# High rise buildings energy assessment towards near net-zero energy consumption

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# Abstract

The residential and commercial urban sprawl towards green future is governed by the ability to overcome the challenges facing the high rise buildings sustainability. This research is dedicated to assess the high rise buildings' energy towards near net-zero energy consumption from the point of view of production (the on-site energy generation *via* renewable technologies) and consumption (the usage of low consumption products).

The features of the high rise buildings limit the on-site renewable energy production to solar energy, therefore the integration of solar application in the building's facade plays a major role in the on-site energy production. Since, the relative roof area compared to the height of the high rise buildings is much less than the single family houses. Therefore, the use of the facade in high rise buildings for clean energy production becomes a major element towards its sustainability.

There are several solar energy production techniques of which the most feasible and effective one is the combined electricity generation and heat collection *via* integrating PV and thermal collector system this system is denoted as solar Photovoltaic and Thermal (PVT) system. PVT system produces both electricity and heat at a higher efficiency from one integrated system on the same surface area exposed to the sun. For instance, PVT system produces approximately 43% more primary energy than a conventional solar thermal collector per unit surface area, and even around 96% more than a conventional Photovoltaic PV system (PVTwins, n.d).

The concept of the PVT system was generated based on the fact that Photovoltaic (PV) system has typically 14-17% efficiency, so the rest of more than 80% is a lost energy; this lost energy goes in a form of heat. This heat could reach as high as 50$^{o}$C above the ambient temperature resulting in structural damage as well as reducing the system efficiency by 25%. Recovering this harmful heat could reach up to five times thermal energy more than electricity from PV array (Hollick, 2011).

From the energy consumption perspective, the air conditioning and ventilation system (HVAC) is considered as one of the highest energy consumer in the overall high rise buildings energy consumption (around 40%). This makes it an essential part of any high rise buildings energy solution therefore several low energy consumption HVAC systems has been developed recently. As such, absorption chiller presents one of the greenest HVAC system whereby it has no moving part, no electricity required, thermal driven system (use heat to produce cold) and could be operated by solar thermal energy.

In this sense, the enterprise should respond to the increasing demand of the high efficiency buildings mainly by developing new solutions that enhance the latest green technologies and overcome the recent energy challenges. To develop a new system, an organization needs to implement some

engineering management principles in order to achieve success. The initial steps of the product development phases play an essential role in this process whereby the design contributes almost 70% of the product success rate. On the other hand, logistic elements shape the product survival and give a competitive advantage. Therefore, they should be inherited in all product development phases as well as throughout the system life cycle.

Furthermore, answering the question of the market acceptance as one of the product development early stages affects the future of the system and its market survival. Market acceptance is governed by two elements, the effectiveness of the marketing strategy and the genuineness of the product unique sales point (USP). This study suggests that marketing strategy should be constructed based on below factors:

- Differentiation: organization should offer a product that unique among its competitors. Product differentiation could be achieved by offering a total energy solution;
- Customer focus: selecting one segment of the expected customer and then adjust the service or product to suit their specific needs. In this sense, organization could implement a customer focus strategy by focusing on the high rise buildings specific requirements.
- Green perception: organization should be seen by the customer as a green firm. There are several ways to achieve such market perception. This study suggested that organization architecture its own green brand name to achieve this target.

Although, offering a green solution is a unique sales point (USP) by itself, firm still needs to prove to the customer that this green claim is legitimate. Such proof could be achieved by obtaining one of the green labels.  There are several green certification systems available worldwide, Leadership in Energy and Environmental Design (LEED) and Energy Star are the most feasible and effective certification systems, as they dominate the green high rise buildings market internationally. Labelling systems provide buildings and investors with several benefits but they require an investment. However, the labelling system investment varies from project to another, but an overall cost feasibility study could be conducted against the conventional systems.

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| | |
|---|---|
| AOEC | Annual Operating Energy Cost |
| COP | Confectioned of performance |
| DOE | US Department of Energy |
| EPA | Environmental Protection Agency |
| EU | European Union |
| FBD | Flow Block Diagram |
| HRV | Heat recovery and ventilation unit |
| HVAC | Heating, Ventilation and Air condition |
| IEA | International Energy Agency |
| LEED | Leadership in Energy and Environmental Design |
| LDB | Logistically Distinct Business |
| Mct | Mean Corrective Maintenance |
| MLHu | Mean Labour Hour per Unit |
| Mpti | Mean Preventive Maintenance Time |
| MTBF | Mean Time between Failure |
| MTTR | Mean Time to Repair |
| MEP | Mechanical, Electrical, and Plumbing |
| MPR | Minimum Program Requirements |
| NPD | New Product Development |
| PV | Photovoltaic |
| PVT | Photovoltaic and Thermal system |
| PEST | Political–legal, Economic, Socio-cultural, Technological |
| PDP | Product development process |
| 5 P`s | Product, Price, Place, Promotion, People |
| QFD | Quality Function Development |
| SEP | System Engineering Process (SEP |
| SOWT | Strength, Opportunities, Weakness, and Threats |
| TPF | Technical Performance Factors |
| TSTC | Transparent Solar Thermal Collector |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USGBC | U.S. Green Building Council |
| USP | Unique Sales Point |
| λ | Failure Rate |

# CHAPTER 1: INTRODUCTION

Engineering management is a very complex process that needs broad understanding of a wide range of knowledge in which it allows the engineering manager to understand problem insights and then to develop a feasible solution. In this sense, there are several engineering management concepts employed to study problems and develop a buildable solution. For instance, the system design process (SDP) described by Chapman et al. (2001) as: "translating the customer's needs into a buildable system design". As such, organizations can gain more market share as well as they can sustain it by differentiating themselves from competitors.

Core competency can be defined in several ways of which all the definitions focus on the processes that allow the company to differentiate itself from competitors. In one definition core competency described as a key business output or process through which an organization distinguishes itself positively. In another core competency defined as a key business process to represent core functional efforts that are usually characterized by transactions that directly or indirectly influences the customer's perception of the company (Wireman, 2005).

Gaining more market share is one of the most important organization goals. One of the straightforward ways to achieve such goal in today`s world is to develop a new product (NPD) to enhance the opportunities and to overcome climate change challenges. However, responding to the customer needs earlier than competitors, and improving the system success rate, even slightly, may result in a competitive edge (Schmidt, 2003). The positive reaction to the climate change challenge could be a great chance for mechanical-electrical-plumbing (MEP) contractors to increase profitability. Therefore, developing clean energy solution systems for high rise buildings could be a great chance to enhance climate change opportunities while managing its threats.

## 1.1 Problem statement and research motivation

Problem identification could be defined as what must be done and not how to do it. A problem statement should be developed in specific "qualitative" and "quantitative" terms and in enough details (Blanchard, 2004). However, stating the problem involves assessing targeted customers as well as identifying customer needs. In this sense, there are two types of system requirements. The first one is the mandatory requirement which specifies the minimum conditions for a system to be acceptable. The second one is the preference requirement which works to increases customer satisfaction. Moreover, considering end users input in problem identification plays a significant role in diagnosing the problem. In the modern business environment, the problem statement starts with a reason for change (Bahill & Dean 2003).

Winzker (2011) believes that humanity development from one age to another is going through a transformation wave. The understanding of this transformation plays a major role in any business survival. The positive response to this wave may shape the future of the enterprise. Today`s world may go through a transformation process from the information age by the wave of “climate change” to what can be called a “green oriented age”. The deep understanding of climate change effects on a particular business area enhances enterprise`s survival and continuous growth.

### *1.1.1 Climate change effect*

Climate change has become a major issue affecting the future of the planet. This, as a result of demand for economical and industrial development still outweighs the demand for a healthy natural environment. Moreover, modern life style which is based on a development model of “urban sprawl” and its high rise buildings, individual vehicle ownership, and high consumer demand, with an industrial infrastructure built to support that model is a good example of energy consumption (Drexhage and Murphy, 2010). However, climate change is one of the most pressing global challenges of the 21st century, and increasing evidence of the present and anticipated impacts of climate change highlights the need for action.

Climate change is commonly characterized as an issue of industrial emissions. The most threatening phenomenon that significantly contributes in climatic change all over the world is $CO_2$ emission. Members of the organization for economic co-operation and development (OECD) recorded the most noticeable $CO_2$ emission which increased by 11.2 % from 1990 to 2007. Developing nations have a considerable contribution in $CO_2$ emissions as well. In 2008 for example, the economic activities in developing countries accounted for half of the total $CO_2$ emissions in the world. This contribution is expected to continue growing if no new polices and measures are implemented to limit this increase (IEA, 2011).

International Energy Agency (IEA) statistics (2011) reported the contribution of different fuels in energy production and the $CO_2$ emission associated with each fuel as illustrated in Figure 1.1. Oil and coal are the most used fuel for energy production but at the same time, they show the highest $CO_2$ emission. Even though the nuclear energy is a clean energy, the increased awareness of the risk associated with it limits the use of it as a source of renewable energy. Germany, for example, has announced that all its nuclear power plants will be phased out by 2022 (BBC, 2011). Moreover, Buildings account for about 30% of energy consumption in most countries, and about 53% of electricity consumption (NRCan 2006a). They also account for around 30% of $CO_2$ emissions as shown in Figure 1.1.

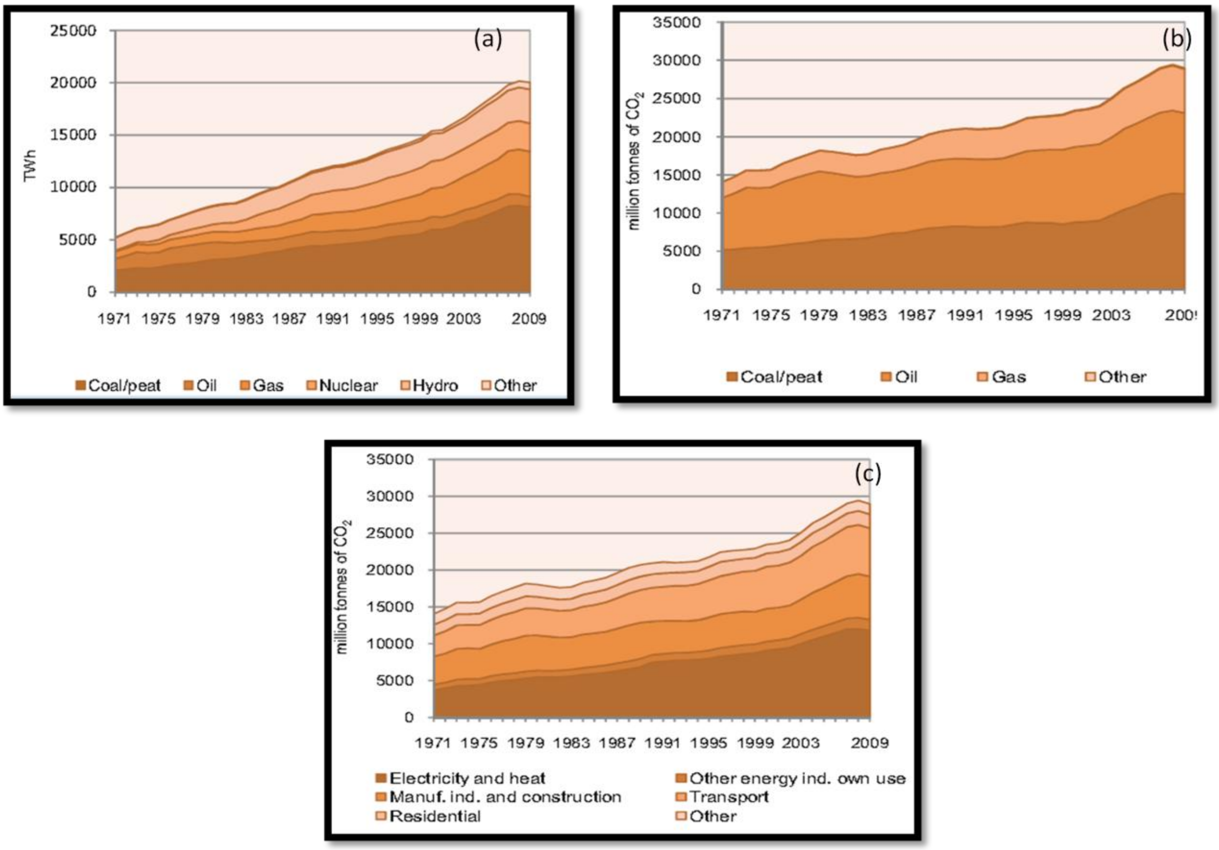


**Figure 1.1: (a) Electricity generation by fuel; (b) $CO_2$ emission by fuel form; and (c) $CO_2$ emission by sector (IEA Statistics, 2011)**



### *1.1.2 Energy demand and production challenges*

Figure 1.2 shows the expected growth of energy consumption for some countries within half century up to 2050. This growth can reach up to 500% of 2007 consumption in some countries. Some may argue that energy needs cannot be avoided. Such arguments are supported by the understanding of the factors behind this energy growth. Factors driving the energy needs growth could be summarised as:

a) Human development: for example, the individual energy needs had grown from 10 Kcal/day for hunting man, 75 Kcal/day for industrial man till it exceeds 210 Kcal/day for the technological man today (Cook, 1971).

b) Population growth: the population increase rate is more than 200,000 people per day. This in turn, affect the energy consumption dramatically (Ngo and Natowitz, 2009).

c) Economy development: energy growth expectation is always linked to economic growth in which developing countries contribute the highest energy consumption growth rate where demand for electric power is driven by strong, long-term economic growth. This argument supported by statistics reported by IEA (2011) where the developing countries such as India, Middle east countries, and China show more energy consumption growth rate compared to the developed countries like North America, Pacific and Europe, Figure 1.2.

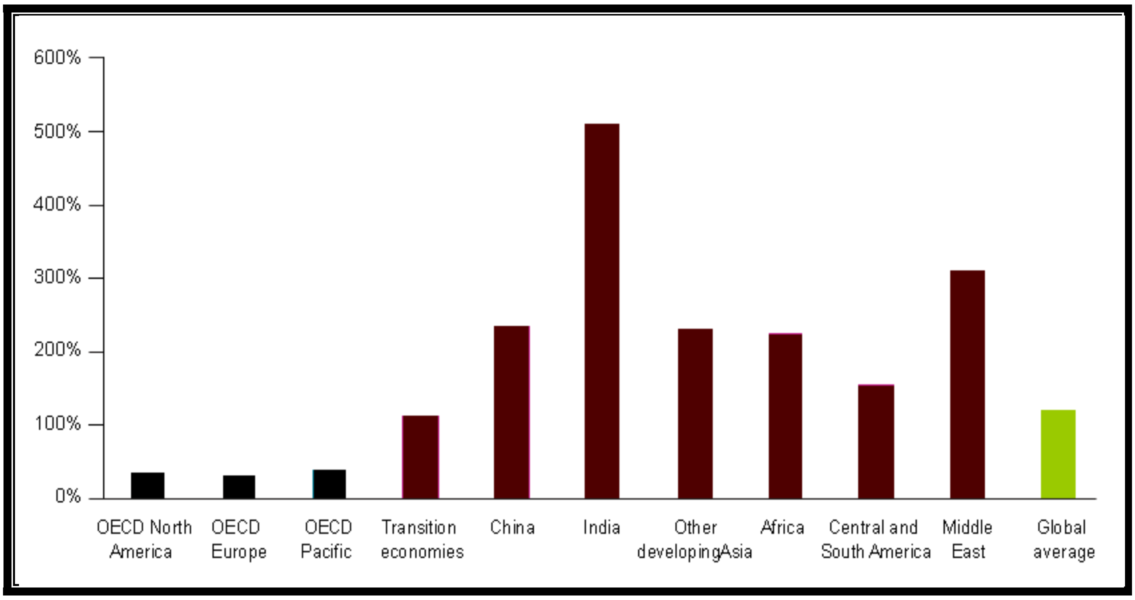


**Figure 1.2: Electricity consumption growth 2007–2050 (BLUE map Scenario) form (IEA, 2011).**

Beside the increase in energy consumption, there are many other challenges such as energy losses. The world energy council (2012) argued that energy loss can reach as high as 25% of the energy production. And they suggested several solutions to eliminate the energy loss some of which include:

- Increase the amount of renewable energy as well as the energy decentralisation.
- Improve energy efficiency by managing the consumption in both new and existing buildings. Managing energy could be achieved using integrated computer-based remote controls and sensors designed to limit the network losses which helps in consumer participation as well as managing the integration of distributed energy sources (renewable, energy storage, combined heat and power).



### *1.1.3 High rise building requirements*

There are two major approaches to define high rise building reported in the high rise buildings manual. First approach identifies high rise building as the highest building relative to the surrounding buildings. Most architectures go with this definition and specifies the highness as two or more floors. For example, a five floors building is considered as a high rise building when the area is dominated by three floors buildings. The second definition specifies minimum height to categorise the high rise buildings. Some of the international data base like skyscrapers.com limited the high rise buildings to 35m height or 12 floors. From safety perspective, there was a consensus reached in Germany to define high rise buildings as “the buildings in which the floor of at least one occupied room is more than 22 m above the natural or prescribed ground level” (Eisele, and Kloft, 2002). For research purpose the last definition will be followed therefore, seven floors and more will be considered as high rise building.

High rise buildings are one of the most resided buildings whether it is residential or commercial buildings. Moreover, there is a dramatic increase in the high rise building over last three decades as illustrated in Figure 1.3 which makes high rise buildings one of the most important energy challenges from consumption prospective.

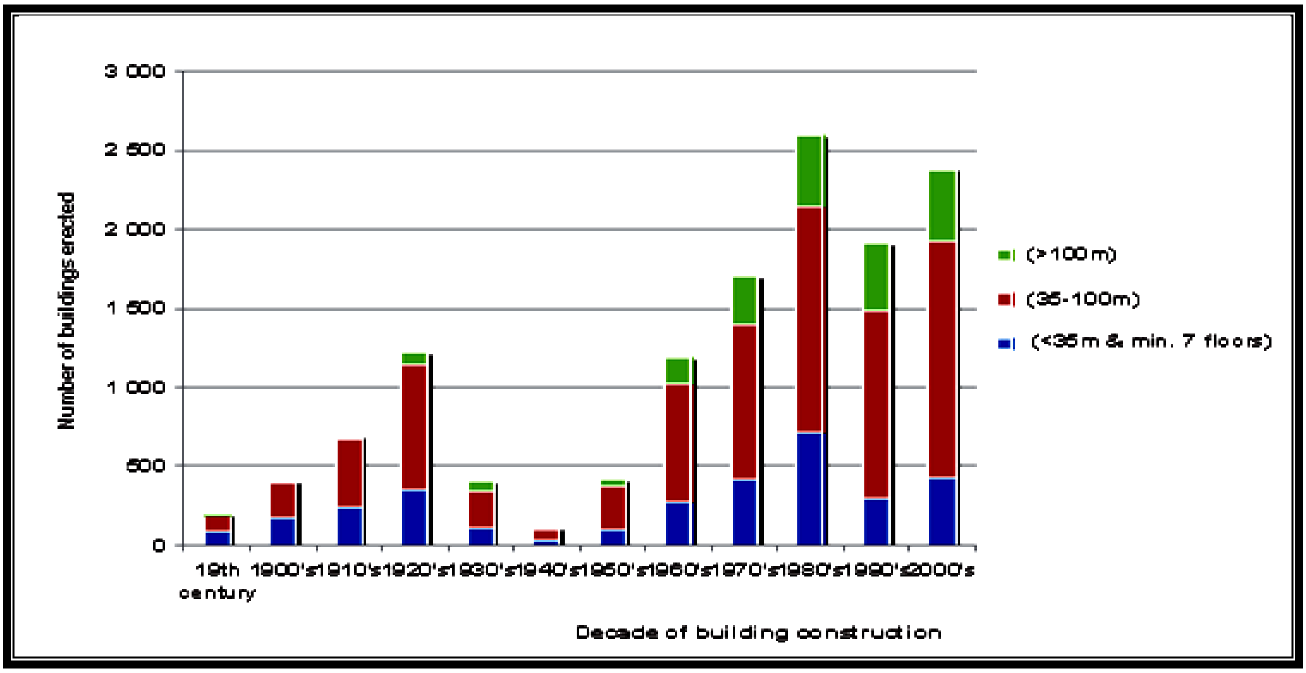


**Figure 1.3: High rise buildings construction for 21st century in the developed countries (Wittstock, 2009).**

Energy usage research conducted by architectures in Australia revealed that high rise buildings had 60% energy embodied in their materials higher than the low to medium-rise buildings. Although this figure has improved due to the improvement in the manufacturing process; the embedded energy is still greater in tall buildings because of higher load requirements. Willoughby Council reported results for their energy auditing study conducted in a common area in Australia saying that high rise buildings produce $CO_2$ emission four times more than the villas and three times more than the medium rise buildings. This all demonstrate that energy usage is significantly large in high rise building. In another study, the New South Wales energy in Australia reported that high rise buildings consume energy 30% higher than the detached houses. Willoughby Council argued that the high energy usage in high rise building is due to the additional centralised plant and equipment that often occur in high-rise buildings such as swimming pools, spas, saunas, cooling towers, pumps and lifts, as well as the car parking which are mostly underground and have no access to the natural lighting and ventilation which requires additional energy supply (Blundell, 2011).

This therefore means that residential and commercial urban sprawl toward green future is governed by the ability to overcome the challenges facing the high rise buildings sustainability. The on-site energy generation *via* renewable technologies as well as the usage of passive heating, cooling, ventilation and day lighting are the major research areas toward green buildings. However, the roof area in the high rise buildings is much less as compared to the single family houses. Therefore, the usage of the facade in high rise buildings clean energy production and passive energy usage becomes a major element towards sustainable high rise building (Blundell, 2011).

### *1.1.4 The potential of the solar energy*

Yearly, Earth receives from 1 to 0.5 kw/m$^2$ energy from sun in a form of solar radiation. This is almost 10,000 times as much as the energy consumed by man-kind. Moreover, 5% of the desert area can produce as much as entire world electricity consumption. As a matter of fact, solar energy may vary from location to another or even within the same location it may vary significantly as the solar density varies during the day hours. The global consumption of renewable resources is less than 0.01% of solar energy reaching the earth surface each year (Kalogirou, 2009; Ngo and Natowitz, 2009).

Photovoltaic (PV) modules generate electricity from the solar energy of which the electrical output is only one component of the total energy produced by a photovoltaic array. A typical photovoltaic (PV) module has ideal conversion efficiency in range of 15% and the remaining energy is heat. This heat can be as much as 50°C over ambient temperature, resulting in two concerns. The first one is being possible structural damage from heat if panels are not properly vented or if heat is not recovered. The second issue is that the efficiency of the PV array decreases as temperature increases. Crystalline cells are affected by temperature and its performance drops as cell temperature rises. It has been shown that for each 1°C increase in temperature, the power production drops by ~0.5% (Hollick, 2011).



### *1.1.5 Summary of Problem statement*

One of the major issues facing world today is the need for low energy consumption buildings as well as to develop alternatives for clean energy sources. Therefore, several researches and applications have been employed in the area of near net-zero energy buildings, mainly using both forms of solar energy electricity production and heat collection. Even though high rise buildings are considered one of the most energy consumer buildings, still inadequate research have been employed to toward a near net-zero energy high rise building.

### *1.1.6 Research objectives*

The main objectives of this research are:

- To assess high rise buildings energy toward near net-zero energy buildings.
- To use engineering principles to develop a feasible solution for high rise buildings toward near net-zero energy.
- To study the possible market acceptance for this system (market opportunities, marketing strategy, green certification and economical feasibility).

