Net-Zero Apartment Buildings;

Design Strategies and Technologies

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To My Beloved Family

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Abstract

Global warming associated with energy crisis has recently brought cautiousness into the field of architecture. The main reason for the increasing global temperature is greenhouse emissions created by the combustion of fossil fuels; consequently, there has been a movement toward clean energies. This global movement is visible in the field of architecture through various recently emerging concepts such as green architecture, sustainability and energy efficiency. Net-zero buildings, a product of this movement, are buildings that produce as much energy as they consume; they integrate energy efficiency and environmental concerns. The Housing sector, as one of the main consumers of energy, has been the target area for architects to take forward this idea.

This research focuses on net-zero apartment buildings to create a ground for developing net-zero residences in the future. An overview of the strategies implemented by architects in net-zero dwellings both in terms of design techniques and utilities is included. In addition, a comprehensive case study of the first highrise net-zero apartment building, the Senior Housing Project in the Olympic Village, Vancouver, Canada is carried out. The case study includes key observations made through a visit to the project, as well as an interview conducted with its architect.

The author concludes that developing net-zero apartment buildings as a prototype of housing is not feasible unless an energy-cautious culture is created among their users. In addition this research leads to particular design suggestions for future endeavours. It was found that the scale of net-zero apartment buildings should increase; as a consequence, it enables the architects to introduce innovative and effective techniques and technologies. Finally, highrise buildings with reasonable footprints that allow current technologies of producing energy to be utilized are the suggested typologies for developing net-zero apartment buildings.

Le réchauffement climatique lié à la crise énergétique a conduit à une prise de conscience dans le domaine de l'architecture. L'augmentation de la température mondiale est due, surtout, aux émissions à effet de serre créées par la combustion de combustibles fossiles. Par conséquent, un mouvement pour des sources d'énergie propre est surgi. Ce mouvement mondial est visible dans le domaine de l'architecture en raison des divers concepts émergeants, telles que l'architecture verte, la durabilité et l'efficacité énergétique. Les bâtiments net-zéro résultant de ce mouvement sont des structures qui produisent la même quantité d'énergie qu'ils consomment ; ils intègrent de l'efficacité énergétique et des préoccupations environnementales. Le secteur du logement comme l'un des principaux consommateurs d'énergie a été une zone cible pour les architectes à la pratique d'édifices net-zéro.

Cette recherche se concentre sur des immeubles net-zéro pour créer un terrain pour le développement des résidences net-zéro dans un futur. Elle offre un aperçu des stratégies mises en place par les architectes en résidences net-zéro à la fois en termes de techniques de conception et des services publics. En outre, une étude de cas complète sur le premier immeuble d'appartements net-zéro au Canada est incluse, en addition d'une entrevue avec son architecte.

L'auteur conclut que le développement de l'édifice net-zéro comme un prototype de logement n'est pas possible sans la création d'une culture de sauvegarde de l'énergie parmi les habitants. En outre, cette recherche dirige à des suggestions de conception particulière pour des entreprises futures. Il a été constaté que l'ampleur des immeubles d'habitation net-zéro devrait augmenter; elle permettra aux architectes d'introduire des techniques et des technologies innovatrices et efficaces. Finalement, les tours avec des empreintes raisonnables supportent l'utilisation des actuelles technologies de production d'énergie. Cette typologie est, par conséquent, proposée pour le développement d'immeubles d'habitation net zéro.

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Chapter 1

Introduction

Insight to the Net-Zero Concept

1.1. Introduction

In recent years, the growing tendency towards energy efficient buildings has led to different emerging companies and organizations working on developing net-zero buildings, in terms of both theory and practice. This movement which was pioneered by developed countries has been mainly experienced in housing. A huge amount of energy is used annually by residential buildings in developed countries; almost 21% of all the energy consumption in the U.S in 2009 was consumed by dwellings (Evans, 2007). Hence associated with commercial buildings, the housing section has been targeted as the main field of activity. In fact, introducing this particular type of building -which includes various types individually- is part of the global sustainable movement. Net-zero buildings are thus a product of the integration of advanced technology and architectural design knowledge. The goal of net-zero buildings is to have as less impact as possible on the environment as well as to reduce the maintenance fees. Although the embodied energy and the initial costs for a net-zero building is obviously more than the same typical building, the advantages of a well-thought of net-zero design make it worthy of observation. These benefits will be discussed comprehensively in the coming chapters.

1.2. Related Definitions

Due to the fact that this study is going to deal with newly developed concepts in architectural and engineering fields, it entails the introduction of some terms which will be used. Some of these terms vary from one country to another and some are only used by either particular organizations or in some countries.

1.2.1. Net-Zero Building

Despite having commonalities in the names “Net-Zero Building” or “Zero Energy Building (ZEB)”, there are some different definitions of what Net-Zero means in practice, with a particular difference being in the usage in North America and Europe. In the United States, ZEB generally refers to the type of building where the amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building. Outside the United States and Canada, a ZEB is generally defined as one with zero net energy emissions, also known as a zero carbon building or zero emissions building (Fig.1.1).

In some cases the cost of purchasing energy is balanced by income from the sale of electricity to the power grid generated on-site. Such a status depends on how a utility credits net electricity generation, and the utility rate structure the building uses.

“Off-the-Grid” buildings are also the other group of ZEBs which are not connected to the power grid. They require distributed renewable energy generation and energy storage capability (for times when the renewable resources are not available temporarily, for instance, when the sun is not shining). These special types of buildings are capable of working off-the-grid and are usually constructed on sites with no infrastructure of a power grid. The reason is that if there is a grid it is less risky to be connected in case of emergency.[1]

Considering all the above mentioned definitions, the author decides to use the following definition in this study as the common one in architecture-related assemblies. “Net-Zero Building” or “Zero Energy Building (ZEB)” is a term applied to a building whose annual energy consumption is equal to its on-site energy production with zero carbon emissions. In the other words a Net-Zero energy building is capable of producing, at minimum, an annual output of renewable energy that is equal to the total amount of its annual consumed/purchased energy from energy utilities.[2]

[1] http://www.nrel.gov/docs/fy06osti/39833.pdf
[2] By The Net-Zero Energy Home (NZEH) - http://www.netzeroenergyhome.ca/

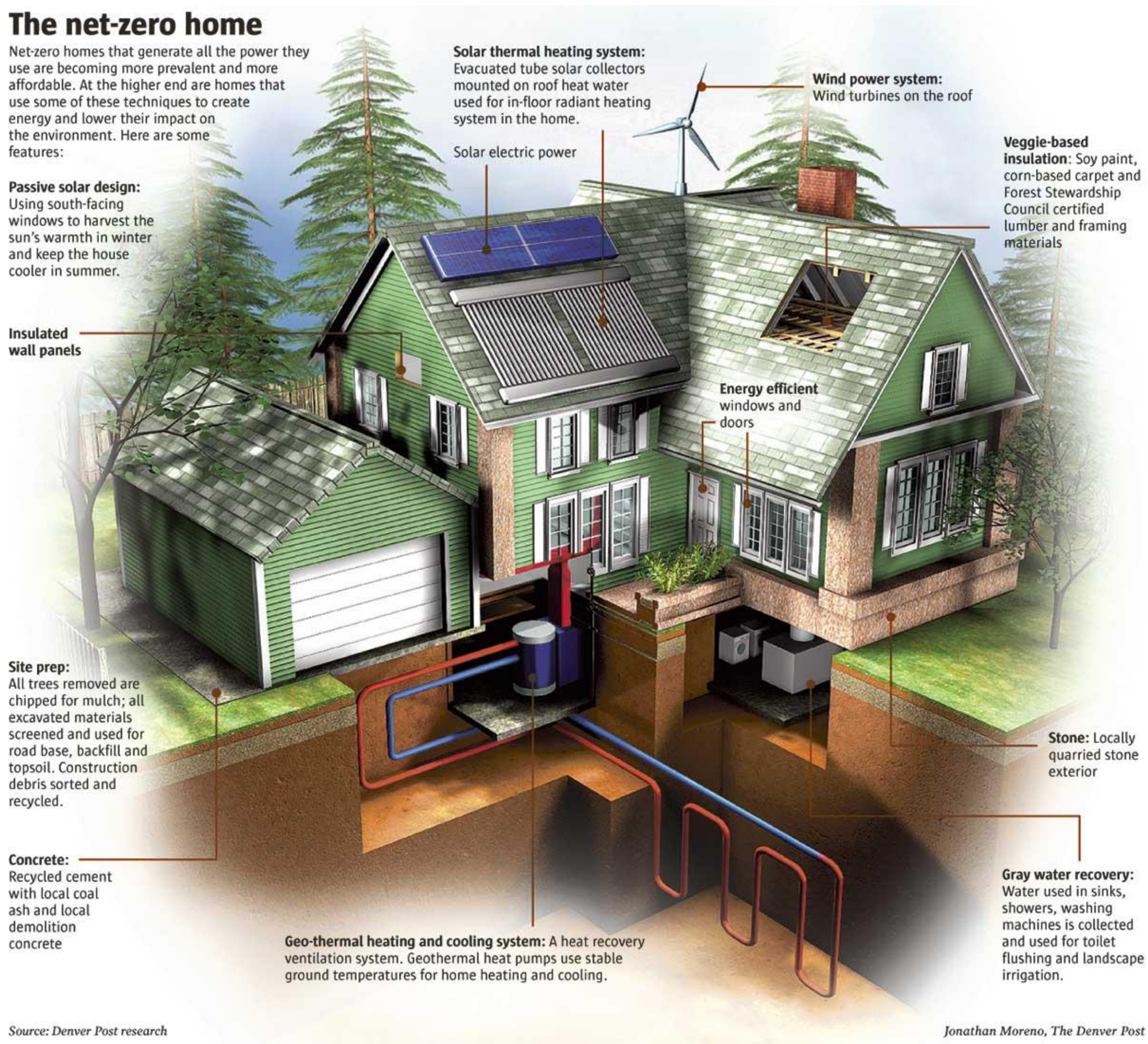


Figure 1-1. A simple example of what features a net-zero entails has and what it looks like
Source: Denver Research - www.denverpost.com/portlet/article

1.2.2. LEED

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System, developed by the U.S. Green Building Council (USGBC), provides a set of standards for environmentally sustainable construction. The hallmark of LEED is that it is an open and transparent process where the technical criteria proposed by the LEED committees are publicly reviewed for approval by more than 10,000 member organizations that currently constitute the USGBC[3].

Individuals recognized for their knowledge of the LEED rating system are permitted to use the LEED Accredited Professional (AP) acronym after their name, indicating they have passed the accreditation exam given by the Green Building Certification Institute (a third-party organization that handles accreditation for the USGBC). The LEED Canada for Homes Rating System works by requiring a minimum level of performance through prerequisites, and rewarding improved performance in each of the above categories. The level of performance is indicated by four performance tiers – Certified, Silver, Gold and Platinum – according to the number of points earned (Fig.1.2).

LEED® Canada for Homes Certification Levels	Number of LEED® Canada for Homes Points Required
Certified	45—59
Silver	60—74
Gold	75—89
Platinum	90—136
Total available points	136

Figure 1-2. LEED Canada for Homes Certification Levels
Source: www.enerquality.ca

Usually net-zero residential buildings have to qualify for the Platinum level to potentially be a zero energy building; however, there is no certain rule which assures that if a house is certified by any level of LEED it would be a net-zero building. The reason is that LEED for Homes includes several factors for assessing the quality of a home. These factors include different aspects such as architectural design features, environmental impact, source usage and even education. The LEED Canada for Homes Rating System measures the overall performance of a home in eight categories which are shown in the Figure 1.3.

[3] Source:"Canada Green Building Council", http://www.cagbc.org/leed/systems/homes

1	**Innovation & Design Process (ID).** Special design methods, unique regional credits, measures not currently addressed in the Rating System, and exemplary performance levels.
2	**Location & Linkages (LL).** The placement of homes in socially and environmentally responsible ways in relation to the larger community.
3	**Sustainable Sites (SS).** The use of the entire property so as to minimize the project's impact on the site.
4	**Water Efficiency (WE).** Water-efficient practices, both indoor and outdoor.
5	**Energy & Atmosphere (EA).** Energy efficiency, particularity in the building envelope and heating and cooling design.
6	**Materials & Resources (MR).** Efficient utilization of materials, selection of environmentally preferable materials, and minimization of waste during construction.
7	**Indoor Environmental Quality (EQ).** Improvement of indoor air quality by reducing the creation of and exposure to pollutants.
8	**Awareness & Education (AE).** The education of the homeowner, tenant, and/or building manager about the operation and maintenance of the green features of a LEED home.

Figure 1-3. Eight performance categories which are measured for LEED Canada certificate
Source: www.enerquality.ca

1.3. Rationale for the Study

The ever-growing demand for energy is one of the main causes of shifting towards clean renewable energy sources. Figure 1.5 shows the growing price of energy in history which has made governments perceive that as part of their politics. On the other hand, the world energy consumption has shown a significant increasing trend in the recent years (Figure 1.4). The United States is currently the largest energy consumer in the world with almost 25% of the world energy (Evans, 2007). The significant amount of energy which is used by buildings in the United States has made them one of the pioneers in energy efficiency movement (Fig.1.6).

