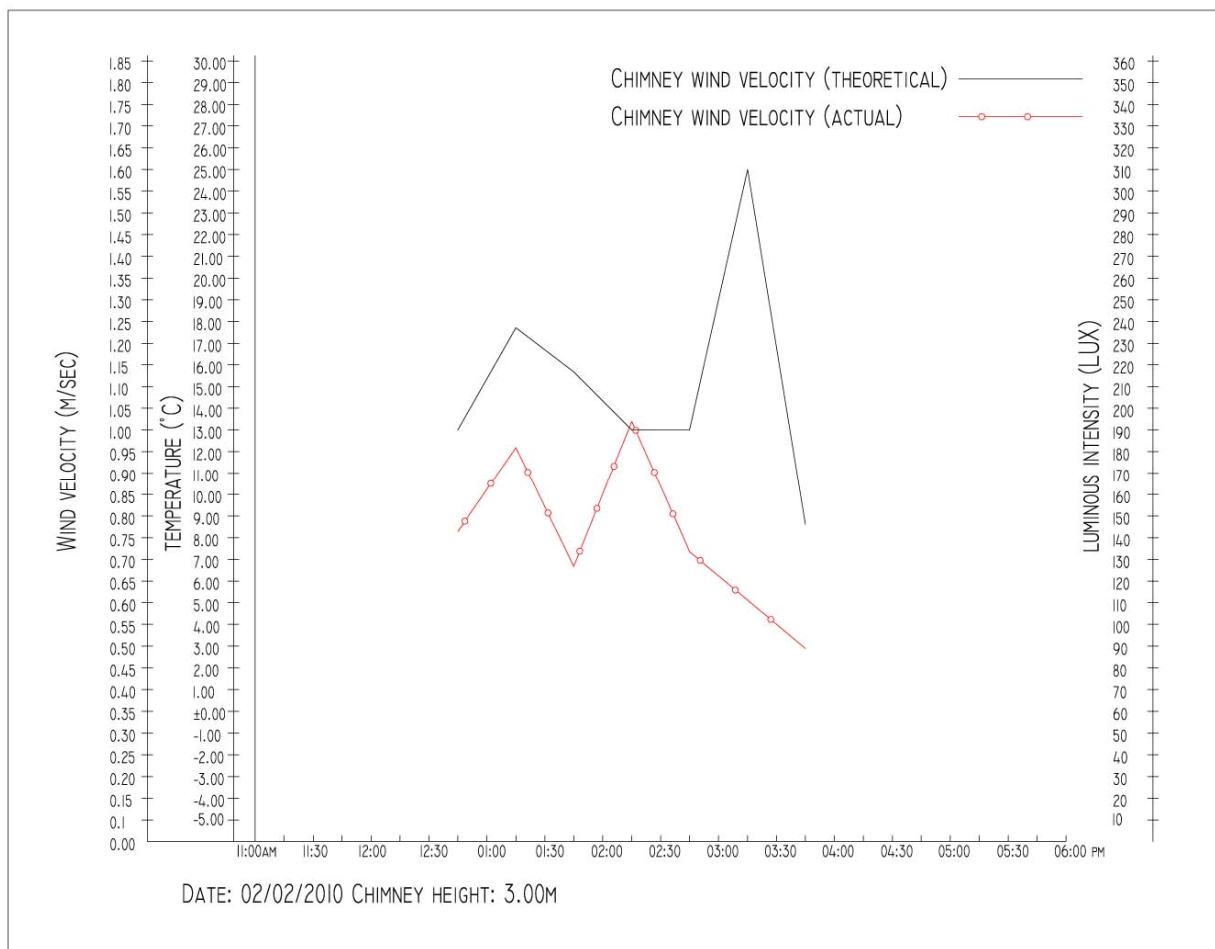


Figure 4.18 shows the information recorded on 2nd February for the chimney of 3 m height. These graphs show a comparison between theoretical wind velocity inside the chimney and the data recorded. Wind velocity inside chimney peaked at 2.18 pm and the respective wind velocity was 1.025 m/sec. Theoretical peak wind velocity happened at 3.15 pm and the predicted maximum velocity was 1.6 m/sec.

The recorded data shows some abnormally low wind velocity in contrast to the theoretical prediction on 01/30/2010 and 02/02/2010 (Refer Fig16 and Fig.17). The probable

explanation of this anomalous result could be the windy and turbulent weather condition on those days. This experiment also shows that in case of such a small solar updraft façade system the wind flow within the chimney can be greatly affected by the external wind flow. A major reason of the lower wind velocity within 3 m tall chimney is the turbulence inside the chimney due to outside wind flow.

Overall the experiment shows a general agreement with the prediction and proves the possibility of the development of a solar thermal updraft façade, which can contribute significantly in alternative power generation. As an example, on an average New York day with an average 4.24kwh/day ([www.synergyenviron.com](http://www.synergyenviron.com)) solar insolation the south façade of the central tower of Rockefeller centre or Met life building can generate 1060 kwh energy using such a solar thermal updraft facade system even with only 1percent efficiency. Although low efficiency is an important issue regarding such a system but experiments with positive results has already been executed (Padki, 1999) regarding the efficiency of solar chimney and those can be applied and tested in farther researches.

The cost of a double skin façade is often a matter of significant consideration. Usually a double skin façade costs double compared to a single skin glass façade. Studies in Europe shows an average cost escalation of 300Euro/m<sup>2</sup> (\$400/m<sup>2</sup>) of the façade (Poirazis, 2004). In this regard a solar updraft double skin façade can be a major incentive. Compared to the conventional double skin façade the only major additional investment in a solar updraft double skin façade is the cost of the wind turbines. The cost of construction for a double skin façade on a 25000 m<sup>2</sup> southern façade of a New York skyscraper can be significantly high. But with a solar updraft double skin façade such a system can produce 1000kwh/day energy which can give a rapid payback. Considering an average energy generation period of eight hours a day a solar updraft



double skin façade of capacity of 1000kwh/day needs 125kw capacity of wind turbines. Presently often the price of small 400-500watt turbines ranges around \$500 to \$700. As an example the ‘AIR X Wind Generator’ (400watt) (www.solar-dyne.com) costs \$699. So for the entire installation of 125kw the total investment will be \$218437.5. In November 2009 average retail price of electricity to Ultimate Customers for commercial sector in New York was 14.49 Cents per kilo-watt-hour (Administration, 2010). With an average production of 1000 kwh/day such a solar updraft double skin façade can save \$52888.5 in a year. In such case the payback period will be around 4.1years.

**Table 4.7 Cost analysis for a solar updraft double skin façade for 1060kwh/day**

Cost analysis for a solar updraft double skin façade for 1060kwh/day in New York	
Required façade area	25000 m <sup>2</sup>
Cost escalation for Double skin facade	\$10000000 (\$400/m <sup>2</sup> )
Additional investment for wind turbines	\$218437.5
Energy saving per Year	386900 kwh
Pay back through the energy cost saving per year	\$56061.81

**Limitation of study:**

This study of renewable energy techniques has some limitations. Except a preliminary design and testing of the model solar updraft façade system all other research on this topic is done on the basis of literature study and no specific system has been tested in Kolkata. The height of the model was small compared to the actual height required and it was not attached to any existing building façade. Moreover for financial and time constraints the preliminary design and testing of the solar updraft façade systems didn’t include a computational fluid dynamic

(CFD) analysis but such an analysis can be helpful for a better understanding before an actual construction.

This research only looked into the relation of temperature rise and wind velocity inside a solar updraft façade system with respect to solar insolation. But this research didn't look into the constructional details and the material aspects of such a system. Besides the CFD analysis it is important to make one true scale prototype system as it was done for solar chimney research in Manzanares, Spain. Such a prototype can give complete understanding of such a system regarding its actual cost, efficiency, and constructional difficulties.

### **Barriers to implementation:**

There are some barriers for the implementation of renewable energy techniques discussed in this section. Cost is a primary barrier to implement a solar updraft façade system. Moreover due to the novelty of this idea it doesn't have any precedence and thus less dependable for the investors.

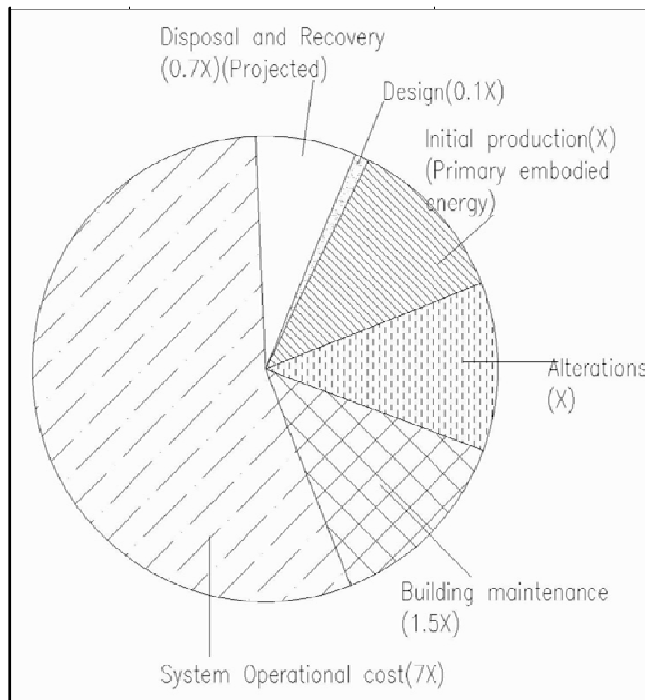
Moreover the electricity tariff in Kolkata is highly subsidized and much less compared to other big cities like Mumbai and Delhi in India (CESC, 2009). With present tariff rate the payback is low but as the tariff is constantly increasing it may become viable in future.

# CHAPTER 5 - Reconsideration of Operational Systems Design In a Residential High-rise Building in Kolkata

## Introduction

Modern civilization is a product of cheap fossil fuel and great exploitation of all natural resources. In contrast to a natural environment where living organisms sustain by passive or organic means with the available natural renewable resources we live in a built environment with mechanically controlled ambience maintained by fossil fuel energy. This leads to the great lifecycle energy cost involved in our lifestyle. This prodigal lifestyle not only caused the huge global pollution but with the end of fossil fuel era it has faced the question of sustainability. To counter this problem a great deal of research has already been done. Many sustainability guidelines suggest to develop a design primer which can generate new design that can sustain by

**Figure 5.1 Lifecycle energy cost (Yeang K. , 1999)**



passive means. In this regard developing a design primer for a sustainable high-rise is important. System operation causes almost sixty percent energy consumption in a high-rise building's entire lifecycle (Refer Figure 5.1); so it is most logical to focus in redesigning the operational systems of a high-rise building to reduce its ecological foot print.

This chapter focuses on the application of alternative design strategies in a residential high-rise building in Kolkata and summaries the possible development through an alternative design. For an analysis this chapter describes the normative practice and carbon footprint in a recently developed thirty five story residential tower in Kolkata as a baseline case study and discusses the possible redesign of the operational systems with alternative design strategies.

This chapter is divided into three sections:

1. Section One: This deals with the discussion of Kolkata context, Description of a thirty five story tower in South city project and the carbon foot print due to the operational systems.
2. Section Two: This deals with the discussion of possible redesign of the operational systems with alternative strategies and their benefits.
3. Section Three: This deals with the economic viability of the proposed redesign of operational systems with alternative strategies.

## Section One: South City Residential tower

### *Kolkata Context:*

Until recently the development in Kolkata was mostly low-rise with high density leading to the enormous metropolitan area of 1854 km<sup>2</sup> with nearly fifteen million inhabitants with a density of 8000persons/km<sup>2</sup>. Moreover the city's linear pattern along river Hoogly pushed the suburbs further away with each stage of growth. The recent economic development increased the demand near central business district (CBD) and the city started to encroach the East Kolkata Wetlands, which is a Ramsar site with great ecological importance and now it has become evident that Kolkata can no longer grow avoiding skyscrapers.