### *1.1.7 Research Questions*

- What are the feasible green systems toward near net-zero energy building that applicable for high rise buildings?
- Is this system feasible from engineering management point of view?
- Is there a market for this system?
- What are the marketing strategies suitable for this system?
- Is this system qualified for green certificate?
- Is this system economical feasible?

## 1.2 Motivation of the research process

The complexity of today`s world require system not to operate individually rather to interconnect with number of other systems. Such systems should be engineered and evaluated in “system of system” or “complex system” context (US air force, 2005). The trade-off between the customer requirements, program management (contract, cost, control, compliance), and the system specification, presents a great challenge facing system development. Customer requirements are normally governed by programme management where the functional concept limits the customer requirements to be fully achieved. Therefore, some sort of modelling should be used to evaluate alternative solutions for customer needs. This trade-off may enhance the chance to achieve the optimal “complex system”.
Rechtin (2000) defines a system as:

> *A construct or collection of different elements that together produce results not obtainable by one element alone. These elements can include people, hardware, software, facilities, policies, and documents. All these elements are required to produce systems-level results. The results include systems-level qualities, properties, characteristics, functions, behaviour, and/or performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by interconnections of these parts.*

The challenge of high rise building energy requires a complex solution based on the high rise buildings needs. Therefore, two engineering management concepts could be integrated together for ultimate solution development process and these are complex system concept and market pull product. Complex system concept is defined as the system that constructed by several subsystems interacting together. While, market pull product initially identifies market opportunities then select the right technology to meet those needs. (Ulrich and Eppinger, 2008).

There are three areas of strategy and engineering management that can be inherited in order to develop the targeted optimum solution for high rise buildings energy and HVAC system: new product development process and phases, logistics and reliability engineering, and marketing strategies which are briefly discussed below.

### *1.2.1 New product development process and phases*

Developing new system or solution should be governed by the product development process (PDP) concepts. PDP is defined by Ulrich and Eppinger (2008) as “the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product”. These steps could be physical steps or intellectual and organizational steps. However, product development is not a straight forward process one can follow to get a successful product at the end. Every organization employs different development process, sometimes, different process could be found within the same organization. Product development literature reported six major product development steps, each has its own interaction with several organization activities and divisions as illustrated in Figure 1.4 (Ulrich and Eppinger, 2008).

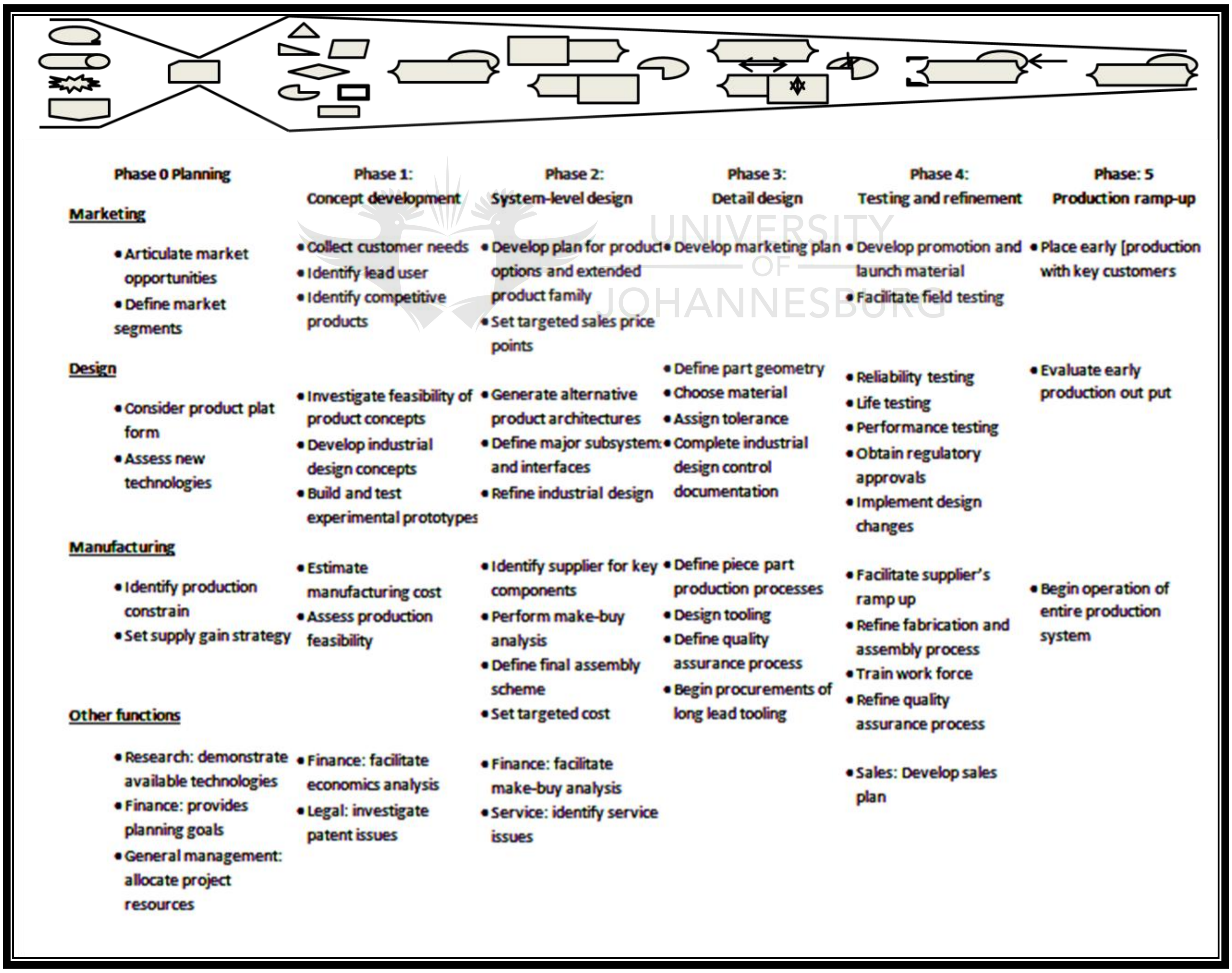


**Figure 1.4: New Product development phase’s intersection with different organization activities and departments (Ulrich and Eppinger, 2008).**

Below are the major product development phases as reported by Ulrich and Eppinger (2008):

1) Planning
2) Concept development
    a. Identify customer needs
    b. Establish targeted specification
    c. Generate product concepts: a description of how the product will satisfy customer needs
    d. Select product concept
    e. Test product concept
    f. Set final specification
    g. Plan downstream development
3) System level design
4) Detail design
5) Testing and refinement
6) Production and ramp-up

In summary, new product development literature has approved that the design may require less than 10 % of the development cost/efforts and contributes more than 70% of the product success rate (Barton et al., 2001; Crow, 2001; Ulrich and Eppinger, 2008). Furthermore, the first three steps of the product development (Planning, Concept development, and System level design) contribute mostly to the design success. Therefore, this research will assess the energy in high rise buildings to develop green system toward near net zero energy building following the new product development first three steps.

### *1.2.2 Logistic and reliability engineering elements*

Inheriting logistics engineering and reliability engineering concepts within over all system development process as well as system life cycle plays major role in the new product success rate. System life cycle consists of nine steps; Figure 1.5 shows the inheriting of logistics elements in system life cycle steps. From the other hand, system engineering process (SEP) is the key aspect of system development success in which it should be inherited with overall system life cycle with particular emphasis in the design and development process (Blanchard, 2004). SEP implementation in new system development improves system success rate and gives the organization a competitive edge (Schmidt, 2003).

The profitable enterprises characterise successful product by one or more of the below elements as reported by Ulrich and Eppinger (2008):

- Product quality: the reliability of the product and product goodness could be shaped by the development efforts. Moreover, product quality affect market share ultimately.
- Product cost.
- Development time.
- Development cost.
- Development capability.

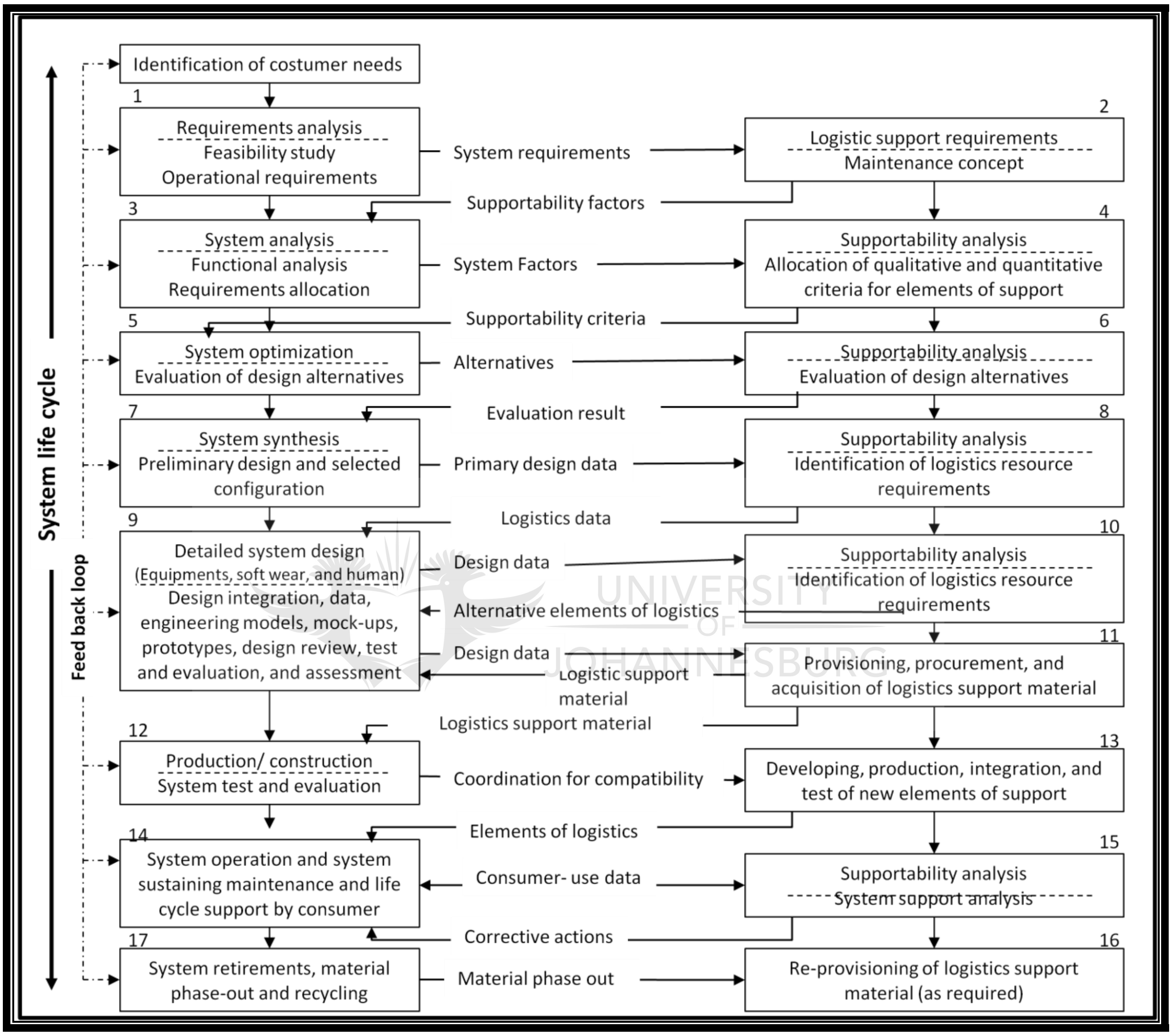



**Figure 1.5: Integrated logistic activities in the system life cycle from (Blanchard, 2004).**

### *1.2.3 Marketing strategies for system acceptance*

This section covers four major areas:

1. Market opportunities: The decision of developing a new system is normally governed by the market needs. The recent awareness of climate change impacts drives the world orientation to the green product, which is shaping the green products market volume and enhancing the product success if these needs are addressed properly.

2. Marketing strategy: For any new system to be accepted in the market, organizations need to develop a marketing strategy using one or more of the marketing analysis techniques. All and above, the marking strategy should be linked with the product unique sales point (USP) to emphasises on the product USP.
3. Green certificates: green claim needs to be proven to the costumers by applying one or more of the global green labelling systems such as Leadership in Energy and Environmental Design LEED or Energy Star.
4. All and above, the new developed system has to demonstrate new benefits and most importantly it has to be economically comparable to the existing system.

### 1.3 Research Process

A structured approach below was followed to answer the research questions:

- Identify the high rise buildings specific energy requirements in order to clarify the problem.
- Review the available green technologies concerning energy production and low energy consumption products that could be applicable for high rise buildings.
- Optimize the near net-zero energy system using the new product development steps and then inheriting logistics engineering requirements.
- Study the system market acceptance possibility from four angles: market opportunities, marketing analysis techniques and marketing strategies (green marketing strategy), and review some of the green certification systems (LEED and energy Star) as marketing tools (requirements and benefits). Finally study the economical feasibility of this system

# CHAPTER 2: TECHNOLOGY VISIBILITY STUDY

Visibility study is a reviewing process that involves an evaluation of different existing technologies which may be considered in response to specific functional requirements and in this case, the high rise buildings requirements. Visibility study also helps in evaluating different design approaches. It consists of three major steps which are; identifying various design approaches available, evaluating alternatives to pick the most applicable candidates, and then recommend the best solution (Blanchard, 2004).

Recently, there are considerable demands for green product research and applications in construction sector more specifically in the high rise buildings energy field. This demand is dramatically increasing especially in the field of low energy consumption items (mainly the heating, ventilation, and air condition (HVAC) systems), as well as the “on-site” renewable energy production (mostly *via* solar energy).

This section of the research is employed to address some of the high rise building`s requirements as well as to review some of the available green technologies for high rise buildings.

## 2.1 High rise buildings requirements

The name high rise buildings called firstly in the early 20th of the last century. Throughout its history, high rise buildings have been developed and changed in which each period have different building`s features. As such, it could be used for high rise buildings categorization, which is the base to address their needs. Koene et al. (2010) categorized high rise buildings to five categories based on the construction dates: Category 1 (1945-1960), Category 2 (1960-1980), Category 3 (1975-1990), Category 4 (1975-1995), and Category 5 (1980-2005)). Figure 2.1 illustrates these categories and their main features.

| Building categories | Post-war, reinforced concrete structure with massive facade | Reinforced concrete with (precast) concrete façade | Skeleton construction with precast concrete panels (strip windows) | Skeleton construction with curtain-wall façade | Tall buildings, Skeleton construction with curtain-wall facade, air-conditioned |
|---|---|---|---|---|---|
| Image |  | | | | |
| category | 1 | 2 | 3 | 4 | 5 |
| time line | 1945-1965 | 1960-1980 | 1975-1990 | 1975-1995 | 1980-2005 |
| main construction | reinforced concrete | reinforced concrete | reinforced concrete | reinforced concrete | reinforced concrete / steel |
| precast | no | possible | possible | no | no |
| facade | load bearing | load bearing | non bearing | non bearing | non bearing |
| stability | facade | facade/core | core | core | core |
| material facade | massive brick, brick cavity wall | brick, natural stone, stucco, ceramic tiles, glass cladding | concrete, metal cladding | metal profiles, metal cladding | metal profiles, metal cladding |
| glazing | single | single/double | double | double | double coated |
| windows | openable | openable | openable | openable/closed | closed |
| floor plan | lineair cell structure | lineair cell structure | core cell structure | cell/open structure | cell/open structure |
| air-conditioning | no | no | no | no | yes |



**Figure 2.1: High rise buildings categories (Koene et al., 2010).**

Reijenga (2009) ranked the above mentioned categories in term of energy consumption as shown in Table 2.1. Category five (relatively new buildings) showed the best energy consumption due to the green orientation during this period while Category 3 (1975-1990) has been ranked as the highest energy consumption as part of that industrial age.

**Table 2.1: High rise buildings energy consumption per category from (Reijenga, 2009).**

| N°. | Description | N°. of Storeys | Total floor space in EU (mill. $m^2$) | Typical annual energy consump. ($kWh_p/m^2$) | Total annual energy consump. (TWh/a) | Rank |
|---|---|---|---|---|---|---|
| 1 | Post-war, massive facade in reinforced concrete structure 1945-1965 | typically 6 or ~10 | 119 | 400 | 47 | 2 |
| 2 | Reinforced concrete with perforated façade, 1960-1980 | typically 6-10 and 15-20 | 53 | 420 | 22 | 3 |
| 3 | Skeleton construction with precast concrete, 1975-1990 | typically 6-8 or ~20 | 119 | 410 | 49 | 1 |
| 4 | Skeleton construction with curtain-wall façade,1975-1995 | typically 8-10 and 15-25 | 16.3 | 380 | 6.1 | 4 |
| 5 | Tall buildings, Skeleton construction with curtain-wall facade, air-conditioned 1980-2005 | typically 20 and higher | 11.6 | 350 | 4.1 | 5 |



More specifically, Koene et al. (2009) reported the overall high rise buildings energy consumption as well as the energy consumption in a form of heating and cooling requirements for each category as illustrated in Figure 2.2. Generally, cooling load contributes around 40% of the total energy consumption in the new buildings (1990 - 2000), while heating is almost 27% of the total consumption of the same category.

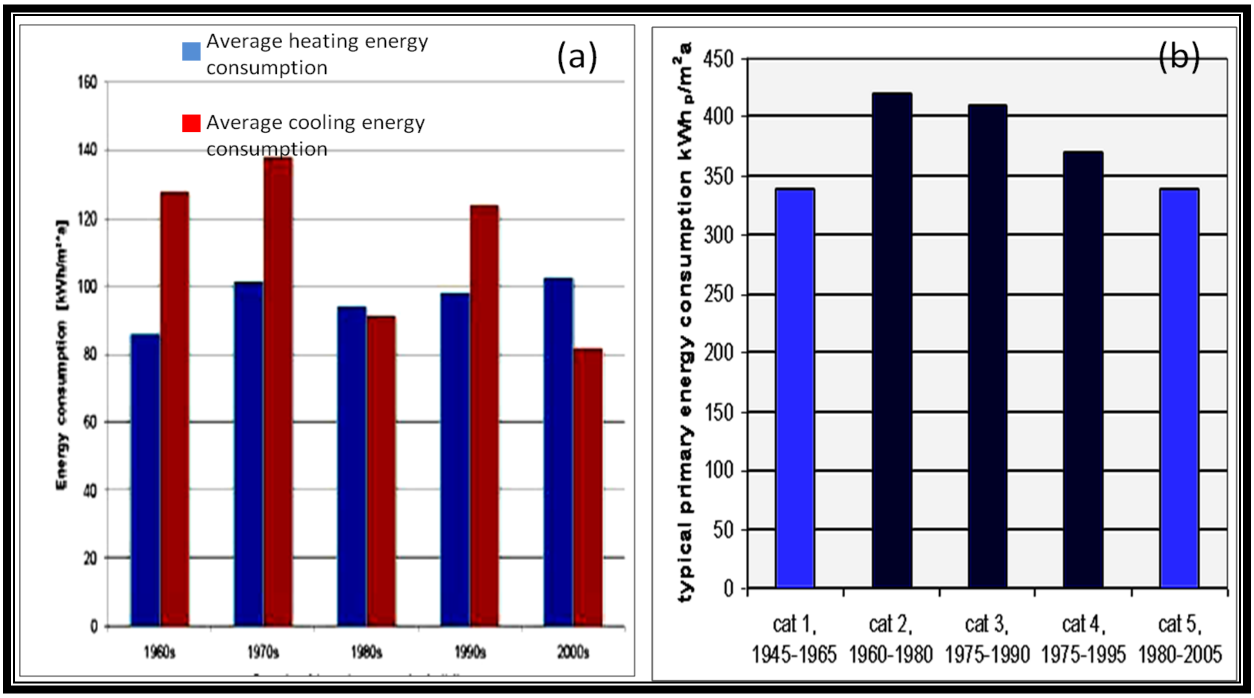


**Figure 2.2: (a) Heating and cooling energy consumption (%), (b) High rise buildings total energy consumption (Reijenga, 2009; USTUTT, 2009).**

In order to produce a clean energy sufficient for high rise building in such high demand, it is mandatory to use the building facades whereby renewable energy in buildings sector is mostly produced from solar energy. Therefore, understanding the high rise building`s facades requirements is an essential part of this process. In this sense, several factors such as wind, day light, heat isolation, and passive ventilation, heating and cooling should be considered in facades design as reported by Eisele and Kloft (2002):



- Wind puts certain loads on the high rise buildings and such loads play a major role in the building's main structural design. However, wind loads are determined not only by winds flow but buildings shapes as well. Moreover, facade structural design is governed by the distribution of the wind`s pressure over building's skin. Since wind loads vary over the building surface, the facade must be divided into zones as well, then apply the right structural requirements in every zone`s facade.
- Interior day light minimum requirements may vary based on the culture and climatic parameters. For instance, cool and even dark atmosphere is preferred in warm regions. However, the facade plays a major role in the day light, still there are several factors shaping day light effects. The overcast sky may reduce day light effects ultimately, beside the position of the sun during the day. Therefore, the level of buildings day lighting may vary in the same building based on the sun angel and the facade transparency level.
- Isolation affects high rise buildings in terms of heat, light, and the solar energy usage. The transparent facade such as glass, allows large portion of solar radiation to penetrate into the

building's interior. As such, it allows the passive heating in the mild or cold regions, while sharply increase the cooling load in warm regions. Where opaque elements in the facade absorb and reflect solar radiation at the external surface resulting in lower cooling loads.

- Besides the passive use of the solar energy heating, ventilation, and day lighting, there are other active uses like the heat collection by the thermal collector and the electricity generation using the photovoltaic as well as the combination of the two. Generally, in high rise buildings the roof area is relatively smaller than the skin area or the facade area. This implies that, the high rise buildings solar energy gain may be more feasible by integrating the solar system with the facade or building`s skin.

## 2.2 Solar heat collector

Solar energy could be collected in a form of electricity or/and heat. Heat generation could reach as high as 3 times the electricity generation at the same location (Hollick, 2011). There are several applications already in the market for solar energy heat collection. Below are some of the technological viable and commercially existing solar heat collection applications:

### *2.2.1 Concentrated solar power plants*

Basically this system utilizes mirrors (reflection) or transparent lenses (refraction) to concentrate the sunlight in a thermal fluid (water or oil) in order to reach high temperature from 100-300$^{o}$C. This hot water/oil is normally used to produce electricity. Kaplan (1985) reported three types of these collectors as illustrated in Figure 2.3.

1) Parabolic troughs; focal line placed in the centre of long trough received a concentrated sunlight. Sun tracker used to maximize the energy collection.
2) Power tower: this consists of a flat or slightly carved mirror driven by a sun tracker to concentrate the sunlight on atop of the tower.
3) Parabolic dish collector: utilizes the optical properties of the parabolic curved surface to concentrate direct light to the focal point.