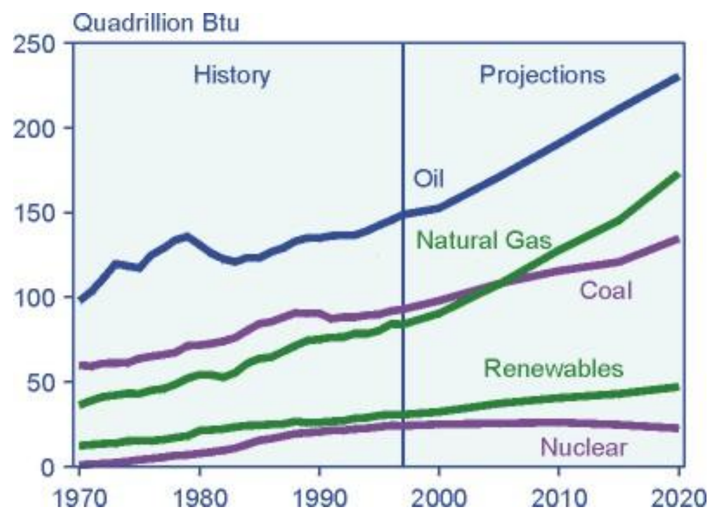


Figure 1-4. World Energy Consumption, 1970-2020
Source: http://telstar.ote.cmu.edu/environ

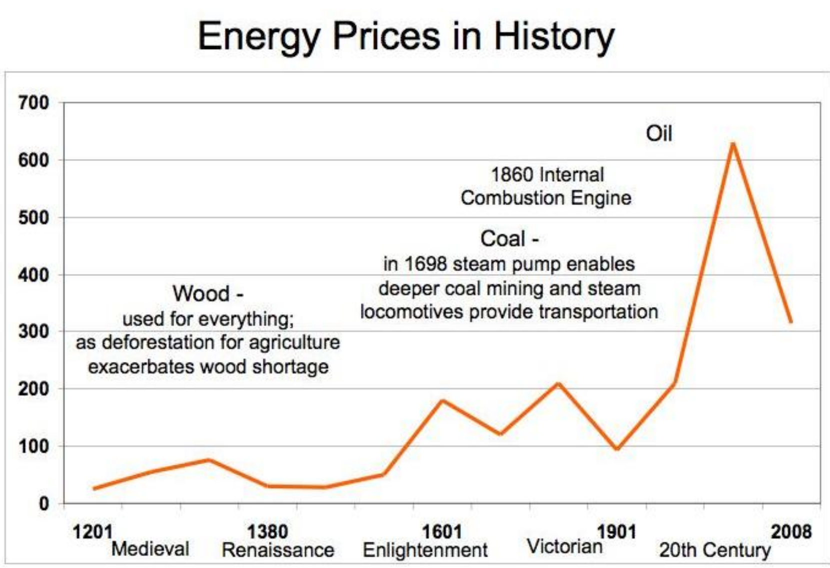


Figure 1-5. Energy price in the History, 1200 - 2008
Source: The Great Wave, David Fischer; The Industrial Revolution in World History, Peter Steams

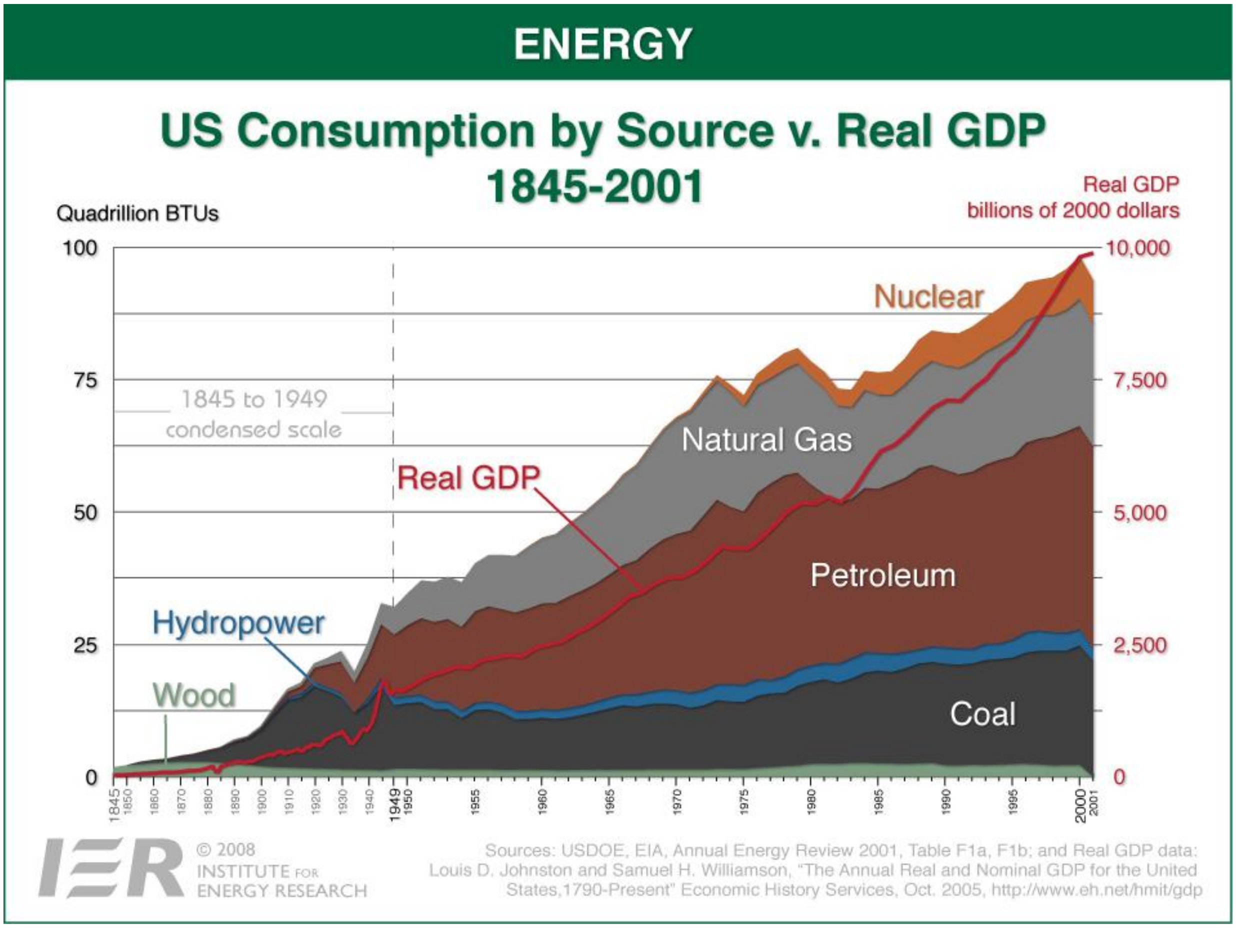


Figure 1-6. US Energy Consumption, 1845-2000
Source: www.instituteforenergyresearch.org/pdf/2008/

Air pollution is one of the other reasons that created the urgency for clean energy sources. With industrialization, the sudden increase in the amount of toxic fumes being emitted by industries, transportation and building sectors has had a very negative effect on the environment. Scientists, researchers and designers have always tried to find the best solution for reducing these polluting emissions. Indeed the combustion of fossil fuels is the main cause for releasing these pollutants. Thus one of the effective ways to reduce these emissions is shifting the priority from energy resources. Climate change, caused by Global Warming, and the cycle of reproducing oil in nature are also two important causes which will be discussed in the following pages. Associated with the above mentioned reasons, these two aspects compel the world to move towards clean renewable energy sources in buildings. This study aims to trace the efforts, especially made by architects, to deal with the issue of energy and focuses on energy related issues in buildings that are the main consumers of energy. The research is hence based on the study of residential buildings as the main parcels of buildings in cities.

1.3.1 Global Warming

Observations show that the global temperature rose by 0.6 degree Celsius during the twentieth century. The prediction of the climate difference for the coming century is a temperature increase of 2 to 5 degrees Celsius by 2100 (Archer, 2007). Scientifically climate change has not been caused only by greenhouse gases; however, the impact of greenhouse emissions is still the most important factor leading to global warming. In the nineteenth century, French scientist Jean Baptiste Joseph Fourier (1768-1830) was the first person who suggested that the Earth's atmosphere is like a greenhouse and traps the radiant heat of the sun. About seventy years later, the idea that massive combustion of fossil fuels could change the atmosphere temperature won the Nobel Prize (Long, 2004).

Carbon emissions, one of the key greenhouse gases, are an inseparable part of fossil fuel combustion. The amount of carbon emissions has increasingly risen, and reached about 6500 million tons in the year 2000 (fig. 1.7). This huge amount of emissions proved to be detrimental and thus created the need for alternative energy sources; one of the responses was substituting recent ways of producing energy with new types such as solar energy. As an important percentage of energy consumers, buildings and particularly residential buildings experienced significant changes in using new energy facilities. Using solar panels to produce electricity which has become wide spread around the world is one the examples.

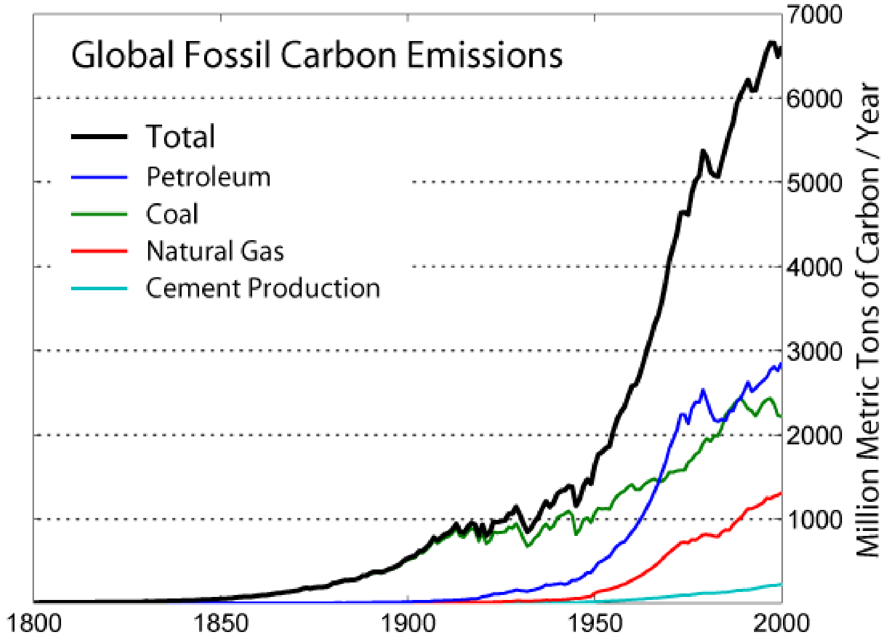


Figure 1-7. Global Fossil Carbon Emissions
Source: www.climatechangeconnection.org

1.3.2. Oil Regeneration Cycle

The growing global demand for energy exerts pressure on traditional fossil fuels, especially crude oil and natural gas. Presently, fossil fuels have dominated the energy usage at almost 80 % (fig. 1.9). The United States is considered as the world's largest consumer of fossil fuels (fig. 1.8). However, as scientists state, fossil fuels will not last for a very long time given the current usage trend. Indeed biological carbon has been converted into familiar fossil fuels such as oil, gas and coal over millions of years; as a consequence, they cannot be replaced easily. Coal is the most abundant type among these, while gas and oil will be exhausted in a few decades. In fact fossil fuels are not considered as sustainable sources of energy taking into account our increasing request for fossil fuels. Some observers have proposed using nuclear energy widely to reduce the importance of fossil fuels but it currently produces about 7% of energy supplies (Fig.1.9). The lack of public enthusiasm towards using nuclear power has thus made it essential to look at developing renewable energy sources.

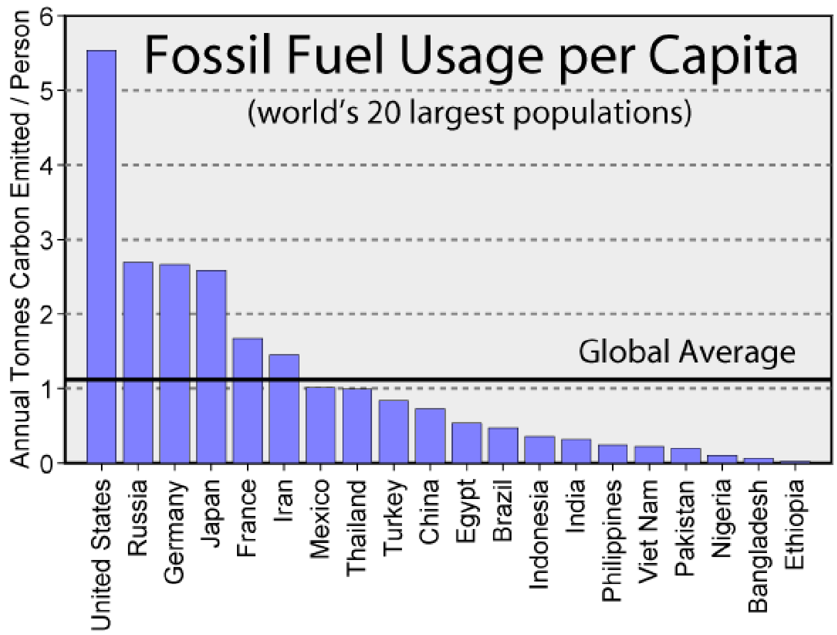


Figure 1-8. Fossil Fuel Usage in the World, 2007
Source: www.physics.utah.edu/

However the best way to have sustainable energy resources which are ecologically clean is using renewable ones such as wind and solar energy. Hence technologies for producing, conducting and using renewable energy have been developed. Now it is the designers' responsibility to implement these technologies and ideas to their design. It is time for architects to make an effort to shift towards using renewable energy sources in buildings.

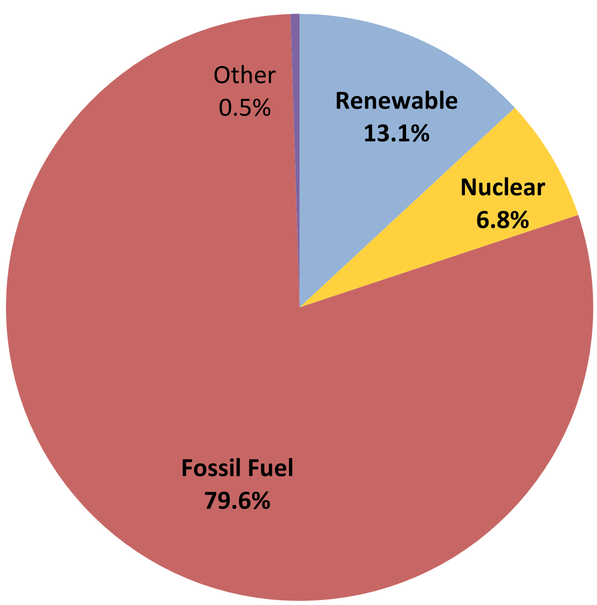


Figure 1-9. World Energy Consumption by Source, 2002
Source: Evans, 2007

1.4. Research Question

This study aims to pursue the contemporary conscious and unconscious efforts of architects and builders to design and build net-zero residential buildings. It will consider these endeavours in terms of utilities (in the engineering field), as well as design techniques. This will hopefully lead to have categorized types of strategies for designing multi-unit net-zero buildings. The research question correspondingly is:

- **What design strategies and technologies can be used by architects to create net-zero apartment buildings?**

1.4.1. Sub-Questions

There are still some sub-questions that can help expand the idea of the study as well as make it rich. These questions can also widen the intended readers and users of this study by answering different questions in terms of net-zero buildings. Some other questions for this study are:

- While designing net-zero apartment buildings, what are the challenges while dealing with several separated units compared to single dwellings?
- What efforts have been done by architects to make these buildings desirable? What particular strategies could improve the quality of housing/living?
- What innovative ideas have been implemented in the design of net-zero apartment buildings?
- What strategies have been used to unplug these buildings?

1.5. Goals and Objectives

Net-zero buildings have recently become wide spread; consequently, a noticeable number of net-zero projects can be seen all over the world, mostly in North America and Europe. This expansion has occurred while there are critical opinions about economic aspects of net-zero buildings. Initial costs of these buildings have remained challenging but recent advancement in construction technologies has convinced builders and developers to build these types of buildings. In fact the attitude towards these buildings has shifted from “costly buildings” to “long-term investment”. On the other hand, environmental attributes of net-zero buildings make up for their probable disadvantages. The economic aspect of net-zero buildings will be discussed briefly in chapter two although it is not the focus of this study.

What is important here is that architects design these buildings. Thus it is imperative to understand what the role of architects in these projects is. Architects’ role is not limited to implementing technological facilities for producing energy developed by the other groups –such as mechanical engineers- into their designs. They are to promote the quality of living besides ensuring their designs are economically or environmentally beneficial. This study thus aims to find the net-zero examples that could create a good environment for living, at least, as well as typical ones.

The net-zero concept has been recently accessible by making it technologically possible to design an energy cycle for buildings that enables them to produce as much energy as they consume. This study is to demonstrate the strategies with which net-zero buildings have been designed. These strategies which include techniques and technologies will be categorized accordingly. It is hoped that this information can be used as a concise source for designing net-zero apartment buildings. Moreover it is hoped to establish a background of experience for emerging innovative ideas which can also help architects continue the sustainability movement. In fact net-zero buildings are not the end; they are a point for further advancement. It is the base point for moving towards unplugged housing or creating positive energy buildings.