**Table 5.1 Development of high-rise buildings in Kolkata: (Emporis, 2000-2010)**

Time-line	Before 1970	1970-1990	1990-2000	2000-2009	Incomplete
No. of High-rise Buildings (more than 20 stories)	-	4	9	20	28
No. of High-rise Buildings (15 to 20 stories)	-	8	12	78	8

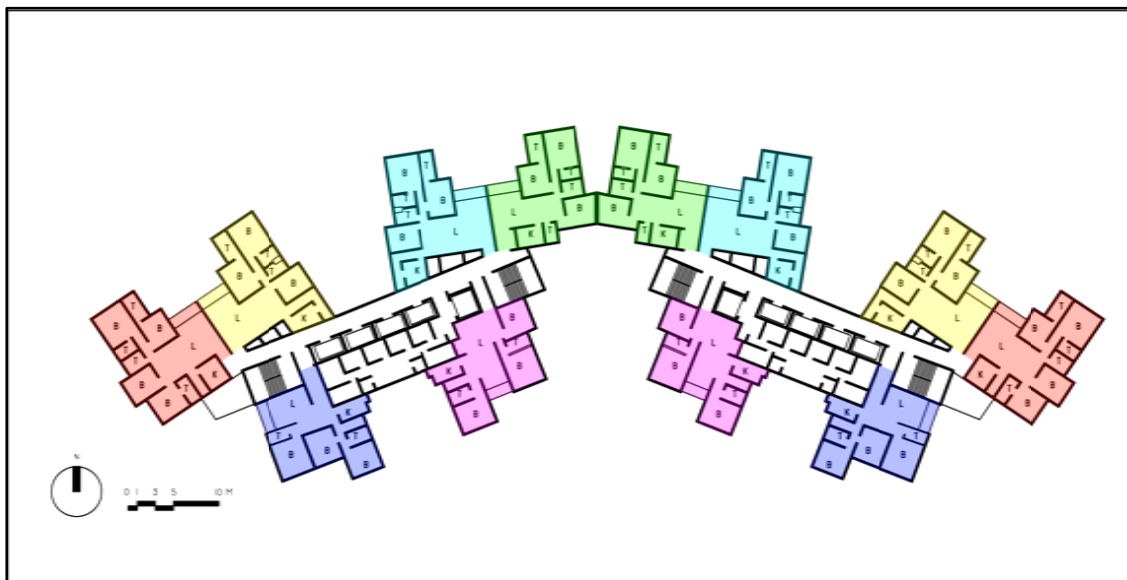
In this context recently there have been a trend of high-rise developments (refer Table 5.1). Most of these projects are being developed on the basis of normative practice using conventional techniques. This has worsened the scenario with increased demand for energy and increased level of pollution. In this context it has become even more important to develop strategies for sustainable high-rise buildings in Kolkata. One of the recent high-rise development in Kolkata is the South city Housing project. This chapter will focus on the applicability of bioclimatic and alternative design strategies in the context of South City project and possible alternative design development for a better high-rise building design with a lower ecological

footprint. For the analysis, this chapter presents a preliminary conceptual sketch design. Primary focus of this sketch design is to present possible design integration of different ecologically considered operational systems within a high-rise building. The floor layout of the sketch design is indicative and can be further developed.

***South City Residential towers:***

South city is a recent high-rise development in Kolkata. The project is situated on a 31.14 acre land by the side of Prince Anwar Shah Road in southern part of Kolkata. The entire project consists of four 35story and one 15 story residential towers, a shopping mall, a school and a club. Each of the thirty five story towers has two double bedroom, eight three bedroom units and two four bedroom units in its first thirty two stories. In the thirty third floor there are six three bedroom units, two double bedroom units and two single bedroom units. In thirty fourth floor there are four triple bed units, two double bed units and two single bed units. In thirty fifth floor there are six double bed units and two single bed units. This chapter will focus on the system operation aspect of one of these 35 story towers (southcityprojects, n.d.).

**Figure 5.2 Plan of south city tower 3(Developed from the source, (southcityprojects, n.d.)**



South City basic facts: (One of the four 35 story towers, Source - Facility consultant and (southcityprojects, n.d.)

Architect- Dulal Mukherjee Associates, (Kolkata, India), Smallwood Reynolds Stewart Stewart & Associates Inc, (Atlanta, USA)

Building Type- Residential

Building Height (Stories)- 35 story = 120 M (Approximately)

Building Area- Approximately 68000 m<sup>2</sup>

Total Electricity consumption- 2 MVA

Total S.T.P. capacity-  $2 \times 125 \text{kw} + 1 \times 5.5 \text{kw} = 230.5 \text{kw}$

D.G. backup- 1160K.V.A

### ***Power consumption in a thirty five story tower of South city apartments***

The power consumption estimation has been carried out on the basis of the information received from the facility consultant and the analysis given in the website of Calcutta Electricity supply Corporation (Power Consumption Guide). For the calculation it has been considered that each bed room has one 23 watt CFL and one A.C. 48” sweep ceiling fan. For living room one 23 watt CFL and two A.C.(alternative current) 48” sweep ceiling fan has been considered. For kitchen and toilet one 23 watt CFL and one A.C. 9” sweep exhaust fan has been considered. One 1.5 ton window A/C has been considered in the master bedroom and a one ton window A/C (air conditioner) has been considered in each of the other bedrooms. In four bedroom and three bedroom apartments an additional six 23 watt CFL and three 23 watt CFL has been considered. One 23 watt CFL for balcony has been considered in each apartment. Besides fan, lights and A/C the power requirement for refrigerator, geyser, personal computer, washing machine and television has been considered.

**Table 5.2 Power consumption in South city apartments**

Calculation for power consumption in South city apartments			
Flat type: 4 Bed room, 4Toilets, 1Living/Dining, 1Kitchen,1Balcony			
Type of Gadget	Nos.	Daily usage hour (hr)	Total consumption (kwh/day)
23 watt CFL Light	18	6	2.16
Air Conditioner 1.5Ton capacity window unit	1	3	5.4
Air Conditioner 1Ton capacity window unit	3	3	10.8
AC Fans 48" sweep	6	12	5.76
Kitchen Exhaust fan 9" sweep	1	4	0.2
Toilet Exhaust fan 9" sweep	4	1	0.2
Refrigerator 180lt	1	24	1.92
Television	2	4	0.48
Personal Computer	3	3	0.99
Geyser	4	0.5	3
Washing Machine automatic 5kg capacity	1	0.5	0.19
Total consumption in one unit			31.1
Flat type: 3 Bed room, 3Toilets, 1Living/Dining, 1Kitchen,1Balcony			
Type of Gadget	Nos.	Daily usage hour (hr)	Total consumption (kwh/day)
23 watt CFL Light	13	6	1.56
Air Conditioner 1.5Ton capacity window unit	1	3	5.4
Air Conditioner 1Ton capacity window unit	2	3	7.2
AC Fans 48" sweep	5	12	4.8
Kitchen Exhaust fan 9" sweep	1	4	0.2
Toilet Exhaust fan 9" sweep	3	1	0.15
Refrigerator 180lt	1	24	1.92
Television	2	4	0.48
Personal Computer	3	3	0.99
Geyser	3	0.5	2.25
Washing Machine automatic 5kg capacity	1	0.5	0.19
Total consumption in one unit			25.14
Flat type: 2 Bed room, 2Toilets, 1Living/Dining, 1Kitchen,1Balcony			
Type of Gadget	Nos.	Daily usage hour (hr)	Total consumption (kwh/day)



23 watt CFL Light	8	6	0.96
Air Conditioner 1.5Ton capacity window unit	1	3	5.4
AC Fans 48" sweep	4	12	3.84
Kitchen Exhaust fan 9" sweep	1	4	0.2
Toilet Exhaust fan 9" sweep	2	1	0.1
Refrigerator 180lt	1	24	1.92
Television	1	4	0.24
Personal Computer	1	3	0.33
Geysers	2	0.5	1.5
Washing Machine automatic 5kg capacity	1	0.5	0.19
Total consumption in one unit			14.68
Flat type: 1 Bed room, 1Toilets, 1Living/Dining, 1Kitchen,1Balcony			
Type of Gadget	Nos.	Daily usage hour (hr)	Total consumption (kwh/day)
23 watt CFL Light	6	6	0.72
Air Conditioner 1.5Ton capacity window unit	1	3	5.4
AC Fans 48" sweep	3	12	2.88
Kitchen Exhaust fan 9" sweep	1	4	0.2
Toilet Exhaust fan 9" sweep	1	1	0.05
Refrigerator 180lt	1	24	1.92
Television	1	4	0.24
Personal Computer	1	3	0.33
Geyser	1	0.5	0.75
Washing Machine automatic 5kg capacity	1	0.5	0.19
Total consumption in one unit			12.68
Total Consumption in one Tower			
No of 3bedroom units in tower	Consumption in each Unit (kwh/day)		Total consumption in tower (kwh/day)
266	25.14		6687.24
No of 4bedroom units	Consumption in each Unit (kwh/day)		Total consumption in tower (kwh/day)
64	31.1		1990.4
No of 2bedroom units	Consumption in each Unit (kwh/day)	Total consumption in tower (kwh/day)	Total consumption in tower (kwh/day)
74		14.68	1086.32
No of 1bedroom	Consumption	Total consumption in	

units	in each Unit (kwh/day)	tower (kwh/day)	
6		12.68	76.08
Total consumption in one tower			9840.04kwh/day
Total Consumption in one Tower for A/C			
Type of Unit	No of units	Consumption in each Unit due to A/C (kwh/day)	Total consumption in tower (kwh/day)
4Bedroom unit	64	16.2	1036.8
3Bedroom unit	266	12.6	3351.6
2Bedroom unit	74	5.4	399.6
1Bedroom unit	6	5.4	32.4
Total consumption in one tower			4820.4
Total Consumption in one Tower for all appliances except A/C			5019.64

***Water Consumption in one South city Residential tower:***

Water is another important resource after energy. In high-rise residential towers the total consumption is significantly high. According to a recent study done by Abdul Shaban in 2008, average water consumption in Kolkata is 115.6 liters per day per capita (refer: Table 5.3) (Shaban, 2008). The study also shows that the consumption per household is 443.2 liters per day (considering an average 3.8members per household). Applying the same calculation the water requirement in one of South city housing towers is 181712 liters per day. Out of the entire water consumption only 4.9 percent is actually used for drinking and cooking;

**Table 5.3 Water usage in Urban India (Shaban, 2008)**

Cities	Per Capita
Delhi	78.0
Mumbai	90.4
Kolkata	115.6
Hyderabad	96.2
Kanpur	77.1
Ahmadabad	95.0
Madurai	88.2

rest ninety five percent is released as waste water (refer Table 5.4). According to this calculation the total waste water produced in one tower of South city housing is 172808.112 liters per day.

**Table 5.4 Details of end use of water in Kolkata (Abdul Shaban, 2008)**

Activity	Kolkata	Type of used water	Percentage of Gray water	Percentage of black water
Bathing	37.1	Gray	37.1	-
Washing clothes	14.0	Gray	14.0	-
Drinking	2.6	-	-	-
Cooking	2.3	-	-	-
Toilets	15.9	Black	-	15.9
Cleaning house	11.7	Gray	11.7	-
Washing utensils	16.1	Gray	16.1	-
Others	0.3	Black	-	0.3
Total	100		78.9	16.2

Besides wastewater such high-rise buildings produce huge amount of waste in the form of garbage. In U.S. average garbage production is 2 kg (4.5lbs) per person per day (Leonard, Fact Sheet, n.d.). In India the amount of garbage production is much less compared to U.S. Even then the total amount of garbage produced can be staggering. If we consider 2kg garbage per household per day in South city housing then the total garbage production in one tower will be .820 tons per day. Electricity supplied to Kolkata is produced from coal fired thermal power plants. A recent study done by ‘Parliamentary office of Science and Technology’ suggests that coal powered power plants have a carbon footprint of 1,000 gCO<sub>2</sub>eq/kWh (technology, 2006). From this data it is possible to calculate the carbon footprint of system operation per day for a tower in South city housing. Table 5.5 shows the carbon footprint of one 35 story tower of south

city. The calculation was done on the basis of the projected electricity consumption (Refer Table 5.2) water consumption and waste water production (Refer Table: 5.3 and Table 5.4). The amount of energy requirement for water purification is shown in Table 4.1. According to Table 5.5 due to the operational systems one 35 story tower of South City Apartments produces 10215831.31 grams of CO<sub>2</sub> equivalent/day. This huge carbon footprint shows the requirement for design reconsideration with the help of ecologically considered operational systems.