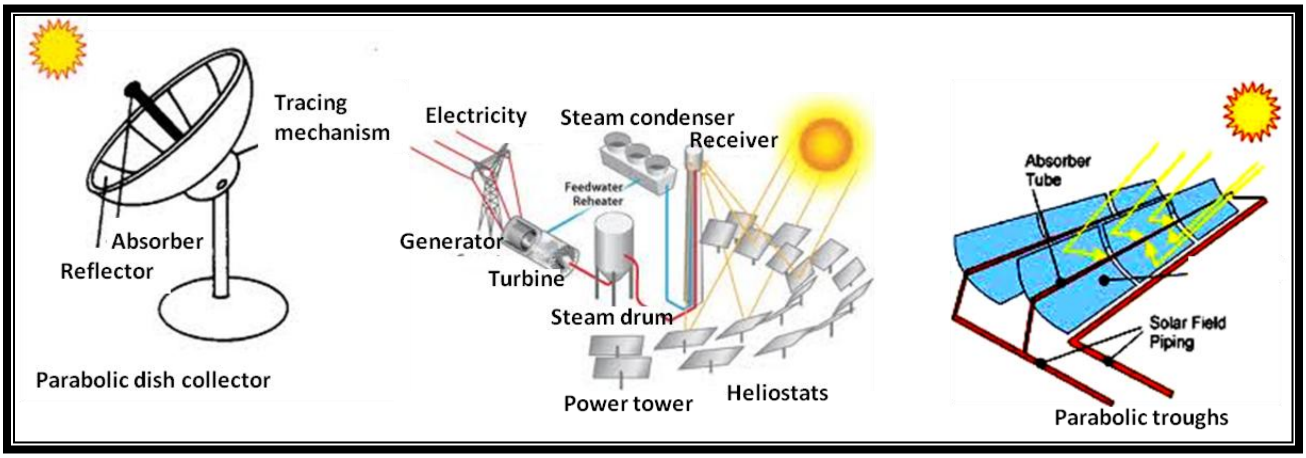


**Figure 2.3: Concentrated solar power collector types (NREL, 2010; Energy works, 2009; Kaplan, 1985).**

### *2.2.2 Solar collector for domestic purposes*

Hot water is produced at temperature range of 30- 150$^{o}$C. The total amount of hot water produced from solar energy using this techniques reaches up to 88 Giga watt thermal (GWth) and it continues increasing at a rate of 14% per year. Generally, the heat is collected by running the water through direct sun radiation and then storing the hot water for later use. Figure 2.4 shows different applications of the commercial solar water heat collector, where a solar heat collector is utilized to heat the water for daily usage. This can be used to heat the swimming pool in winter and as hot water source for other uses (Ngo and Natowitz, 2009).



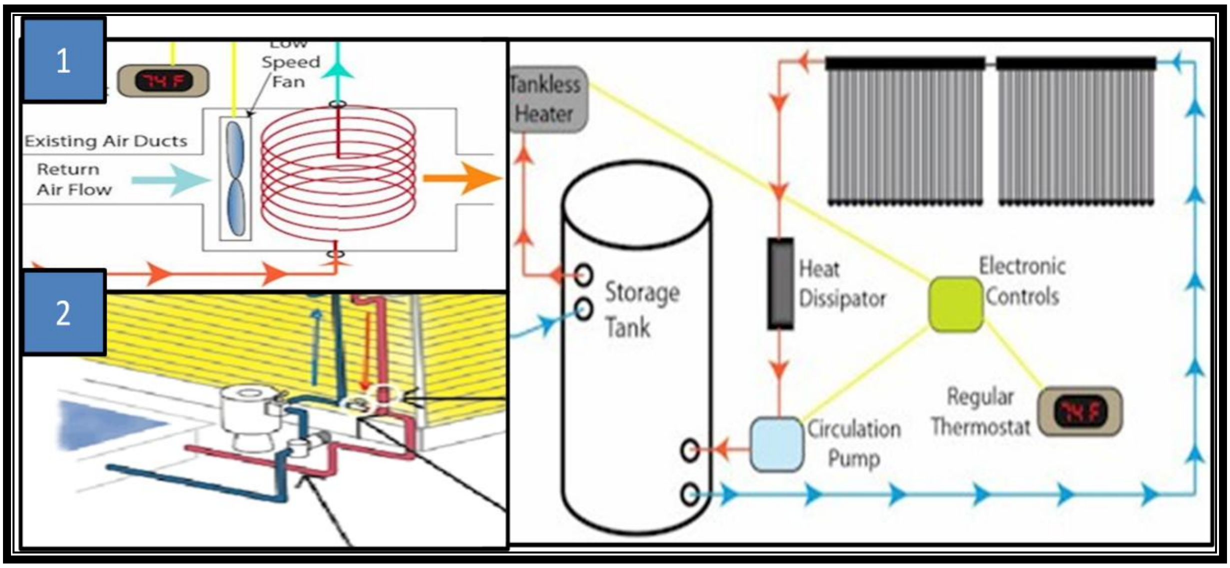


**Figure 2.4: Solar water heat collector usage in the residential and commercial buildings.**

### *2.2.3 Solar towers or Chimneys*

This is another way to produce electricity using solar heat but without concentration of a sun light where a tall chimneys stands in the middle of circular green house collector with radius of approximately 5 km (Ngo and Natowitz, 2009).

## 2.3 Solar Photovoltaic system (Electricity production)

Photovoltaic (PV) system transforms the sunlight directly to electricity. Most of the PV cells are made from silicon. Till 2002, PV market was dominated by one type of silicon (microcrystalline silicon) which is very expensive. The continuous increase of silicon prices has driven a development of other cheaper alternatives but in a lower efficiency. Most of these alternatives were made by cheaper silicon and some used other materials. The highest efficiency obtained in the laboratory for the PV system was 27%, but the typical commercial use operates at efficiency between 14 to 17% (Ngo and Natowitz, 2009).

## 2.4 Integrated Photo-Voltaic and Thermal collection system (PVT)

The companied heat collection and electricity production using solar energy is denoted as Photo-Voltaic Thermal (PVT) system. Since the PV system has typical 14-17% efficiency, meaning the rest of more than 80% is the lost energy in a form of heat. This temperature could reach as high as 50$^{o}$C above the ambient temperature resulting in structural damage as well as reducing the system efficiency by around 25% (Hollick, 2011). International Energy Agency (IEA) (2007) has proved that it is possible to capture five times thermal energy than electricity from PV array. Moreover, they said that capturing this heat could play as venting system to the PV array resulting in significant improvement in the PV system efficiency.

In summary, the combined electricity generation and heat collection via the integrated PV and thermal collector system is defined as a combination of PV and solar thermal components which produces both electricity and heat from one integrated system from the same surface area exposed to the sun (Hollick, 2011; IEA, 2007). PVTwins (n.d) (one of the PVT system producer) defines PVT system as "combination of photovoltaic cells with a solar thermal collector, forming one device that converts solar radiation into electricity and heat simultaneously". PVT system is therefore a combination of two systems work simultaneously as illustrated in Figure 2.5

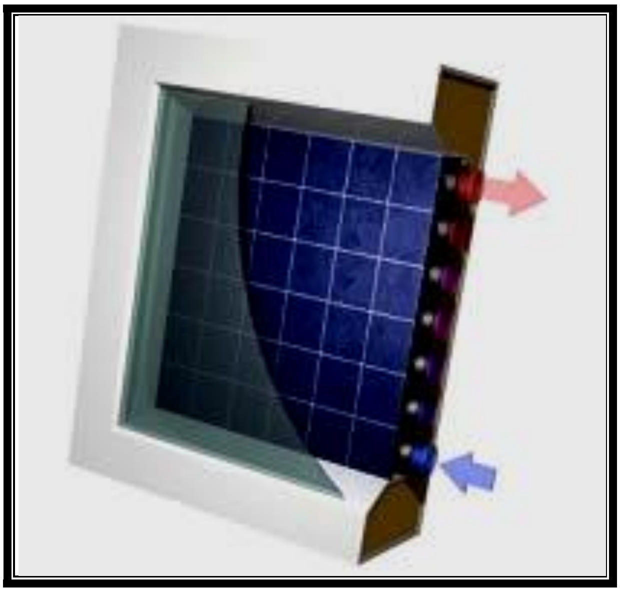

**Figure 2.5: Integrated Photo-Voltaic and Thermal (PVT) collection system (PVTwins, n.d).**

Removing the harmful heat from the solar PV array may even increase the electricity production efficiency as well as increase the heat collection from the same system. For instance, PVT system produces approximately 43% more primary energy than a conventional solar thermal collector per unit surface area, and even around 96% more than a conventional PV system. . In addition, the integration of the two technologies and using one element to produce both forms of solar energy leads to large potential savings in material use, production as well as balance the system and installation costs. On the other hand, PVT system could be a replacement of any conventional solar thermal collector or PV system. In other word, it suits any situation where the conventional systems are suitable (PVTwins, n.d).

## 2.5 Passive use of solar energy

Thermal behaviour of buildings is affected by several parameters, some of which are controllable and others are not. Even though the environment or the climate at the particular location and time shapes the uncontrollable parameters, still the right design or "passive" design may enhance some of these environmental parameters for cooling or heating purpose. For instance, using passive cooling design may significantly reduce cooling load (Dimoudi, 1996).

There are several elements that affect the passive solar systems; some of them act in opposite directions. Therefore, evaluating each and every factor in terms of its advantages and disadvantages compared to the other factors using decision tree could be the right tool to achieve the optimum passive design. Moreover, the effect of the buildings material on the solar energy gain varies from building to another. Litter and Thomas (1984) have reported some of these elements:

- Glazing: skin preferred to be weatherproof to drive rain and winds, highly transparent, and has a reasonable life time.
- Single and multi glazing: multi glazing is used to reduce the heat lose from/to the building, especially if an air gap is used between the glasses. It may also reduce transparency.
- Insulation and shutters: due to the significant heat lose through the glazing it might be necessary to use different types of insulation and/or shutters whether internal or external.
- Reflectors usage: could be used to enhance the radiation.
- Thermal storage: storing energy to be used when needed most, mostly use water as storing device. The amount of energy that can be stored as sensible heat is given by below formula

$$\text{Energy stored (KJ/m}^3\text{)} = \rho . C_p . \Delta T \qquad (1)$$

Where: $\rho$ is the density of the material kg/m$^3$

: $C_p$ is the specific heat

: $\Delta T$ is the change in temperature

Dimoudi (1996) believes that passive cooling strategy could be designed in three levels:

1) Prevention of heat gains whether from internal or external source using the modulation of the microclimate of the building.
2) Modulation of heat gains could be achieved mainly by using energy storage techniques.
3) Rejections of the heat to a natural sink (upper atmosphere, ambient air and earth).

Furthermore, there are several passive techniques available to utilize solar energy, some of these techniques reported by Eisele and Kloft (2002) are listed below:

- Solar chimneys: basically it is a hollow channel used as ventilation system constructed from a thermal conductive material.
- Trombe wall: this is an air channel, confined between a sealed insulated glass and a wall build with high specific heat material.
- Solar roof pond: it is a passive heating and cooling system consists of a water tank in a transparent plastic tank located behind a movable insulating cover which enable the use of the tank for heating purpose by uncover the tank during the day to heat the water then store this water and use it at night when the tank is covered again, then vice versa for cooling purpose.

### 2.6 Integration of near net-zero energy consumption house (heating)

Athienitis (2011) introduced the concept of net-zero energy consumption houses by reporting two models. These houses were designed to enhance concepts and systems for combined electricity and heat generation from building-integrated photovoltaic systems with heat recovery (PVT system).

The key renewable generation system is a 1904W PVT which can also produce 4-8 kw of heat at 200 L/s of air flow. The flow velocity of the air under the PV vary from a minimum of 0.5 m/s to a maximum of about 1 m/s and the outlet air temperature typically from 30°C to 15°C higher than the ambient air temperature. Figure 2.6 shows a sample of the integrated net-zero energy consumption using air/water as a heat recovery for PVT system.

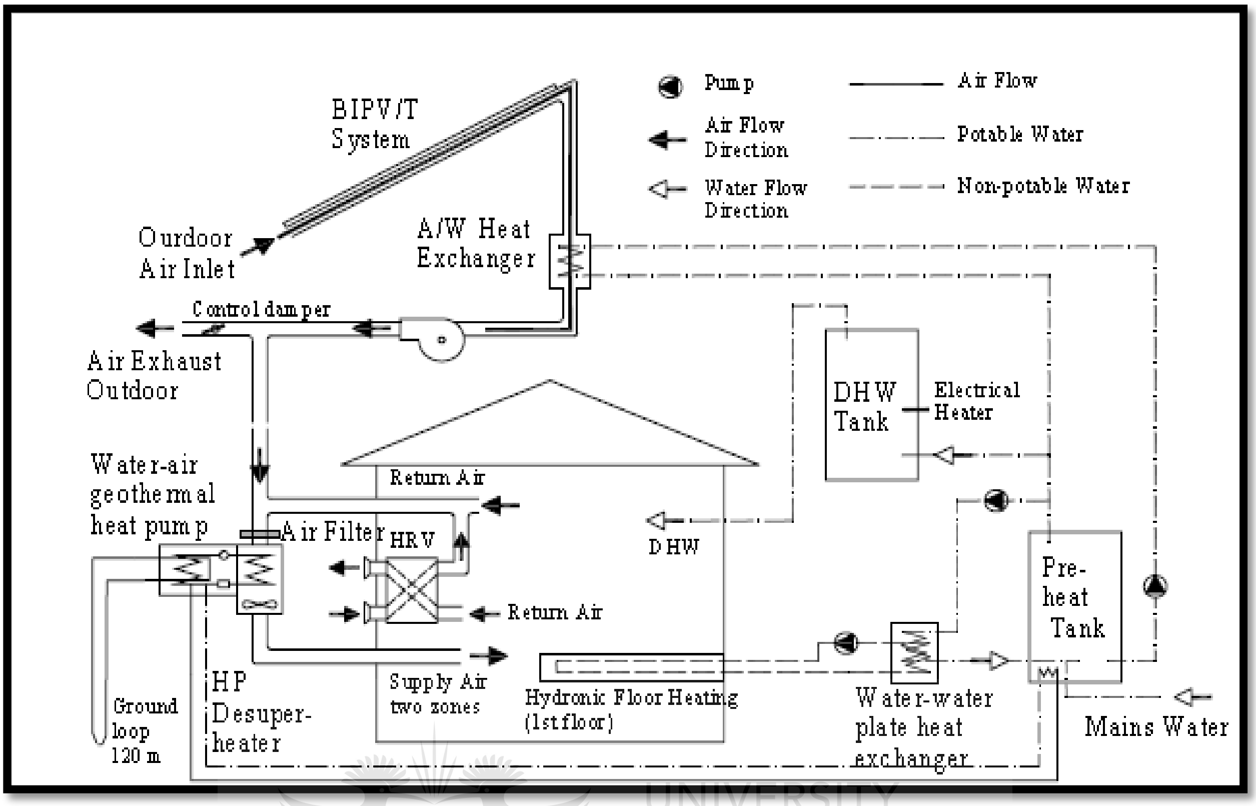


**Figure 2.6: Integrated near zero energy consumption house (Athienitis, 2011).**

The key features of the energy system shown in Figure 2.6 are the following:

- The 2.2 ton two-stage geothermal water/air heat pump (120 m deep borehole) with a 10 kw auxiliary electric heating coil (normally off). It is connected to a two-zone air distribution system (HRV connected to the return) carefully designed to optimize distribution of passive solar gains when heating is not required and the ECM fan operates at low speed.
- Duct from PVT roof that brings hot air to the mechanical room to heat water (or as fresh air).
- Two 272-litre water tanks connected in series. The low-temperature preheat tank water is heated through an air/water heat exchanger by the PVT air and the heat pump super heater. It then enters the high temperature (60°C) DHW tank.

## 2.7 Active solar facade

The word "facade" comes from the French word "façade", which in turn comes from the Italian "facciata", meaning face (oxford dictionaries, 2012a). In buildings sector, facade is defined as external face of the building and it is normally used for the high rise building skin (Cambridge dictionary, 2011a). More specifically, the term facade applies only when the building`s exterior is structurally designed and where the orientation of the skin is considered (McGraw-Hill Dictionary of Architecture and Construction, 2012). As such, in the high rise buildings sector, it is important to consider the facade structural design and material requirements as an essential part of the facade design.

Building's facade could be used as a multipurpose element. Eisele and Kloft, (2002) reported two types of multipurpose facades, in the first one facade used as sky garden by growing wind resistant plant. In the second application, building skin was used as a power plant by extracting the air *via* venturi wing. Furthermore, transforming facade to energy gain element was the main purpose of European Union (EU) project called "cost effective" (Tilmann and Kuhn, 2009).

In case of single family houses and two storeys factory/ commercial buildings, (the relatively big roof space compare to the height of the buildings) the roof is sufficient to produce energy from solar equal or more than the energy yearly loaded in that particular building. Whereas, in the high rise buildings, where the roof is relatively small, it is mandatory to use the facade in order to achieve a near net-zero energy. Therefore, converting facade to a multi-functional energy gain component is a key element for high rise buildings towards near net-zero energy.

Shading from surrounding buildings may affect high rise buildings in many ways (view, day lighting, passive solar, *etc*). Therefore, there is regulation for minimum distance between buildings and this regulation may vary from country to another. Turrent et al. (1980) provided several rules for buildings distance for two storey buildings based on the sun angle over the buildings as well as the building height as follow: day light (6-10 m), direct sun light (10-16 m), privacy (15-18 m), and passive solar (20-23 m), however, such rules could be employed for any building using building unique data. Furthermore, the direction of the site may shape the solar gain. For instance, the countries below the equator may get the maximum solar gain when orienting north (Litter and Thomas, 1984).

Maurer and Kuhn (2011) reported five types of the active multi-functional energy gain facade developed by the EU cost-effective project as illustrated in Figure 2.7. Below is a detailed description for these types.

1) Transparent Solar Thermal Collector (TSTC): the technical concept is the integration of apertures with angular selective transmittance into a solar absorber, which is included in the transparent part of a facade. TSTC structure, as illustrated in Figure 2.7 has been designed to include both an air-tight tripled-glazing unit and a closed cavity facade, which is a double skin facade with a pressurized system used to flush dry and clean air inside the cavity (Pavan et al., 2011). Therefore, TSTC is a multi function facade that benefits buildings with the following:
    a. Allows a visual contact to the exterior.
    b. Provide glare control for day lighting.

c. Collect heat achieved by the high absorption coating using a magnetron sputtering technique. The system is operated with a water based solution of glycol and a special mixture of corrosion inhibitors.

2) Facade integrated ventilation with decentralized heat recovery reported by Jacobs and Meester (2011): in this system no pre existing ventilation and no duct work is required. This makes it one of the best green solutions for existing high rise buildings renovation. Moreover, it is also less noisy; hence it has no individual room fans.
3) Active solar system consists of new unglazed facade collector and new heat pump Figure 2.7. In this concept, a new facade element is coupled to a heat pump for the distribution supply of heat and cold to the existing high rise buildings where space restriction dictate system implementation.
4) Transparent building integrated PV component prototype consists of laminated glass panes with two series of opaque stripes, one is between the two laminated glasses and the second is at the inner surface of the facade Figure 2.7. System concepts mainly depend on the view direction, when looking downward the transmission is very high, while when looking upward, directly to the sun the transmission is almost zero (Kuhn and ISE, 2011). This facade provides buildings with the following merits
    a. Visual contact to the exterior.
    b. Solar and glare controlling the different refractive indices of air and glass besides the specific position of the opaque stripes on the glass and the use of colours in the facade. All these provide the best control of glare and reduce cooling load.
    c. Generation of electricity
5) Vacuum tube solar air collectors are used to support the heat supply. The concept mainly is to use the incident irradiation to heat the fluid inside the absorber tubes. Below are some advantages of this system (Maseda, et al., 2011).
    a. Support buildings with heat to operate HVAC- cooling system with renewable energy.
    b. Provide additional shadowing to reduce the cooling load.

System structure consists of three elements as below:

- Absorber tubes (vacuum tube) which convert the sunlight to heat. This is to enhance the parallel connection vacuum tube designed with one or both ends opining to handle the air between the facades.
- Ducts to distribute air to the tubes and to the building.
- Vacuum insulation results in a high efficiency at high temperatures or low irradiation.

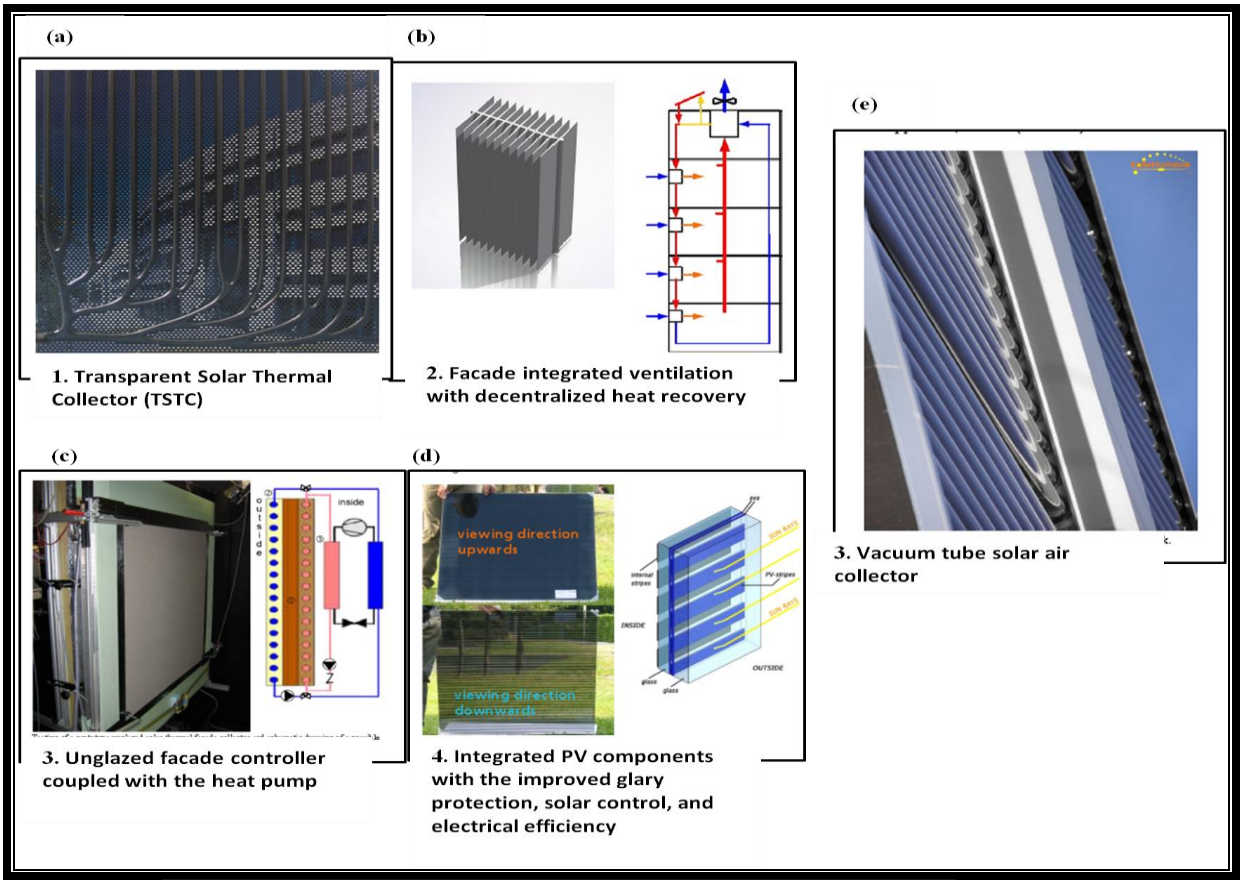


**Figure 2.7: Five multi function facade components (Maurer and Kuhn, 2011).**



## 2.8 Ice slurry-based air conditioning system

The Ice slurry based air condition could be considered as one of the green central air-conditions systems that reduce refrigeration machinery together with ammonia (primary) and urea based slurry ice which result in minimum direct and indirect environmental impact. Moreover, the system also acts as a standby system which results in reducing energy consumption and first cost (Epsltd, 2012).