1.6. Methodology

Gathering information will be mostly on case study method. Owing to the fact that “net-zero” is a new concept, there are a few source books on net-zero buildings; as a result, books mostly in other fields are used for the study. This literature review will be carried out in the second chapter. Some general design strategies will be overviewed in different cases in chapter two as well. Architectural design concerns for apartment buildings will be based on a case study analysed in chapter three. The existing buildings especially in Canada will be used as case studies for this research.

1.6.1. Literature Review

Regarding the nature of the study used articles and books are mostly from the field of mechanical engineering (e.g. energy design for buildings usually cannot be found in architectural sources). Architectural texts are used for sustainability related fields and ecological design matters which could be the background of “net-zero” in the field of architecture. One of the issues which has become the centre of attention in the eco-architectural field is “green building”. One of the net-zero goals is to have the minimum possible impact on the environment –hopefully zero- therefore the background of these buildings could be pursued in ecological design texts. All the above mentioned sources will be used as the material for generating the theoretical framework of net-zero buildings in chapter two of this study.

1.6.2. Case Study

The net-zero concept is highly practical; the theories should be examined and applicable to real projects. Despite many other movements which may start from theory, net-zero could commence from sporadic experiences by engineers, architects and even builders whose concerns were environment, economy or sustainability.

An important part of this study relies on the information and analysis from a real constructed project. This part which forms chapter three of this study includes an analysis of architectural plans, details and materials used by the architect. It will be integrated with acquiring ideas of the designers through conducting an interview with the architect of the project. The case study will also be enhanced by visiting the projects for on-site observation which can result in finding some other facets that are not mentioned elsewhere. It is also helpful to experience the quality of spaces in these projects to observe unintentional contributions towards the architectural design of the project.

1.7. Intended Readers

The aim of this study is to provide a source for a wider range of audience; it can benefit either academically or practically. Classifying techniques and technologies helps architects use experienced ones and encourages them to find new ideas as well. Hence the first target readers are architects who want to enter the field of green and energy efficient buildings. Moreover this study could be beneficial to those who want to develop ideas for energy related matters in architecture and even at larger scales. It hopefully creates a potential ground for further detailed researches in this field.

On the other hand for builders and developers this can be an introduction to one of the probable futures of residential buildings. Being acquainted with new concerns in design, the builders expect more from an architectural design. It will thus lead to have designs which are not only concerned with aesthetics or style, but also with energy and environmental issues.

1.8. Scope of the Study

ZEB (zero energy building) includes a vast range of building types. It can range from a bungalow to a commercial skyscraper. These different types entail different scales and even techniques of energy design. In addition the type of environmental impacts as well as environmental opportunities for producing energy may be partially different in these cases. As it was mentioned before, a huge amount of energy is used by homes annually -almost 21 % of the energy in the U.S is consumed by residential sector (Evans, 2007) - therefore the residential sector is considered as the target for this study. In fact net-zero single dwellings have been widely experienced. However, apartment buildings (multi-unit buildings) with several separate units are more complex than single-unit dwellings. On the other hand apartment buildings are more important in terms of investment and economic aspects. Hence the study focuses primarily on high-rise multi-unit residential buildings. Single family dwellings in this study are used to exemplify the effect of simple common techniques and technologies in energy design. These illustrations will be included in the second chapter when required.

1.9. Report Organization

This research is organized in four chapters. Chapter one is the introduction which provides the rationale for the study. The author tries to create the required framework for the study and identify the goals, objectives, users and scope of the work. Chapter two includes a brief history about energy design, sustainability and energy efficiency movements. It finally deals with introducing some particular technologies and systems which are used in net-zero buildings with the use of existing articles and texts. Chapter three focuses on a case study which is a net-zero apartment building. In this chapter, analysing a real case leads to extracting architectural design techniques which are considered by the architect to achieve net-zero goals. In chapter four, the strategies of net-zero apartment buildings will be suggested. Hopefully some guidelines for the future of this movement, especially net-zero apartment buildings, will be represented.

Chapter 2

Literature Review

Net-Zero Background and Strategies

2.1. Introduction

In a sense “Net-zero building” is not a new concept; in fact, homes before the invention of electricity has had the attributes of net-zero buildings. They deal with the definition of net-zero buildings; the required energy was produced on-site and they had a very low impact - almost ignorable- on the environment and finally they worked off-the-grid. However, the concept of net-zero is defined in the modern-life context. It means it is defined for the buildings that provide the required facilities and standards of living for the residents. The invention of electricity was the most effective incident on human’s life standards in this sense. It created the ground for other important technologies to emerge. Now we as humans are living in societies where heating and cooling systems, kitchen appliances, television and other electronic devices are considered as basic facilities for a standard living. Hence the challenges to achieve the state of being net-zero have been intensified. It is again the role of intellectuals to find new ways to implement advanced technology to overcome these challenges.

2.2. History of Energy Design

Energy design has very deep roots in the history of human beings on Earth. From evidence found in different places around the world, it is learnt that the initial energy design was basically insulation techniques and solar design in the ancient world. This included using thick walls with certain materials to decrease thermal conduction. Solar orientation was the factor which shaped many old communities in terms of orientation of buildings. In this sense the sun was the primary type of passive solar energy and design accordingly.

2.2.1. Ancient solar design

By observing the sun carefully, ancient cultures had a considerable knowledge about solar design. “The early astronomers, historians, farmers, and religious leaders who precisely understood the annual movement of the sun were better prepared to predict the seasonal weather changes, know when to plant and harvest crops, and how to orient their houses to gather sunlight in winter, while blocking its heat in summer… 2400 years ago, the Ancient Greek and Egyptian educators and philosophers all understood the easy-to-observe critical solar design parameters”[4]. Socrates (469 BC–399 BC) wrote: “In houses that look toward the South, the sun penetrates the portico in winter” (Johnston & Gibson, 2010). There are some evidences for particular ancient cities that show these cities have been formed by considering the sun path. “Community planners laid out entire cities in Greece and Asia Minor, including the well-documented City of Priene on the Southeast slope of Mount Samsun to allow every home clear access to the essential sunlight that warmed their porticos in the winter (Fig.2.1). Energy conscious legislation was written to prevent new buildings from blocking solar access to existing homes” (ZED EBook). This cautiousness about the sun’s energy can be seen in the architecture of different ancient cultures in different places around the world.

Figure 2-1. Priene; an early example of a city with solar orientation
source : www.travel.webshots.com/photo

[4] Zero Energy Design EBook (ZED EBook), www.zeroenrgydesign.com

2.2.2. Energy Design Before Industrial Revolution

Energy design later was very different from one place to another according to the location, climate and culture. In America, "early native American settlers of the American southwest were very conscious of the movement of the sun and built their pueblos so that the community had access to southern sun" (Johnston & Gibson, 2010). The examples of these communities can be seen in the Anasazi culture that inhabited Colorado, Utah, New Mexico and Arizona (Johnston & Gibson, 2010). A more recent example of solar design was seen in the architecture of early colonists in New England around 1700s. They used a particular typology of houses that was a two-story house facing south which is known as the "Classic Saltbox" (Johnston & Gibson, 2010). As it can be seen in Figure 2.2 the northern part of the roof sloped down to one storey and usually had a few windows. It also benefited from certain shutters for the windows that reduced heat loss and summer overheating (Johnston & Gibson, 2010).

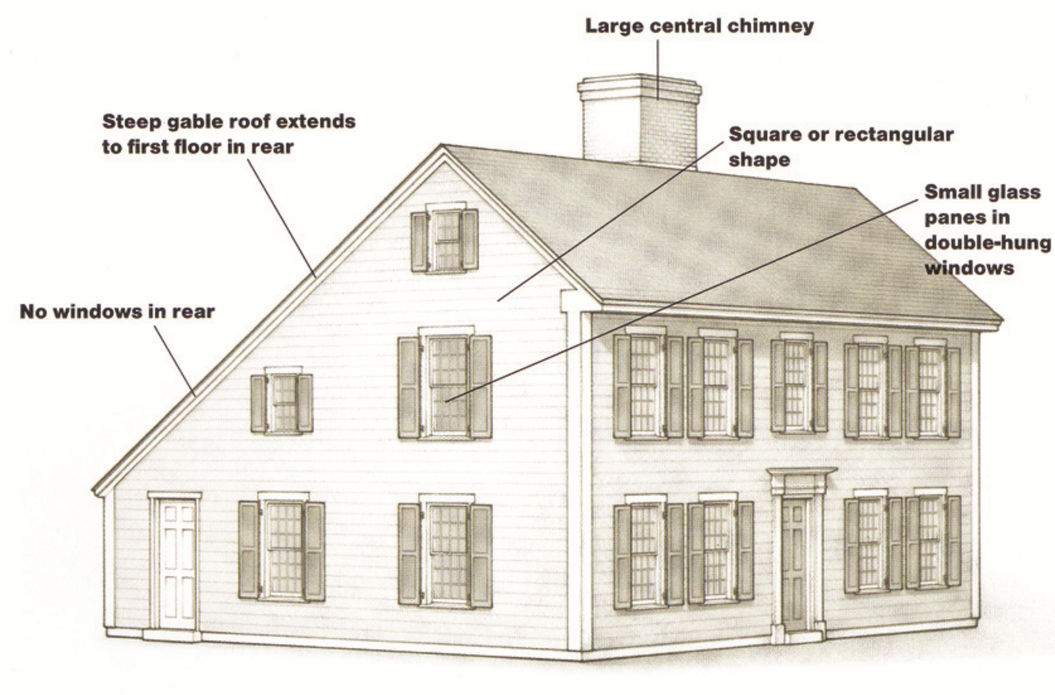


Figure 2-2. The Classic Saltbox – New England
The southern part of the house has two storeys which maximizes solar gains and the northern part is one story and usually without windows.
Source: (Johnston & Gibson, 2010)

2.2.3. Industrial Revolution and Post-War Housing and Energy Design

During the industrial revolution (from 18th to the 19th century) the world encountered a "rapid socioeconomic transformation brought about by industrialization and made possible by fossil energy was without precedent in world history. The pace of change was as dramatic as the changes themselves...Electricity, essentially absent from the daily lives of Americans in the 1880s, was widespread in offices, factories, and homes a few decades later, allowing light to displace the dark and the productive day to be lengthened"[5]. Energy crisis which was intensified after the industrial revolution caused a great attention to energy consumption. As Figure 2.3 represents, world increasing demand for energy, which will continue in the coming years, raised the importance of energy in the world again. After the industrial revolution, the rapid increase in the amount of toxic fumes being emitted by industrial, transportation and building sectors had a negative impact on the environment. Scientists, researchers and designers have always

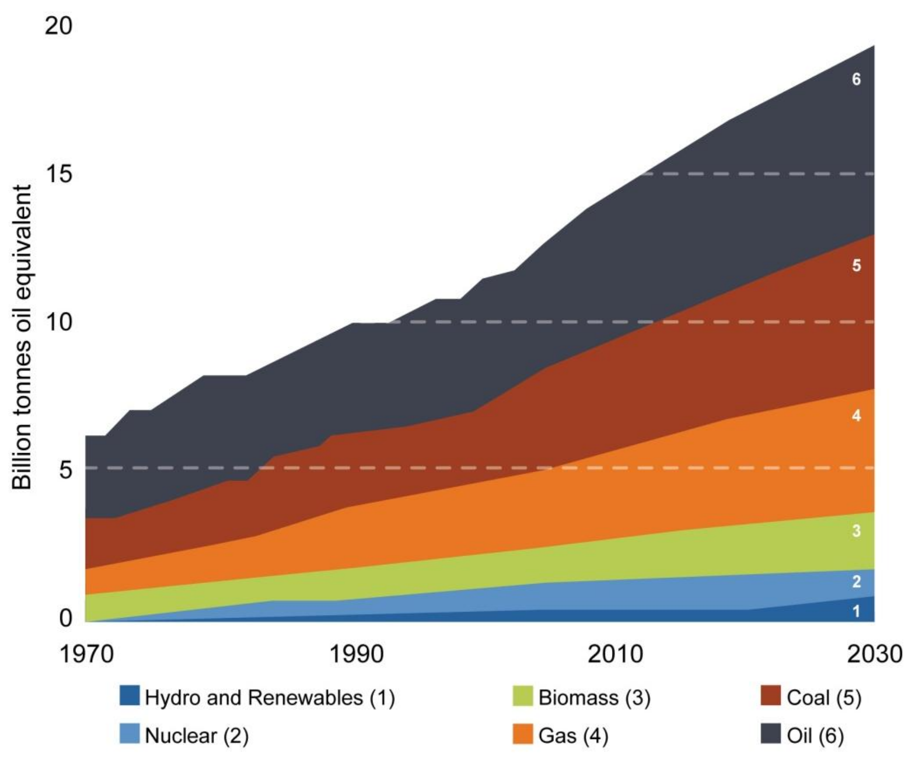


Figure 2-3. World Energy Demand by Fuel Type 1970-2030
Source of Information: International Energy Agency, World Energy Outlook 2006
Source: CO_2 Capture Project - www.co2captureproject.com

[5] www.instituteforenergyresearch.org

tried to find the best solutions for reducing these polluting emissions. These issues indeed started great developments in the way of developing alternative energy forms. It was during these years that many new alternative sources that we know today became feasible. In this sense, the crisis acted as a catalyst for a positive change in the world, both in perceptions and priorities[6].

On the other hand, in the field of architecture the story was different. “By the middle of the twentieth century, with the invention and commercialization of air-conditioning, we started to lose direct contact with variations in climate and weather. After thousands of years of planning settler around the cycle of the sun, we stopped worrying about where the sun would be located in the summer and winter sky” (Johnston & Gibson, 2010). In fact energy design was not in the circle of attention in post-war housing which followed industrial revolution. In fact the housing sector which always has been the largest part of the communities shows the notion of the community toward energy related issues. In post-war communities, the increasing need for housing associated with improved technological means of production started to change the density (Rowe, 1960). Introducing contemporary high-rises to communities as a result of the opportunities given by technologic advancements happened at that time. In fact these changes in communities were mostly without cautiousness for the environment. The only important thing in this change was reducing expenses and going toward mass construction to be able to deal with the growing need of housing (Rowe, 1960). However the notion did not remain constant; “when the oil embargo struck an unwary America in 1973-1974 and gas lines stretched around the block”, American architects turned again to the sun as the source of energy (Johnston & Gibson, 2010). Correspondingly in different countries solar design started to be experienced again as the passive home movement was born in 1996 in Germany (Johnston & Gibson, 2010).

[6] Zero Energy Design EBook, www.zeroenrgydesign.com

2.3. Energy Cautiousness Movement

The energy crisis triggered shifting toward energy efficiency and using alternative energy sources as well. This movement was started in other fields than architecture such as industrial design especially the automobile industry. The car industry pioneered many innovations in energy related issues among transportation systems such as using solar cars or introducing electric, hydrogen and hybrid cars. All these innovations were only some ideas at first and it has taken a long time to develop them and make them appropriate for mass production. A good example of these technologies is using solar panels in cars (Fig.2.4). However, in 2009, the market faced a mass produced car by Toyota which made use of solar panels called “Prius” (Fig.2.5)[7]. Using solar panels, Prius utilizes the generated electricity for its ventilation and cooling system. It is now a movement by almost all car companies to shift toward energy efficient and green products. General Motors in the United States will invest 336 million dollars in a Detroit-area assembly plant, bringing to 700 million dollars total investment in eight Michigan facilities to begin mass production of the rechargeable Chevrolet Volt electric car in late 2010 (Fig. 2.6)[8].