**Table 5.5 Ecological footprint of one tower of South city housing**

Ecological Footprint of one Tower of South city Housing		
Type of consumption	Total consumption	Carbon footprint
Electricity consumption	9840.04kwh/day	9840040 grams of CO <sub>2</sub> equivalent/day
Water consumption	181712 liters per day	192614.72 grams of CO <sub>2</sub> equivalent/day (in extended aeration process energy requirement = 1.06kwh/m <sup>3</sup> )
Waste water production	172808.112 liters per day	183176.59 grams of CO <sub>2</sub> equivalent/day (in extended aeration process energy requirement = 1.06kwh/m <sup>3</sup> )
Garbage production	.864 tons per day	-
Total Carbon footprint		10215831.31 grams of CO <sub>2</sub> equivalent/day

## **Section Two: Reconsidering the design of South city Tower with ecologically considered operational systems**

### ***Reconsideration of the high-rise design in Kolkata on the basis of existing knowledge of bioclimatic design strategies and new developments in environmental system design:***

To minimize the negative impact of high-rise building a lot of researches have already been done. These research findings usually give us a set of design primer which can help us to mitigate the negative impact of the normative design practice in high-rise buildings. Architect Ken Yeang has done considerable amount of research on passive bioclimatic strategies for skyscrapers. Previous researches done by Ken Yeang on passive bioclimatic design strategies include (Yeang K. , 1999);

1. Building form and orientation
2. Design of façade systems and fenestration details
3. Use of natural ventilation
4. Water conservation, rain water collection, waste water recycling and sewage treatment
5. Use of daylight
6. Integration of plants with buildings
7. Renewable energy production

This section will focus in the discussion of these bioclimatic design strategies along with other developments and their applicability to develop an alternative design for a high-rise tower in Kolkata with similar requirement as that thirty five story tower of South city residential project.

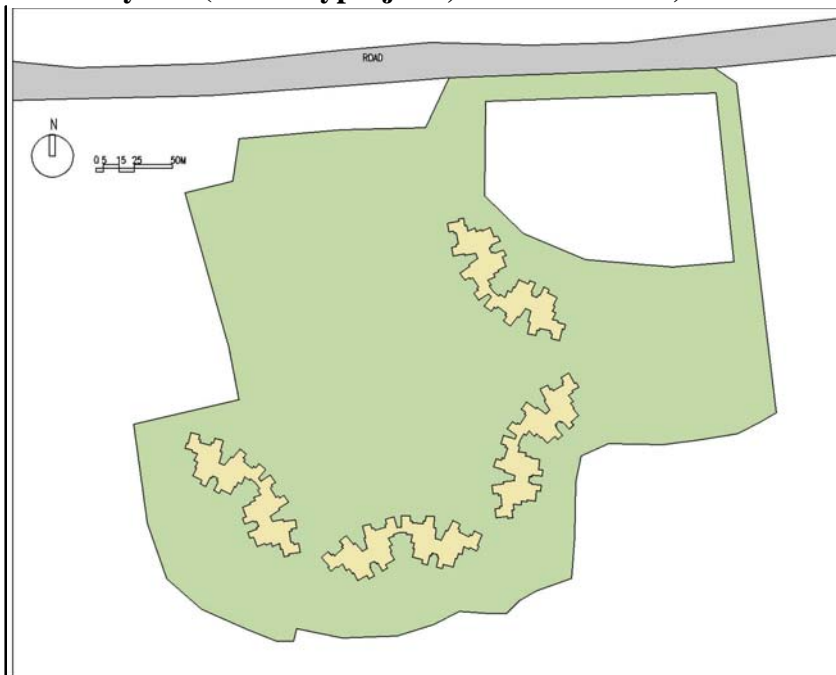
### ***Built form and orientation***

In case of high-rise design the built form and orientation has been discussed in detail in The green skyscraper: the basis for designing sustainable intensive buildings, by Ken Yeang. Yeang suggested an optimum specific aspect ratio of buildings (Refer Table 5.6) in each climatic zone and best orientation of the main façade (Yeang K. , 1999).

**Table 5.6 Orientation and Aspect ratio of High-rises in different climates (Source: Yeang, 1999)**

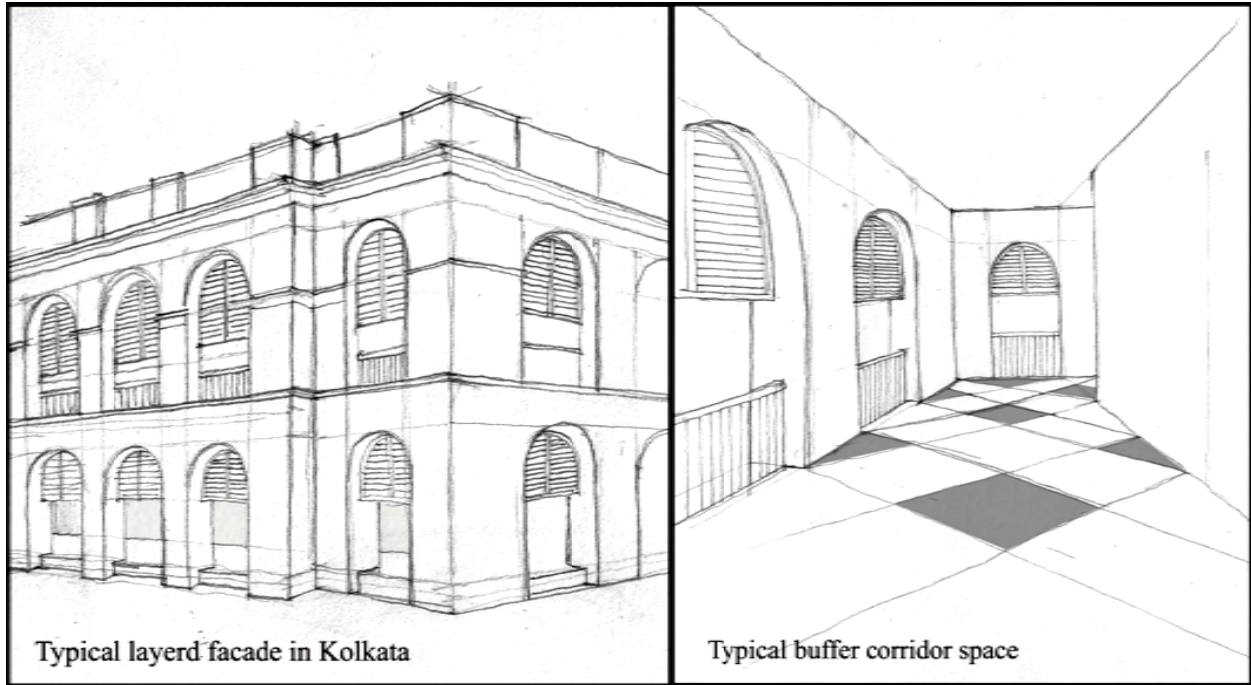
Climatic zone	Aspect ratio	Orientation of main facade
Cool	1:1	South, South East, South West
Temperate	1:1.6	18° South East
Arid	1:2	25° South East
Tropical	1:3	5° South East

**Figure 5.3 Residential tower position and orientation on south city site (southcityprojects, Sketch: Author)**



Although these strategies are well accepted but may not always be applicable in an urban site due to the restrictions the site shape, orientation and overall planning issues as it is observed in South city site plan (refer Figure 6.4). Due to these reasons a vernacular strategy of layered

**Figure 5.4 Use of Layered facade in Kolkata building (Sketch: Author)**



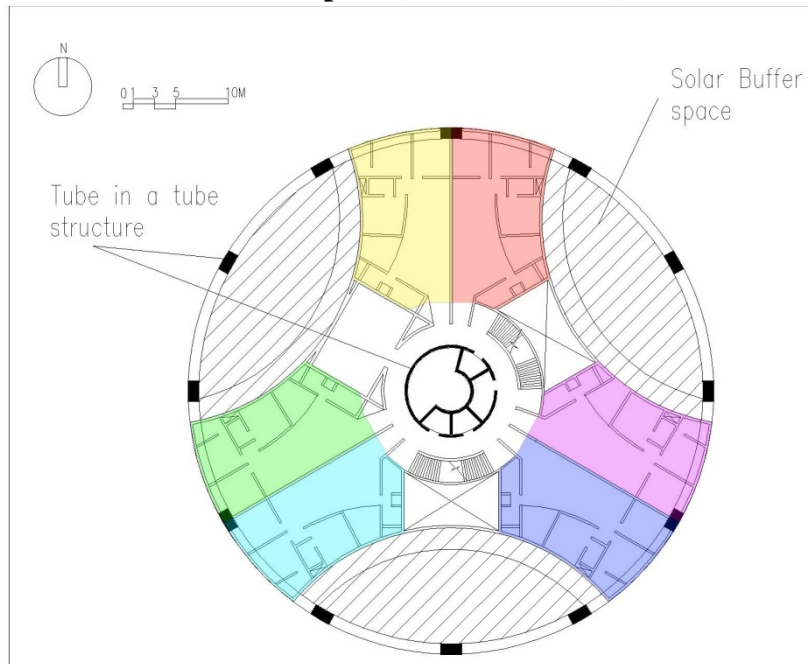
façade was developed in this region. A buffer space in the form of corridor was applied in most of the Kolkata buildings. Besides Kolkata, use of such layered façade is quite common in the architecture of this entire climatic region. A layered façade creates a buffer space and cuts down

**Figure 5.5 Use of Layered facade in the architecture of Geoffrey Bawa (Photo Author)**



the direct solar radiation on the surface of building core while allowing ventilation. The main problem is that these buffer spaces use up a major portion of useable floor plate and are not financially viable in a high-rise building. To counter this problem the tube in tube type structural

**Figure 5.6 Alternative floor plan of tower with six three bed room units and buffer space (Sketch: Author)**



system can be of good help. Instead of an usual structural grid if the structural members are shifted to the periphery and a central core then it can give great flexibility in the floor plan as well as the space between the floor plate and the peripheral structural system can work as a buffer zone.

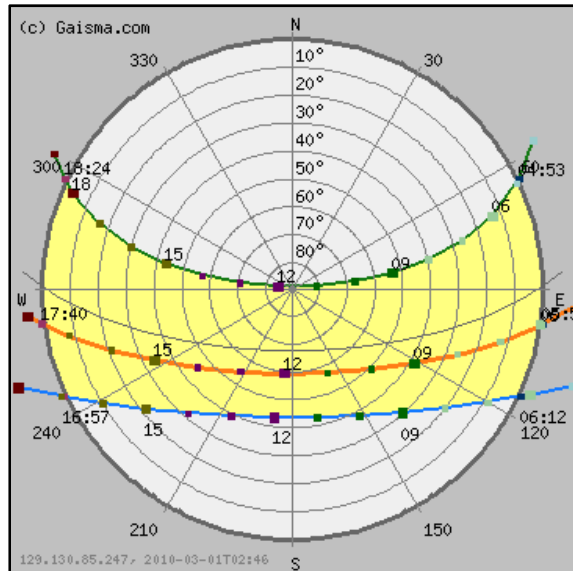
### ***Design of façade systems and fenestration details***

In case of high-rise buildings the envelop area is considerably high compared to the floor area. For this reason the design of façade system is the most important issue in designing its operational system. It is important to balance between the solar heat gain through the glazing



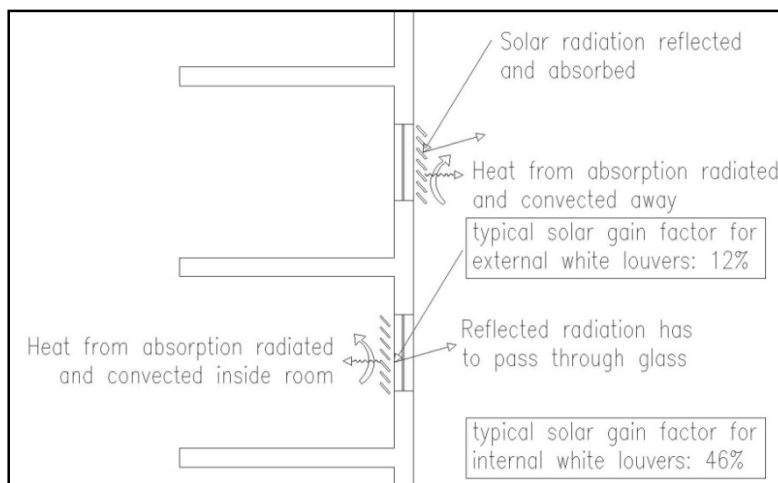
system and maximum utilization of daylight. In the design of solar shading sun path diagram is a major consideration. As the climate remains hot and humid throughout the year a horizontal sun protection can be a considerably big projection. A vertical louver system is a better solution, which can protect the sun without much projection. Such louver system was also a common