An ice slurry-based air conditioning system normally employs three independent circuits as illustrated in Figure 2.8: a refrigerant circuit, an ice slurry circuit between the ice slurry generators and a circuit between the ice slurry system and the building in which it consist of a heat exchanger, storage tank and a chilled water. The second concept is pumping the ice slurry directly to the load from the storage tank. The other design approach is that common refrigerant circulated between the condenser and evaporator by gravity using the ice slurry as a driving force (Wang and Kusumoto, 2001).
The ice slurry system may enable the air conditioning designers to use more efficient design parameters such as a cooler air distribution temperature of 12$^{o}$C rather than the normal temperature of 15$^{o}$C by taking advantage of the low temperature of the ice slurry. This in turn reduce the first and operating cost by reducing the air flow requirements from 41 to 32 m$^3$/h, hence small size equipments are used as well as lower power requirements. Moreover, the cold air supply temperature enhances the

potential for lower space humidity and a more comfortable space environment (Kuriyama and Sawahata, 2001).

In a further study, power consumption for the ice slurry generators, pumps and air circulation fans was measured from 15 July to 27 September 1996. The results were compared with predicted energy consumption for an equivalent conventional ice thermal storage system and high temperature air distribution for the building. The ice slurry plant energy consumption was found to be higher by around 22 MWh than the conventional plant, while the air distribution costs were found to be lower by 47 MWh for the ice slurry plant, resulting in 25 MWh savings which represent 4% savings in the overall energy consumption of the building. (Tassou and Bellas, 2005).

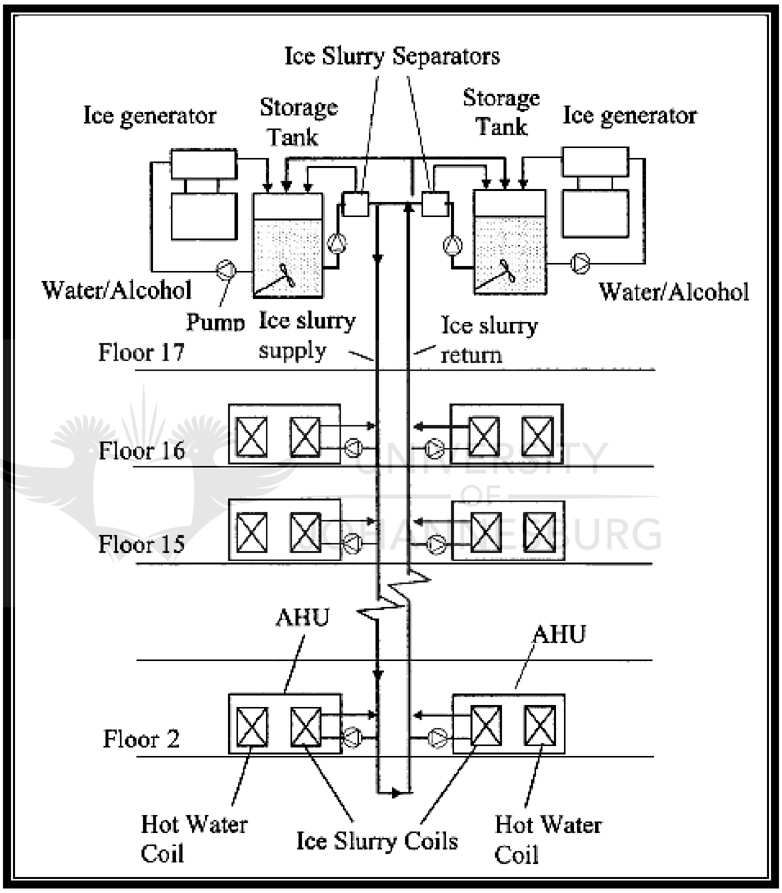


**Figure 2.8: schematic diagram of the ice slurry cooling system (Tassou and Bellas, 2005).**

## 2.9 Thermal driven chillers

An absorption refrigerator is a refrigerator that uses a heat source (e.g., solar, kerosene-fueled flame, waste heat from factories or district heating systems) to provide the energy needed to drive the cooling system (Wikipedia, 2011 b). Absorption chiller air conditioners are well developed and very widely deployed technology. They have been commercially used in U.S. since early 20$^{th}$ century and they are also very popular in Asian countries like Japan. Furthermore, absorption chillers present a viable alternative for high rise buildings cooling system (Eisele and Kloft, 2002).

Absorption chiller is a thermal driven cooling system, which differentiate it from the conventional chiller (electrical chiller). Typically absorption chiller evaporator allows the refrigerant to evaporate and to be absorbed by the absorbent. This process extracts heat from the building and the combined fluids go to the generator. The generator heats the fluid using gas, steam or any other heat source. Thereafter, the refrigerant goes to the condenser to be cooled down to become liquid again. At the same time the absorbent is being pumped back to the condenser. The cooled refrigerant is then released through an expansion valve to the evaporator and the cycle repeats (New Buildings Institute, 1998).

There are several absorbent fluid in use for solar thermal closed-loop absorption air conditioning such as: ammonia/water, water/lithium bromide, water/lithium chloride, water/silica gel or water/zeolite, and methanol/activated carbon (Wikipedia, 2011 a). Most common technology is the lithium bromide-water or ammonia-water. This system uses lithium bromide as the absorber and water as the refrigerant.

The conventional absorption chiller commonly categorized to direct, indirect fired or hybrid systems. Direct fired uses gas or other fuel to be burned inside the unit as a heat source while indirect uses other fluid such as steam to transfer heat from separate heat source such as a boiler or heat recovered from an industrial plant. A hybrid system is a combination of gas systems and electric systems for load optimization and flexibility (New Buildings Institute, 1998).

Recently, another categorization has been developed based on the unit efficiency as illustrated in Figure 2.9 (New Buildings Institute, 1998):



1) Single effect has been invented in the early 40th and it use low pressure steam or hot water as the heat source. The hot water evaporates and extracts heat in the evaporator. Single effect chiller reported lower thermal efficiency.
2) Double-effect uses the same concept of the single effect with two condensers and two generators to allow maintaining more refrigerant boil-off from the absorbent solution. It has been developed in the late 50th.
3) Triple effect utilizes the refrigerant vapour from the high and medium temperature generators which is then condensed and the heat used to provide heat to the next lower temperature generator. The refrigerant from all three condensers flows to an evaporator where it absorbs more heat. Triple effect was patented in 1985.

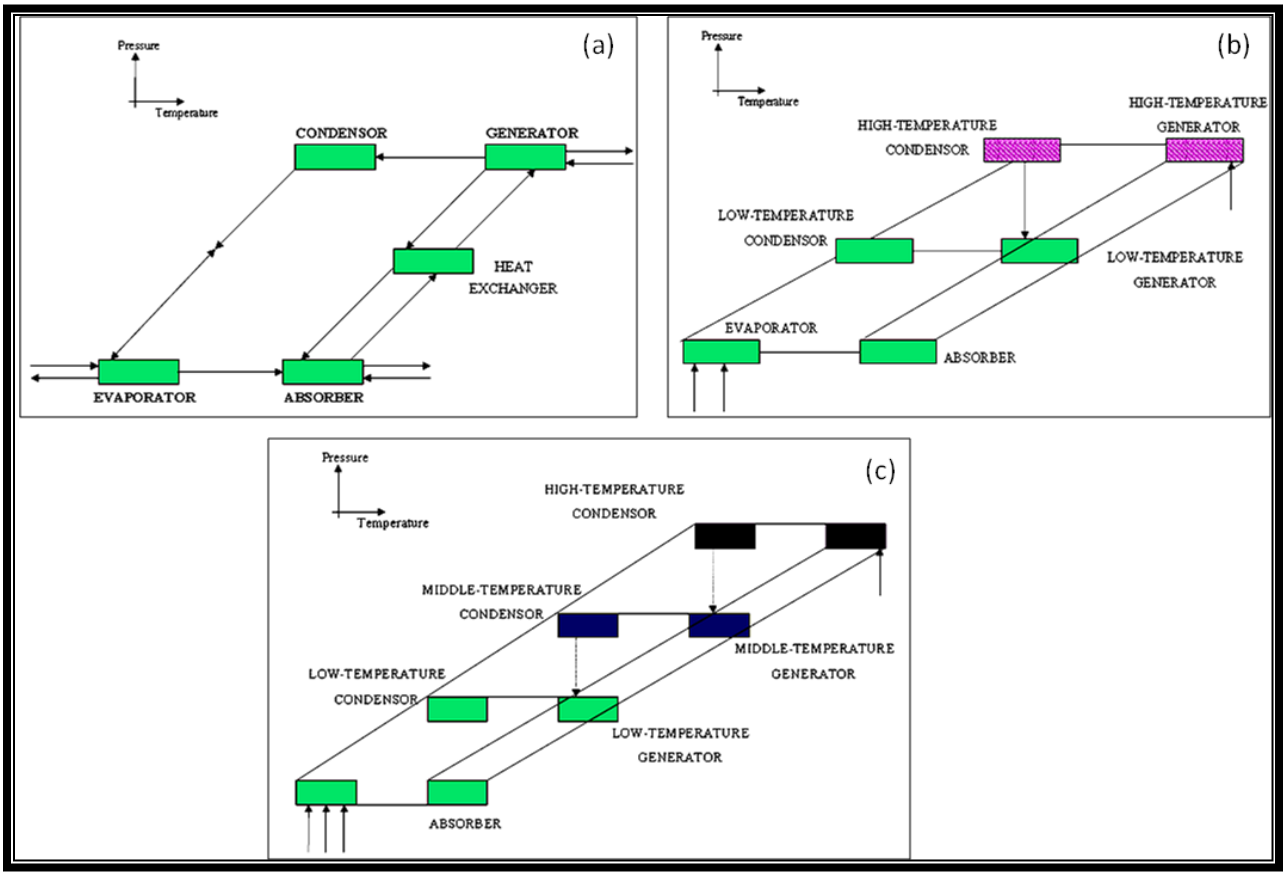


**Figure2.9. (a) Single effect absorption chiller, (b) Double effect absorption chiller and (c) Triple effect absorption chiller (New Buildings Institute, 1998).**

Absorption chiller has been commercially produced in a capacity range from 3 to 1700 TR. There are several manufacturers for the absorption chiller worldwide below are a list of some these manufacturers and their capacity ranges:

- Robur Single-Effect, 3 to 25 ton
- Yazaki LiBr Double-Effect, 20 to 100 ton
- McQuay LiBr Double-Effect, 20 to 100 ton
- Carrier Absorption Chillers, 100 to 1,700 ton
- Trane Absorption Chillers, 100 to 2,000 ton

Solar thermal collector could be used as heat source to operate the thermal driven absorption chiller whereby the efficient absorption chillers require hot water in a minimum temperature of 88°C. Hence, the concentrated solar heat collector could reach a temperature up to 300°C (Kaplan, 1985). The typical thermal solar abortion chiller uses 1200 gallon of hot water at 93°C to operate 10 TR absorption cooling chiller (Hamasaki, 2007). In large scale installations there are several solar driven absorption chiller projects in operation worldwide that successfully produces temperatures over 93°C.

There are several thermal solar absorption chiller projects all over the world. The Audubon Environmental Centre in Los Angeles is one of the oldest projects. The Southern California Gas

Company tested this system in their energy resource centre in California (Nathan, 2009). Masdar city installed this system in Abu Dhabi- United Arab Emirates (Masdar, 2011).

Concentrating solar collectors required for absorption chillers is less effective in hot humid, cloudy environments, especially where the overnight low temperature and relative humidity are uncomfortably high. Where water can be heated well above 88°C it can be stored and used when the sun is not shining beside the possibility to use a additional heater such as electrical or gas heaters (Wikipedia, 2011 a). Figure 2.10 from Sundakorea (n.d) shows a solar collector connected to the absorption chiller and the operation mechanism of the solar heat collector absorption chiller.

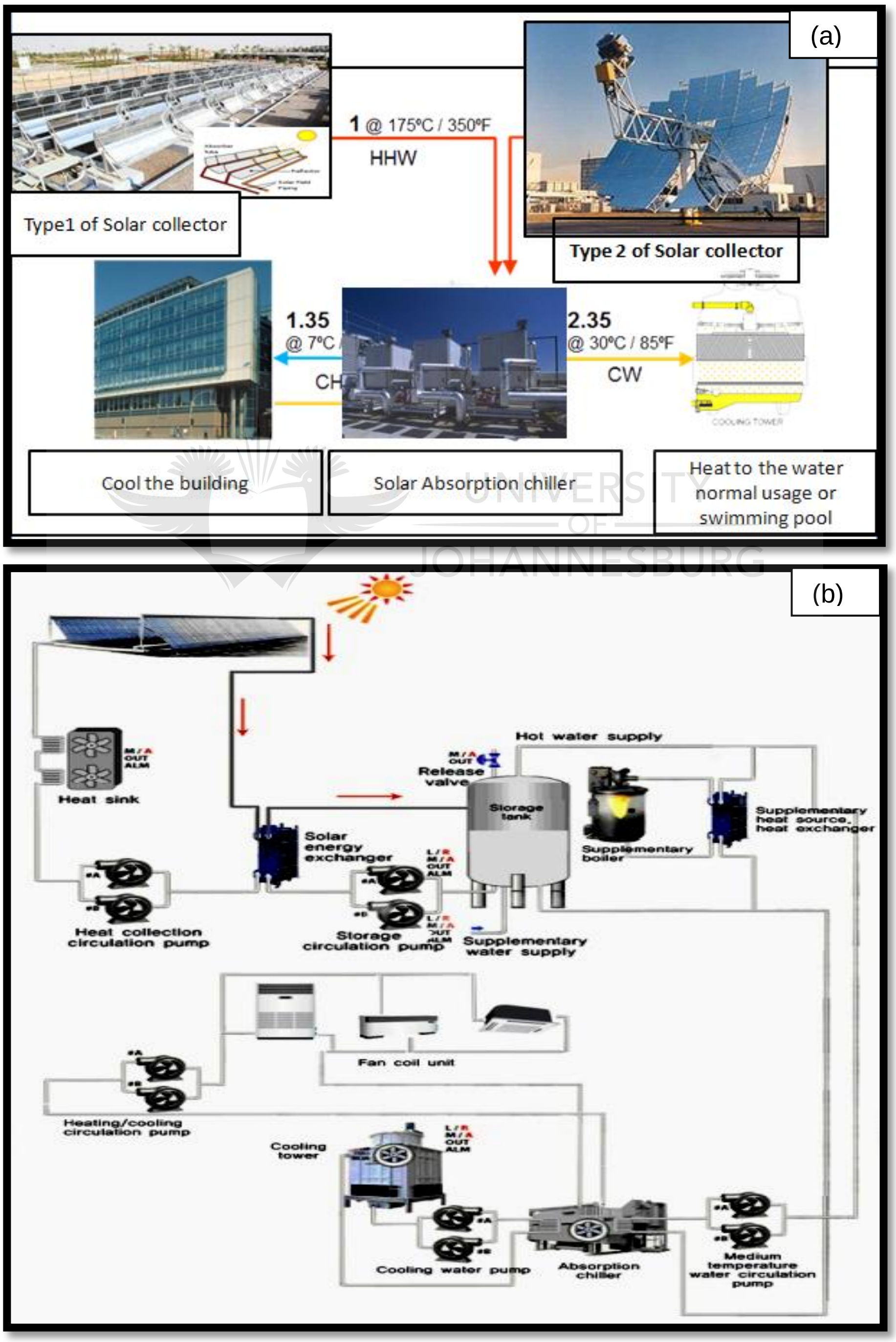



**Figure 2.10: Thermal solar absorption chiller (a) overview and (b) schematic diagram.**

## 2.10 Chapter summary

Concept generation starts with the problem clarification by decomposing it into sub-problems, then searching for solutions for each sub-problem, finally explore the possible solutions in a systematic way. As such, in order to address the high rise buildings requirements they have been categorized to five main categories based on the construction date. The most recent category (1980 to 2005) is the target buildings because it is almost similar to upcoming buildings. This category require yearly energy of around 4.1 TWh/a with approximate floor areas of 11.6 $m^2$. The cooling and heating system of this category require energy of almost 40% and 27% respectively of the total energy consumption. Beside the energy requirements, high rise buildings share same facade requirements in terms of structural design as well as the multi functional use (daylight and passive ventilation, heating and cooling) (Koene et al., 2009; Reijenga, 2009; USTUTT, 2009; Koene et al., 2010).

There are several solar application could be considers in a response of the high rise buildings energy requirements in order toward near net-zero energy building. These solar technologies have three major approaches which are electricity production, heat collection and a combined heat collection and electricity production. Electricity is normally produced directly from the sun`s radiation using photovoltaic (PV) system. Thermal collector collects heat from the sun using several techniques such as concentrated solar power plants, solar collector for domestic purposes and solar towers or chimneys. A combination of these two concepts (thermal collection and electricity production) in a single system donated as (photovoltaic thermal system PVT). This system produces more energy and provides higher efficiency than each system alone. A PVT system produces approximately 43% more primary energy than a conventional solar thermal collector per unit surface area and even around 96% more than a conventional PV system (PVTwins, n.d; Kaplan,1985; Ngo and Natowitz, 2009; Energy works, 2009; NREL, 2010; Hollick, 2011)

Using high rise building's facade as an energy gain component is mandatory for on-site energy production due to the relative small roof area compared to the height of the buildings. Since buildings features limits on-site renewable energy to the solar energy, integration of solar application in the building's facade plays a major role in the on-site energy production. There are five multi function active facade developed by EU cost effective project. All of these facades have been developed with a purpose of gaining energy from solar which then is used to produce either thermal energy or electricity (Litter and Thomas, 1984; Tilmann and Kuhn, 2009; Maurer and Kuhn, 2011).

The cooling loads consume approximately 40% of the high rise buildings energy consumption. So any energy solution has to consider HVAC system requirements. Two type of green HVAC system applicable for high rise buildings has been introduced: ice slurry and absorption chiller. Ice slurry helps buildings designers to use more efficient design parameters such as a cooler air distribution temperature to almost 12°C which in turn benefits buildings with either reducing the operating cost or minimum the refrigeration machinery and equipments cost and enhance the potential comfortable space environment. Absorption chiller could be considers as the most green HVAC system in which it has no moving part, no electricity required, thermal driven system (use heat to produce cold), and could be operated by solar thermal energy (New Buildings Institute, 1998; Tassou and Bellas, 2005; Epsltd, 2012).

Follow the technology review introduced in this chapter is the navigation for the best candidates and combination in the concept selection phase or the optimization of the system. The following chapter will provide an overview of the concept selection and system optimization based on the above reported technologies and solutions.

# CHAPTER 3: CONCEPT SELECTION

System concept described by Ulrich and Eppinger (2008) as "an approximate description of the technology, working principles, and form of the system". It also gives a brief description of how the system will satisfy user needs. Therefore, the success on the concept generation phase is a necessary condition for any commercial success.

Several solutions for the high rise building`s energy challenges have been identified in the visibility study (chapter 2). Following is the Navigation for optimum solution, which normally starts by organizing and presenting the solutions in a systematic way in order to pick the most applicable candidate and the possible combination. There are several concept generation techniques such as the classification tree, and the combination table (Ulrich and Eppinger, 2008). It seems more useful to combine both techniques in order to enhance their advantages and minimize their disadvantages.

Figure 3.1 shows system concept generation for the high rise buildings energy challenges using a combination of the classification tree approach and the combination Table.

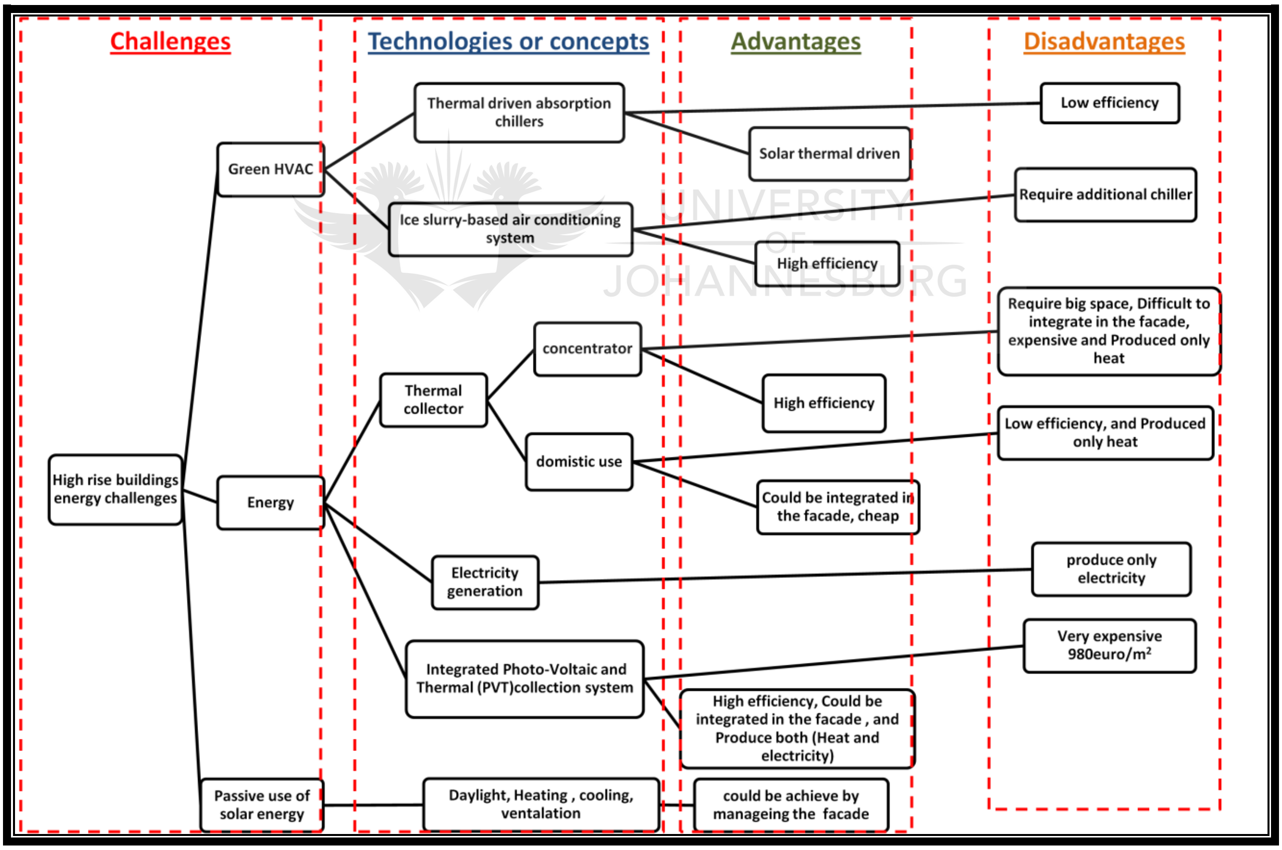


**Figure 3.1: High rise building energy solutions tree.**

Removing the excess heat build up under the PV modules, increases the electrical output. Generally, modules can commonly operate at temperatures over 50°C above the ambient temperature, resulting in a performance reduction of more than 25%. It has been shown that for each 1°C increase in temperature, the power production drops by around 0.5% which means that a PV 100 W crystalline module at 65°C only delivers 80 W. Therefore, dissipating the heat from the module and lowering the operating temperature significantly increase the module efficiency as well as the ability to utilize the heat for practical heating purposes (Hollick, 2011).