Figure 2-4. Concept car with Solar panels and wind turbine
Source: www.therawfeed.com/2006/10/solar-car-charges-self-and-its-too

[7] Source: Toyota website: www.toyota.com
[8] Source: General Motors website: www.gm.com

Figure 2-5. Toyota Prius - The first mass produced car with solar panels as the sunroof.
Source : www.toyota.com/prius-hybrid

In fact all the technologies which had been conceptual were developed and entered the mass production industry in the field of automobile design. The role of designers can be visibly seen in how they have applied these technologies to the cars accompanied by a thoughtful design and consideration of aesthetic aspects. That is the integration of design and technology which is the key point in designing net-zero buildings too.

Figure 2-6. Chevy Volt – GM electric car
Source: www.rechargenews.com

2.4. Alternative Energy Sources

Global warming, environmental pollution and increasing demand of energy all made humans switch to renewable and clean energy sources. World energy consumption of renewable energy sources has increased noticeably but it is still providing a small portion of global energy consumption (Fig.2.7 and Fig 2.8). Some of these sources can be used for buildings according to the scale of the building while some have not been integrated yet. Alternative energy sources as a field is very vastly covered in several books and articles in engineering and environmental fields. What the author is concerned with in this research is not directly alternative energy sources as an independent part. The relationship between alternative energy sources and architecture is the main concern. Thus what is represented here is a brief summary of several books to make the readers familiar with different energy resources which will be discussed in terms of their use in architecture later.

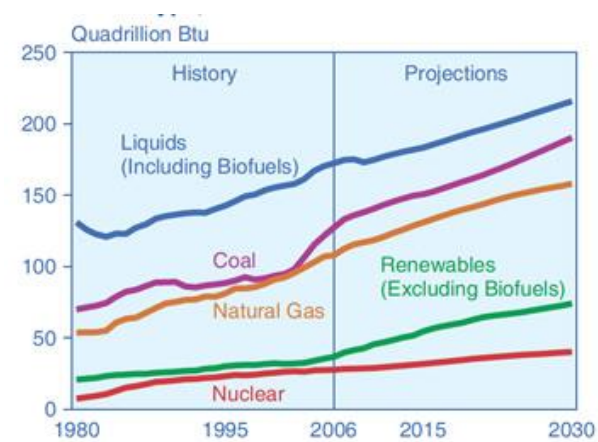


Figure 2-8. World Energy Consumption by Fuel Type
Source of Information: International Energy Agency, World Energy Outlook 2006
Source:www.eia.doe.gov/oiaf/ieo/world.html

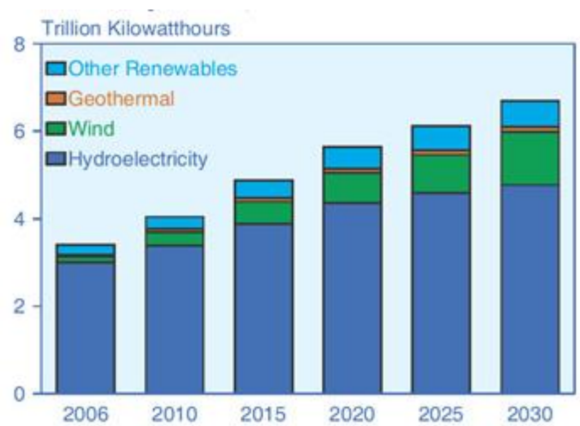


Figure 2-7. World Electricity Energy Generation
Source of Information: International Energy Agency, World Energy Outlook 2006
Source:www.eia.doe.gov/oiaf/ieo/world.html

2.4.1. Solar Energy

"As a continuously operating fusion reactor with an interior temperature of several million degrees Kelvin, the sun radiates energy throughout the solar system" (Kruger, 2006). The sun is the most important provider of the energy for life on Earth. This abundant energy can be converted to electricity by using contemporary technologies. The idea of producing electricity from light goes back to the 19th century. “In the latter part of the nineteenth century, physics discovered a new phenomenon. When light is incident on liquids or metal-cell surfaces, electrons are released” (Gevorkian, 2008). However there was no clear explanation for that until the turn of the century when Albert Einstein (1879-1955) provided a theory for this phenomenon that won the Nobel Prize in physics and created the theoretical frame for the theory of photoelectric effect” (Gevorkian, 2007). Nowadays solar farms where the required electric power for communities is produced are widespread (Fig.2.9). “Large-scale solar electricity can be generated by two major conversion technologies: solar thermal and solar electric. *Solar thermal* is achieved by concentrating the energy of incoming solar radiation into a *heat carrier* and then converting the heat of the heat carrier into electricity...the latter includes direct conversion of solar radiation into electricity by using solid-state photovoltaic cells” (Kruger, 2006). “Solar, Or Photovoltaic (PV) cells are electronic devices that essentially convert the solar energy of sunlight into electric energy or electricity” (Gevorkian, 2007).

Figure 2-9. Photovoltaic panels in a solar farm
Source: http://www.ecoconsciouspioneers.com/2009/07/20/endless-power-from-the-sun/

2.4.2. Fuel Cell Technology

"Fuel cells are energy-conversion devices that produce electricity through the chemical oxidation of a reactant, or fuel, and an oxidant" (Gevorkian, 2008). This type of energy production is not considered as a totally sustainable source because of the changes in the natural elements involved in this procedure (Fig. 2.10). A very small portion of renewable energy is currently produced by Fuel cell technology.

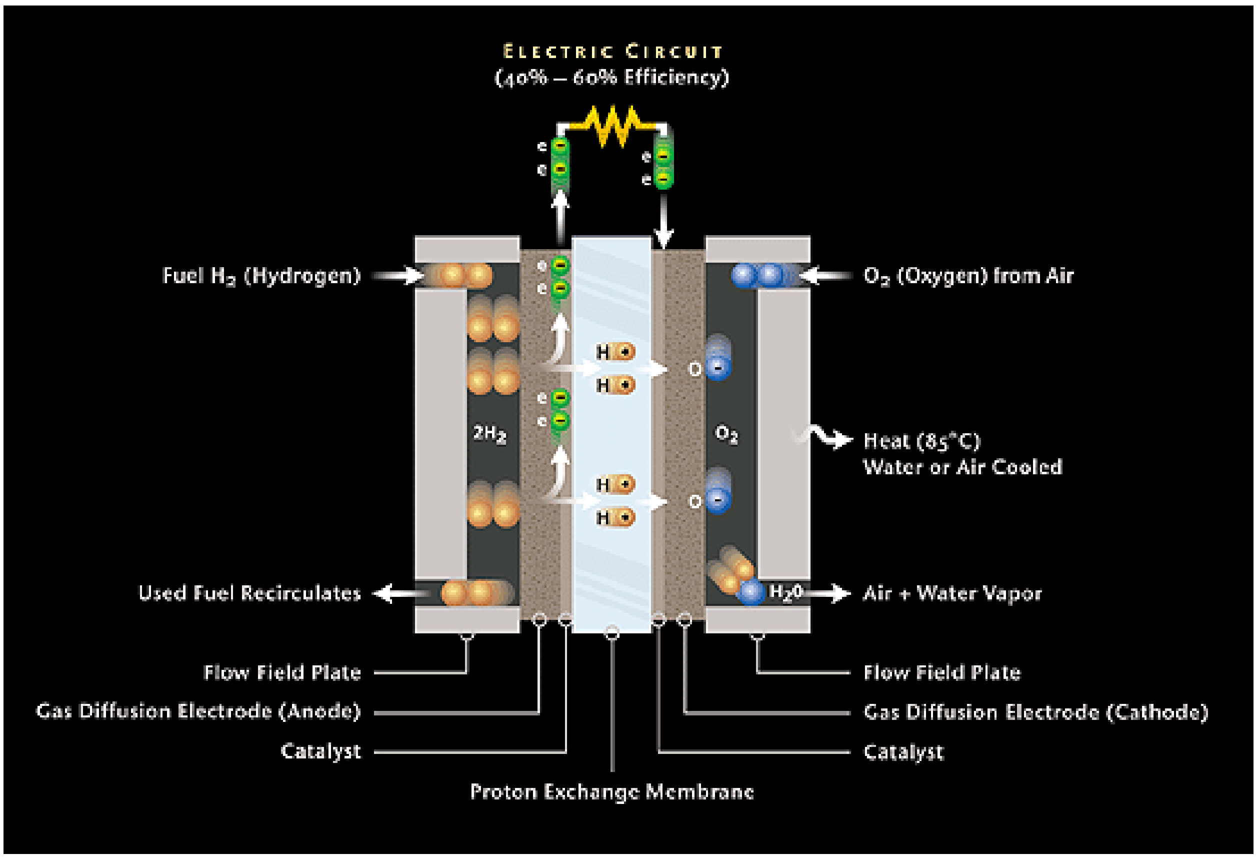


Figure 2-10. Fuel Cell with H2 Usage
Source: http://people.bath.ac.uk/mjb28/alt_fuels.htm

2.4.3. Wind Energy

"Wind power generation results from the conversion of wind kinetic energy into electricity through the use of especially designed wind turbines" (Gevorkian, 2008). Wind turbines are being used widely in many countries as a developing source for producing energy. For instance, it is the second largest source of producing energy among renewable sources in China after Hydroelectric power (Fig. 2.11). Huge wind harvesting farms can be seen in windy areas in North America (Fig. 2.12).

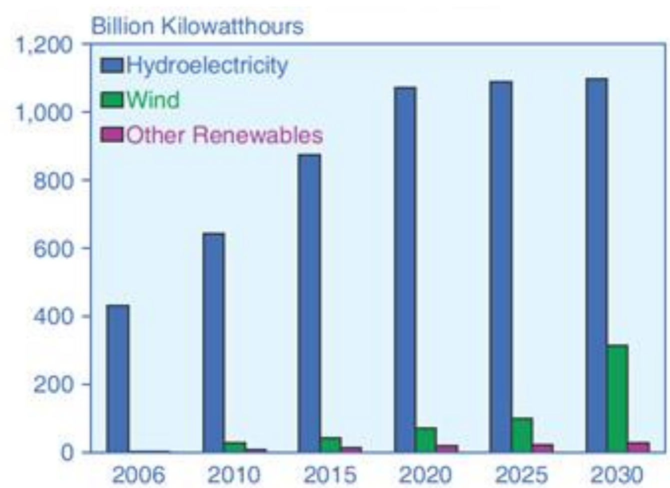


Figure 2-11. Renewable Energy Production in China
Source of Information: International Energy Agency, World Energy Outlook 2006
Source: Source:www.eia.doe.gov/oiaf/ieo/world.html

Figure 2-12. Wind Harvesting Farm
Source: www.clarification.files.wordpress.com/2010

2.4.4. Tidal Power

Tidal power is the other type of producing energy. “Tidal movement occurs as a result of the twice-daily variations in sea level caused primarily by the moon and, to some extent, the sun. Tidal power has been used in milling grain since the eleventh century in Britain and France” (Gevorkian, 2008). In fact it generates electricity by using turbines as shown in Figure 2.13. Similar as Fuel Cells this type is not a widely used energy source because of the initial expenses and low energy productivity but it is still a clean energy source.

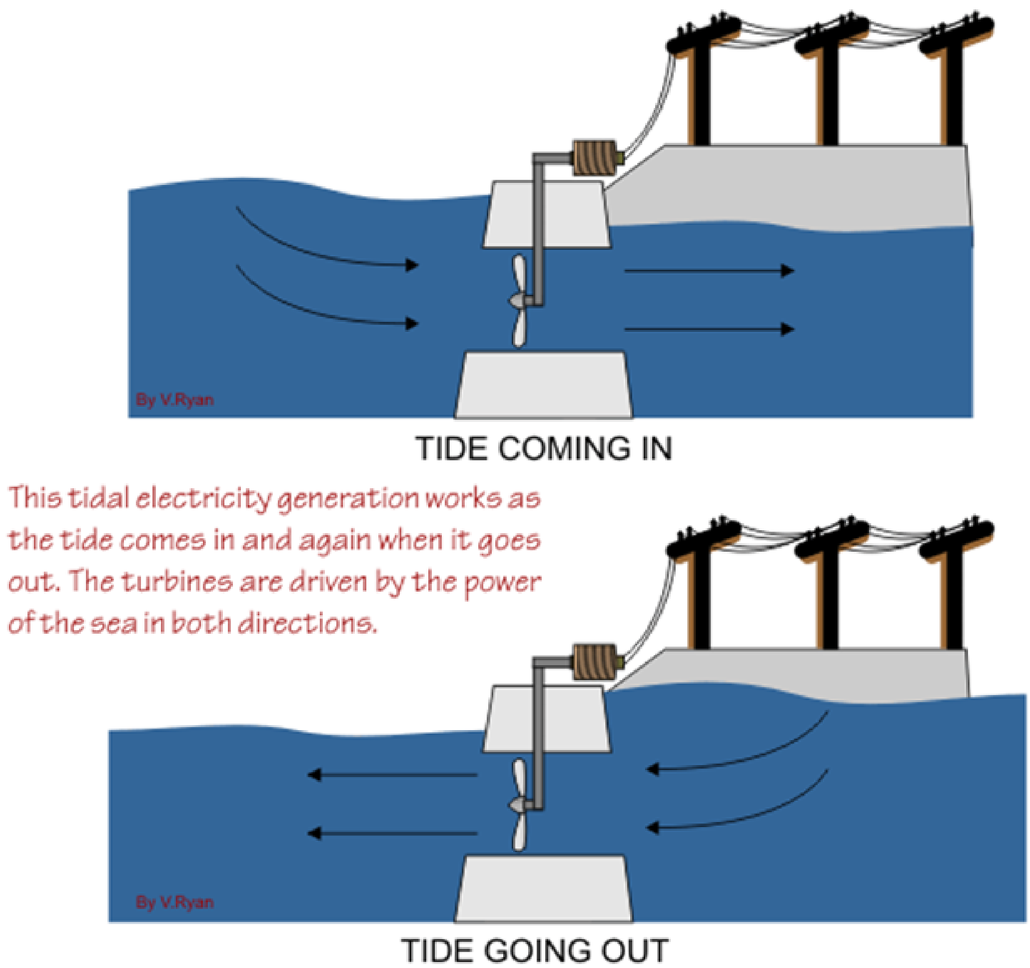


Figure 2-13. Tidal Power Working System
Source: http://www.mywindpowersystem.com

2.4.5. Hydroelectric Power

Hydroelectric power is simply using flowing water such as rivers to produce electricity by using particular types of turbines as is done in dams (Fig. 2.14). “Among the variety of renewable energy resources, hydroelectric power is the most desirable for utility systems and has a long, successful proven track record. Power generated from hydroelectric plants can exceed 10 GW" (Gevorkian, 2008). The statistics show that this type is the first renewable source of producing electricity in the world (Fig. 2.7). This source is also the main energy provider for some countries such as Norway; 98 percent of electric energy is produced by hydroelectric power in this country (Gevorkian, 2007).