**Figure 5.7 Sun path diagram Kolkata (Gaisma)**



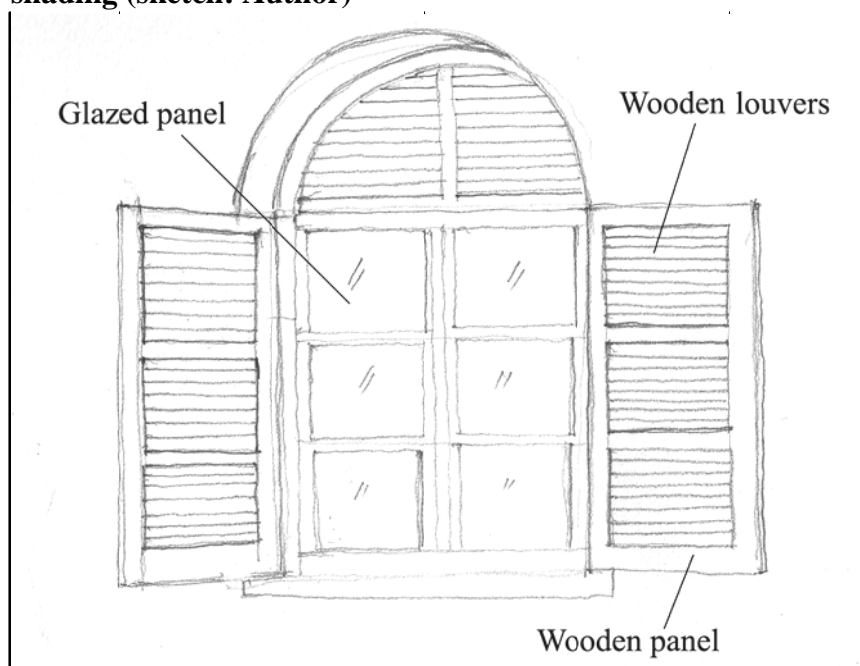
feature in vernacular architecture. So it is also a part of the local cultural aesthetics. While designing a vertical louver system it should be placed outside the glazing. Research observation confirms that an exterior louver works much more efficiently compared to a louver placed inside

**Figure 5.8 Use of louvers for solar shading (Yeang K. , 1999) (Sketch: Author)**



the glazing (Yeang,1999). This issue was addressed in traditional Kolkata building by a two layer shutter system. Usually in windows there were two parallel panels. Usually there was a louvered wooden panel on top of a glazed inner panel (refer Figure 5.8). In high-rise building these systems can be very effective, although there are some issues with the building elevation and maintenance. Considering all these issues the double layer façade system can be effective in

**Figure 5.9 Use of louvered panel in Kolkata windows for solar shading (sketch: Author)**



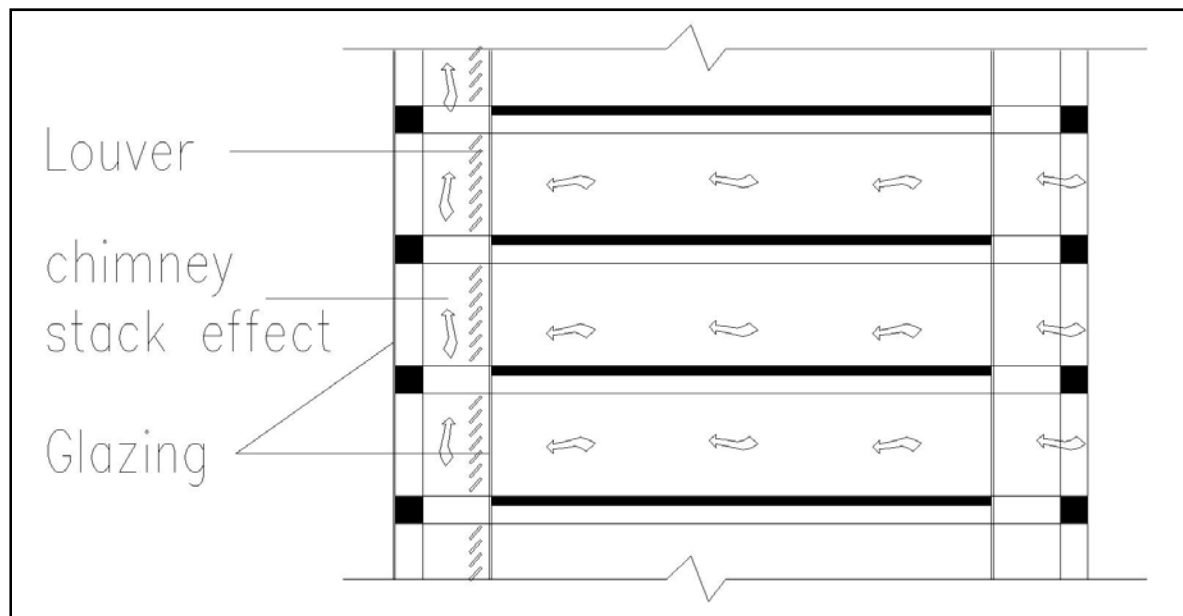
Kolkata (refer Figure 5.9). In case of a double layer façade in high-rise the major issues of aesthetics regarding elevation design can be handled on the outer layer while the inner façade can be handled according to the environmental requirement. A double layer façade is even more applicable to high-rise in a hot humid climate as it can allow natural wind flow between these two layers which can keep the inner layer cool.

### ***Natural ventilation***

In case of high-rise buildings specifically two systems consume the maximum share of its energy requirement, the illumination and the HVAC (refer Figure5.1). Moreover it becomes

crucial for high-rise buildings as it has little opportunity to use natural ventilation as the wind speed rises considerably with the increased height. In this context double skin façade is a good solution. “Double Skin Facade system is essentially a pair of glass skins separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often

**Figure 5.10 Double skin façade allowing natural ventilation (Sketch: Author)**



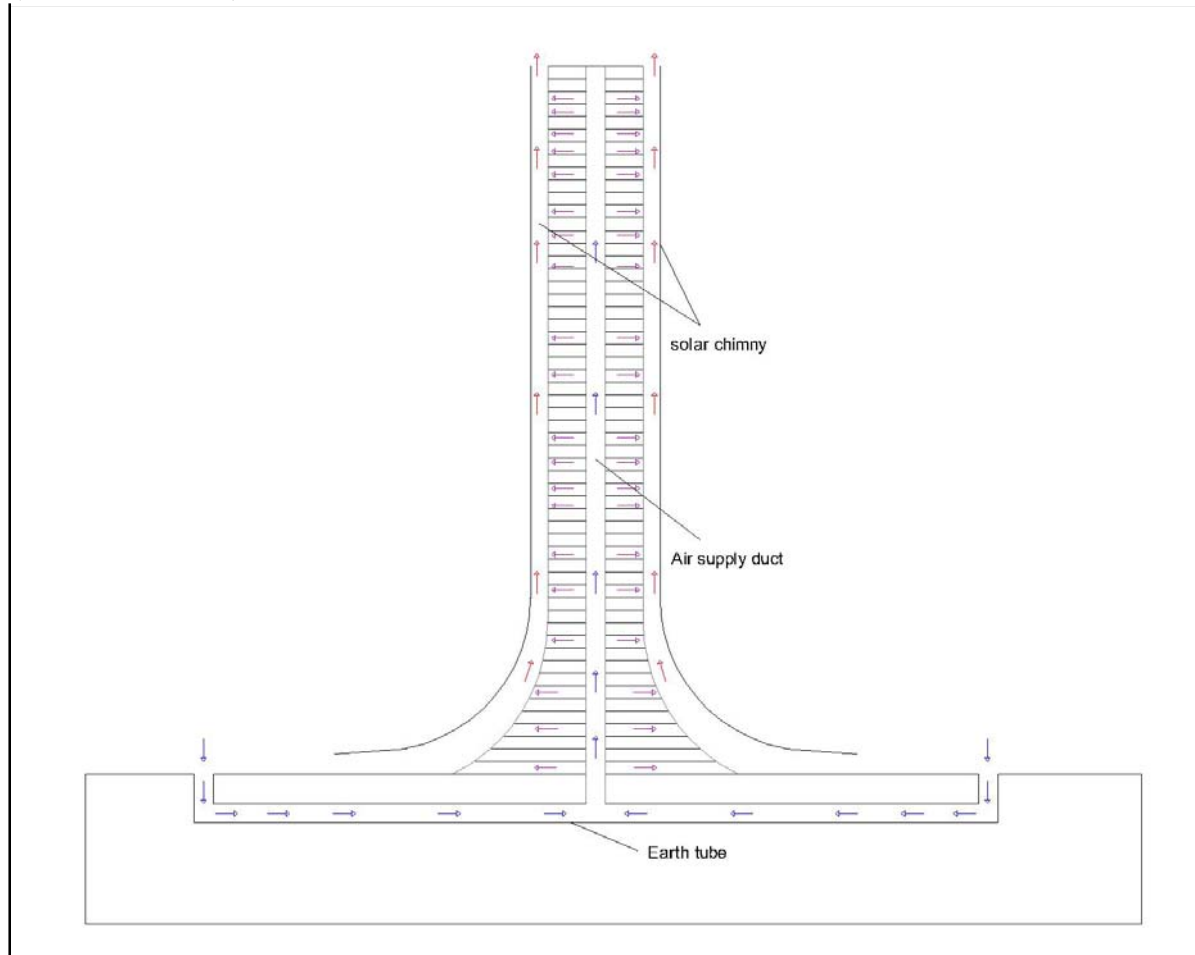
located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes” (Poirazis, 2004). A double skin façade is often used in combination with a louver system which protects the building core from insolation. Double skin façade can work differently as in winter mode or in summer mode in different climatic condition. In case of Kolkata which has a predominantly warm humid climate the double skin façade can be used for enhanced stack ventilation. As the air inside that double skin gets heated it can generate convection current and can work as a suction pump to enhance ventilation through the building. Moreover there has been an experiment in University of Nebraska which shows that if earth tubes are coupled with a solar chimney then the combined

system can work as an electricity energy free cooling system. For the experiment a cooling tube was buried underground to absorb cooling from low temperature soil. The outside air flowed through the tube to bring cooling from the soil to building and maintain comfort room temperature during summer. A chimney was installed to draw the air through the tube. The experiment proved that a solar chimney can work as a suction pump to make such a passive solar cooling system.

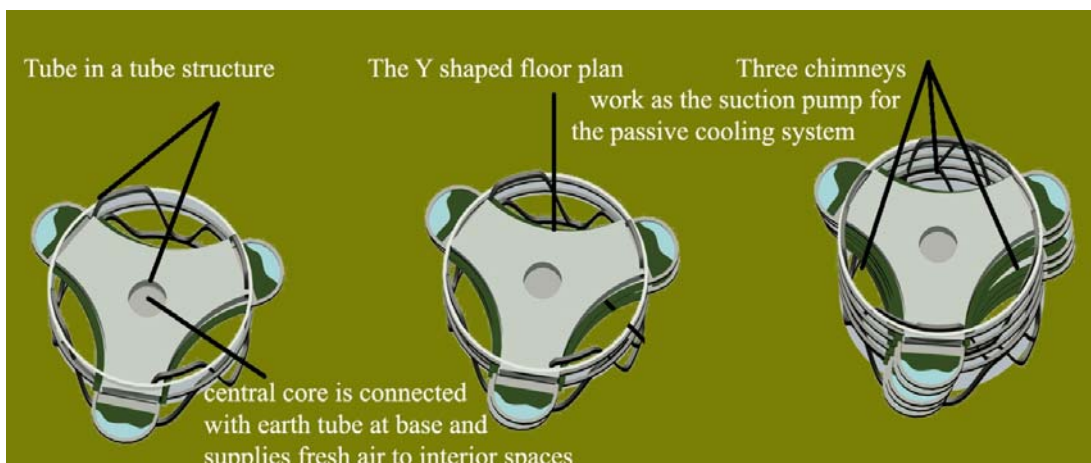
Such a system can work well in case of high-rise building if its double skin envelop system is designed properly to work as a solar chimney (refer Figure 5.11 and Figure 5.12). In Kolkata such a system can work effectively as the average solar insolation is  $4.93\text{kwh/m}^2$  (Resources, 2010) and the average ground water temperature is around  $25^\circ\text{C}$ . In case of a high-rise building effective cooling effect of supply air duct may drop with the increasing height. To increase the efficiency of such a system a solar heated absorption or adsorption cooling system can be integrated with it.

In case of a solar powered single effect absorption cooling system hot water is collected from a solar collector and accumulated in the storage tank. The hot water from storage tank is supplied to the generator to boil water vapor from a solution of lithium bromide and water. Then the water vapor is cooled down to condense in a condenser and passed to the evaporator. In the evaporator the water is again evaporated at low pressure and gets cooled. This provides useful cooling to the required spaces. On the other hand the strong solution leaving the generator to the absorber passes through a heat exchanger in order to preheat the weak solution before entering the generator. In absorber the strong solution is used to absorb the water vapor leaving the evaporator.