Absorption chiller may operate using water at 88°C while, the integrated photovoltaic and thermal system PVT may reach temperature of 88°C in case of ambient 38°C which is sufficient to drive the absorption chillers. Additional electric heater or gas flamer could be connected to the outlet of the panel to maintain the water inlet of the absorption chiller system above 93°C. Therefore, building a sensitive water system to control the hot and cold water becomes mandatory to achieve the highest possible efficiency.

The target of the system is to reach a near net-zero energy building, therefore the net-zero energy houses concept (introduced in chapter 2) should be implemented. As such, the water should be controlled in three levels based on the water temperature:

1) Super heated water sourced from the PVT system and additional super heater, operates the absorption chiller and serves as a heat source for other usage if required.
2) Minimum hot water sourced from the HVAC outdoor unit (condensing unit) used to heat the water for normal usage (summing pool, hot water for daily usage).
3) Cold water from the absorption chiller operates the HVAC system indoor units to cool the buildings as well as supply the HRV units coil.

The heat recovery system HRV basically works in two steps: first utilizes the wasted cold in the extracted air from kitchens and bathrooms using a heat exchanger to cool the fresh air, and then cool the fresh air using a cooling coil supplied from the chiller.  Generally, the HRV unit supply the building with its requirements of fresh air. Since the fresh air cannot reach the indoor temperature only by the cold recovery, the HRV should be connected to the absorption chiller as well. Figure3.2 shows an overview of the suggested system concept.

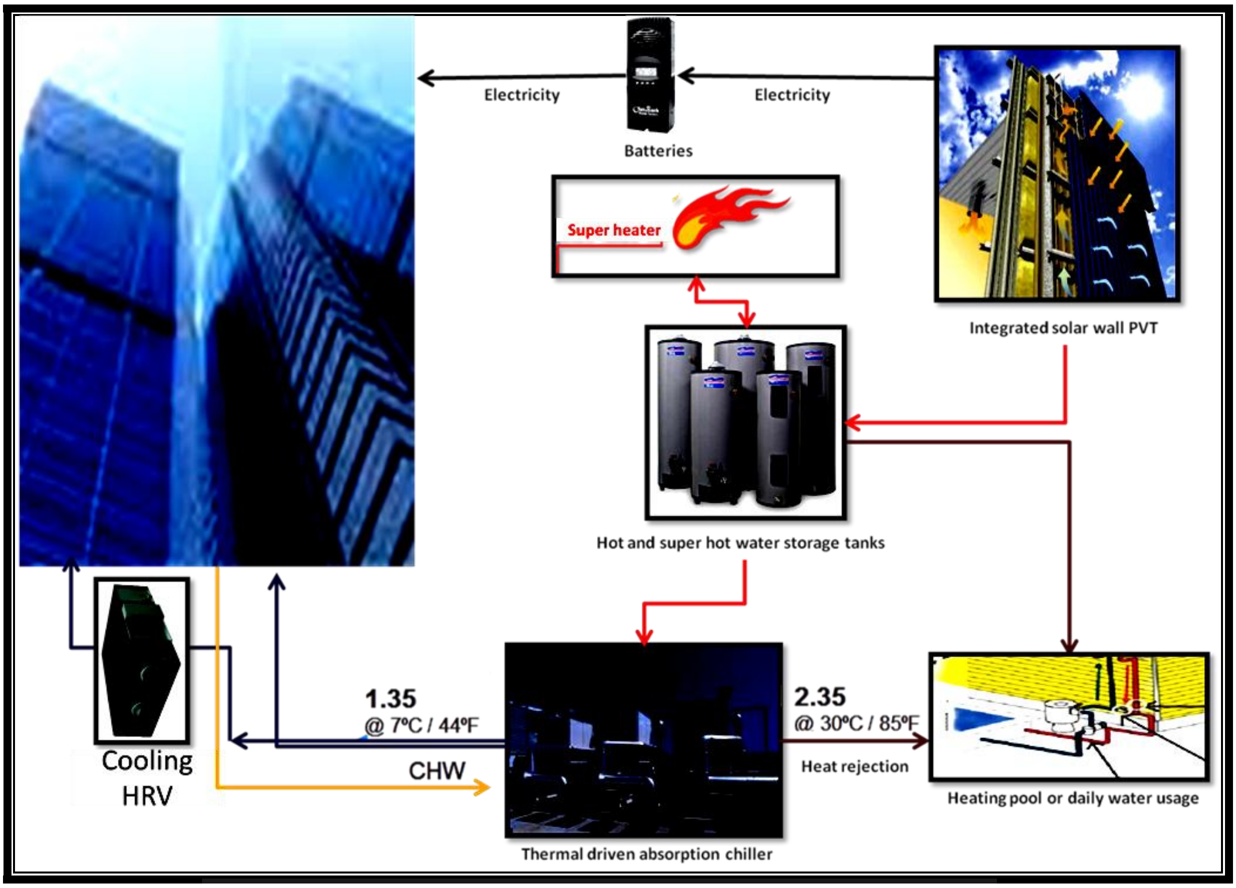


**Figure 3.2: Integrated solar PVT and absorption chiller in the high rise buildings concept.**



### 3.1 Mission identification:

Part of the pre-project planning is the identification of the project mission (Ulrich and Eppinger, 2008). Mission identification is to identify the system primary and secondary mission by answering what is system to accomplish and how to accomplish that. The system primary mission is to provide a total energy solution for high rise building. This solution consists of below steps:

1) Starts by installing solar wall PV arrays to supply the building with its required electricity energy for the normal use (lighting, electronics, *etc*).
2) Integrating solar heat recovery system using water to recover the heat build up under the solar wall PV array.
3) Storing the hot water in the storage tanks to supply hot water as per demand to the thermal driven absorption chiller and to the building respectively.
4) Super heating the water using solar thermal collector or gas or electric heater to obtain the required temperature for the chiller
5) Operating the thermal driven absorption chiller using hot water from storage tanks.
6) Supplying the building with cold water to operate air-condition indoor units.

7) Use cooling tower, swimming pool, and building heaters storage tanks as condensers for the absorption chiller.

### 3.2 General specification

Normally, needs are presented in the form of user wording like "fast car" such words unlikely to be feasible unless it has been translated to specification words like (speed limit of 300 Km/h, or reach 60 km/h in a min) (Ulrich and Eppinger, 2008). Establishing product specification is an essential part of the early product development stages. Product specification is normally developed through two steps which are setting targeted specification and establishing final specification, targeted specification represents the hope and aspiration. These targets should be revisited several times and final assessment should be conducted after the system concept selection and then establishing the final specification (Ulrich and Eppinger, 2008).

Targeted specification has several steps to be developed starts by preparing the list of metrics, and then collect the competitive benchmark information. Finally there is need for setting either ideal or marginal targeted values (Ulrich and Eppinger, 2008). Furthermore, targeted specification could be described as an identification of the system function in terms of performance parameters and its relation to the mission. Below are the performance parameters related to each of the mission items:

1) Solar wall PVT system: because there are no sufficient experiments for the integrated PVT system in the building's facade, the performance parameters will therefore be assumed initially based on three concepts: normal PV system electricity production, solar Wall thermal collectors, and PVT roof system.
   a. PV system produces electricity at around 4.3 KWh per $m^2$ if it is fixed and 5.9 KWh per $m^2$ if two ways sun tracker system is installed (Greentoronto, 2010).
   b. Solar wall thermal collector: recovered heat should be measured between 55 to 90$^{o}$C based on the type of the approach used (Zalewski et al., 2011).
   c. Solar PVT system: produces averages of 115 W/$m^2$ electricity and 600W/$m^2$ thermal energy (Zondag, 2006).
2) Storage tank: should be isolated with minimum heat losses (KJ). Storage tank capacity measured as volume in $m^3$. Storage tank losses is given by equation (2) (Muneer and Uppal, 1985):

$$S = 4.1A_s\ (t_{fi} - 25) \quad (2)$$

   Where: $A_s$ is the surface area of the storage tank and is given by $A_s = 5.556\ (rA_c)$

   : $A_c$ is the solar collector area
3) Super heater: dependent on the type of the additional heat source, but the stored temperature should be within 90-110$^{o}$C.

4) Absorption chiller: is described by its efficiency presented in a coefficient of performance COP concept which could be calculated by use of equation (3 1 COP (Lizardos, 2007):

$$COP = a_0 + a_1t_8 + a_2t_8^2 + a_3t_c + a_4t_gt_c + a_5t_8^2t_c + a_6t_c^2 + a_7t_gt_c^2 + a_8t_g^2t_c^2 \text{---------} (3)$$

Where: $75\,^oC < t_g < 100\,^oC$

: $24\,^oC < t_c < 31\,^oC$

: $t_g = b_0 + b_1Y + b_2Y^2 + b_3t_c + b_4Yt_c + b_5Y^2t_c + b_6t_c^2 + b_7Yt_c^2 + b_8Y^2t_c^2$

: Y is the capacity of the chiller (kw)

: $1 \text{ kw} < t_g < 13 \text{ kw}$ $\quad$ $24\,^oC < t_c < 31\,^oC$

: *a* and *b* values are given factors drawn from tables

5) Indoor units: are measured in BTU/h upon the required capacity of the specific space calculated using the heat load calculators of approximately 300 BTU/$m^3$ for the tropical regions.

6) Cooling tower or any other condenser: measured as temperature in $^oC$ using equations (4) (Muneer and Uppal, 1985):

$$t_c = c_0 + c_1t_h + c_2t_h^2 + c_3t_w + c_4t_ht_w + c_5t_h^2t_w + c_6t_w^2 + c_7t_ht_w^2 + c_8t_w^2t_h^2 \text{-----------} (4)$$

Where: $32\,^oC < t_h < 42\,^oC$

: $24\,^oC < t_w < 29\,^oC$

## 3.3 Logistic requirements



Several studies have been employed for the relationship between logistics and the performance and operation requirements. UOP (n.d) supported the same idea and argued that operation and maintenance dimensions may shape the overall system performance as demonstrated in Figure3.3.

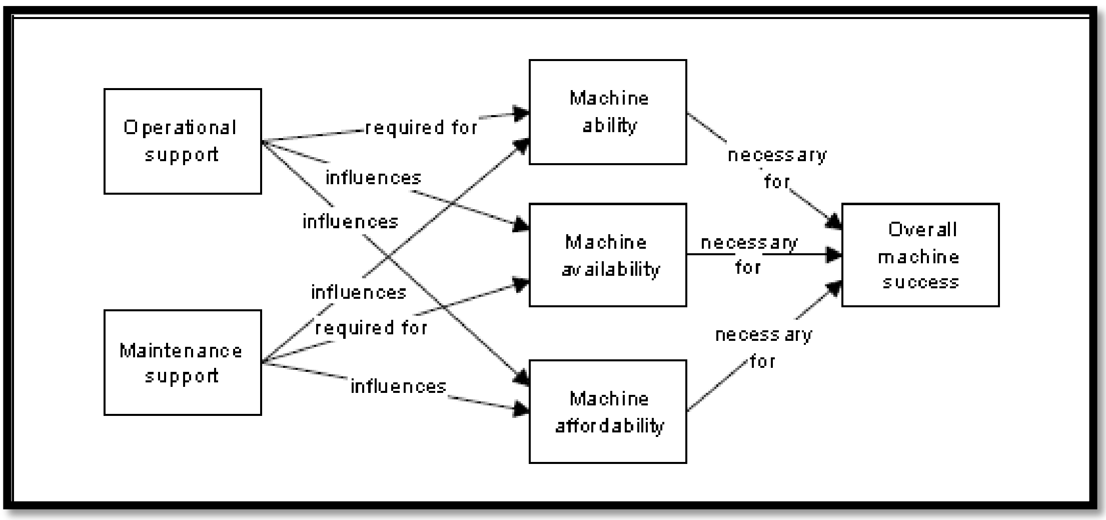


**Figure 3.3: The relationship between the two dimensions of integrated logistic support and the system measurements (UOP, n.d).**

In order to determine the operation logistics requirements associated with every sub-system at a particular time, it is mandatory to have an overview of the system operation scenarios using qualitative and quantitative analysis for each system`s element utilization in terms of personnel and equipments, life cycle, and system environment (Blanchard, 2004) as illustrated below:

1) The solar wall PVT system produces electricity as well as heat. Electricity generation should be as per the building demand. Solar PVT system produces average of 115 $w/m^2$ electricity and 600 $w/m^2$ thermal energy (PVTwins, 2012) (more experiments are needed in this area). Solar wall quantity varies based on the building surface area that it should cover all or part of the building skin. Generally the effectiveness of the solar panels could be determined in a form of electricity produced per area unit ($kw/m^2$) and the thermal energy produced per unit area ($^oC/m^2$). The velocity of the heat recovery fluid under the solar wall must be lower than 1 m/s to obtain absorption chiller required temperature (88$^o$C). The number of the solar walls could be determined based on the building cooling load considering the fact that approximately each 1 $m^2$ could operate a chiller to produce around 4 kBTU/h (Zhai et al., 2011).
2) Absorption chiller capacity varies based on the building cooling capacity. The primary selected brand, Yazaki, has a capacity rang form 60 KBTU/h to 360 KBTU/h (Yazaki, n.d). The effectiveness could be measured in form of confectioned of performance COP in a range of 1 COP (Lizardos, 2007).
3) Storage tank capacity requirements depend on the amount of hot water generated from solar wall and super-heater. Consider the solar collector as a base for this study assumptions, where each 1 $m^3$ of the hot water storage tank filled by 25 $m^2$ of flat-plate collectors produces around 102 KBTU/h cooling from the absorption chiller (Zhai et al., 2011) (more experiments are needed in this area). The amount of temperature loses per $m^3$ determines the efficiency of the storage tank.
4) Operational life cycle: when the system will be in use?, and who will operate it?. The system operational life cycle depends on the building type whether it is residential or commercial. The start up could be decided based on the building construction time line. Regarding the operator, the building management in charge should decide on the operator but the selected one should be trained by the mechanical electrical plumbing contractors (MEP) before the start up.
5) Utilization requirements: it is the level of customer usage of the system and usage parameters. The system utilization is also dependent on the building type. It could be assumed that, the operation time is 8 hours per day as an average of the building air-condition usage.
6) Environment: identified by the operation field whether tropical operation or milt operation. The equipment should be selected based on the operation environment. For example, the tropical conditions require equipment with operation range up to 50$^o$C, while the cold weather requires anti-freezing devise in order to protect the unit from being blocked by ice.

## 3.4 Maintenance and support concept

Cooper et al. (1988) defined the service as “a process for providing significant value-added benefits to the supply chain in a cost-effective way.” Thus, it is important for customer service in creating value for the whole supply chain as well as for the end user (Carothers, 1991)

Maintenance concept is defined as “being a before-the-fact series of illustration and statements on how the system is to be designed for supportability”. Maintenance plan is defined as “the requirements of the system support based on a known configuration”. So maintenance concept is an input affecting the design, while maintenance plan is the result of the design. Therefore, developing maintenance concept during system design is an essential part to achieve the optimal design for supportability (Blanchard, 2004).

Typically, maintenance concept answers the flow of maintenance activities and information from end user to manufacturer or supplier and back to the end user. Blanchard (2004) suggested six steps to construct the maintenance concept and briefly discussed below:

### *3.4.1 Repair policy*

Exceeding costumer service requirements is one of the competitive advantage sources. Understanding service requirements starts by identifying the accurate customer service needs (VanHuss, 1993). As such, companies should adopt a strategy that proactively focus on customer service based on understanding customer`s own logistic processes and designing the logistic system to meet their needs. The ultimate objective is to create value for the customers by enabling them to achieve their own objectives more efficiently (Korpelaa et al., 1998).

The tied relationship between service and logistic requirements has been proven. Neil and Iveson (1991) argued that logistic strategic management determine the cost-effectiveness of the service provided to the customer. On the other hand, market share is influenced by the maintenance perception, which is shaped by maintenance quality (Schary, 1992; DeRoulet, 1993).

Continual improvement is a part of maintenance excellence whereby organizations keep providing value to the costumers through service. Neil and Iveson (1991) suggested an external audit with the objective to identify the importance of the customer service elements and to determine how customers perceive the service level provided by the company and its competitors. Based on the external audit, organization need to classify and prioritise the service elements.

The primary objective of any customer service strategy is about reducing the customer’s cost of ownership. DeRoulet (1993) suggested some acceptable steps to ensure that service provided is serving the primary service objectives, as follow:

1) Building a case for action;
2) Customer segmentation analysis;

3) Evaluation of current processes;
4) Developing service visions and requirements statements for market segments;
5) Identifying commonalities between market segments;
6) Developing value-added initiatives of mutual benefits.

Several steps have been suggested by Korpelaa (1998) to develop an effective strategic maintenance concept which follows the below sequence:

a) Start by the logistically distinct business (LDB) which is a concept that dividing customers into LDBs means segmenting customers exactingly by means of customer-specific criteria related to logistics. Thus, each LDB has its own logistic system matching the service requirements as accurate as possible.
b) Analysis of the importance of the logistic service element.
c) Benchmarking the performance against competitors.
d) Analysis the strengths and weaknesses.
e) Definition of action plans for improving logistic service.
f) Implementation of plans.

The detailed warranty policy should be developed and handed to the customer based on the particular project details in the guide line of:

- manufacturing faults handled by equipment supplier via supplying the equipment then labour work should be done by MEP contractor,
- installation defects handled by MEP contractor labour and parts,
- Misuse should be handled by MEP contractor at the expense of the costumer,
- Preventive maintenance should be done by the costumer.



### *3.4.2 Level of maintenance*

a) Organizational maintenance: it deals with low skills preventive maintenance like cleaning, besides identifying the faulted items. Organization should monitor the effectiveness parameter as well.
b) Intermediate maintenance: consist of two levels which are mobile service and intermediate workshop service. Mobile one is employed to provide replacing fault items and repair the items that require intermediate skills as well as the installation changes. Workshop serves as a provider for the repair of the complex fault items and investigates the manufacturing defects claims.
c) Supplier maintenance: reinvestigates the manufacturing defect claims and supplies the parts as well as providing information to improve the design.

### 3.4.3 *Organizational responsibility:*

Each level of maintenance has its own maintenance responsibility as follow:

a) Customer/building owner handles the organization level maintenance responsible for the non warranty maintenance and the checking for the fault items plus the non skills preventive maintenance.
b) MEP contractor is responsible for intermediate level maintenance and responsible for the installation defects as per the warranty policy.
c) Supplier is responsible for the manufacturer level maintenance as well as training the MEP contractor.

### 3.4.4 *Maintenance support elements*

MEP contractor supply customer with the non skills maintenance tools as well as a computer programme to monitor the system effectiveness and to detect the faulty items. MEP contractor should prepare a mobile workshop to handle in-site maintenance work. MEP contractor intermediate workshop should be furnished with full equipments required to treat the all installed items (a list of the required equipments should be developed and fulfilled in advance before starting the contracting work).



### 3.4.5 *Effectiveness requirements*

Maintenance effectiveness factors can be determined from the system operational requirements as below:

- Solar panels → $kw/m^2$, and $^oC/m^2$.
- Chiller → confectioned of performance (COP).
- Storage Tank → temperature loses per $m^3$ capacity.
- Cooling tower → cooling temperature $T_{c.}$
- Then over all system effectiveness factors.
- $\lambda$ → failure rate.
- MTBF → mean time between failures.
- MDT → maintenance down time.

### 3.4.6 *Environment*

The environmental requirements developed in the operational requirements stage are applicable here with some additional elements concerning the level of usage and the misuse like un-clean machines which result in reducing the efficiency as well as damaging the machines themselves.

### 3.5 Identification and prioritization of technical performance measures (TPM)

There are several elements which are important factors throughout system concept development, logistic requirements study, and maintenance concept development. These factors could be considered as technical performance factors in which they affect the design as well as the supportability. Moreover, logistics, maintenance, and support factors could be listed among the critical technical performance factors (TPF). However, numbers of metric measures are applicable in measuring the TPF based on the type of studied factors. The focus on this stage is to prioritize each factor relative to others. Such prioritization plays a major role in design trade-off (Blanchard, 2004).

Evaluating and rating TPM factors is important, hence it shapes the final system design trade-off, and it could result in customer un-satisfaction. Moreover, customer input at this stage is the key aspect of the system`s success. However, rating TPM starts by customers but the technical requirements can limit it. So the matrix of customer requirements and technical specification should be developed in the system level.

There are several techniques available to rate the TPM. Quality function development (QFD) is an excellent tool to rate TPM with special consideration of costumer desires and needs. QFD presents the customer`s requirements in a form of attribute, and then scoring them based on the degree of importance to satisfy most of the costumers (Cohen, 1995). In this study, costumer technical performance requirements are mainly developed by experience hence, this study argues that most of the projects share almost same major requirements. Table 3.1 illustrates some of HVAC projects TPF.



**Table 3.1: Technical performance measures factors.**

| Factor | Importance (%) |
|---|---|
| Cooling capacity BTU/h per space | 25 |
| Solar panel power supply KW | 20 |
| MTTR | 20 |
| MTBF | 15 |
| Installation space m length | 12 |
| Hot water supply $m^3$ | 8 |

### 3.6 System level design overview

Product development basically has two fundamental approaches which are functional and physical. Functional approach analyzes the system functional requirements to determine the sub-systems and components that contribute to the overall system performance. System functional approach is normally described in a form of schematic, and then reduces to the specific components. The physical approach can be described as the assembly of sub-systems or components to build the final system capable to do its desired function. Furthermore, physical approach is constructed by building the flow block diagram FBD of the sub-systems and its components (Ulrich and Eppinger, 2008). FBD is a suitable technique to develop the functional elements as well.

The concept of the FBD is about translating the system requirements into functional terms by demonstrating the system organization as well as identifying system functional interfaces. Typical FBD demonstrates the system level requirements then break those requirements into sub-systems and component levels in terms of function, organization, operation and maintenance (Blanchard, 2004).

Designing "optimal" system is not an accurate description, but rather it can be described as producing design that is "good enough" (Chapman, 2001).The system design approach using FBD can be characterized as follows: Define series of potential components (Zi) that constitute of the available technologies to build the desired system each have a time index (Ti), an input port (Ii) and an output port (Oi). The ports provide the means of connecting the devices together to form a system. The components connect the output ports with the input ports using system coupling recipes (SCR) to form a potential system (Rozenblit et al., 1994).

All subsystems should be integrated together to reach the desired system outcomes but special consideration to be paid to the interface between subsystems and between the system and environment. Rechtin (2000) defined system integration as:

> *The structure in terms of components, connections, and constraints of a product, process, or element. By definition, each system has architecture, explicit or not, which can be viewed from many perspectives.*



Block diagram demonstrates the relationships between the system and its subsystems and components. As such, there are four types of system configuration which are series system, parallel system, parallel series system and complex system. Figure 3.4 shows an example of the complex configuration (Connor, 2002).