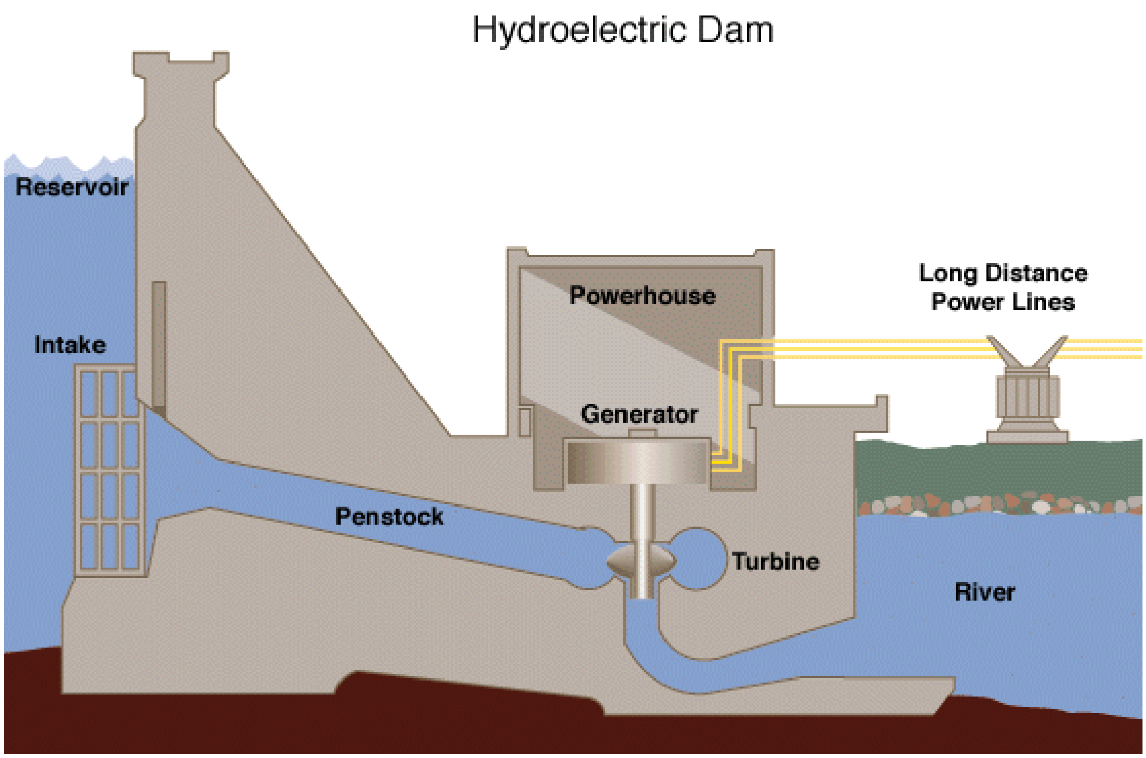


Figure 2-14. Different Parts of a Dam
Source: www.greenfriendlyglobe.com/Hydroelectric.php

2.4.6. Geothermal Energy

"The term geothermal is a composition of two Greek words: *geo*, meaning Earth, and *therm*, meaning heat; combined, geothermal means heat from the Earth (Gevorkian, 2007). The Earth's centre is made of molten iron located about 4000 miles from its crust. The estimated temperature of the Earth's core is about 5000°C" (Gevorkian, 2007). Making use of this abundant energy source is the target in this system. In power plants this energy is usually used as heated water or hot steam to turn turbines and generate electricity (Fig. 2.15).

“The concept behind Geothermal Power is not entirely new, having first been harnessed in Italy circa 1904. Geothermal power is generated by utilizing the earth's heat in areas where ground temperatures are very high at shallow depths” [9]. There are four types of power plant systems today which are used to convert the geothermal energy into other practical kinds of energy; dry-steam plant, flash steam plant, and binary plants (Gevorkian, 2008). “In the United States, the Pacific Northwest has the potential to generate up to 11,000 MW of the electricity from geothermal power...Although geothermal power is one of the less polluting power sources, it must be sited properly to prevent potential negative environmental impacts. New geothermal systems re-inject water into the earth after its heat is used in order to preserve the resource and to contain gases and heavy metals sometimes found in geothermal fluids” (Gevorkian, 2007).

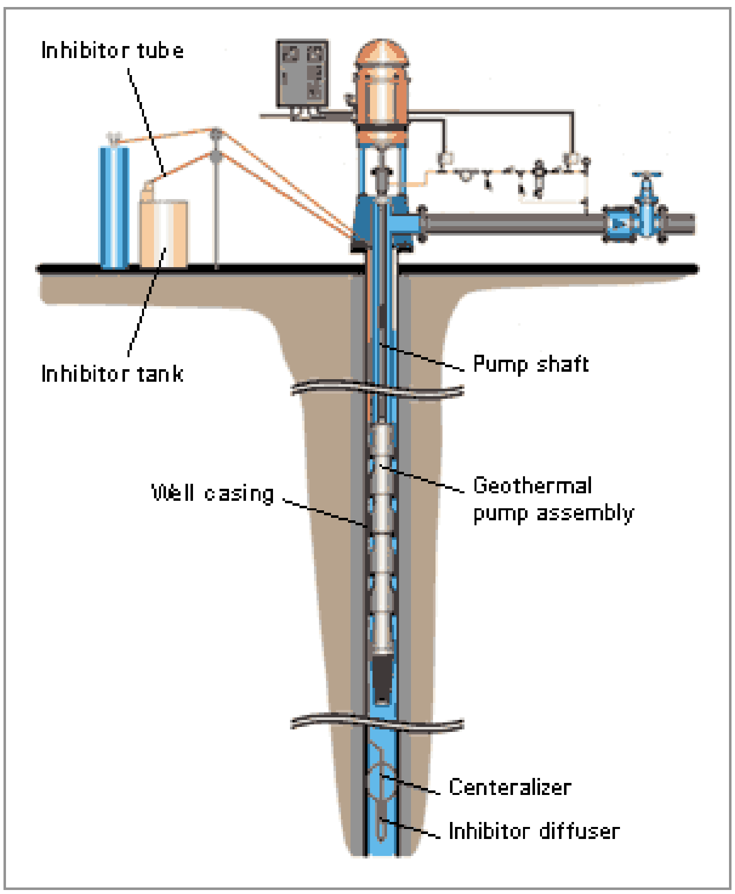


Figure 2-15. Geothermal Energy Production
Source: http://www.camdelmetals.com/pages/products

[9] Source: http://www.camdelmetals.com/

2.4.7. Biogas

Biogas is a controversial resource for energy although it is not vastly used. The system of biogas is not a complicated process of producing energy. “Methane gas is commonly generated in very large volumes as a by-product of the biologic degradation of organic waste or as a result of numerous industrial processes” (Gevorkian, 2007). Methane is an excellent waste-gas fuel for micro turbines and it can also be burned for generating heat (Fig. 2.16). It is not a totally a clean energy source but it is at least a waste using generation of energy.

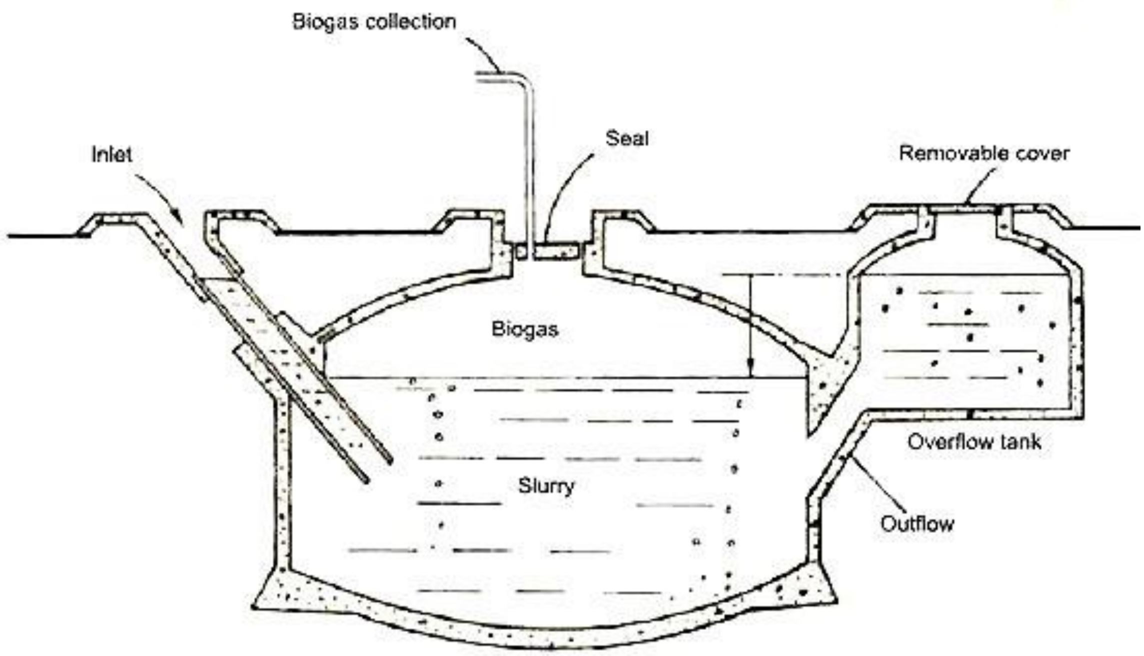


Figure 2-16. A Biogas Plant in China
Source: http://www.i-sis.org.uk/BiogasChina.php

2.4.8. Nuclear Power

Nuclear power is the most controversial alternative energy source. This source of energy was the topic of discussion for many years as to whether it is a clean energy source or not. But the fact is that it is not totally clean. The radioactive radiation is dangerous to living organisms. In addition it is not totally renewable; however, it can be considered as a renewable energy according to the abundant amount of Uranium -which is the main fuel in this type- on Earth. Other radioactive elements that appear in nature are Polonium, Astatine, Radon, Francium, Radium, Actinium, Thorium and Protactinium. There are two main processes of generating nuclear power; nuclear fission and fusion reactor technology. Indeed the latter is the sustainable form of generating nuclear power. Fission reactor technology provided about 17 percent of the world's electricity and 15 percent of the United States' electricity in 2008 (Gevorkian, 2008) (Fig. 2.17).

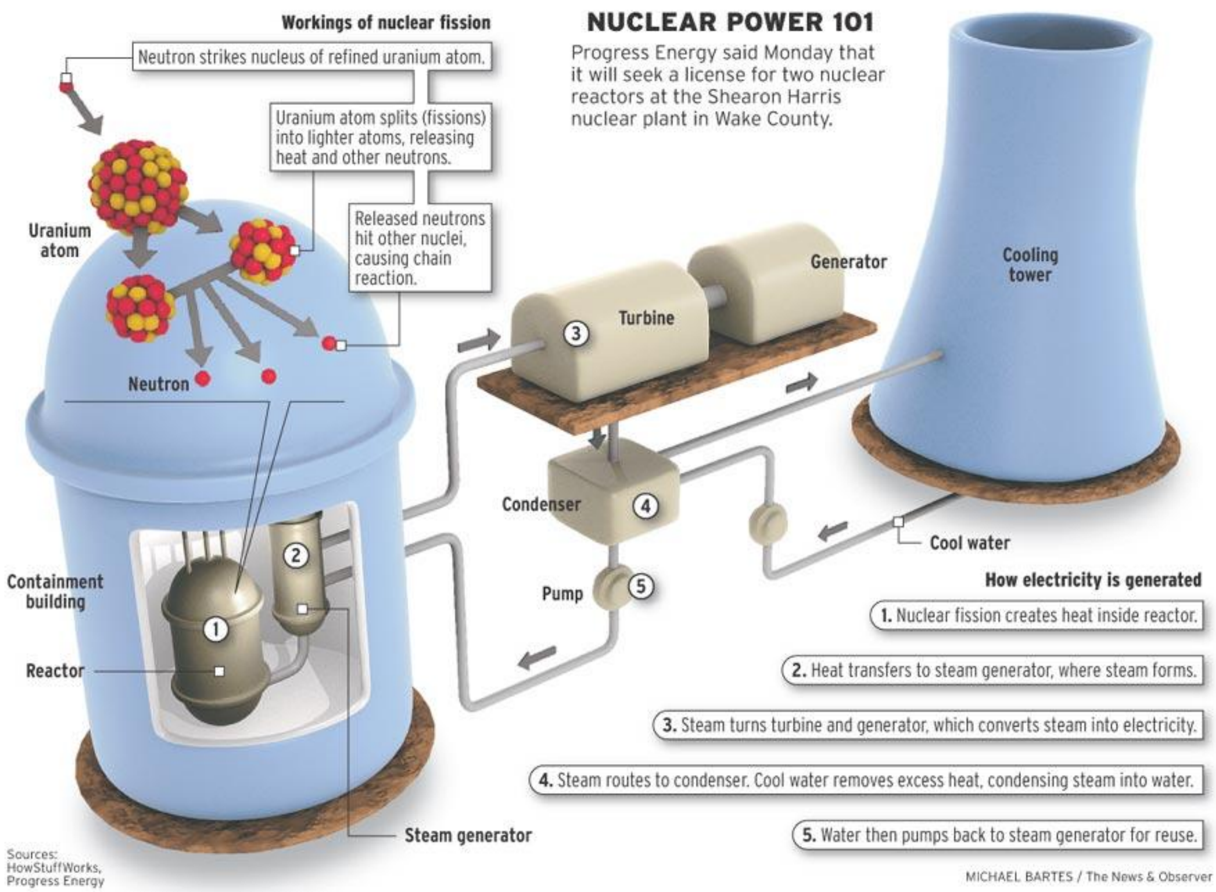


Figure 2-17. Fission Nuclear Power
The figure shoes different parts of a typical fission nuclear power with uranium fuel
Source: http://papundits.files.wordpress.com/2009/04/ph_three_mile_island500.jpg

2.5. Net-zero Buildings and the Involved Groups

In fact different actors are involved in developing net-zero buildings. In addition to architects, different groups such as builders, governments and even private clients have very important roles in developing net-zero buildings. Governments can have the most important role among them regarding their power to legislate monetary opportunities for developers and builders. Indeed governments in long-term view will achieve their environmental and energy-related goals with paying attention to net-zero concepts for the residential sector. Governments should target large-scale developments of residential projects. Builders and private clients' cautiousness about energy and environmental aspects is also essential to experience these particular types of buildings on a wider range. Supportive policies can also create incentives for builders to go toward building net-zero projects despite their initial costs or other negative aspects.

Different organization and companies both in private and public sectors are currently working on net-zero buildings either in theory or in practice. Most of the active groups in this field concentrate more on the practice especially on single dwellings. Different fields of working related to net-zero buildings are education, developing technologies and construction. Some organizations educate architects about energy design issues. This includes different courses which are held about LEED certificate. Canada is one of the countries has had noticeable stress on energy matters and environmental issues. Canada is also one of the most active countries in energy design fields in architecture. Canada Mortgage and Housing Corporation (CMHC) is a governmental organization which has had some activities in this field. An example of these efforts that led to introducing some net-zero homes is a program called EQuilibrium™. EQuilibrium™ is a national Sustainable Housing Demonstration initiative conducted by CMHC that "brings the private and public sectors together to develop homes that combine resource- and energy- efficient technologies with renewable energy technologies in order to reduce their environmental impact[10].