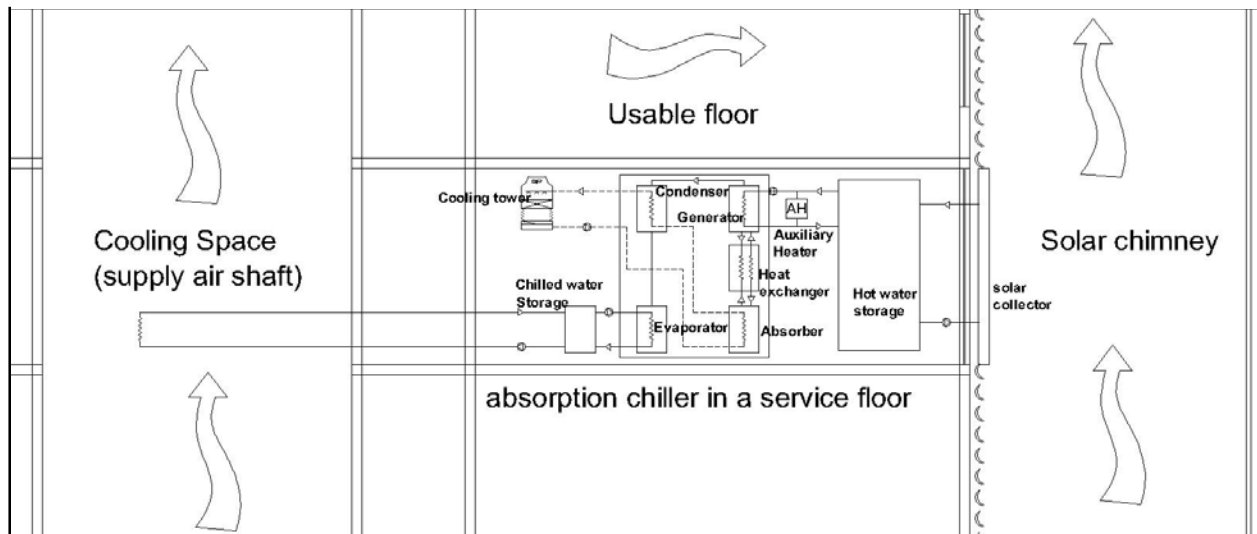
**Figure 5.12 Passive solar cooling system by integration of solar chimney and earth tube**  
 (Sketch: Author)



**Figure 5.11 Solar chimney and cool air supply tube shown in plan (Sketch: Author)**



**Figure 5.13 Absorption cooling system (Sketch: Author)**



Adsorption cooling system is a new idea in cooling techniques. In case of adsorption cooling system an adsorbent such as silica gel is used instead of an absorption cooling mixture as an example lithium bromide water mixture or ammonia water mixture. An adsorption cooling system has several advantages over an absorption cooling system; some of them are mentioned in a Table in Appendix B.

***Water conservation, rain water collection, waste water and sewage treatment strategies***

Water conservation is another important aspect in developing a sustainable high-rise building. Actual amount of potable water on earth is very limited. Out of all water on earth ninety-seven percent is saline ocean water and only three percent fresh. Even out of that three percent freshwater about 69 percent, is locked up in glaciers and icecaps, mainly in Greenland and Antarctica. Only about 0.3 percent of all the freshwater on Earth is in rivers and lakes, which is the only available water we use in our everyday lives (Survey, 2009). Although globally per day four trillion gallons of water precipitation is available most of it either evaporates or goes into runoff. The scenario worsens with wastage. The United States uses three times more water

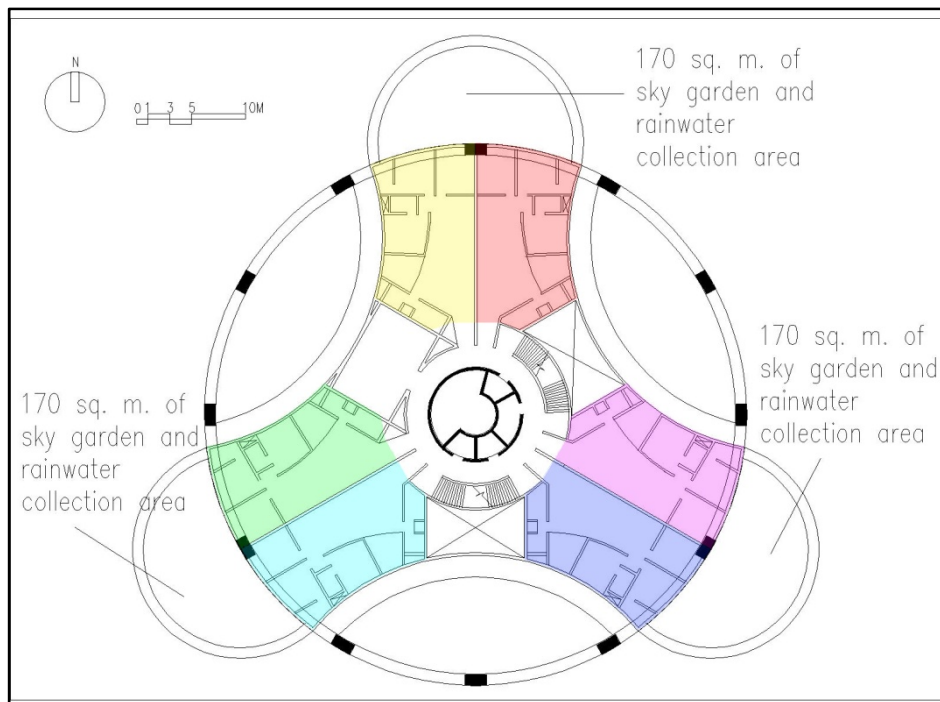
(578liters per person per day) compared to average European country and considerably more than most of the developing countries (Yeang K. , 1999).

Kolkata receives considerable amount of rainfall per year. Average annual rainfall in Kolkata is about 160cm (Geography of Kolkata , 2008 ), most of which falls during the rainy season between May to September. Although abundant rainwater is available, Kolkata often suffers from water crisis. Huge population growth in Kolkata is exerting tremendous pressure on its water supply system. Moreover a centralized water supply system is less efficient and needs huge infrastructure. In vernacular practice of this region people depends on ponds and tanks which they create by cut and fill method. This process helps to restore rainwater onsite and use it in dry seasons. Such rainwater harvesting is even more important regarding the city sewerage system. Kolkata sewerage system is incapable of the huge runoff it faces each year during the rainy season. Most of the rainy days with excessive shower lead to flooding. Rainwater is a great resource to Kolkata. If it is harvested and used properly then it is possible to fulfill the need of water in a high-rise with the water that fall on site. In Kolkata the average domestic water usage is around 115 liter per capita per day (Shaban, 2008).

A close survey of the domestic end use of water shows that almost eighty percent of the discharged water is gray water when nearly sixteen percent is black water. It means that if the water used in toilet (urinal and W.C.) is supplied from the primarily treated gray water then the total requirement of water can be brought down to eighty four percent of the present requirement. Moreover after a complete treatment the gray water can be supplied for almost ninety five percent of the water usage (except drinking and cooking). Although this will not be practically possible; as if a biological treatment process is used then major portion of gray water will be either evaporated or used up in the process of treatment. But still it is safely possible to consider

that in this process the primary supply of water can be brought down to sixty percent of its initial demand. Moreover water efficient toilet gadgets can also help to reduce the demand of water. If the water requirement is brought down to sixty percent of the present requirement then the water requirement per capita per day in Kolkata will be 69.36 liter which is equivalent to 25.3 m<sup>3</sup>/year. With a fifty percent efficiency of rainwater collection and considering an annual precipitation of 1.6 m for per person only 31.6 m<sup>2</sup> of water collection area is required. The roof of a high-rise building is small compared to its total floor area so it is difficult to collect all the required water from roof and store it in a tank near roof. In a high-rise building façade contains a significantly

**Table 5.7 Rain water collection area on projected balconies (Sketch: Author)**

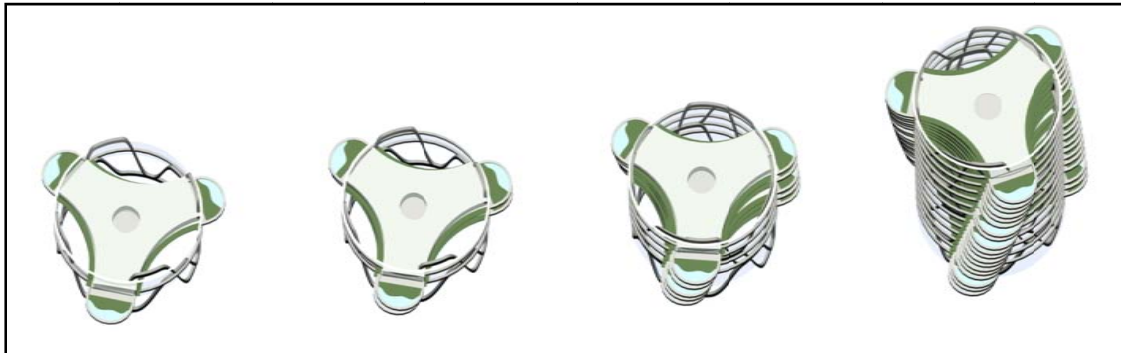


high amount of area compared to its roof so if properly designed then a major portion of the required water can be collected in some projection from the façade and the collected water can be supplied by gravity flow. As an example if three 10 m cantilever semicircular projection is made from the outer structural system then it can generate total 510m<sup>2</sup> projected surface area per

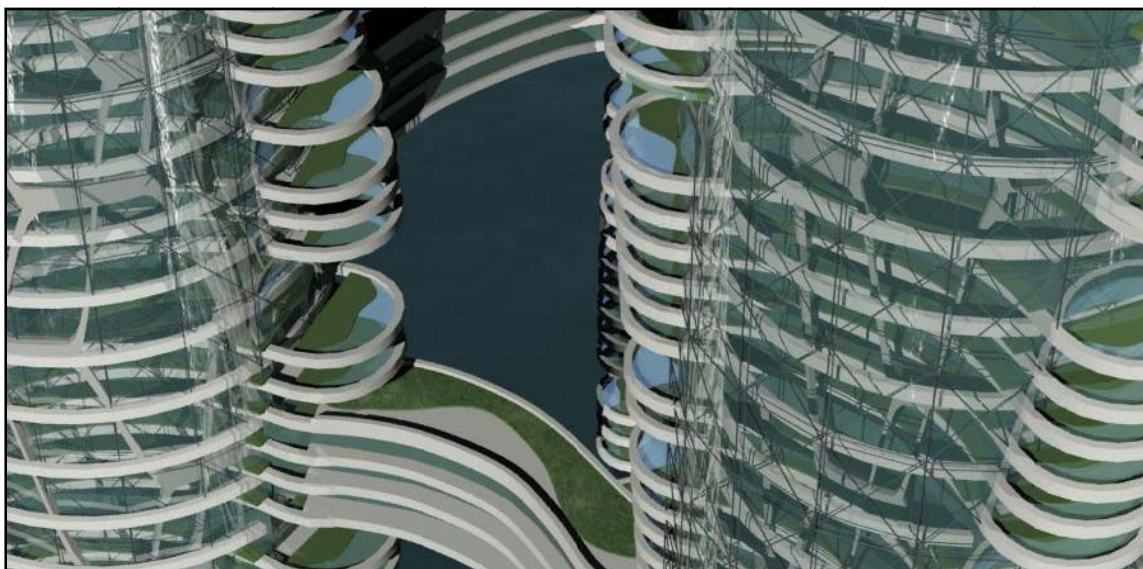


Floor (refer fig.14). Considering a seventy story tower the total projected area will be 4200m<sup>2</sup>. To increase the efficiency of collection the floor plates need to be rotated to expose each of the collection area partially to the sky. Considering thirty percent of the total projection area for rain water collection the tower can have a 1260 m<sup>2</sup> collection area on the tower surface. Although this area is not sufficient but it can provide 5.1 percent of the required water, sufficient for drinking and cooking purpose. The rest of the water can be collected on ground. Besides serving as a rainwater collection area such projections can become outdoor garden and food production area in the sky connecting the residents to nature.