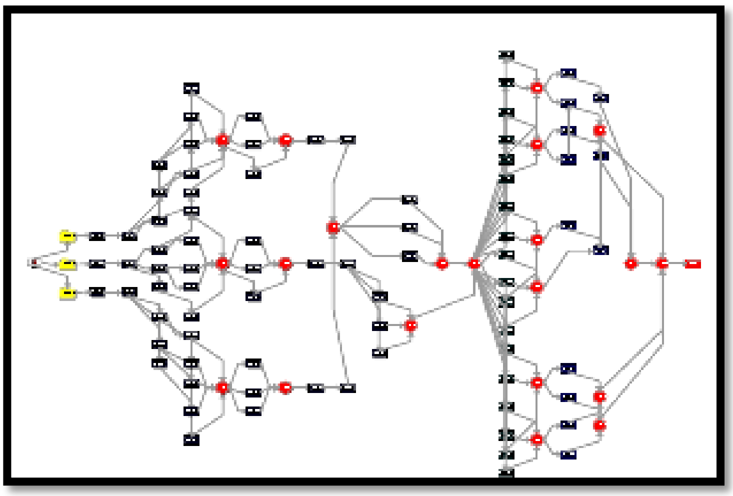

**Figure 3.4: Complex configuration system**

### *3.6.1 Functional approach (functional analysis and functional elements identification)*

Functional analysis is a key aspect of the conceptual and primary design which serves the identification of the required resource for system to accomplish its objectives. Functions could be described as a number of specific actions important for the system to achieve its mission. Therefore, operational and maintenance actions (necessary for system mission accomplishment) are essential part of the desired functions for the functional analysis (Blanchard, 2004).

In order to identify system functional elements, a model should be constructed for both product and process. First, overall system should be broken to identify the subsystems required to achieve system goals. These subsystems should be listed in a sequencing way to help manage the system throughout its entire life cycle. Many techniques are used to construct and demonstrate models, e.g., block diagrams, physical analogs, analytic equations, state machines, functional flow diagrams, object-oriented models, computer simulations and mental models. Secondly, engineering analysis should be conducted by professional engineers to identify the possible improvement based on the current system achievements using “reengineering” for major changes or “total quality management” for minor changes (Koehler and Weissbarth, 2004).

The integrated solar wall PVT system and the absorption thermal driven chiller could be considered as a system of system in which it consists of four major systems that interact with each other to provide a total energy solution for high rise buildings and these are:



- First system: integrated solar wall PVT system.
- Second system: thermal driven absorption chiller.
- Third system: water system (circulation, storage, super heating, cooling tower or condenser, *etc*).
- Fourth system: control software.

Using the same concept of the complex configuration, each system could be broken into sup-system levels and then further into components. First draft subsystem decomposition based on the operational functions is demonstrated in Table 3.2.

**Table 3.2: System functional decomposition for subsystem level.**

| Subsystem functional analysis | | | Function |
|---|---|---|---|
| **1** | **Solar energy system** | | • Electricity production<br>• Solar heat collection |
| | 1.1 | PV array | |
| | 1.2 | Solar wall heat recovery | |
| | 1.3 | Cables | |
| | 1.4 | Transmitter | |
| | 1.7 | Thermostats | |
| **2** | **Absorption chiller** | | • Receive heat and transfer it to |
| | 2.1 | Absorption chiller | |
| | 2.2 | Ammonia/water solution | |

| | | | |
|---|---|---|---|
| | 2.3 | Chilled water pump | cold and then distribute it to the rooms AC indoor units |
| | 2.4 | Expansion tank | |
| | 2.5 | Indoor units | |
| | 2.6 | Thermostats | |
| **3** | **Water systems** | | Circulate hot and cold water throughout the entire building as below:<br>• Solar system to heat exchanger and back<br>• Heat exchanger and storage tank<br>• Tanks to the HVAC system and back<br>• HVAC system to the condensing system and back (cooling tower)<br>• HVAC outdoor to the indoor units |
| | 3.1 | Circulating pump from solar wall to the heat exchanger | |
| | 3.2 | Circulating pump between solar collector and heat exchanger | |
| | 3.3 | Circulating pump between heat exchanger and storage tank | |
| | 3.4 | Circulating pump between storage tank and absorption chiller | |
| | 3.5 | Circulating pump between absorption chiller and cooling tower | |
| | 3.6 | circulating pump between absorption chiller and Indoor units | |
| | 3.7 | Cooling tower | |
| | 3.8 | storage tank | |
| | 3.9 | heat exchanger | |
| **4** | **Control system** | | • Control water circulation<br>• Control air conditioning<br>• Control solar energy system |
| | 4.1 | solar wall Sensors | |
| | 4.2 | Water system Sensors | |
| | 4.3 | Absorption chiller Sensors | |
| | 4.4 | software | |
| | 4.5 | PC computer | |

### *3.6.2 Physical approach (System synthesis and design optimization)*

Physical approach basically organizes the sub-systems and components in major physical building blocks called chunks. Each chunk is constructed by a collection of components. Moreover, the architecture of the system is a scheme that partitions the functional elements into physical chunks as well as provides an overview for chunks interactions (Ulrich and Eppinger, 2008). More specifically, system synthesis is a structure of the system components that presents feasible system (Blanchard, 2004). System synthesis initially describes the basic relation among various components. Therefore, modelling is an essential part of the physical approach. Figure3.5 demonstrates the modelling of integrated energy system (solar wall PVT, absorption chiller, and HRV).

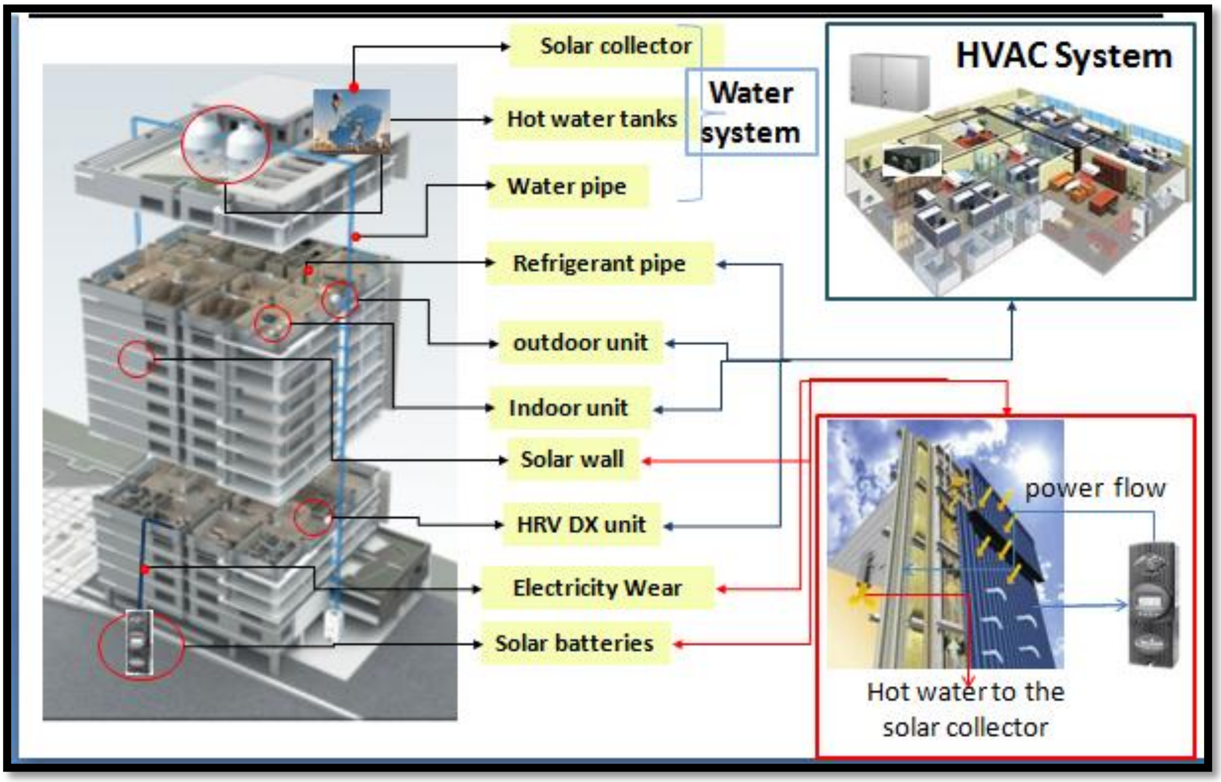


**Figure 3.5: Thermal solar wall PVT integrated with absorption chiller in a high rise building.**

## 3.7 Requirements definition and allocation

Following the identification of the subsystems and components is the grouping of these components in "partitions" based on their similarity in terms of common resources requirements, location, common environment, and functions. Such grouping should be at a minimum interface level. System components partitions help in meeting system requirements *via* allocating those requirements from system level to the partitioned units. In sum many requirements allocation has two major areas which are reliability and maintainability allocations (Connor, 2002; Blanchard, 2004). Due to the lack of information, this study will be limited in providing literature review for the above mentioned requirements allocation knowledge areas to serve as guidance for further studies:

### *3.7.1 Reliability requirements allocation*

Reliability requirements could be allocated to the partitioned units using the flow block diagrams. Reliability, MTBF and λ should be predicted for the system and subsystem levels from components or assumed by experts or past experience. The desired requirements should be paid back to the components level to meet the system level requirements; otherwise system design should be re-reviewed.

### *3.7.2 Maintainability requirements allocation*

The reliability factors specially the MTBF of the partitioned units are essential parts of allocating maintainability requirements. There are three major elements governed the maintainability or supportability which are corrective maintenance, preventive maintenance, and the maintenance labour hour per operating hour.

a) The expected corrective maintenance of system components could be determined using equation (5)

$$Mct = MTBF.(1 - A_i)/A_i \text{------} (5)$$

Where: Mct – is the mean corrective maintenance

: $A_i$ – is the system availability

While system level Mct is determined as below

$$Mcts = \sum C_t / \sum C_f \text{------} (6)$$

Where: $\sum C_f$ = Q( number of the units) * λu

: $\sum C_t$ = Cf * Mctu

b) Preventive maintenance could be predicted as follows:

$$Mpt = \sum(fpti) * (Mpti)/ \sum fpti \text{------} (7)$$

Where: ∑(fpti) – is the frequency of unit preventive maintenance per system operating hour

: Mpti – is the unit required preventive maintenance time

c) Maintenance labour hour per operating hour (MLH/OH) is an important maintenance requirement factor which should be consider during the primary design. MLH/OH could be determined using equation (8)

$$MLH = \sum(\lambda u) . (MLHu)/ \sum \lambda u \text{------} (8)$$

Where: ∑(λu) – failure rate per unit

: MLHu – mean labour hour per unit

### 3.8 Chapter summary

Generally, to develop new system or solution, organization needs to implement some engineering management principles such as new product development (NPD). NPD literature gives a frame work for developing new system. In summary, NPD literature argues that design affects the product success rate by more than 70%. Furthermore, some of the NPD researchers argue that the first three steps of the product development (Planning, Concept development, and System level design) contribute mostly to the design success.

Organization needs to develop a system concept by generating concepts out of the available literature and technologies and then selecting the best candidates and combination. In this sense, an optimum solution for high rise building energy challenge has been introduced in a form of general concept. It consists of five major technological concepts: The integration of near net-zero energy houses concept, heat recovery system HRV concept, absorption chiller, integrated solar photovoltaic and thermal collector system PVT, and the integration of the solar application in the building facade.

An essential part of the new product development process is the product planning which should be fulfilled and presented in a form of system mission statement. In this study the system mission was stated as: to provide a total energy solution for high rise building.

Identifying the system marginal specification is also an essential part of the product concept optimization. In this study the system general specifications has been addressed using two techniques. First for the commercial existing systems, it was drawn from the primary selected brands catalogue and second it was assumed based on the most similar well developed technology for the parts that require more experiments. For instance, absorption chiller used Yazaki brand data, whereas the solar wall PVT system data was assumed based on date from PV system, solar wall collector, and PVT roof system.

The identification and prioritization of technical performance measures (TPM) has been listed based on the experience, hence the projects major requirements don't vary much. The cooling capacity has the most priority (25% importance) and the hot water supply has lowest importance (8%) in the targeted regions (hot and mild regions).

Inheriting logistics engineering principles in the product development in early stages plays a major role in product survival. Logistic elements have two forms, operational requirements and maintenance or supportably requirements. Operational requirements address the requirements of the operational scenarios for solar wall PVT system, absorption chiller, hot water storing, life cycle, utilization, and the possible operation environment while supportability requirements cover both policies and processes. In terms of policies, they cover the maintenance and support concepts and strategies as well as the repair policy, while the process covers the level of the maintenance, organizational responsibility, maintenance supports elements, and effectiveness parameters. On the other hand, reliability requirements allocation is an essential part of the system design early stages. Although, the reliability requirements vary based on the components selection (which is not available for this research), this study has provided a literature review of the reliability requirements allocation techniques.

Finally, the system level overview was introduced in form of functional and physical approach whereby, functional approach covered the components integration to fulfil the system desired functions. Physical approach covered the physical components interactions and interfaces. System level was developed using flow block diagram method (FBD) by breaking the system into subsystems. Four major subsystems were introduced: solar energy system, absorption chiller, water system and control system.

# CHAPTER 4: MARKET ACCEPTANCE

One of the essential parts of the product development early stages (especially the project selection process) is investigating the market acceptance. Market acceptance is defined as a condition in which a product or service satisfies the needs of a sufficiently large number of customers to develop new product or continue and increase the production of existing one (BusinessDictionary.com, 2012b). Market acceptance starts by identifying the market opportunities as well as the market future trend.

In order to achieve a successful market acceptance, organization needs to develop an effective marketing strategy. Marketing strategy is defined as:

> *An organization's strategy that combines all of its marketing goals into one comprehensive plan. A good marketing strategy should be drawn from market research and focus on the right product mix in order to achieve the maximum profit potential and sustain the business. The marketing strategy is the foundation of a marketing plan" (BusinessDictionary.com, 2012c).*

In this sense, marketing strategy should be drawn from a comprehensive marketing research using the right techniques, and then break it into organization specific marketing goals. Moreover, marketing strategy should stands on a foundation of the products or service unique sales points (USP). Therefore, the genuineness of the product/service USP claims plays a major role in any marketing strategy success.



In the studied system, the green claim of the buildings has to be proven to the customers in order to gain their trust and increase the market share of the new developed green product or solution. Since there are globally recognized green product certification systems, labelling the green building with one or more of these certificates supports penetrating the market as well as gaining considerable market share (Patterson, 2012). On the other hand, new system whether green or not has to be economically comparable to the conventional systems.

This chapter will cover the possible opportunities available for the suggested system as well as reviews some of the marketing analysis techniques and marketing strategies that are applicable for such system as a green system. A review of some of the powerful green certificating systems as a marketing tool is also presented. Finally the chapter concludes by conduct a general study of the economical feasibility of the new system.

## 4.1 Global response to the climate change as market opportunities for green products

Copenhagen convention, is one of the greatest responds to the climate change challenges, where over than 100 world leaders participated in the climate change negotiation at the 15$^{th}$ meeting of the United Nations framework convention on climate change (UNFCCC, 2010) in December 2009. The basic intention of Copenhagen was to create and develop a solid foundation and framework to help countries to start responding effectively to the climate change. The most important outcomes from Copenhagen were: keeping maximum global temperature increase to below two degrees, reducing emissions by 2020, reducing emissions from deforestation and forest degradation in developing countries (a program known as REDD), and most importantly, the agreement to mobilize US$100 billion for the period 2012-2020 which is known as Copenhagen green climate fund (UNFCCC, 2010).

Recently, international climate policy has increasingly focused on reducing temperature increase in order to achieve greenhouse gas concentration related objectives. The agreements reached at the United Nations Framework Convention on Climate Change conference in Cancun in 2010 recognize that countries should take urgent action to limit the increase in global average temperature to less than $2^oC$ relative to pre-industrial levels (UNFCOCC, 2010). Although climate change issues drive a global orientation towards low-carbon economy, still this is shaped by the global activities towards a sustainable energy from both production and consumption sides (World Energy Council, 2012).

After Copenhagen, more attention has been paid to climate change polices. This trend is likely to continue with more extreme polices and regulations (Hedger and Bird, 2011). Development cooperation relationship has helped to raise the adaptation agenda within climate change policy circles and the importance of governance and institutions for an effective response to climate change (Peskett and Brown, 2011). For instance, European Union had established a plan towards a green future consists of several points of which the most important agreement was concerning energy production as well as smart energy consumption. Regarding the energy production, European countries had agreed towards the energy independency by 2050 with milestone review to be conducted in 2020. Therefore, the transformation of the construction sector implies the necessity of such dramatic changes in both energy consumption part and energy production part. Therefore, the change in the construction sector energy is a must and non avoidable (Tilmann and Kuhn, 2009).

The expectation of strong activities for green buildings energy has been increased recently. These green activities in the buildings sector have been employed in the existing buildings as well as the new buildings. It opens a great chance to develop new product in a form of sustainable industrial activities. The success in the PV-industry could be considered as a strong example for this argument. Moreover, there are large numbers of energy-efficient technologies that have been developed recently to face the increasing demand of high efficient energy products. Although, there are hundreds of new technologies that are targeting to improve the energy use in buildings and they are already well understood and gradually penetrating the market, still more advanced technologies will be introduced in the future (Tilmann and Kuhn, 2009). Furthermore, these transformation activities are still facing a great challenge categorized by (World Energy Council, 2012) to three major categories:

a) Business case and financing
b) Regulations

**c)** Public awareness / acceptance

In this sense, Unruh and Ettenson (2010) reported that from 2007 to 2009 the eco-friendly products have increased 500%. The public awareness about climate change effects as well as their purchasing power toward green future has given firms a competitive edge. Recently there was a considerable growing segment of the consumer known as Lifestyles of Health and Sustainability consumers "LOFLVS" which is calming to be 25-30% of the adult consumers in US. They are a type of consumers who cares about their health, environment, and social justice by being restricted in investing only where it reflect their values (Papmehl, 2006).

There is an increasing demand of design and construction of low-energy and near net-zero energy consumption residential and commercial buildings. Recently, the International Energy Agency (IEA) has approved the establishment of a new task focused on net-zero energy solar buildings (IEA, 2008). Moreover, many countries have also established tasks toward net-zero energy buildings as a short term goal. European Union for instance, had officially announced that new buildings have to be a net-zero energy by 2020 and some public buildings already after 2018. Regarding the existing buildings and renovation EU stated that it is not mandatory to be net-zero energy, but annual primary energy balance is the target (Tilmann and Kuhn, 2009). Generally, the common elements to describe the net-zero energy buildings is that it utilizes the solar thermal and solar photovoltaic (PV) technologies to generate as much energy as they yearly loaded (Charron and Athienitis, 2005).

Such transformation towards low energy consumption buildings will not be feasible unless it considers building air conditions, where they may contribute up to 40% of buildings energy consumption. On the other hand, global orientation of keeping the temperature increase in two degrees and the concern about energy consumption, presents a threat and opportunities to the air-condition business. The threat is that air-condition represents the most energy consumption item contributes in the overall building sector consumption, while the opportunities is linked to the global warming increase by $2^{o}C$ which will result in increasing the demand of air-condition need.

## 4.2 Marketing

One of the most challenging elements of the marketing strategies is to achieve a sustainable competitive advantage over the other competing products and firms in the market. A competitive advantage is an advantage over competitors gained by offering the consumers greater value (Riley, 2012). Moreover, firms could claim that it has a sustainable competitive advantage only if their marketing strategy enables them to sustain above-average profitability for number of years. Generally, competitive advantages vary upon the situation and the time in which it could be categorised on four major areas as suggested by Vectorstudy.com (2008):

1) Low cost operation

2) High and consistent quality
3) Time element effects on both development and/or delivery.
4) Variety, flexibility, and ability of customization.

### *4.2.1 Marketing analysis techniques*

There are several marketing techniques that have been employed to analyze the firm, competitors, and the market to enable the firm to develop a competitive advantage marketing strategy. The marketing strategy normally varies from one organisation to another and from one market to another. This study therefore provides an overview of some of the most powerful marketing analysis techniques to serve as guidance for the different situations.

#### 4.2.1.1 Strength, Weakness, Opportunities and Threats (**SWOT**)

SWOT analysis is a marketing analysis tool that identifies the strengths, weaknesses, opportunities and threats of an organization. Generally, it helps the firm to identify what is possible and what is not, as well as identifying the potential opportunities and threats. Basically SWOT takes the information from the environmental analysis and separate them into internal (strengths and weaknesses) and external issues (opportunities and threats) as illustrated in Figure 4.1. A successful SWOT analysis determines what may assist the firm in accomplishing its objectives and what obstacles must be overcome or minimized to achieve the desired results. (Investopedia US, 2012; Businessdictionary, 2012).



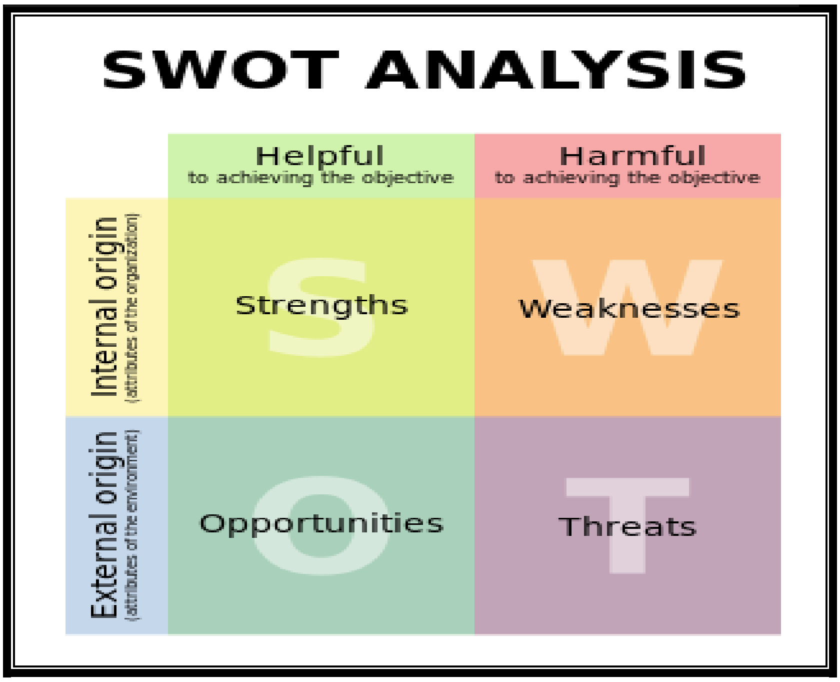


**Figure 4.1: SWOT analyses (businessteacher.org, 2011).**

4.2.1.2 **PEST** analysis (Political–legal, Economic, Socio-cultural ,Technological)

It is a type of situation analysis in terms of Political–legal (spending, government stability, taxation), economic (interest rate, inflation, employment), socio-cultural (income distribution, education, and demographics), and technological (conservation of the discoveries into system). Generally, this technique examines the organization long term plan against the facts (Businessdictionary, 2012).