[10] Source: www.cmhc.ca

2.6. Net-Zero Buildings and the Economic Aspects

The most challenging issue about net-zero buildings that have been always a barrier to developing them is the financial aspect. The initial costs of facilities which should be installed for producing energy on-site plus the higher costs of purchasing high efficiency windows, doors and appliances discourage builders. In a highrise condominium project, for instance, the builder is primarily concerned with the budget. The fact is that the typical building has lesser cost of construction compared to the net-zero versions with the same floor planning. Spending more money on construction, the builder has to sell the units at a higher price. On the other hand, buyers should purchase the apartments at a higher price. Instead they will have no cost for electricity, heating and cooling systems. Now it is the role of the builders whether to take this risk or not. Besides, adding any type of complexity to the building will take more time and labour. As it can be clearly seen in the real market, builders prefer the shortest and easiest way to have their money and its interest back. In this sense, as mentioned before, awareness of builders and buyers about energy and environmental issues is important to make this cycle work.

The other critique of many net-zero residential buildings is that the embodied energy –the embodied energy is the amount of energy which is consumed to build a building or product- for such technological devices (e.g. photovoltaic panels) is sometimes more than the energy these devices produce in their lifetime. This is a very important point that should be taken into consideration by designers and producers of such facilities. However this challenging factor is not the architects' responsibility, thus it entails the consciousness of the industry sector.

There is another point of view in terms of economy for net-zero buildings which refers to the construction cost but is within architects' responsibility. As OAQ (Ordre des architectes du Québec) published in the Code of Practice[11], life cycle cost (LCC) is introduced as an important factor in the architectural projects. The life cycle studied for buildings is usually shorter than the

[11] Ordre des architectes du Québec (OAQ) Publication, www.oaq.com

intended life of that facility; standard life cycle is usually 20-40 years in Canada[12]. The analysis of life cycle cost for the building requires the following steps:

1. Specifying the objectives and constraints of the analysis
2. Identifying options to achieve the objectives (Here it is achieving net-zero goals)
3. Specifying various assumptions regarding discount rate, inflation rate, economic life, etc
4. Identifying and estimating relevant costs
5. Converting all costs into constant dollars and to a common base
6. Comparing the total life cycle costs for each option and selecting the one with the minimum total costs
7. Analyzing the result for sensitivity to the initial assumption

In a more specific way:

1. For each year:

   Net benefit = Benefits – Costs (e.g. Net Energy Saving = Energy Saving - Costs)

2. Finding the present worth of the net benefit (present worth is how much the savings are worth today – use the discount rate for this purpose)
3. Sum of the present worth for each year over the life of the option. (This is the total present worth)
4. Compare the total present worth to the total investment. (This is the Saving-to-Investment ratio or SIR)

With this approach architects can find convincing financial support to replace the options for achieving net-zero concepts. For instance replacing typical windows with energy efficient windows in a project can be observed financially. These estimations create a good market-related framework for architects in designing net-zero buildings.

[12] Ordre des architectes du Québec (OAQ) Publication, www.oaq.com

Final consideration related to net-zero residential buildings is the scale of the building. Simply there is a connection between the number of units using energy producing facilities and the economic reasonability of the project. In the case of single family dwellings the total expenditure on energy producing facilities imposes increase in initial costs on one family. However in a multi-unit residential building there could be common facilities; as a result, the expenses would be distributed to several families. In addition wholesale purchase can have the advantage of lower cost in comparison with retail purchase. The matter of proximity is also important in these buildings. Being close to the source of producing energy decreases the cost of transferring energy from the producer to consumer. Combining proximity and scale together, there should be a balance between these two aspects to achieve efficiency.

2.7. Utilities and Technologies in Net-Zero Buildings

Alternative energy sources which were introduced before can be implemented into the design of the buildings -in this research, residential buildings- to enable them to produce the energy on-site. Undoubtedly making use of these energy sources in the real projects depends on many design aspects as well as economic ones.

2.7.1. Photovoltaic (PV) or Solar Panels

As described before there are two ways of generating electricity from solar radiation. In small-scale buildings, such as typical single-family dwellings, using photovoltaic panels is more feasible (Fig. 2.18). In fact calculation of the performance of PV panels is not complicated and can be done according to certain features given in their brochures. As far as the author of this research is concerned with these technologies in terms of architecture, there are some key points in implementing solar panels into the buildings which are introduced accordingly.

Figure 2-18. Alouette Ecoterra EQuilibrium House with BIPV-T Roof
The photovoltaic panels are integrated with the architecture of the house
Source: www.cmhc.ca

- **Intensity and Duration**

The first important point is to increase the intensity and duration of the sun's heat. Intensity as described scientifically depends on the angle of solar rays and the *normal line* of the PV surface. In fact the intensity of solar radiation is different from one place to another one according to longitude and altitude of those places. There is also another factor which is the angle of solar rays which depends on time. Basically designers can use certain diagrams called *sun path diagrams* to find the information about the angle of solar rays during different months and times of the day (Fig. 2.19). It simply means that the designers should try to put PV panels in a position that is as close as possible to vertical angle with solar rays. In addition the duration of radiation of the light on the PV panels is an important factor. In addition designers should put the panels in the positions that can be exposed to the direct light as long as possible. Duration is sometimes more effective than the intensity according to the nature of the place. There are some formulae with which energy designers can find the most efficient angle for the panels but observing the sun angles at particular times of the year can give architects approximately a good angle to situate the panels.

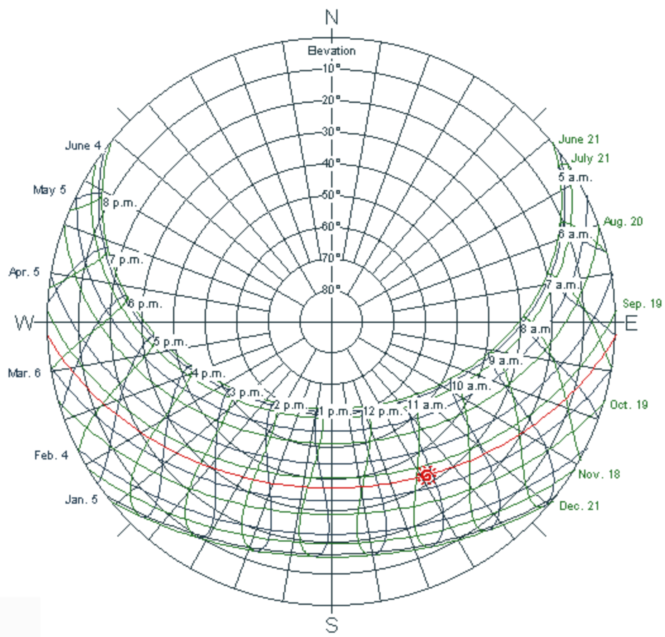


Figure 2-19. Sun Path Diagram
Source: www.solosol.net/images/

Sometimes designers have to make a balance between these two factors (intensity and duration) according to the particular design limitations. A possible technologic solution for maximising intensity and duration is the solar tracking system. “Tracking systems are support platforms that orient solar PV module assemblies by keeping track of the sun’s movement from dawn to dusk, thus maximizing solar energy power-generation efficiency” (Gevorkian, 2008). Generally in fixed cases without solar tracking system, the photovoltaic panels should face south in the northern hemisphere and they should face north in the southern hemisphere—the degree depends on the abovementioned factors.

- **Shading analysis**

Shading analysis is an important part in finding proper location for solar panels. It means that the shadows of the building itself and other neighbouring buildings should be considered. Being in the shade, photovoltaic panels fail to gain direct sunlight thus the output noticeably declines. Regarding this factor it is more preferable to locate the solar panels at the highest level of the building. That is one the reasons that photovoltaic panels are usually installed on the roof with a reasonable distance from parapets.

- **Considering precipitations**

One of the issues in cold climates is snow related problems. Locating the photovoltaic panels horizontally or even with a low slope can lead to being fully covered by snow in winters. In fact cleaning the panels from snow can damage the panels as well as be dangerous for the person doing it (Gevorkian, 2008). Hence depending on the climate it is appropriate to set the panels with a reasonable angle to avoid consequent problems.

- **Maintenance and service**

As mentioned before photovoltaic panels are sensitive and damageable. They also need to be checked and probably serviced eventually; consequently, being positioned in an appropriate place to be reachable is a significant consideration.

2.7.2. Solar Water Heating Systems

Solar power is used also for heating the water directly without being converted to electricity. The heated water then can be used for different purposes such as heating air for heating system. There are three different types of solar hot water systems in terms of the collector panels.

- **Flat-Plate Collector** (Fig. 2.20)

This type is the most common type of hot-water collectors which consists of a series of tubes inside a glass-covered frame. Water or a heat transfer fluid picks up energy from the sun to heat the domestic water supply" (Johnston & Gibson, 2010).

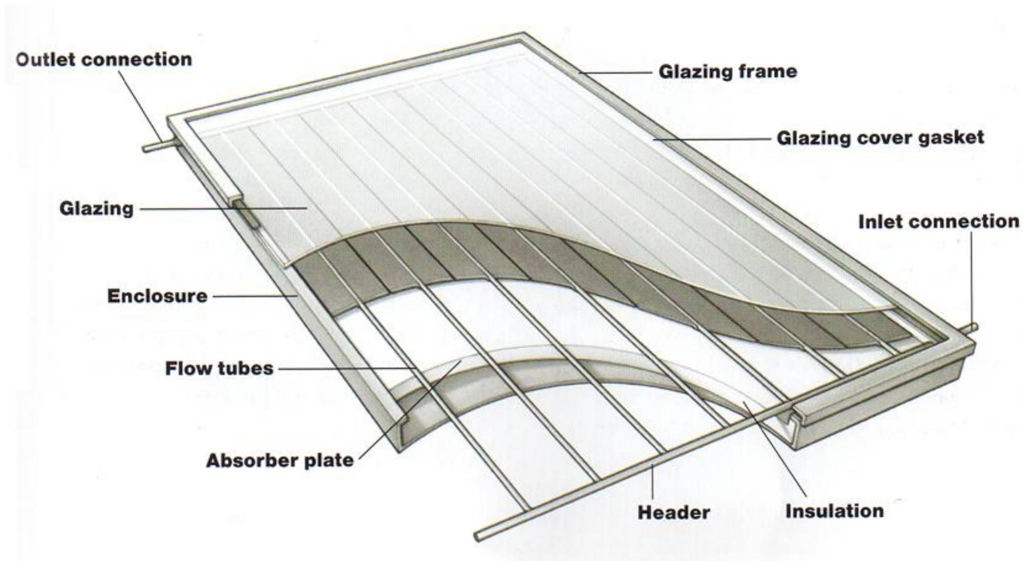


Figure 2-20. Flat-Plate Collector
The figure shows different parts of a typical fat-plate collector
Source: (Johnston & Gibson, 2010)

- **Evacuated Tube Collector** (Fig. 2.21)

"These collectors consist of parallel rows of glass vacuum tubes. Inside, a fin absorbs heat from the sun and transfers it to a liquid medium. Evacuated tube collectors are sometimes specified in cold climates because of their high efficiency. They are more expensive than conventional flat-plate collectors" (Johnston & Gibson, 2010).

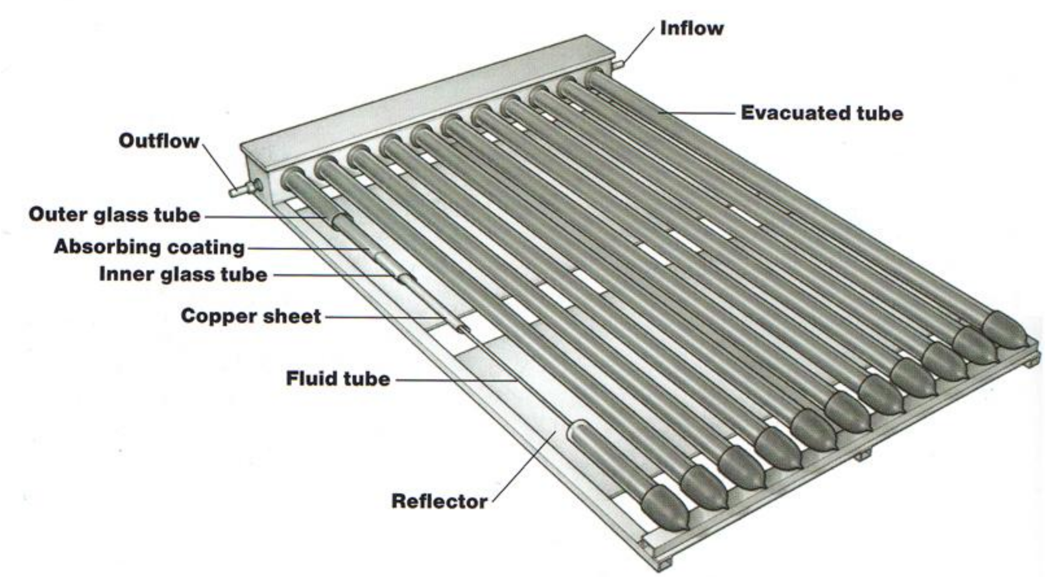


Figure 2-21. Evacuated Tube Collector
The figure shows different parts of a typical Evacuated Tube Collector
Source: (Johnston & Gibson, 2010)

- **Integral Collector (**Fig. 2.22)

"Integral collectors combine solar energy collection and water storage in a single unit. They are the best suited to mild climates" (Johnston & Gibson, 2010).

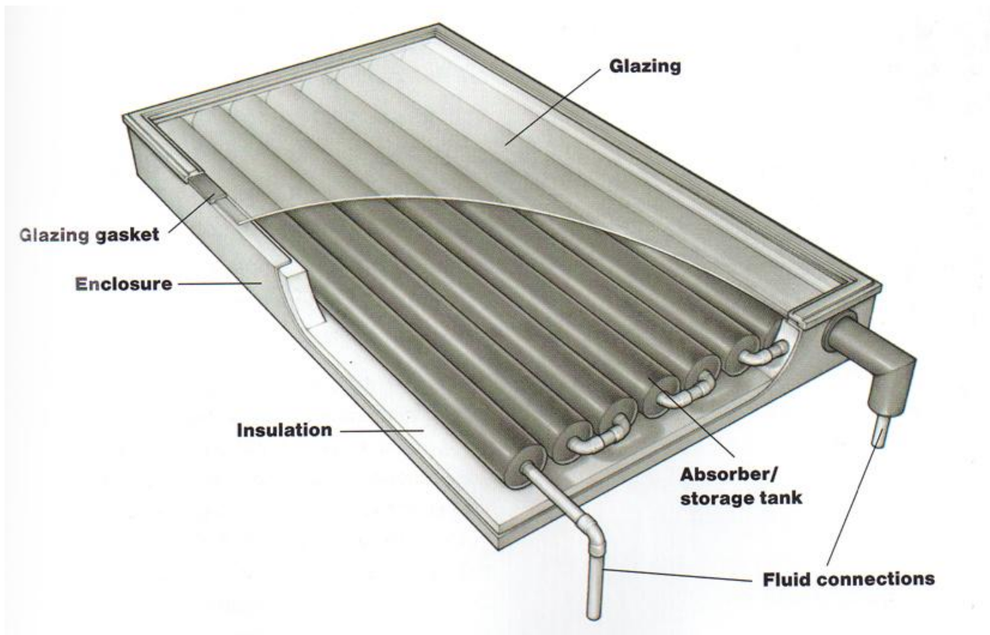


Figure 2-22. Integral Collector
The figure shows different parts of a typical Integral Collector
Source: (Johnston & Gibson, 2010)

- There are some particular hot-water systems that work without the need for pumps called *thermosiphon* collectors. These types "rely on natural convection to move water from the collectors to a storage tank, which is located above the collector" (Johnston & Gibson, 2010). The collector in this approach can be flat-plate or evacuated tube collectors (Fig. 2.23).