**Figure 5.14 Rotation of floor plates increase rain water collection area (Sketch: Author)**



**Figure 5.15 View of rain water collection on projected balconies (Sketch: Author)**

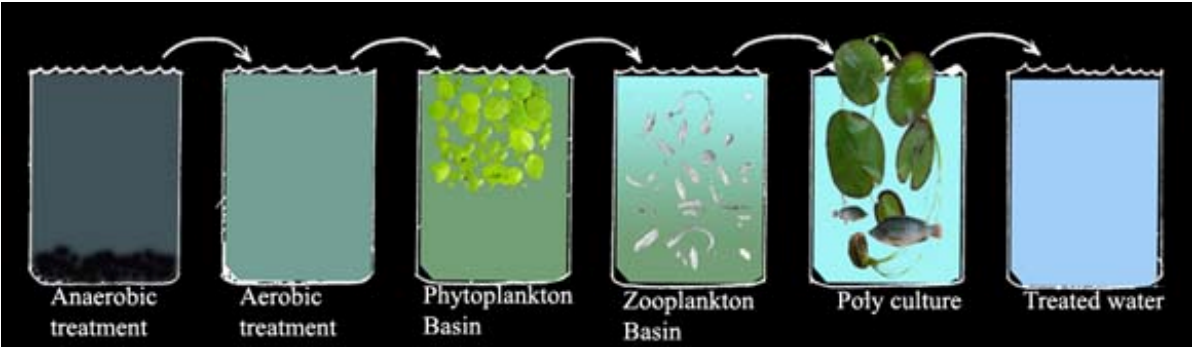


**Figure 5.16 Sky gardens (Sketch: Author)**



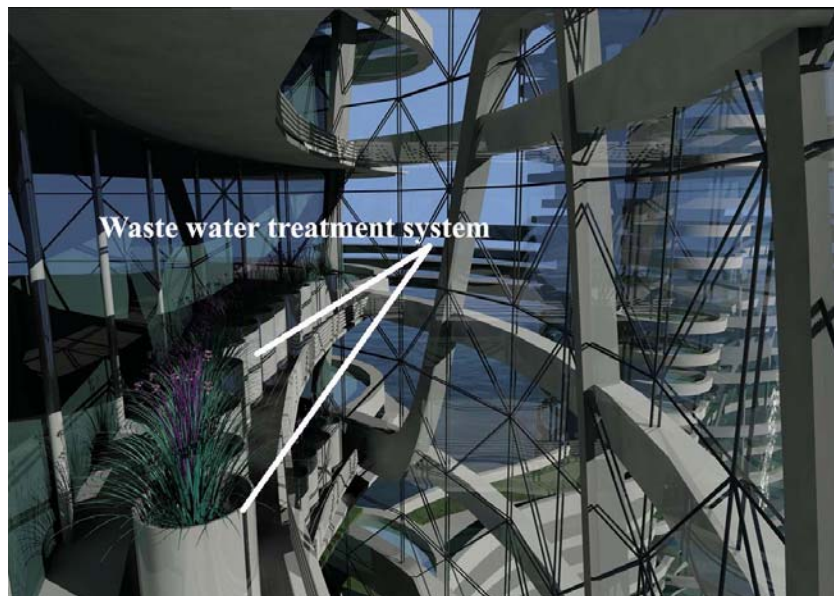
Besides rainwater harvesting waste water recycling and sewage treatment are important issues in high-rise buildings. Beside energy efficiency a proper sewage treatment strategy can provide usable biogas and potential food growth. One of the most effective alternative sewage treatment strategies is the living machine. In hot humid Kolkata climate a living machine system can work throughout the year and can save a significant amount of energy consumption. A complete living machine system is comprised of an anaerobic treatment, an aerobic treatment, a phytoplankton

**Figure 5.17 Living machine system (Sketch: Author)**



basin, a zooplankton basin and a poly-culture basin. In this system the first stage generally is aseptic tank or a settlement tank which can also be designed as a biogas plant. Such a biogas plant can not only treat the sewage but also the kitchen solid wastes to produce biogas (refer chapter 4). Biogas is a mixture of methane and carbon dioxide, which can be used as a fuel. Besides producing bio gas such a treatment system can also produce food in the poly-culture stage. The only source of energy required for such a system is sunlight but it also needs a huge

**Figure 5.18 Living machine within the double skin envelop system (Sketch: Author)**



space for the effective treatment. In case of a high-rise building it also can be very effective if such a system is integrated within the façade. If such a system is integrated with in a double skin envelop system then it can receive the useful daylight required for the treatment, provide shade to the interior glazing whereas the stored water can act as a thermal storage for the effective use of the chimney during night. Other than food production algae can also be cultivated in such a high-rise waste water treatment system. Algae being highly concentrated with bio diesel can be very useful as a source of alternative energy.

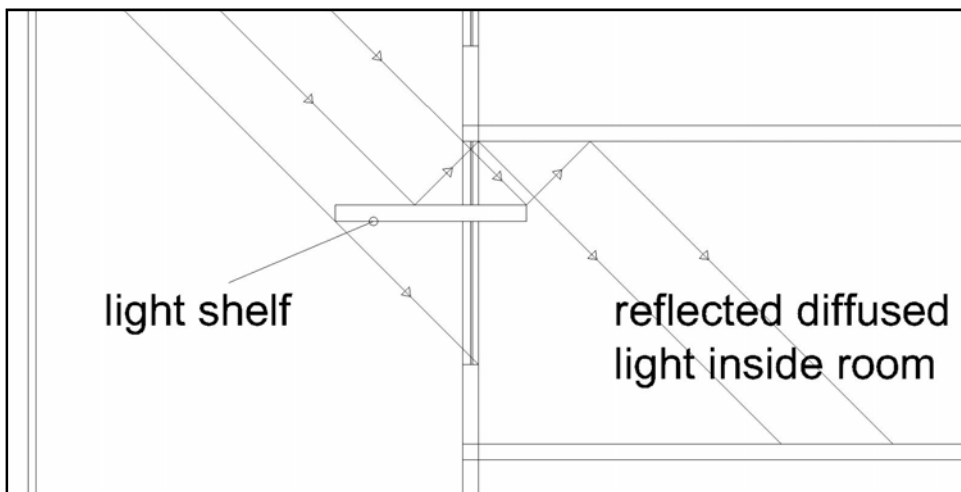
### Solid waste recycling:

Solid wastes generated in a residential tower are principally of two types. The kitchen wastes (the leftovers after cooking and eating) and the paper wastes from packaging, used up stationary, envelopes etcetera. For recycling the kitchen waste can be fed to the biogas plant whereas the paper wastes can be used as bio-fuel for water heating or power generation. Besides kitchen waste and paper wastes there are some wastes like metal scraps or plastics which cannot be used up directly. These garbage can be recycled onsite or sent to some recycling plant.

### *Use of daylight*

Interior illumination is a major issue for energy usage in a high-rise building. A double skin façade system can also be very effective for the effective use of day lighting. A double skin

**Figure 5.19 Use of light shelf to enhance effective use of daylight (Sketch: Author)**



façade coupled with a solar shading device inside the two layers of glazing can trap the solar heat inside the chimney and supply the cool reflected daylight inside the building. The shading device can also be designed in such a way that they work as a light shelf to provide illumination in the deeper portion of the interior space. For the perfect day light illumination the depth of the

building is an important factor. Some European design code guide that for maximum effectiveness of daylight the farthest workable space inside a building should be within 5m to 7.5m ( a depth of 2.5 times the window height) of the external glazing (Yeang K. , 1999). The shape and size of shading device is also an important issue. The shading device should be designed in such a way so that it can provide shading during summer but allow sunlight during winter. An adjustable blind is a very effective strategy as it can be adjusted according the user need. Glare is an important issue with daylight. Glare is developed due to the high contrast between window areas to the darker surroundings. A beveled window edge (jamb and sill) can be an effective solution to reduce glare.

### ***Integration of plants with buildings***

In integration of plant with the high-rise building is an important issue which has been elaborately discussed in the book green skyscrapers by Ken Yeang. The many important advantages of plant integration discussed in Green Skyscraper are;

1. Reduction of roof discharge by vegetative roof
2. Cooling the building surface by moisture infusion
3. Purification of air by the absorption of contaminants

By the side of the above mentioned effective advantages there is another major advantage that is food production. High-rise farming is an effective and economically profitable idea. Particularly in hot humid Kolkata climate high-rise farming can end up with a significant food production. Moreover in aquaponic system such high-rise food production can be integrated with the poly-culture stage of the sewage treatment system.

Aquaponic farming is a bio-integrated system that links recirculation of aquaculture waste with hydroponic plant production. In a typical aquaponic system fish waste is used to

supply nutrients for the growing plants and the plants provide a natural filter for the water the fish live in. Fish effluent supplies ammonia, nitrate, nitrite, phosphorus, potassium, and other secondary and micronutrients required to produce hydroponic plants. Some plant species are better adapted to this system than others but overall this technique creates a sustainable ecosystem where both plants and fish can thrive. Lettuce, herbs, spinach, chives, basil, and watercress etcetera. have low to medium nutritional requirements and are well adapted to aquaponic systems. In Kolkata there is already an existing practice of fish cultivation in sewage fed fisheries. Research conducted by department of Biotechnology, West Bengal University of Technology, confirms that fish and food produced with the waste water in east Kolkata wetlands don't contain any significant contamination.

In high-rise building the total building envelop area is significantly high compared to the floor area, but commonly it remains unused. If such a high-rise food production system is integrated within envelop then it can effectively use a huge commonly unused surface in high-rise building. To give an example the central tower of Rockefeller centre has a total surface area of nearly 80000 m<sup>2</sup> which is equivalent to eight hectares of land area. If even fifty percent of the area utilized then it can produce significant amount of cultivable land.

### ***Renewable energy production***

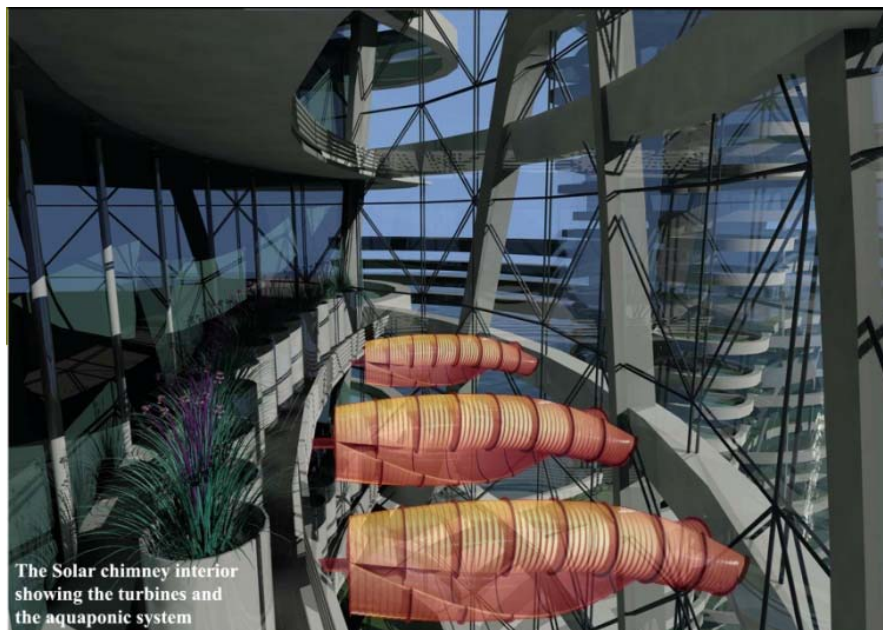
Harvesting onsite renewable energy sources is another important criterion for a high-rise building. Commonly building integrated photovoltaic systems and building integrated wind turbines are popularly used for onsite power generation. But it is difficult to use either of these systems in Kolkata.

Solar photovoltaic technology is a quite developed technology. Although the net efficiency and EROEI of PV cells are still in question but with the development of thin film

technology significant improvement in EROEI is expected. Presently the most assessments of silicon-crystal cells suggest a net return of less than 1, the newer thin-film and DSC technologies may be able to achieve a substantially more favorable EROEI (The more optimistic assessments of silicon crystal cells suggest a current net return of roughly 10). It is expected that with the new technological development the net energy available from PV electricity will overtake the EROEI that can be derived from petroleum, as the latter is depleted (Heinberg, 2003). The cost of PV panels is another major concern and that puts the use of PV cells in serious question. The most effective means of using PV panels in high-rise building is to use it as solar glass panes. Solar glass is a kind of building integrated photo-voltaic application. Solar glass is an effective mean to generate electricity, it occupies building surfaces that would otherwise require reflective glass and window shades to avoid the sun's heat. But the major drawback to solar glass is low efficiency, and it's fairly expensive (about five times as much as regular glass, not counting components such as wiring and inverters). Strict analysis of energy cost savings shows that integrated solar glass rarely pays for itself. (Thomas, Solar Glass at Hong Kong Science Park, 2006). The economic aspect of solar photovoltaic panels is even critical in Indian context. Due to the difference of currency value PV cells appear to be abnormally costly and economically not viable in Indian context.