*4.2.1.3* "5 P,s" (Product, Price, Place, Promotion, People)

5P`s is an analysis technique used mainly to achieve customer satisfaction using suited combination of the 5 P`s based on the consumer requirements and market offers. Although, 5P`s are controllable elements but internal (organizational) and external (market) factors are affecting it. Initially they were 4 P`s then the 5$^{th}$ P was added (Bivines, 2004):

1) Product: refers to all features, benefits, and advantages that the customer could benefit from the product. Generally, the firm`s target is to have a unique product above its competitors. Therefore, a firm needs to compare its product against the competitor`s same product or any alternative to benchmark their success points.
2) Price: the pricing strategy for the product should consider the market range of prices and how much the customer prepares to pay as well as the payment methods. There is a lot to say about the pricing but basically pricing starts with determining the cost and the other overhead costs then dividing it into products to determine the minimum price and then study the market and position the product or service correctly to determine the maximum price.
3) Place: answer how the firm is going to get the product to the customer. There are several marketing meanings for the place besides the retail shops such as: online shopping, distributors, corporate channels, merchandising, engineering sales, and *etc*.
4) Promotion: promoting product or service is an essential part of the business success. The advertising is one of many promotion activities. Each product or service has its own suited promotion techniques like the merchandising, engineering sales, conferences, consultant service, *etc*.
5) People: refers to the staff and sales people. Basically, in the last 20 years, the marketing has shifted from being product centric to relationship centric by realizing the power of relationships. Therefore, hiring better staff compared to the competitors could be one of the most powerful elements contributes on the business successes

### *4.2.2 Marketing strategies*

Constructing a strategy consists of two elements: declining the business target "where you want your business to go" and the way to get there "deciding how to get there". Marketing strategy could be defined as combination of firm marketing goals into a comprehensive plan. Generally, marketing strategy is drawn from a marketing research with a clear desire of maximising profit as well as sustaining the business. Marketing plan is different form marketing strategy in that the plan serves to achieve the strategy (businessdictionary.com, 2012a). There are two interesting marketing strategies modules that could be effective for the new product or service: the Porter's generic competitive strategies and the green products focus marketing strategy.

#### 4.2.2.1 Porter's Generic Competitive Strategies (ways of competing)

The strategy theory has been developed by a university professor, Michael Porter at Harvard business school. Basically, it says that business can achieve and maintain a competitive advantage over competitors in three major ways as illustrated in Figure 4.2 (Cambridge Business English Dictionary, 2011; Porter, 1985; Porter, 1996; Vectorstudy.com. 2008):

1) Cost leadership: being a low cost producer or provider.
2) Differentiation: in this strategy, firm seeks to be unique by offering products that are different and adding value to the customer.
3) Focus: focusers normally select one or more of the market segments that have particular needs then adjust the strategy to be more focused to serve these segments well.



| | | **COMPETITIVE ADVANTAGE** | |
|---|---|---|---|
| | | Lower Cost | Differentiation |
| **COMPETITIVE SCOPE** | Broad Target | 1. Cost Leadership | 2. Differentiation |
| | Narrow Target | 3A. Cost Focus | 3B. Differentiation Focus |

**Figure 4.2: Porter's Generic Competitive Strategy from (Vectorstudy.com, 2008).**

These three generic strategies could be defined along two dimensions:

a) Strategic scope: is the demand-side dimension looks at the target market size and its composition.
b) Strategic strength: refers to the supply side dimension mainly cares about the firm strength or firm core competency.

4.2.2.2 Green products marketing

During the last decade there is a mind-set shifting toward green products and services among the investors and executives. Papmehl (2006) argued that almost two-third of the executives see sustainability as a revenue driver besides its competitive advantage adding. Such shifting could be a platform for differentiation as well as growth. Papmehl (2006) has suggested some tips for green marketing:

- Consumer purchasing is govern by consumer psychology and needs.
- Identify and link the non-green attributes to the marketing plans (quality, price, convenience, reliability and efficiency).
- Compare the price of marketed environmental product to the conventional ones.
- Ensure the performance and the quality of the environmental product is equal or beating the conventional one.
- Approve to the customer that the green product claim is legitimate.

Although the green transformation is part of many leader`s top agenda, still the way to get there is not clear. Unruh and Ettenson (2010) have suggested three major marketing paths toward green transformation as illustrated in Table 4.1.



### *4.2.3 Marketing strategy recommendations*

Considering the facts that the proposed system is a unique green system providing solution particularly for the high rise buildings, therefore the marketing strategy should be based on three elements:

1) Focus: marketing strategy should focus on the high rise buildings by fulfilling their special requirements.
2) Differentiate: marketing strategy should emphasis the uniqueness of the system as a complete energy solution provider for high rise buildings.
**3)** Greenness: since this system is a solution provided by MEP contractor, then organization need to implement the architect green marketing technique introduced in Table 4-c.

Table 4.1: Green path and analyzing growth options (Unruth and Ettenson, 2010)

## Accentuate

(a)

| FIRST STEPS | YOUR PORTFOLIO | YOUR CUSTOMERS | YOUR COMPETITORS | RED FLAGS |
|---|---|---|---|---|
| **What's our strategic goal?**<br>• To leverage latent assets?<br>• Revitalize existing brands?<br>• Broaden appeal to green customers?<br>• Gain green credibility?<br><br>Are there potential green brands in our portfolio?<br><br>Do we have the resources and capabilities needed for this initiative? | **How will this initiative affect the positioning of and resources for our existing brands?**<br><br>Should our greened brand be a stand-alone or a strategic brand that puts a green halo on the business as a whole? | **Which consumers in the category are looking for greener products?**<br><br>Does our candidate brand have "permission" to enter the green space?<br><br>Can we enhance the value of green in the category? | **Are our competitors greening their existing products?**<br><br>Can we differentiate our brand?<br><br>How can we exploit our competitors' green weaknesses?<br><br>How can we capture a "share of voice" in the category? | **Do we have environmental skeletons in our current portfolio or business model?**<br><br>**Will our green claims be credible—or are we vulnerable to accusations of "greenwashing"?** |

## Acquire

(b)

| FIRST STEPS | YOUR PORTFOLIO | YOUR CUSTOMERS | YOUR COMPETITORS | RED FLAGS |
|---|---|---|---|---|
| **What's our strategic goal?**<br>• To capture customers?<br>• Bring in new green capabilities?<br>• Broaden access to mainstream customers?<br>• Gain green credibility?<br><br>Which companies would make attractive green acquisitions?<br><br>Do we have the resources and capabilities needed for this initiative? | **How will this initiative affect the positioning of and resources for our existing brands?**<br><br>Will the initiative provide new abilities that can be applied to other brands?<br><br>Should our acquired brand be a stand-alone or a strategic brand that puts a green halo on the business as a whole? | **Can we sell the green brand to our current customers?**<br><br>Will acquired customers view us as a credible steward of the brand? | **Is this the prototypical brand in the green niche?**<br><br>How can we exploit our competitors' green weaknesses?<br><br>How can we prevent competitors from poaching our newly acquired customers?<br><br>Can we add green attributes to the new brand or emphasize existing attributes to increase competitiveness? | **Do we have environmental skeletons in our current portfolio or business model?**<br><br>**Will our green claims be credible—or are we vulnerable to accusations of "greenwashing"?**<br><br>**Does the proposed acquisition have an iconic founder, a countercultural workforce, or some other aspect that might create culture clash?**<br><br>**Can we preserve the integrity—"the magic"—of the acquired brand?** |



## Architect

(c)

| FIRST STEPS | YOUR PORTFOLIO | YOUR CUSTOMERS | YOUR COMPETITORS | RED FLAGS |
|---|---|---|---|---|
| **What's our strategic goal?**<br>• To create new green solutions?<br>• Develop unique competencies?<br>• Respond to new market needs?<br>• Gain green credibility?<br><br>Will an independent business unit be required?<br><br>Do we have the resources and capabilities needed for this initiative? | **How will this initiative affect the positioning of and resources for our existing brands?**<br><br>Will the initiative provide new abilities that can be applied to other brands?<br><br>What will be the relationship between the parent and the new line? | **What innovations are consumers looking for in a greener alternative?**<br><br>Does our parent brand have "permission" to enter the green space?<br><br>Will this initiative require us to develop a new brand?<br><br>Will we need to educate and develop the market and bring new customers into the category? | **Are we creating a new green category?**<br><br>Can we differentiate our brand?<br><br>How can we exploit our competitors' green weaknesses?<br><br>Does the category already have entrenched competitors? | **Do we have environmental skeletons in our current portfolio or business model?**<br><br>**Will our green claims be credible—or are we vulnerable to accusations of "greenwashing"?** |

### 4.3 The genuineness of the green product claim

There is a dramatic increase in green building construction whereby there are more than 500 million square feet of green buildings under design, development, and implementation worldwide. However, this increase in green buildings is not keeping up with the market demand (Patterson, 2012; Bob Moore Construction, 2010). The construction field is facing a great challenge to meet the increasing demand of green buildings. Such demand should be enhanced by contracting companies by adopting practices that improve the energy efficiency, durability, and indoor air quality of buildings. Moreover, the increasing public awareness of the climate change impacts could shape the continued expansion of the green buildings demand. On the other hand, the green technology growth affects the green market and opens new venues.

Although 30% of the consumer see themselves as environmental friendly, research conducted by a British marketing strategist argued that only 3% of this percentage has actually translate this concern into purchase. Bob Willard said that "Features and benefits that are unrelated to a particular customer's needs are unlikely to grab that customer's interest." There is a strong argument that customer wouldn't buy "green" product unless it delivers on quality, been convenience enough, and been in a fair price (Papmehl, 2006). Therefore, having environmental friendly product is not enough implying firms need to reach the consumer expectations and exceed them.

From marketing perspective, builders need to prove to the costumers that their buildings are legitimately green (Patterson, 2012), which drive the development of several voluntary and mandatory green certificates worldwide. Voluntary environmental certification systems are Green Star (Australia), LEED (U.S.), ENERGY STAR (U.S.), Green Globes (U.S.) and BREEAM (U.K.). There are also mandatory certifications like Energy Performance Certificates and Display Energy Certificates which had been drown from European Union Energy Performance of Buildings Directive. (Kotchen, 2006; Patterson, 2012).

Although green labelling could be part of green polices in several countries to increase supply of environmental public goods (Kotchen, 2006), educating consumers about the alternative eco-friendly products results in increasing market size of the environmental labelled products as well as encouraging producers to shift towards more environmental labelled products voluntarily. Generally, integration of polices and the voluntarily third parties eco-label programmes has increased the environmental commercial buildings. Policies normally order mandatory minimum standards, offer fiscal incentives, and use 'positive discrimination' procurement, while voluntarily eco- labels add a competitive advantage as well as helping buildings to achieve a cost effectiveness eco transformation (Fuerst and McAllister, 2009).

Although there are several green certificate for buildings available worldwide, still green high rise buildings market internationally are dominated by LEED and ENERGY STAR labels (Nelson, 2007).

This section provides a review of the Leadership in Energy and Environmental Design (LEED) and green star certification systems requirements and benefits as well as a comprehensive comparison for these two certification systems.

### *4.3.1 Leadership in Energy and Environmental Design (LEED)*

As response to the growing demand for sustainable buildings, U.S. Green Building Council (USGBC) realized that the sustainable building industry needs a system to define and measure "green buildings". Therefore, they launched the first edition of the Leadership in Energy and Environmental Design (LEED) program in 1998 referred as LEED version 1.0. After several mortifications, LEED v2.0 was released on March 2000 with LEED v2.1 in 2002 and LEED v2.2 in 2005. Finally in 2009 the most recent edition was released named LEED v3 (LEED v3.0, 2009).

LEED is a third party certificate that intends to provide a concise framework for identifying and implementing practical and measurable green buildings design, construction, operation and maintenance solutions to ensure that the buildings are environmentally compatible (Bob Moore Construction, 2010). LEED rating systems are totally voluntary and market driven systems where the commercially available and proven technology shape the environmental evaluation from a whole building perspective over a building's life cycle, providing a definitive standard for what constitutes a green building in design, construction and operation.

Generally, LEED was defined by (USGBC) as:

> *A set of performance standards for certifying the design and construction of commercial or institutional buildings and high-rise residential buildings of all sizes, both public and private. The intent is to promote healthful, durable, affordable, and environmentally sound practices in building design and construction" (LEED v3.0, 2009).*

LEED rating system has been designed for both existing and new commercial, institutional and residential buildings. The integration of the environmental principles, practise, and energy provides an overview of the LEED systems (LEED v3.0, 2009). Since its inception, there was a huge growth for U.S. Green Building Council coverage in which it encompass more than 7,000 projects in the United States and 30 different countries, covering over 140 km² of development area (USGBC, 2011). The main reason behind such success over the other green certificates is that it is an open and transparent process where the technical criteria are publicly viewed and approved by around 20,000 organizations that currently constitute the USGBC. Moreover, LEED stand on an effective measuring system as well as wide environment elements addressed by LEED system, which make it more likely to provide a global framework for green buildings international standard (LEED v3.0, 2009).

There are minimum program requirements (MPR) for any building to apply for LEED v3.0 for new construction and major renovations. These requirements, reported by LEED v3.0 are outlined below:

1. Must comply with environmental laws.
2. Must be a complete, permanent building or space.
3. Must use a reasonable site boundary.
4. Must comply with minimum floor area requirements. The LEED project must include a minimum of 93 $m^2$ of gross floor area.
5. Must comply with minimum occupancy rates full time equivalent occupancy. The LEED project must serve one or more Full Time Equivalent (FTE) occupant(s).
6. Must commit to sharing whole-building energy and water usage.
7. Must comply with a minimum building area: the gross floor area of the LEED project building must be no less than 2% of the gross land area within the LEED project boundary.

After becoming eligible to apply for LEED by complying with the MPR, buildings need to achieve a minimum score to be able to obtain one of the rating certificates. Generally rating system allocates points based on the potential environmental impacts and human benefits with respect to a set of impact categories. The impacts are defined as the environmental or human effect of the design, construction, operation and maintenance of the building. More specifically, credits that most directly address the most important impacts are given the greatest weight. Generally, LEED v3.0 for new construction and major renovations certifications are awarded according to the following scale:

1. Certified 40–49 points
2. Silver 50–59 points
3. Gold 60–79 points
4. Platinum 80 points and above

LEED v3.0 for new construction and major renovations address seven main areas as reported by LEED v3.0 (2009):

1. Sustainable Sites (SS): refers to the site location and construction effects on the environment and it has a 26 possible points.
2. Water Efficiency (WE): effected by the water usage efficiency and reduction as well as waste water innovations technology usage and it has almost 10 possible points.
3. Energy and Atmosphere (EA): has almost 35 possible points. This element could be the most weighted point and it has been the most important point described in this research. Below are the EA elements along with their weights:

- Prerequisite 1: Fundamental Commissioning of Building Energy Systems (Required).
- Prerequisite 2: Minimum Energy Performance (Required).
- Prerequisite 3: Fundamental Refrigerant Management (Required).

- Credit 1: Optimize Energy Performance (from 1 to 19 points).
- Credit 2: On-site Renewable Energy (from 1 to 7 points).
- Credit 3: Enhanced Commissioning (2 points).
- Credit 4: Enhanced Refrigerant Management (2 points).
- Credit 5: Measurement and Verification (3 points).
- Credit 6: Green Power (2 points).

4. Materials and Resources (MR): about the waste management and recycling as well as on site reuse, it has 14 possible points.
5. Indoor Environmental Quality (IEQ): refers to the indoor air quality, air management, thermal comfort, and optimum day lighting, it has 15 possible points.
6. Innovation in Design (ID): has 6 possible points.
7. Regional Priority (RP): has 4 possible points.

### *4.3.2 ENERGY STAR*

Energy star initially started in 1992 and was introduced by Environmental Protection Agency (EPA) as a voluntary labelling program designed to identify and promote energy-efficient products. In 1996, EPA partnered with the US Department of Energy (DOE) mainly to promote Energy Star label whereby each agency taking responsibility for particular product categories. This becomes a dynamic government/industry partnership which made it easy for businesses and consumers to save money and protect the environment (Energy Star, 2012).



Thereafter, Energy Star has expanded dramatically in US to cover new homes, most of the buildings sector, residential heating and cooling equipments, major appliances, office equipments, lighting, home electronics, and more (Energy Star, 2012). EPA continued to expand internationally by gaining partners all over the world. It maintained collaboration under the Asia Pacific Partnership as well as renewed its Energy Star agreement with the European Union on specifications for Energy Star office equipment. EPA also agreed to cooperate with the China Standard Certification Centre (CSC) in standardizing information on their respective energy efficiency labels for consumer electronics and office equipments (Energy Star annual report, 2006).

Energy Star label could be obtained by meeting minimum energy efficiency requirements. EPA has established guide line principles to obtain the label reported in the Energy Star web page as outlined below:

- Product categories must contribute significant energy savings nationwide.
- Qualified products must deliver the features and performance demanded by consumers, in addition to increased energy efficiency.

- If the qualified product costs more than a conventional or/and less-efficient counterpart, supplier should approve that the purchasers will recover their investment in increased energy efficiency through utility bill savings within a reasonable period of time.
- Energy efficiency can be achieved through broadly available non-proprietary technologies offered by more than one manufacturer.
- Product energy consumption and performance can be measured and verified with testing.
- Labelling would effectively differentiate products and be visible for purchasers.

The Energy Star program serves as a credible objective source of information for decision makers interested in improving the energy efficiency of their products, practices, services, homes and buildings. EPA is qualifying several applications: consumer products, single family houses, industrial, and commercial buildings. As of 2006, Energy Star labelled more than 40,000 products in a wide range of products, around 12% of the new houses in US and around 3200 commercial buildings (Energy Star annual report, 2006).

EPA has developed a minimum energy saving criteria for each product to be qualified for Energy Star label. For instance, air source heat pumps and room air condition should save 10% energy compared to the standard product, while central air conditioners should have a 15% energy saving above the standard HVAC. On the other hand, commercial buildings have certain guidance to be qualified for Energy Star label. This guidance serves as an energy management guidance to increase energy usage efficiency as well as reduce overall energy consumption. This guidance consists of seven steps as demonstrated in Figure 4.3.



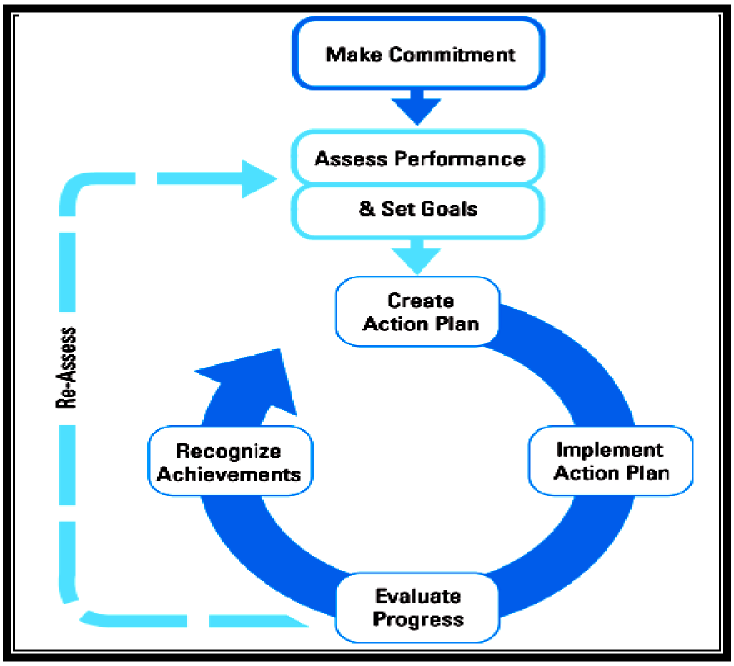


**Figure 4.3: ENERGY STAR Guidelines For Energy Management from (Energy Star, 2012).**

#### *4.3.3 Green labelling recommendations (LEED Vs Energy Star certification systems)*

Energy Star is used more for existing buildings because it is more about assessment of buildings' energy performance. Furthermore, Energy Star offices tend to be large, tall, and located in major metropolitan markets. From occupancy perspective, Energy Star has recorded 90% of its buildings as multi-tenanted with occupancy rate of 3% over the non labelled buildings. While the structure of LEED certification system by different categories make it more comparable to the other eco-certification system worldwide which enhance LEED capability to provide the framework for prospective harmonized global standards. Moreover, LEED-labelled buildings tend to be more diverse than Energy Star label. Regarding the occupancy, 60% of LEED buildings are multi-tenanted with occupancy rate of 8% over the non labelled buildings (Fuerst and McAllister, 2009).

Therefore, LEED is recommended over energy star for its economical adding benefits over the energy star, as well as the cheap implementation. Above all, because of the LEED ability to work as international standard which make it more suitable for non US projects where it could be associated with local green polices.

### 4.4 Economical feasibility

As essential part of the green transformation, cost plays a major role in the green seeking transformation as well as obtaining green label among developers. Both mandatory and voluntary environmental labelling are gaining a dramatic attention in the commercial real estate sector due to the marketing values added by those certification systems. Moreover, eco- labels become an important signal of a building's environmental performance whether it is provided by independent, government-sponsored, or third-party organizations (Fuerst and McAllister, 2009).

#### *4.4.1 Green labelling cost*

Since the legitimacy of green claim is tied to the eco-labelling, studying the green cost along with the cost of the green label is mandatory for cost effective green transformation. LEED certification system has some prerequisites, therefore, the cost of these prerequisites are essential part of any cost study. In summary, 80% of the respondents for the cost survey conducted by WHITE PAPER (2008) said that LEED prerequisites elements have a low cost or no cost. Furthermore, there are strong arguments published by (Langdon, 2007; Morris and Langdon, 2007) saying that LEED and non LEED projects have almost the same project budget range. More specifically, LEED certified buildings cost higher than the conventional buildings in the rage of 1% to 2 % (equivalent to a LEED Silver rating) (Greg, 2003; Hershfield, 2005; Matthiessen and Morris, 2006; Morris and Langdon 2007; Berry, 2007). In 2002, U.S. General Services Administration published a cost study to obtain LEED certificate for three certificate levels for both low and high cost buildings as shown in Table 4.2

**Table 4.2: LEED implementation cost for new buildings (LEED® Cost Study Final Report, Inc, 2004).**

| | New Building (262,000 GSF, base construction cost = $220/GSF | | | | | |
|---|---|---|---|---|---|---|
| | Certified | | Silver | | Gold | |
| | 1 A Low cost | 2A high cost | 1 A Low cost | 2A high cost | 1 A Low cost | 2A high cost |
| LEED construction cost impacts | | | | | | |
| **$/GSF** | $ -0.76 | $ 2.18 | $ -0.07 | $ 9.57 | $ 2.97 | $ 17.79 |
| **% Change** | -0.40% | 1.00% | -0.03% | 4.40% | 1.40% | 8.10% |

A cost study of obtaining LEED label for existing buildings (LEED-EB) conducted by WHITE PAPER (2008) showed that the overall cost of LEED-EB implementation and certification ranges from $0.02 to $5.01 per square foot of floor space, with an average of $1.58 per square foot. This numbers do not necessarily go with the level of certification as illustrated in Figure 4.4. This is because the certification level is dependent on the pre-LEED-EB implementation performance rather than the implementation.