Figure 2-23. Thermosiphon Collectors
Source: http://www.chinasolarheater.cn

Considerations for these devices are the same as photovoltaic panels. One of the most important points in designing solar water heating systems is that the heating system is usually used in winter; as a result, the optimum angle for positioning the panels often is set based on the sun's path in the winter in that particular place. The difference between the angle of photovoltaic panels and solar water heating panels in some cases is caused by considering this fact (Fig. 2.24).

Figure 2-24. Yannell House, Chicago.
The figure shows different angles of installing photovoltaic panels and hot water collectors
Source: www.theyannellhouse.com

2.7.3. Wind Harvesting Systems

There are three types of turbines for taking advantage of wind power: the horizontal axial propeller, the vertical axial Darrieus and Savonius turbines (Figures 2.25, 2.26, 2.27 and 2.28). These three types include some sub divisions but the total function is almost the same (Denoon, 2009). The Horizontal Axis type as mentioned before is the type which is usually used in large scale production of energy.

Figure 2-25. Bergey Excel Horizontal Axis
Source: (Denoon, 2009)

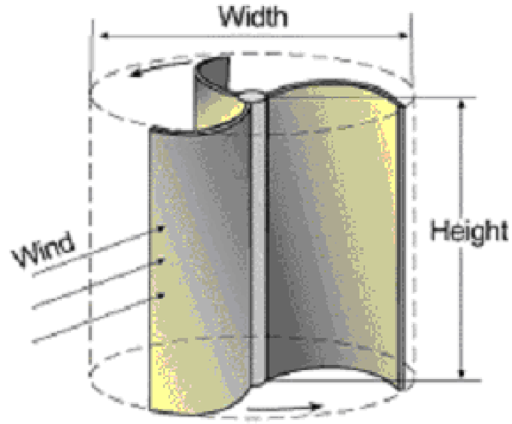


Figure 2-26. Vertical Axis Rotor
Source: www.tfcenergy.com/the-technology

Figure 2-28. Turby twisted Darrieus wind turbine
Source: (Denoon, 2009)

Figure 2-27. PAC Wind H-Darrieus wind turbine
Source: (Denoon, 2009)

In a recent article some of the members of CPP (Denoon, 2009), Wind Engineering and Air Quality Consultants discuss the benefits and practical aspects of using wind turbines in tall buildings. In a sense they unconsciously contribute to developing high-rise net-zero residential buildings despite the existing urgency of building net-zero single dwellings. The authors introduce key factors in designing and integrating wind turbines into tall buildings. There are some key points in utilizing wind turbines in building design. The direction of the wind we aim to use for generating electricity is the most important and basic key in utilizing the wind turbine for buildings. Basic equation of wind power generation indicates that the power output of a wind generator scientifically depends on these factors (Denoon, 2009):

1. Air density, kg/m3
2. Wind speed approaching the wind turbine, m/s
3. Wind turbine efficiency
4. Projected area of the turbine

Considering these factors, the designers can increase the generated power of the turbines with their design. The wind speed and projected area of the turbine can be modified by the architectural design. Modifying the environment indeed is the key here to increase the efficiency of the design. “Shaping of tall buildings can be used effectively to enhance the performance of wind turbines” (Denoon, 2009). One examples of this is the Pearl River Tower in China (Fig. 2.29). “In the Pearl River Tower slots through the tower are used to relieve the pressure between the front and rear faces of the tower with these slots being aerodynamically shaped to increase flow through them. Again, this approach is most efficient for only a few wind directions but has the advantages of not only accelerating the flow but by the compressing nature, decreasing turbulence” (Denoon, 2009).

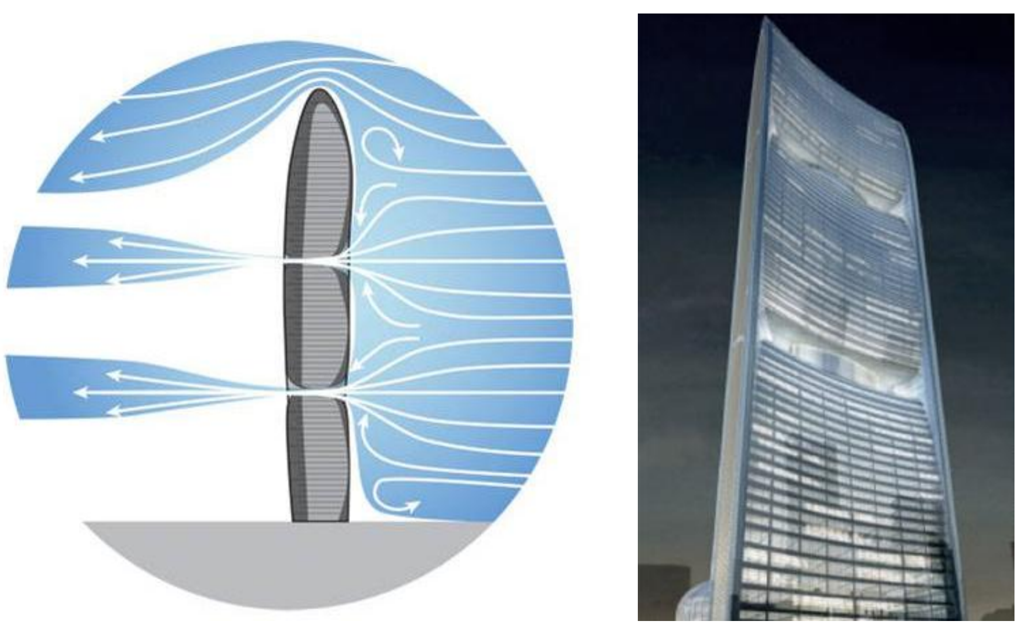


Figure 2-29. Pearl River Tower, China - The design contributes to the wind turbines to produce energy
Source: www.sustainabledesignupdate.com - www.greendiary.com

“It is desirable to locate turbines in regions of high wind speed and low turbulence... Turbulence intensity is the ratio of the fluctuating velocity to the mean velocity and is a measurement of the gustiness of the wind” (Denoon, 2009). The wind harvesting system is probably not suitable for single dwellings or even low-rise buildings because of initial expenditure on its system, including the turbine and low speed of the wind. Hence going to higher elevations makes a better environment for taking advantage of the wind power. In this sense high-rise buildings are potential targets for net-zero residential developments.

2.7.4. Geothermal Heating and Cooling System

Geothermal heating and cooling system for homes is a relatively new system which can be almost utilized in all places. The water in geothermal systems can be directly used for heating system or can be used to heat or cool the air for air conditioning system.

- **Heating**

During the winter, heat from the ground is absorbed by a water solution as it circulates through pipes in the ground. The warm water is carried into the home where a water-to-air heat pump concentrates the thermal energy and transfers it to air in a conventional ductwork system, which is circulated to heat the home (Fig. 2.30). A water-to-water geothermal heat pump can utilize the same heat energy for a hydronic radiant floor system or domestic hot water heating. “During the heating cycle, the fluid circulates through the loop extracting heat from the ground. The heat energy is transferred to the geothermal unit. The unit compresses the extracted heat to a high temperature and delivers it to your home through a normal duct system or radiant heat system”[13].

[13] Source: http://www.blackwellhvac.com

- **Cooling**

"For cooling, the process is simply reversed. Because the earth is much cooler than the air temperatures on a hot day, the geothermal system removes heat from the home and deposits it into the ground. The fluid is cooled by the ground temperatures and returned to the unit for cooling your home"[14]. A geothermal heat pump transfers heat from the air back to fluid in the ground loops and back to the earth. The cooled air is then dispersed into the home (Fig. 2.30).

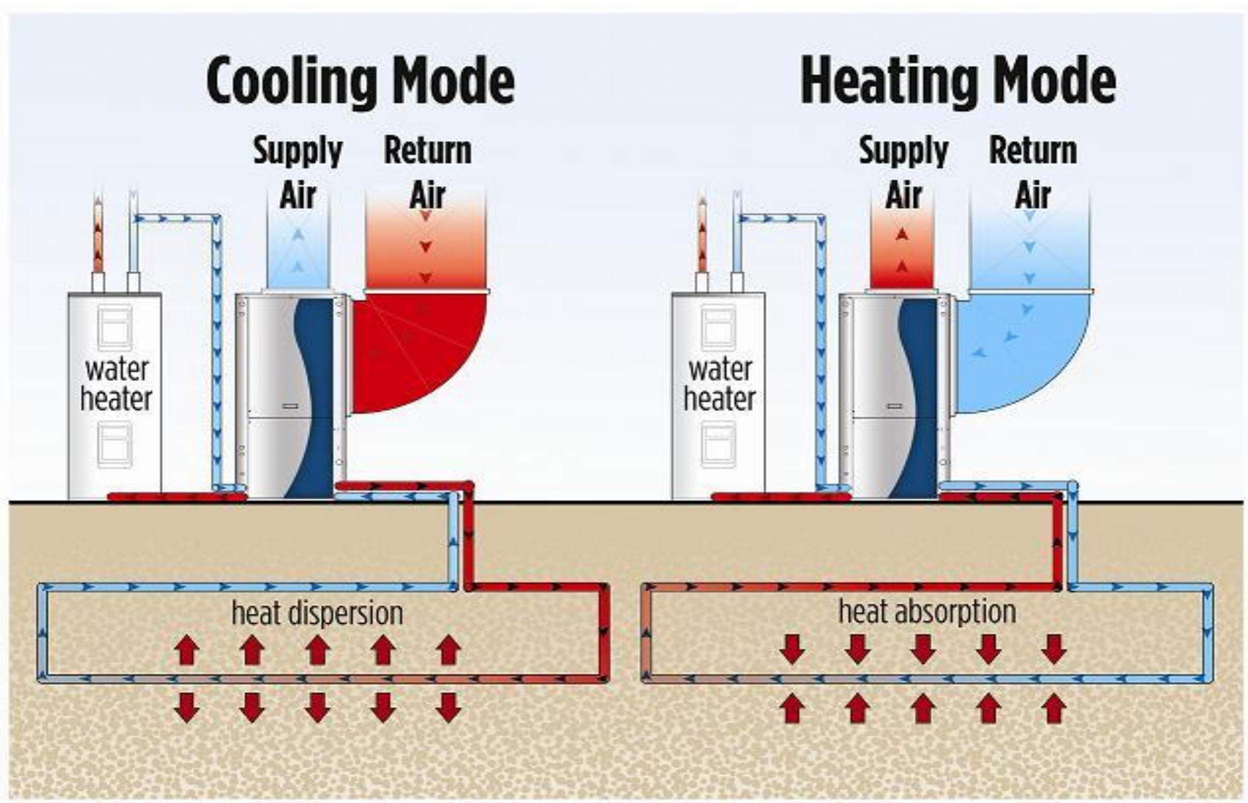


Figure 2-30. Geothermal Heating and Cooling Systems
Source: www.platinumleedhome.com

2.7.5. Hydroelectric power

It rarely happens that a building has access to flowing water to make use of, especially for residential ones. It will be probably the case for particular residences within a natural area or

[14] Source: http://www.blackwellhvac.com

for large-scale projects that cover a whole region such as mega projects that are constructed in the Emirates (e.g. Dubai Marina, U.A.E).

In fact this type of producing energy has not been developed for residential projects according to abovementioned reasons and also high initial cost of installations. There is a system called "pumped-storage hydro power" that can be used for any project even without direct access to the water (Gevorkian, 2008). This system includes two storage places at different levels, thus the gravity can be used to circulate the water in the system. In this case micro hydroelectric turbines should be able to at least provide the required electricity for pumping water to the higher level (Fig. 2.31).

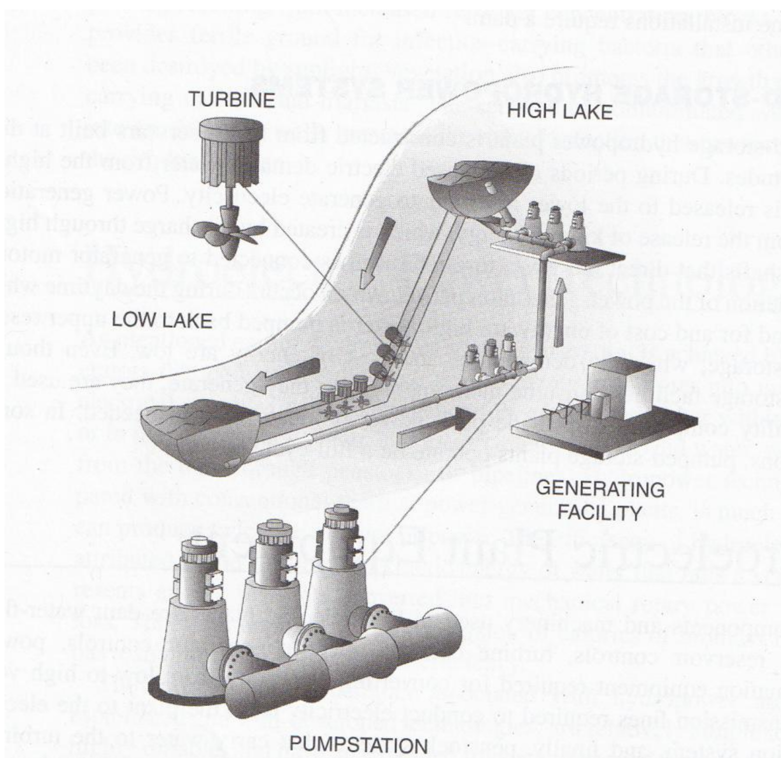


Figure 2-31. Artificial Water Circulation
Source: Alternative energy systems in building design

2.7.6. Biogas Heating System

Biogas systems as described before make use of wastes. This is the reason that it is listed here despite the fact that it is contrary to the net-zero definition which indicates zero carbon emissions as a factor for net-zero buildings. It cannot be ideally accepted for “net-zero” projects (e.g. in Canada) but in a sense it can be used as a mean to unplug the buildings from the grid power. In this system released gases are burnt to heat water for the heating system (Fig. 2.32). Hence there will be some CO2 emissions while it is considerably less than the combustion of other fossil fuels.