Although in the economic aspect wind turbines are much more effective but they performs poorly when integrated with high-rise buildings. Wind speed in Kolkata is not considerably high during most of summer except some storms but then it becomes very much turbulent. Moreover in an urban context the presence of other buildings effect the wind movement and make it even more turbulent. Wind-turbines perform best with strong laminar wind, in which all of the air flows in a single direction. But in case of high-rise even very tall buildings, wind flow is highly turbulent. It happens due to fluid dynamic property of wind explained by Bob Thresher, director of the National Wind Technology Center at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. According to his explanation as wind flow comes over the edge of a roof or around a corner, it separates into streams and this

**Figure 5.20 Solar chimney energy production (Sketch: Author)**



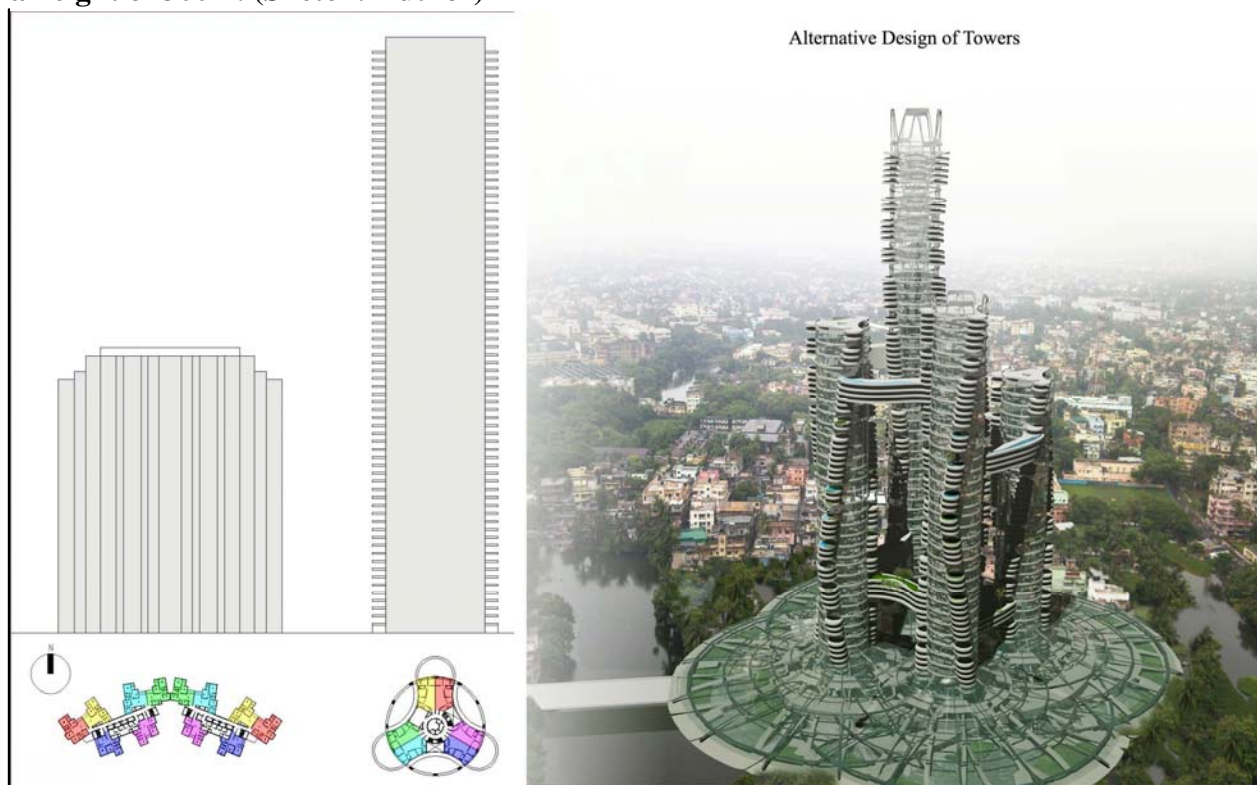
creates the turbulence. This turbulent flow confuses a wind turbine and affects its performance (Thomas, World's First Building-Integrated Wind Turbines, 2007).



Considering all the aspects building integrated solar chimney seems to be a more effective technology. Solar chimney uses solar insolation energy to produce an updraft through a chimney which is eventually used to rotate turbine. Thus a solar chimney can produce a laminar wind flow through the chimney for effective use of wind turbines. If the solar chimney is integrated within a double-skin facade of a high-rise building then the issue of its primary cost involvement can be handled and the system can become effective. Moreover using the building surface as solar collector can reduce the need of a huge collector area at the base of the chimney thus it can become applicable even in urban environment. Although the efficiency of a solar chimney power plant is very little (varies between .5percent to 1percent) it can produce significant amount of electricity if integrated within the envelope of a high-rise building. As an example if such a system is used only on the south façade of Rockefeller centre's central tower, which is nearly 25000m<sup>2</sup> then with an average New York Solar irradiation of 4.2kwh/m<sup>2</sup> (Resources, 2010) such a system can produce nearly 1MWh of electricity per day (considering 1percent efficiency).

The efficiency of solar chimney increases with the increasing height, so for better output it is suggestable to increase the height by reducing the footprint of the tower. If a tower has half

**Figure 5.21 Doubling the height by reducing the footprint an alternative design can achieve a height of 300m. (Sketch: Author)**



the footprint of South city then with the equal floor area the tower height can be nearly 300m, which is good enough to generate a significant updraft. A 'Y' shaped floor plan can generate three chimneys each having a significant exposure from east, west or south sun. Moreover a rotation in plan can give even more optimal exposure to each of the chimneys to south sun. According to the floor plan shown in Figure 5.8 the chimney outer perimeter length in a floor is 105 meter. Considering 300 meter total height the total chimney surface area is  $31500 \text{ m}^2$ . Considering one percent efficiency and average solar insolation of  $4.93 \text{ kWh/day}$  these towers can generate  $1552 \text{ kWh}$  of electricity per day.

**Discussion:**

Considering all these aspects if a tower is designed in Kolkata then it can reduce the ecological impact to a significant extent. Compared to one thirty five story residential tower of south city project such a seventy story tower can sustain with much less consumption of resources and production of much less waste. With the use of adsorption cooling system and passive solar cooling system the tower can get rid of window air-conditioners, this can reduce almost fifty percent of the energy requirement. Production of electricity by solar updraft tower system will also reduce the electricity demand of the tower.

**Table 5.8 Comparative analysis of carbon footprint**

Usage	A 35 story tower of south city	A 70 story tower with alternative design strategies
Electricity consumption	9840.04kwh/day	3467.64kwh/day
Water consumption from grid	181712 liters per day	0 liters per day
Waste water production	172808.112 liters per day	0 liters per day
Garbage production	.864 tons per day	0 tons per day
Food production	0	2acres of aquaponic food production area
Carbon footprint	10215831.31 grams of CO <sub>2</sub> equivalent/day	3467640grams of CO <sub>2</sub> equivalent/day

## **Section Three: Cost Analysis**

### **Cost analysis:**

To understand the viability of an alternative technology the cost analysis is an important issue. There are four different alternative strategies discussed in this chapter for the development of an alternative tower design; 1. passive solar cooling system; 2. living machine waste water treatment system; 3. rain water collection on building surface; 4. solar updraft façade system for energy production. Cost analysis was done on the PWD (public works department) schedule of cost of construction and the market rates in Kolkata.

### **Passive solar cooling system:**

Although the running cost of an alternative passive solar cooling system is nominal compared to a conventional HVAC system but the initial investment cost is usually higher. But considering two years payback period of adsorption cooling system (refer Appendix B) the initial cost is around \$80 per square meter (considering 15 cents per unit of electricity and 1kw energy per tonnage of conventional HVAC). This is equivalent to the cost of conventional central plant HVAC system.

Usually the cost of earth tube cooling systems are considered to be high and economically not viable in U.S. This is primarily due to the high labor cost in the U.S. In contrast to U.S., labor cost in India is significantly low. Moreover during the construction of a high-rise building significant amount of excavation is required. Considering all these issues the cost of earth tube can be viable in high-rise buildings of Kolkata.

### **Living machine waste water treatment system:**

Initial investment cost for a living machine system is equivalent to a conventional waste water treatment system. But for the integration of such a system in a high-rise building there will be some additional cost of construction. For the waste water treatment an additional 11000 m<sup>2</sup> of

area is required for construction. Although this will be under service area and doesn't need much finishing this will require a significant initial investment. Considering the construction cost for reinforced cement concrete floor slabs to be 2000 rupees (\$40) per square meter the total cost will be Rs. 22000000 (\$440000).

### **Rain water collection:**

In comparison to all other systems the building integrated rainwater collection and sky parks needs maximum investment. For rainwater collection an additional 4200 m<sup>2</sup> projection area has been proposed. As this balconies will be a part of the building elevation and the projection is significantly high, these areas will require a significant investment. Considering a construction of Rs.10000 per square meter (\$200/m<sup>2</sup>) the total construction cost will be Rs. 42000000 (\$840000). As the cost of water supply is low in Kolkata so the payback period for such a system will be quite high and will not be economically viable. But considering the ecological benefit and quality of life this system can be considered.

### **Solar updraft façade system:**

The principle cost of a solar updraft façade system is in the construction of the envelop. According to an analysis presented by Harris Poirazis in Europe a double skin façade usually costs double compared to a single skin glass façade. In Europe an average cost escalation of 300Euro/m<sup>2</sup> (\$400/m<sup>2</sup>) of the façade has been observed (Poirazis,H.2004). Considering the cost of single skin façade system in Kolkata it can be concluded that such a system will incur an additional investment of Rs.5000 per square meter (\$100/m<sup>2</sup>) of the chimney skin area. Considering the total chimney surface area as 31500m<sup>2</sup> the total construction cost will be Rs.157500000 (\$3150000).

Considering an average energy generation period of eight hours a day a solar updraft double skin façade of capacity of 1552kwh/day needs 194kw capacity of wind turbines. Presently often the price of small 400-500watt turbines ranges around \$500 to \$700. As an example the ‘AIR X Wind Generator’ (400watt) (solar-dyne.com, 2009) costs \$699. So for the entire installation of 194kw the total investment will be \$339015.

Considering the cost of envelop and the wind turbines total \$3489015 of initial investment is required.

**Payback period:**

The cost of energy per unit in Kolkata is low compared to other Indian major cities. According to the 2008-2009 tariff order of CESC (Calcutta electric supply corporation), the average tariff per unit electricity in Kolkata is Rs. 3.91 (\$.078/kwh) (CESC, 2009). Considering this tariff the annual saving from electricity will be Rs.9094370.66 (\$181887.41). Considering a payback of \$181887.41/year the total payback period of a solar updraft façade system is 19 years. But considering the annual escalation of electricity tariff it is obvious that the payback period will be much lower with time.

**Table 5.9 Calculation of payback period**

System	Additional investment cost (\$)	Annual electricity saving	Cost Savings per year
Passive solar cooling system adsorption cooling system and Earth tubes	\$136000 (considering \$2/m <sup>2</sup> floor area)	1759446kwh	\$ 137588.68
Living machine waste water treatment system	\$440000	66859.46kwh	\$5228.4

Rain water collection	\$840000	70304.37kwh	\$5497.8
Solar updraft façade system	\$3489015	566480kwh	\$44298.74
Total	\$4905015	2463089.83kwh	\$192613.62
Payback period for the entire systems		25.46 years	

### **Conclusion:**

Kolkata is a big and growing city. Studies done in initial chapters show that with the economic development number of high-rise buildings in this city is growing. The studies also show that within the present context normative practice in high-rise buildings in this city needs to be reconsidered.

Research and analysis done in previous chapters show the possible reduction of ecological footprint of high-rise buildings in Kolkata by the development of ecologically considered building operational systems. This research generates an understanding that high-rise is a special building type which has problems as well as advantages. Height and large surface areas are typical features of this building type. If tackled in proper ways then this height and large surface areas can give several advantages.