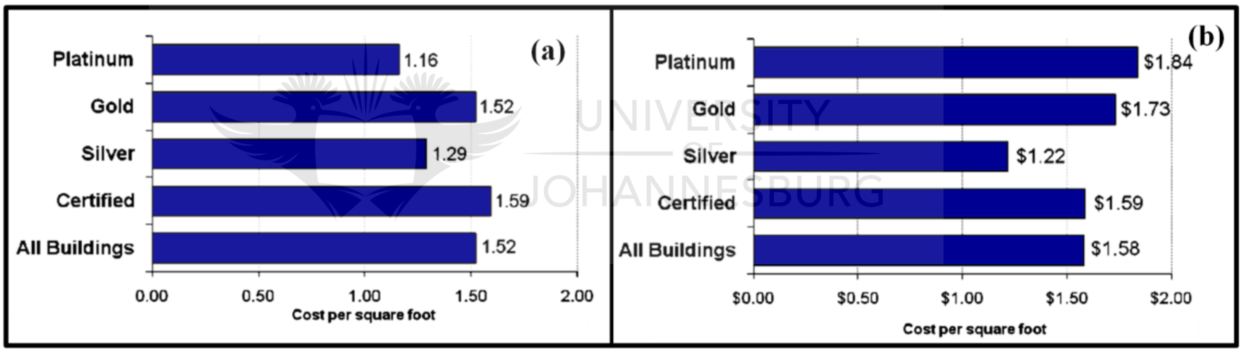


**Figure 4.4.Total Green certification cost per square foot by level (a) Median and (b) Mean (WHITE PAPER, 2008).**

### *4.4.2 Green labelling return*

There are three financial concepts that govern the profitability of the buildings from real estate point of view and these are capitalization rate, occupancy rate and capital value. Capitalization rate is defined as "a rate of return on a real estate investment property based on the expected income that the property will generate" (Investopedia, 2012b). Capitalization rate is used to estimate the potential return on investment by dividing the potential yearly income over the total value (Investopedia, 2012b). While occupancy rate is defined as the percentage of the rented units out of the total number of the units in the buildings (WordNet 3.0 and Farlex Financial Dictionary, 2012), Occupancy rate is important in the real estate investment, because it provides an indication of anticipated cash flows (Investopedia, 2012c). Capital value is defined by Cambridge Dictionary (2012) as the value of an asset or investment.

Figure 4.5 shows a comparison between Energy Star and LEED on the average price, capitalization rate and rental price, using data collected from several eco-labelled projects in US (Miller, n.d).

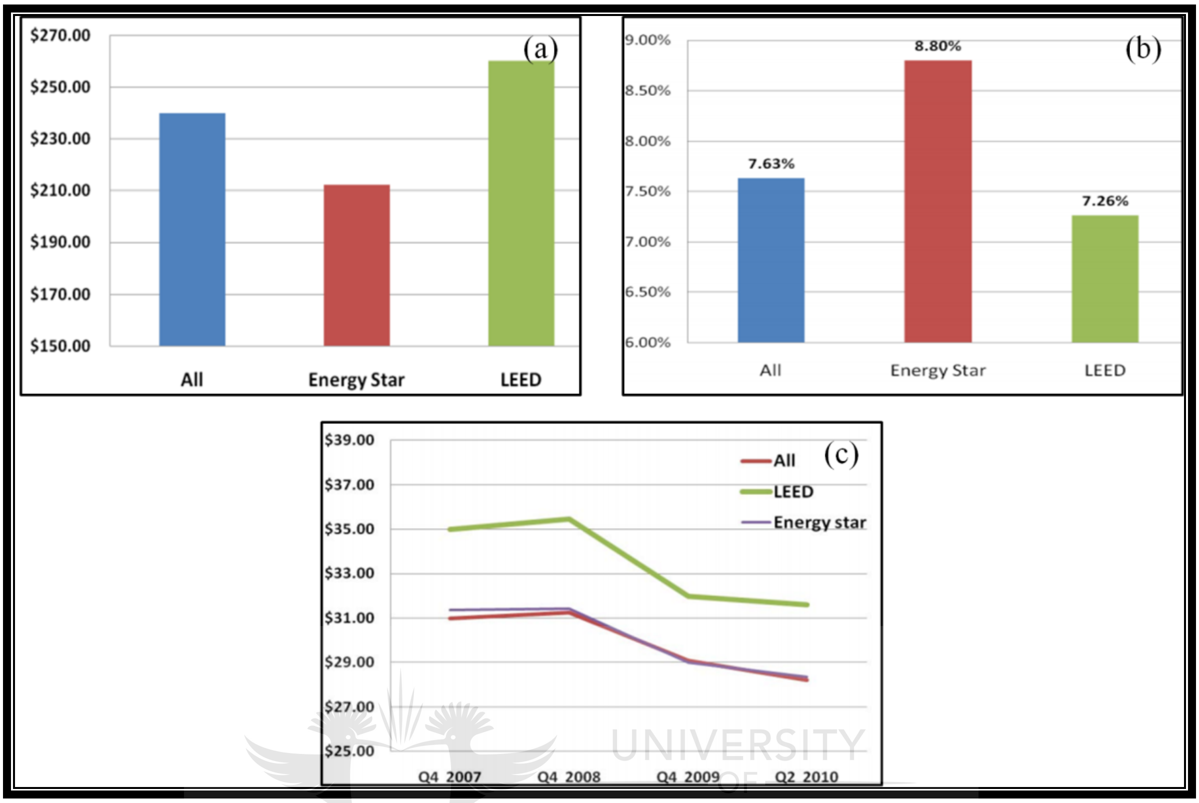


**Figure 4.5: LEED VS Energy star (a) Prices per Sq Ft (class A), (b) Capitalization Rate (class A ) and (C) Average rents price.**

Furthermore, gaining a green label results in increasing occupancy rate as well as taking building to where it become eligible for higher rent (Miller, n.d) (Figure 4.5). In the investigation of the effect of Eco-Labelling on offices occupancy rates Fuerst and McAllister (2009) found that occupancy rates are approximately 8% higher in LEED-labelled offices and 3% higher in Energy Star labelled offices. Generally, a combination of occupancy rate and the capital value concepts may result in more accurate signal of the building profitability. Lingdon (2007) has reported a study comparing the combination of these two concepts against the construction cost and the carbon emissions. He found that the combination of occupancy rate and the capital value increased with the construction cost, at the same time the carbon emission decreases as illustrated in Figure 4.6.

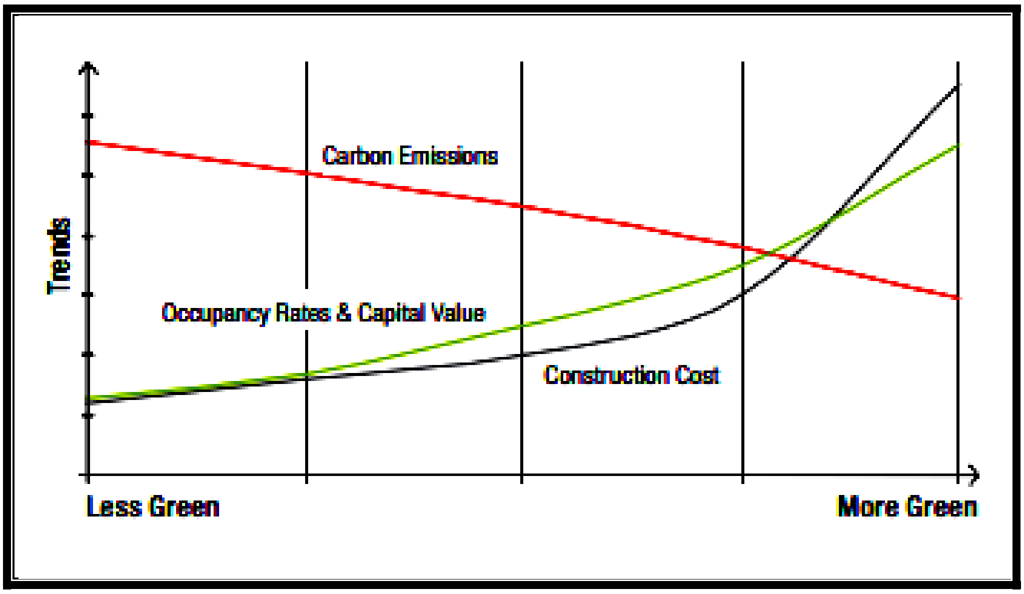


**Figure 4.6: Green buildings cost Vs benefits (Langdon, 2007).**

### *4.4.3 Facade renovation cost*

Since the facade plays an essential role in high rise buildings green transformation, any cost study has to cover the cost of reinvading the facade to become green oriented. Steven Winter Associates, Inc in their LEED® Cost Study Final Report (2004) has reported two types of facade renovation cost (Table 4.3): minimal facade renovation (window replacement, minor repairs) and full facade renovation (new cladding and facade design, new windows, new insulation).



**Table 4.3: Facade green renovation cost in high rise buildings.**

| | Facade cost for high rise buildings (306,000 GSF, base construction cost = $130/GSF | | | | | |
|---|---|---|---|---|---|---|
| | Certified | | Silver | | Gold | |
| | 1 B Min. Facade | 2B Min. Facade | 3B Min. Facade | 4B Min. Facade | 5B Min. Facade | 6B Min. Facade |
| LEED construction cost impacts | | | | | | |
| **$/GSF** | $ 1.78 | $ 2.73 | $ 3.94 | $ 5.55 | $ 10.58 | $ 10.22 |
| **% Change** | 1.40% | 2.10% | 3.10% | 4.20% | 8.20% | 7.80% |

### *4.4.4 Solar wall PVT system cost and comparison*

The cost of the proposed system seems to be very expensive since the cost of the proposed facade is around 980 €/m$^2$ (1270 \$/m$^2$) (Zondag, 2006). This cost should not be seen alone but associated with the produced free energy, considering the current and expected energy prices. Zondag (2006) reported the energy production from the integrated photovoltaic and liquid thermal collectors PVT system (roof installation) as 115 W electricity /m$^2$ and 600 W thermal/ m$^2$. Since there are no experiments to report the exact energy production of the integrated facade PVT system, the roof data will be used to determine the approximate saving from this system and the capital recovery.

First Cost FC= 980 €/m$^2$ = 9800 R/m$^2$ (PVTwins, n.d)

Energy produced = 115 W electricity /m$^2$ and 600 W thermal/ m$^2$ (PVTwins, n.d)

Energy prices = 0.122 R/KW (Eskom, 2012)

Total high rise buildings energy production (Table 2.1) = 4.1TWh (60% electricity and 40% air-condition).

Total high rise buildings energy consumption per kwhour = $\frac{4.1*114000}{360day*8hours\ a\ day}$ = 162 kwh

Total number of PVT area in m$^2$ = 162 kwh/.715 = 227m$^2$

Total cost of PVT = 227m$^2$*980€/m$^2$ = 222,442€ = 2,224,420R

Total energy cost = 4.1*114,000*0.122 = 57,000R

Capital recovery = $A\frac{(1+i)^n-1}{i(1+i)^n}$ ------------------------------------------------------------------------- (9)

***Based on this calculation, the capital recovery is not feasible because it requires more than 50 years.***

### *4.4.5 Absorption chiller cost and comparison*

Absorption chiller cost feasibility has been introduced in a comparison against the conventional electrical chiller (electric centrifugal chiller as an example) in a form of life cycle cost considering the Annual Operating Energy Cost (AOEC) and the first cost as below.



AOEC= OCF – Operating Cost Factor x EF – Efficiency Factor x EC – Energy Cost

OCF ≅ 40% of total energy consumption

OCF ≅ 0.4 x 114,000KWh= 45,600KWh/year

EF ≅ $\frac{TON}{TON/KW}$ / COP = 3.51/6.1 = 0.58 KW/TR (Lizardos, 2007)

Energy cost = 0.122 R/KWh

AOEC = 3226.656 R/TR per year

Considering the assumption that the integration of PVT system and absorption chiller has 0 AOEC

The retail price (FC) of electrical centrifugal chiller is around $24/TR based on the McGraw brand in US (McGraw-Hill Companies, 2004 has reported the price of 500 TR centrifugal chiller as 12000 $).

Electrical centrifugal chiller FC = 24 ($/TR)*1.15(TAX)*8.5(R/$)= 235 R/TR

While the absorption chiller price per TR based on Yazaki brand retail prices in South Africa (5TR chiller =267700R) (Quotation obtained from Yazaki South Africa dealer Voltas Technology)

Absorption chiller FC = 55.182 R/TR

Taking 10% as the primary interest rate then the capital recovery will be calculated by below equation:

Capital recovery = $A\frac{(1+i)^n-1}{i(1+i)^n}$

***According to the above calculations, absorption chiller seems to be not feasible as it requires more than 50 Years.***

## 4.5 Chapter summary

The most essential part of product development early stages especially the project selection process is answering the question of the market acceptance. Market acceptance starts by identifying the market opportunities as well as the market future trend. Mostly, the market opportunities in the field of green buildings are linked with the climate change concerns and the global green orientation. This concern has been translated to green policies as well as governmental incentives for green transformation, together with the media role to increase the public awareness. These global activities toward a sustainable energy have been deployed from both side of energy challenge production and consumption. Therefore, developing an energy solution for high rise buildings associated with green HVAC system seems to be promising.

Developing marketing strategy plays a major role in penetrating market as well as sustaining business. Marketing strategy should be developed based on a market research using one of the marketing analyses techniques such as 5Ps, PEST analysis and SWOT analysis. The basic principles of these techniques were introduced. Thereafter, marketing strategy should be developed based on two possible marketing strategies: Porter's Generic Competitive Strategies and Green products marketing. Firms could implement either one of them or a combination based on the market study. This study recommends net-zero energy solution as a differentiation element, and high rise buildings focus strategy as well as architecting a new green brand.

Organizations need to prove to the costumer the genuineness of the green claim and green certification system presents a great chance for this purpose. There are several green certification systems worldwide, LEED and Energy Star are the most recognizable certification systems. The LEED and Energy Star principles and benefits were introduced beside a general comparison to indentify the best for high rise buildings. This study recommends LEED over Energy Star based on some facts such as LEED-labelled buildings tend to be more diverse than Energy Star label, has different categories which make it more comparable to the other eco-certification and make it more applicable to harmonized global standards. Finally LEED has a high occupancy rate (8% compare to 3% in Energy Star) as well as higher sales and rental prices.

Cost plays a major role in the green transformation. Studying the green cost along with the cost of the green label is mandatory for cost effective green transformation, hence, the legitimate of green claim is tied to the eco-labelling. It has been recorded that constructing new LEED certified buildings cost higher than the conventional buildings in the rage of 1% to 2%, while the cost of obtaining LEED label for existing buildings (LEED-EB) is from $0.02 to $5.01 per square foot of floor space. The return of green labelling (data from US) starts with the occupancy rate where LEED labelled buildings recorded 8% higher than non labelled buildings beside recording higher rental and sales prices by 35$ and 250$ per square feet respectively. Furthermore, the cost of construction goes parallel with the capital recovery and the occupancy rate.

The green transformation in high rise buildings requires the use of facade as well. The LEED cost of facade reinvention has been introduced whereby the cost of minimum facade renovation vary from 1.4% to 7.8% and the major reinvention cost from 2.1% to 8.2% based on the certification level (certified, silver, and gold). The capital recovery of the energy gain PVT system facade was calculated against the electricity prices in South Africa and it was founded not feasible that it require more than 50 years to recover the capital.

Absorption chiller was compared economically to the centrifugal chiller (McGraw). Although, it was found not feasible where it require more than 50 years to recover the capital, but the green products are gaining marketing advantage not because of the price but because of the impact on the environment which is provided through this system.

# CHAPTER 5: CONCLUSION

The world today is going through a transformation wave toward a green future. The deep understanding of climate change effects on a particular business area enhances enterprises survival and continuous growth. Moreover, the positive response to the climate change challenge earlier than competitors could be a great chance for Mechanical-Electrical-Plumbing (MEP) contractors to gain more profit. Mainly by developing clean energy solution systems for high rise building to enhance climate change opportunities while managing its threats. A straightforward way to achieve such goal is to develop a new product (NPD) (Schmidt, 2003; Drexhage and Murphy, 2010; Winzker, 2011).

Although, the high rise buildings have shown high energy consumption compared to detached houses (30% higher), there is still a dramatic increase in the high rise buildings constructions over the last two decades. This makes the high rise buildings one of the most important energy challenges from consumption perspective. Therefore, the residential and commercial urban sprawl toward sustainability is governed by the ability to overcome the challenges facing the high rise buildings sustainability (Blundell, 2011; Wittstock, 2009).

Product development has sequence of steps which an enterprise employs to conceive, design, and commercialize a product. Design is the major element in product development in which it contributes around 70% of product success whereas it only requires 10% of the efforts and cost. This study implements the first three steps of the product development (Planning, Concept development, and System level design) to assess high rise buildings energy to develop a feasible energy solution towards near net-zero energy building. On the other hand, system survival is shaped by the logistic engineering requirements as such, it is mandatory to inherit the logistics element in the product development early stages (Ulrich and Eppinger, 2008; Blanchard, 2004; Schmidt, 2003; Barton et al., 2001).

## 5.1 Research findings and recommendations

System planning is the first phase of product development. This phase consists of motivation identification and mission statement. In this study the system mission was stated as:

*To provide a total energy solution for high rise building.*

The product concept development consists of six elements. This research studied four necessary elements for product concept: identifying customer needs, established targeted specification, concept generation, and concept selection process. The customer needs were identified for high rise buildings energy requirements as well as the special features of the high rise buildings in terms of cooling energy, facade structural design, and facades architectural requirements. Concept generation normally begins with identifying the customer requirements then search for the applicable solution in literature and in the market. These candidates inters then into a selection process.

High rise buildings sustainability actions were presented in two ways increasing the amount of renewable energy by implementing an on-site energy production and improving buildings efficiency by using low energy consumption products in both new and existing buildings.

### *5.1.1 On-site energy production*

Mostly, the on-site energy production in the buildings sector is solar energy application whether electricity production (PV system), heat collection (Concentrated solar applications and solar heater for domestic use), or a combination of both in a form of integrated photovoltaic and thermal system PVT.

Photovoltaic (PV) modules generate electricity, but the electrical output is only one component of the total energy produced by a photovoltaic array. A typical photovoltaic (PV) module has ideal conversion efficiency in range of 15% and the remaining energy is dissipated as heat. This heat can be as much as 50°C over the ambient temperature, resulting in two concerns: first the possible structural damage from heat if panels are not vented or if heat is not recovered. Second issue is that, efficiency decreases as temperature increases. Crystalline cells are affected by temperature and their performance drops as cell temperature rises. It has been shown that for each 1°C increase in temperature, the power production drops by ~0.5%. On the other hand the solar heat collectors produce thermal energy in a range of 50 to 300 $^{o}$C, but these systems require big space to be implemented (Hollick, 2011).

The combined electricity generation and heat collection *via* the integrated PV and thermal collector system is denoted as solar Photovoltaic and thermal (PVT) system. PVT system produces both electricity and heat at a higher efficiency from one integrated system on the same surface area exposed to the sun. For instance, PVT system produces approximately 43% more primary energy than a conventional solar thermal collector per unit surface area. And even around 96% more than a conventional PV system (PVTwins, n.d).

The roof is sufficient to produce energy from solar equal or more than the energy yearly loaded in the detached houses. Whereas, in the high rise buildings; where the roof is relatively small, it is mandatory to use the facade in order to achieve near net-zero energy. Therefore, converting facade to a multi-functional energy gain component is a key element for high rise buildings towards near net-zero energy. This approach was found to be feasible and five types of energy gain facade were introduced in chapter two (Tilmann and Kuhn, 2009; Maurer and Kuhn, 2011).

This study recommends the use of the integrated PVT system in high rise buildings skin by using the facade as an energy gain component. Facade design in the high rise buildings should consider the structural requirements (wind loads) and architectural requirements such as the isolation, which may enhance the possible benefits in the field of interior day light as well as the passive cooling, heating and ventilation.

### *5.1.2 Low energy consumption HVAC systems*

Air condition consumes almost 40% of the total high rise buildings energy requirements. As such, HVAC system is essential part of any energy solution for high rise buildings. However, there are several types of green HVAC systems that applicable for high rise buildings. Two of them were introduced, ice slurry and absorption chiller. Ice slurry helps building designer to use more efficient design parameters such as a cooler air distribution temperature to almost 12$^{o}$C which in turn reduces the operating cost as well as the refrigeration machinery and equipments cost. Besides There is a potential comfortable space environment. Absorption chiller could be considered as the most green HVAC system in which it has no moving part, no electricity required, thermal driven system (use heat to produce cold) and could be operated by solar thermal energy **(**Reijenga, 2009; USTUTT, 2009; Hamasaki, 2007; Tassou, and Bellas, 2005; New Buildings Institute, 1998)

> *Therefore, this study suggests the integration of solar PVT in the high rise building's facade to drive a thermal driven absorption chiller. This presents a feasible solution for high rise buildings energy challenges as well as its HVAC system.*



## 5.2 Market acceptance

Answering the question of market acceptance is one of the most essential parts of the product development early stages (especially the project selection process). Marketing acceptance is governed by the market opportunities as well as the effectiveness of marketing strategy. Market opportunities were introduced in a link to the global response to the climate change. An effective marketing strategy is shaped by the accurateness of implementing the marketing analysis techniques. Three marketing analysis techniques were introduced (5P`s, SWOT, and PERT), these techniques serve as tools to analyze the market, firm, competitions, and the situation or the environment. Thereafter, two effective marketing strategy modules were introduced (Porter generic strategy and green product marketing strategy).

The study suggested a combination of the above mentioned strategies to be implemented. In terms of Porter module, a firm should differentiate itself by introducing new solution which is the near net-zero energy high rise buildings, at the same time the firm needs to focus on the targeted customers only. From green marketing perspective, organization should work on architecting in house new green brand.

On the other hand, organizations need to prove to the costumer the legitimate of the green claim by obtaining a green label. This study was reviewing principles and benefits for two of the most effective green certification systems LEED and Energy Star. The study recommends LEED over Energy Star because the former tend to be more diverse than Energy Star label. The LEED has different categories which make it more comparable to the other eco-certification and more applicable to harmonized global standards. Finally LEED has a high occupancy rate (8% compare to 3% in Energy Star) as well as higher sales and rental prices (Fuerst, and McAllister, 2009; Miller, n.d; Langdon, 2007).

Cost also plays a major role in the green transformation. Since the legitimate of green claim is tied to the eco-labelling, studying the green cost along with the cost of the green label is mandatory for cost effective green transformation. It was found that: Implementing LEED in new buildings cost higher than conventional system by around 2%, and for existing buildings it cost in a range of $0.02 to $5.01 per square feet, while the facade renovation cost from $1.4 to $8.2 based on the desired certification level and the level of building`s cost (max and min). On the other hand, the green labelling return on investment has been introduced in a form of occupancy rate where LEED labelled buildings recorded 8% higher than non labelled buildings. Rental and sale prices have been recorded higher than conventional system by $35 and $250 per square feet respectively. (WHITE PAPER, 2008; Langdon, 2007; Morris and Langdon, 2007; Steven Winter Associates, Inc, 2004)

On the other hand, the cost of the integrated PVT system in the building`s facade and the absorption chiller has been studied and compared to the conventional system; electricity prices from Eskom (South Africa) and a centrifugal chiller from McGraw respectively. It has been found that the integrated PVT and absorption chiller system is not feasible where it require more than 50 years to recover the capital. However, green products are gaining marketing advantage not because of the price, but because of their positive impact on the environment (PVTwins, n.d; Zondag, 2006; Lizardos, 2007; Yazaki, n.d; McGraw-Hill Companies, 2004)

### 5.3 Future Research

- Technical research is required for the PVT panels to confirm the energy production data.
- Technical research is required for the integration of the PVT system in the building's facade to determine accurate data for the energy production.
- Technical research is required in the structural implementation of the PVT system in the building`s facade
- Technical research is required on the integration of the absorption chiller with the PVT system and whether the PVT system is sufficient to drive the chiller.
- Cost study to identify the real cost of the PVT per m2 as well as the real cost of the absorption chiller per TR.

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