Many of the alternative strategies and systems studied in this thesis are already well established and can be easily integrated with an existing high-rise building or a new development. This research also shows the possibility of developing alternative systems in high-rise buildings. Already there is a research being done for the development of zero energy cooling systems by integrating earth tubes with solar chimneys. Building on ideas from this earth tube

and solar chimney design study an elementary study was completed during this research to develop a solar updraft façade system. This system shows the possibility of developing a viable ventilation and power generation system in high-rise buildings. In addition to the ventilation and power generation this research also examined the possibility of alternative waste water treatment and high-rise food production. These alternative strategies can be effective for resource recovery in future high-rise buildings.

In the last section of the last chapter of this thesis the author attempts to reveal the financial feasibility of these alternative strategies. Based on the general understanding of the context and the available data a preliminary cost estimate was completed. Although this analysis gives an approximate idea of feasibility, to get a complete picture several other issues like government incentives etcetera need to be considered.

**Research limitations:**

This research primarily focused in understanding different ecologically considered building operational systems and their possible integration in high-rise buildings. Due to time and financial constraint this research could not go into detail onsite investigation of all the proposed systems which leaves a scope for further research. Besides actual on-site investigation further research is required to determine details of design techniques for implementation. This research also leaves the scope for further detailed study of financial feasibility of such a development.

The study of alternative cooling techniques has some inherent limitations as the entire research was done on the basis of literature study and no specific system has been tested in Kolkata. Although there were some previous researches and testing on different systems like: double skin façade system; absorption cooling system; geothermal heat pump; geothermal earth



tubes; and desiccant cooling systems but none of these have been tested in a contemporary Kolkata high-rise building.

To develop a cooling system by the integration of geothermal earth tubes and solar chimney a research was done in the University of Nebraska but no such system has been tested in a high-rise building. For the further conclusive development of these systems a thorough on-site testing or through computer generated fluid dynamic analysis is important.

The entire study of waste water treatment and high-rise food productions was also done on the basis of literature study and no specific system has been tested in a contemporary Kolkata high-rise building. For a conclusive development of a waste water treatment and high-rise food productions system a thorough on-site testing and analysis is important.

In the study of renewable energy techniques except a preliminary design and testing of the model solar updraft façade system all other research was done on the basis of literature study and no specific system has been tested in Kolkata. The height of the model solar updraft façade systems was small compared to the actual height required and it was not attached to any building façade. Moreover for financial and time constraints this research didn't include a computational fluid dynamic (CFD) analysis but such an analysis can be helpful for a better understanding before an actual construction.

This research only looked into the relation of temperature rise and wind velocity inside a solar updraft façade system with respect to solar insolation but it skipped the constructional details and the material aspects of such a system. Besides the CFD analysis it is important to make one true scale prototype system as it was done for solar chimney research in Manzanares, Spain. Such a prototype can give complete understanding of such a system regarding its actual cost, efficiency, and constructional difficulties.

**Barriers to implementation:**

There are some barriers for the implementation of alternative cooling strategies discussed in this thesis. Cost is a primary barrier to implement a double skin façade.

Kolkata is a hot-humid climate region where ordinary geothermal earth tubes are not suitable as the tubes may have condensation and fungus formation inside. But the good quality earth tubes like Awaduct thermo is not presently manufactured in Kolkata and thus cost and availability is not dependable. Presently in Kolkata Absorption and adsorption chillers are also not readily available so for the initial projects there will be an issue of cost effectiveness.

Moreover until the systems are successfully tested in Kolkata and in an actual condition and analyzed for efficiency and cost effectiveness it will be difficult to implement because of the skepticism of developers.

Kolkata climate is suitable for living machine waste water treatment systems and can make such a system cost effective but the major barrier is a lack of skilled labor force in Kolkata to manage such systems. Moreover until the systems are tested for a conclusive finding of applicability, it will be difficult to implement because of the skepticism of developers.

There are also some barriers for implementation for the renewable energy techniques discussed in this thesis. Besides the high primary cost involvement the novelty of this idea is also an obstacle as it doesn't have any precedence and thus less dependable for the investors.

Moreover with present tariff rate of Kolkata the payback for such a system is low. Electricity tariff in Kolkata is highly subsidized and much less compared to other big cities like

Mumbai and Delhi in India (CESC, 2009) but as the tariff is constantly increasing it may become viable in future.

**Future directions:**

This research investigates the possible carbon footprint reduction in high-rise buildings of Kolkata by design integration of several ecologically considered operational systems.

This research is a broad analysis of possible integration of ecologically considered operational systems in high-rise buildings. For a better understanding and development of ecologically considered operational systems further researches need to be carried out regarding constructional detailing, cost analysis, material aspects, and management of these systems.

This thesis also presented a conceptual design of an alternative high-rise building but for practical implication further investigation is required to develop a complete architectural planning and designing of such a tower.

Most of the research in this thesis was done on the basis of literature study. For a better understanding of performance of different ecologically considered operational systems it is important to make prototypes and do some experiments in Kolkata.

In this thesis only the solar updraft façade system was tested with an experiment. But the prototype model was fairly small and the experiment was carried out in Kansas State University campus. For better understanding of such a system it is important to develop a true scale prototype in Kolkata for further experiment. Moreover for the development of a solar updraft façade system a thorough study by CFD analysis is also important.

Cost is one of the biggest barrier for the practical implementation of such ecologically considered operational systems. A thorough research is important to check the actual investment

and payback and as well as alternative funding opportunities in the form of public private partnership.

Finally this research is just a beginning for many possible investigations in future.

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## Appendix A - Survey of some contemporary projects in Kolkata

### Highland Park



**Building Name-** Highland Park

**Architect-** Dulal Mukherjee & Associates

**Building Type-** Residential

**Building Height (Stories)-** G+27

**Building Area-** 6 apartments per floor (floor plans not available)

**Total Electricity consumption-**

1 MVA

**Total H.V.A.C. consumption-**  $6 \times 27 \times 2 \times 1.5 \text{ T.R.} = 586 \text{ T.R.}$

**Total S.T.P. capacity-** 1x20H.p. pump

**D.G. backup-** 320 K.V.A

**Information received From-** Mr. Samar Ghosh(senior Shift Engineer), Mr. V.K. tewari(Facility Executive)

**Building Name-** South City

**Architect-** Dulal Mukherjee, Smallwood Reynolds Stewart Stewart & Associates Inc, based in Atlanta, USA

**Building Type-** Residential

**Building Height (Stories)-** G+36

**Building Area-** 12 apartments per floor

**Total Electricity consumption-** 2 MVA

**Total H.V.A.C. consumption-**  $12 \times 36 \times 2 \times 1.5 \text{ T.R.} = 1172 \text{ T.R.}$

**Total S.T.P. capacity-** 2x125kw+ 1x5.5kw

**D.G. backup-** 1160K.V.A

**Information received From-** Amal Chatterjee (Facility consultant)

Building Name- **Eco-Space** (Platinum rated Green Building by LEED (pre-certified))

Architect- RSP Architects Planners and Engineers Private Limited

Building Type- Commercial

Building Height (Stories)- G+7

Building Area- 2 million sqft.

Total Electricity consumption- 10.4 M.V.A.

Total H.V.A.C. consumption- 2000 T.R.

Total S.T.P. capacity- N.A.

D.G. backup- N.A.

Information received From- Joydeep Mukherjee(Senior manager - Bengal Ambuja)

**Sunrise Point**(source: www.surekaproperties.com)



Name- **Sunrise Point**

Architect- **Mr. Kabir Ray**

Aruden Consultancy Services

Kolkata, **Mr.Stephen. A.**

**Coates** a C T a International

Singapore

Building Type- Residential

Building Height (Stories)- G+14

Building Area- (G+14) x 7 x 6000

sqft.(appx) = .63 million sqft.(appx)

Total Electricity consumption- 2M.V.A.

Total H.V.A.C. consumption-  $\{(3 \times 6 \times 8 + 3 \times 4 \times 6) + (4 \times 4 \times 14)$

$= 146 + 72 + 216\} \times 2 \times 1.5 = 414 \times 3 = 1242$  T.R.

Total S.T.P. capacity- N.A.

D.G. backup- N.A.

Information received From- Ashok Deb (Site Engineer)

**Login Hospitality** (source: [www.surekaproperties.com](http://www.surekaproperties.com))



Building Name- **Login Hospitality**

Architect- Acta International, Singapore /  
Edifice Architects Private Limited,  
Kolkata

Building Type- Hospitality

Building Height (Stories)- B+G+10

Building Area- 133221 sqft.(super builtup)

Total Electricity consumption- 1.5M.V.A. (0.6  
KVA per 100 sq ft of super built-up area.

This includes power required for AHU and  
fan coil/cassette unit, raw power for  
lighting and other office equipment. It  
does not include power

required for central chiller, cooling tower,  
all common areas including basement and

other services.)

Total H.V.A.C. consumption- 400 T.R.

Total S.T.P. capacity- 85 Cum/Day

D.G. backup- 100percent

Information received From- [www.surekaproperties.com](http://www.surekaproperties.com)

**Globsyn crystal** (source: [www.surekaproperties.com](http://www.surekaproperties.com))



Building Name- **Globsyn crystal**

Architect- Amatrix/Edifice

Building Type- Commercial

Building Height (Stories)- G+11

Building Area- .45million sq.ft.

- Total Electricity consumption- 6 M.V.A. (**Electrical:** 33KV HT connection through RMU)
- 3# 1600 KVA Dry Type transformer
- Captive generation to meet 100percent power back-up.DG sets with auto synchronizer and AMF panel
- Emergency panel for fire alarm control, EPABX, emergency lighting in each floor, fire pumps, sump pumps and hydro pneumatic systems
- Capacitors for power factor connection
- Provision for control access and electronic surveillance  
Required illumination through UPS for emergency evacuation

Total H.V.A.C. consumption- 2100 T.R.

Total S.T.P. capacity- 300Kilo lt/Day

D.G. backup-

Information received From- Jyotirmoy Acharya (Site Engineer) / [www.surekaproperties.com](http://www.surekaproperties.com)

**Development Consultants LTD**

Building Name- **D.C.L**

Architect- D.C.L

Building Type- Commercial

Building Height (Stories)- G+7

Building Area- .1million sqft

Total Electricity consumption- 800 K.V.A

Total H.V.A.C. consumption-

Total S.T.P. capacity-

D.G. backup-

Information received From- Dr. Susanta Biswas

Building Name- **Haldia Commercial complex**

Architect- Partho Ranjan Das

Building Type- Commercial

Building Height (Stories)- G+38

Building Area- Total Area : 6,54,301 sqft. AC area : 442414 sqft.

Total Electricity consumption- 4396 KW

Total H.V.A.C. consumption- 1200 TR ( 900 TR installed equipment + 300 TR STL)

Total S.T.P. capacity-

D.G. backup-

Information received From- Mr. Debasis Das (Services consultant)



## Appendix B - Comparison between Adsorption and Absorption chiller

### Comparison between Adsorption Chiller and Absorption Chiller (Adsorption Chiller VS Absorption Chiller hot water fired)

	Adsorption Chiller	Absorption Chiller
Refrigerant	Water	Water
Adsorbent/Absorbent	Silica-Gel	Lithium-Bromide
Adsorbent/Absorbent Costs	is included, does not need to be replaced	\$ 1,200.00 for 30 gallons
Vacuum Pump	Yes (but operates 1 hour out of every 40)	Yes
Refrigerant Pump (Water)	Runs only when chiller unloads	Continuous
Absorbent Pump	not applicable / not required	Magnetic, continuous operation required
Automatic Valves	Butterfly Valves (simpler operation)	3 Way Control Valves
Coefficient of Performance	0.7	0.7
Cooling Tower Size	Heat of rejection equals Cooling	Capacity plus amount of heat input
Corrosion	None	Strong Corrosion
Crystallization	None	Crystallization happens 1. On low temperature cooling water 2. On air leakage into the machine 3. On power loss/ failure of dilution Malfunction 4. On failure of a pressure-reducing valve
Warm up (Start)	0 to 7 minutes after long stop	Loss of Heat source - 30 min.
Dilution Cycle (Stop)	Not applicable	Yes 15 min.
Inhibitor	None required	Inhibitor with heavy metal, check inhibitors' warning label
Chiller Life Expectancy	More than 30 years	7 to 9 years
Frequency of replacement of adsorbent or absorbent	Not necessary	Every 4 to 5 years

Required Hot Water Temperature	Operates down to 122°F (but no problem if temperature goes below this)	Shut down at 180°F or need back up heater to avoid crystallization
Chilled Water Temp.	37.4°F is available as standard	48°F normal / 41°F for experimental
Maintenance	Very minor service every 3 years	Expect continuous service tasks & monitoring
Reliable	Yes - very simple, very reliable	No
Pay back	Less than 2 or 3 years	Doubtful