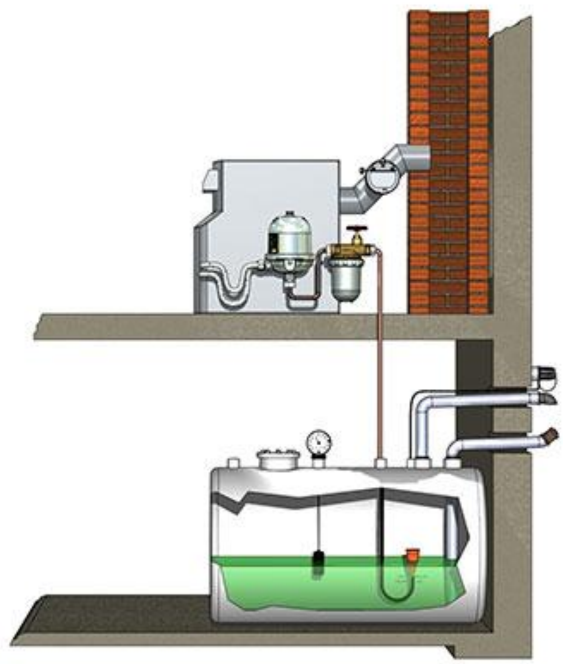


Figure 2-32. Biogas Heating System for Homes
The figure shows different parts of a biogas system including the tank (down) and the burning device (up) in which the water is heated
Source: www.johnson-pump.com/tigerholm

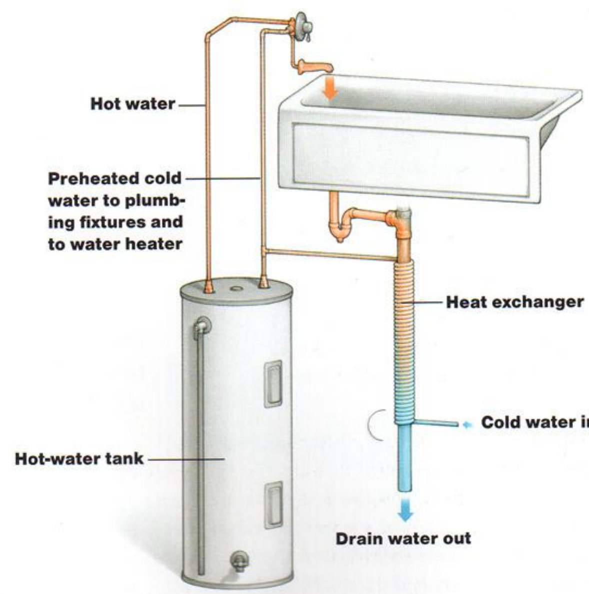


Figure 2-33. Drain Water Heat Recovery System
The figure shows different parts of a simple water heat recovery system.
Source: (Johnston & Gibson, 2010).

2.7.7. Drain Water Heat Recovery

“Hot water takes a lot of energy with it when it goes down the drain. In a drain water heat-recovery system, a heat exchanger made from copper tubing picks up heat that would otherwise be lost and returns it to the hot-water supply. Systems without a dedicated storage tank work only when hot water is being drawn at the same time it is discarded, as is the case when someone is taking a shower (Fig. 2.33)” (Johnston & Gibson, 2010).

2.7.8. Insulation Technologies

Conservation of energy produced on site is an inseparable part of the zero energy design. It simply means making use of produced energy as much as possible. Thus the building envelope is an important part of this procedure. The energy which was used for heating or cooling the building can be easily wasted by improper thermal insulation of the envelope. Nowadays insulation techniques have become a very vast area of research and development. There are various types of insulation techniques for the building envelope. There are many companies with different exclusive techniques or materials for thermal insulation. In fact, which type of insulation is used for a building is not as important as having a cohesive insulation for all parts and ensuring a proper sequence of priority for insulated surfaces. Firstly, if the insulation of one part (e.g. windows) is less efficient than the other parts it will be a point for losing energy, although walls, for instance, have the best technologies of insulation. This aspect is very important in terms of economy of the project, thus architects should distribute the budget over different parts wisely. It is also important to know which parts need more attention for insulation. For instance the roof is the most important part if it is directly in touch with the outside—it is not that important in units located between two other residential levels. In terms of exterior walls, different walls are not in the same range of importance. Generally the northern part of the building -in northern hemisphere- which does not get adequate sun is very important to be well insulated thermally. In projects that target energy efficiency, the windows on the northern facade are different from the windows on the southern facade. Since openings are related to architectural design, they will be discussed under architectural techniques. Two important aspects in thermal insulation are air tightness and conductivity. R-Value and Air Infiltration are related to air tightness and conductivity respectively and will be discussed below.

- **R-Value and Air Infiltration**

“An R-value is a measure of a how much time it takes 1 Btu of energy to pass through a given material” (Johnston & Gibson, 2010). Air infiltration means the ability of insulation to prevent air and moisture infiltration. “When evaluating an insulation product, it is important to look more than just the R-value of the product. Because the available R-value rating for insulation materials do not account for the affects of air movement" (Johnston & Gibson, 2010). Indeed insulation systems such as polyurethane foam have much higher performance than their actual R-value (Johnston & Gibson, 2010).

- **Glazing**

Windows which were introduced as an important part of insulation have different rates of performance. "To assess widow energy performance, NRCan has established the Energy Rating (ER) System, which takes into account the thermal properties of the frame, sash and glazing. It provides an easy-to-understand method of comparing windows, where a positive ER number means a window gains more energy than it loses, and a negative number applies to net energy losers"(Friedman, 1996). Figure 2.34 shows two examples of high performance windows with double and triple glazing systems.

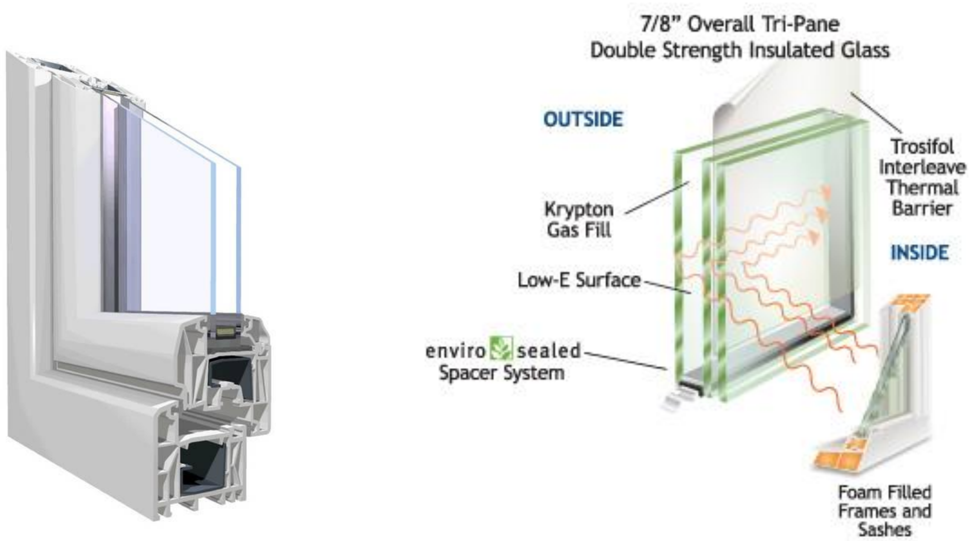


Figure 2-34. Different parts of thermal windows
Right: Double-glazed PVC window – Left: Triple-glazed PVC window
Source: www.americanjewelwindows.com

- **Walls and Floors**

In apartment buildings, insulation of shared walls and floors are not that important and exterior walls including openings are the primary concern. However it is the case when different levels have different ownership because it might be possible that some units remain vacant while the others are occupied. Thus the energy is wasted through the surfaces which are connected to those units. In exterior facades different types of walls can be used such as thick-wall, wrap-and-strap, double-wall and truss-wall (Friedman, 1996). Figure 2.35 shows the insulation of a typical truss-wall. However each system imposes particular expenses on the project which should be considered. In some cases architects use innovative materials or techniques for thermal insulation to achieve both energy efficiency and for economic aspects. A good example is the approach used in the Grow Home considering both financial and functional aspects (Friedman, 1996).

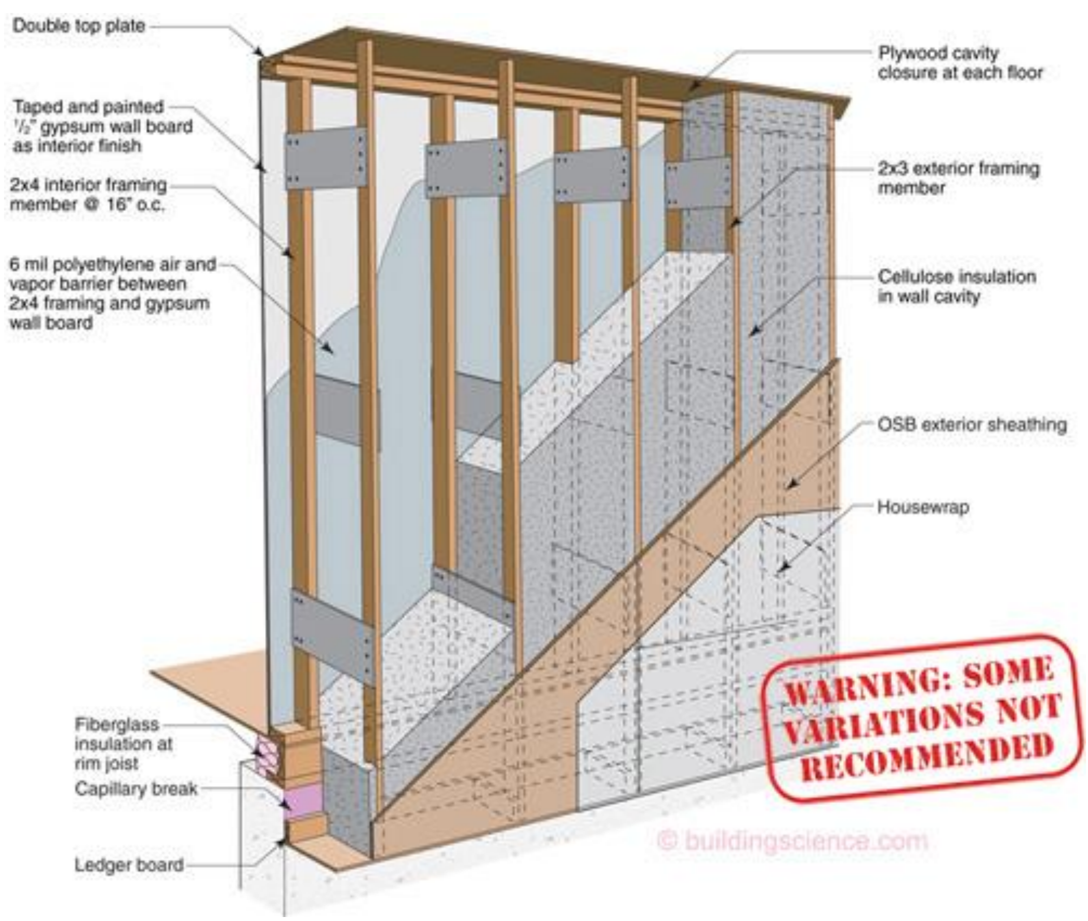


Figure 2-35. Sample Insulation technique for truss walls
Source: www.buildingscience.com/documents

2.7.9. Energy Efficient Appliances

Using energy efficient appliances is a key factor in net-zero buildings. In fact reducing the consumption of energy helps to reduce investment on producing energy. Nowadays appliances are ranked in terms of efficiency of their energy consumption in many countries. The notion of using energy efficient appliances for homes has had a profound impact on the market. Indeed it is a standard for appliances to have this label in developed countries (Fig. 2.36). Energy star is one the famous standards in Europe and North America which is supported by their governments (Fig. 2.37). "The ENERGY STAR® program has been a tremendous success in its first decade. Established by the U.S. Environmental Protection Agency (EPA) in 1992 for energy-efficient computers, the ENERGY STAR program has grown to encompass more than 35 product categories for the home and workplace, new homes, and superior energy management within organizations"[15].

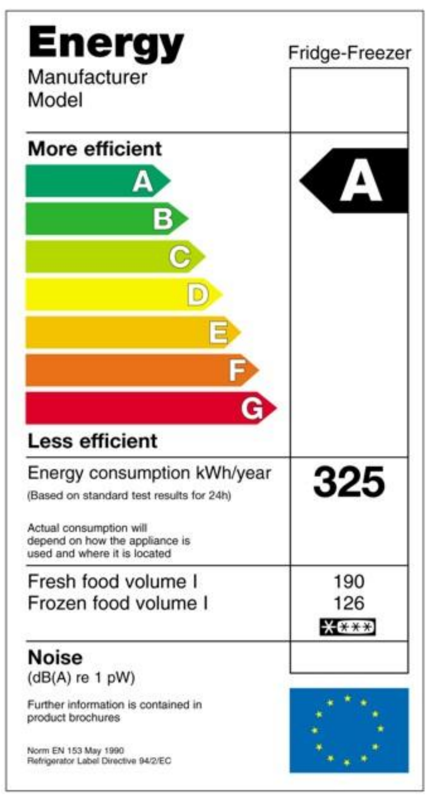


Figure 2-37. Energy Efficiency Label; England
Source: www.fareham.gov.uk/council/departments/housing

Figure 2-36. Energy Star for appliances
Source: www.energystar.gov

[15] United States Environmental Protection Agency. www.energystar.gov

2.7.10. Smart Energy Controlling Systems

Controlling the temperature and energy usage in the building is of high importance. But it is not the only requirements in a net-zero home; there are several other items that should be controlled manually or automatically to keep the performance of the home high enough. Currently there are many different types of controlling and monitoring energy systems that can be installed. They vary from simple energy indicators to complex energy managers that can be programmed to save energy in homes. Figure 2.38 shows a relatively advanced controlling panel that can control different parts in the house.

Figure 2-38. Energy controlling panel
Source: http://www.archithings.com/wp-content/uploads/2009

2.8. Architectural Design Techniques in Net-Zero Buildings

Design techniques used by different architects cannot be comprehensively gathered and observed according to their variety and vast usage; however there are certain scientifically proven and customary design techniques which will be introduced.

2.8.1. Passive Solar Design

Passive solar design (PSD) simply includes design techniques to take advantage of the sun's heat when it is beneficial and to avoid it when it is disrupting. PSD can be considered as the cheapest and the most cost effective factor in net-zero buildings. Applying PSD in homes in colder climates can reduce the heating load by up to 60 percent (Johnston & Gibson, 2010). Passive solar design can be achieved by using any technique that leads to allowing the sun rays in or blocking them when is required according to the climate condition at different times of the year. PSD directly depends on the sun angle at different times of the year. PSD only works when south-facing windows are shaded during the summer.

Overhangs are the most common features in PSD that can thoroughly do this job for architects. One early example of using overhangs in a very sophisticated way is Wright's Home in Oak Park, Illinois designed by Frank Lloyd Wright (1867- 1959) in the late 19th century (Fig. 2.40). While designing overhangs the architects should be familiar with the sun path diagram that was introduced in this chapter. In fact the designers should consider that the sun reaches the lowest point in the sky on December 21; in contrast, it reaches its highest point on June 21 (Johnston & Gibson, 2010). The best design also is concerned with the duration that the sun rays can enter the building. Figure 2.39 shows the simple rule of designing overhangs that can block the sun's heat in the summer and allow them to enter during the winter. Moreover, there are some important aspects in solar design that directly contribute to passive solar design which are introduced.

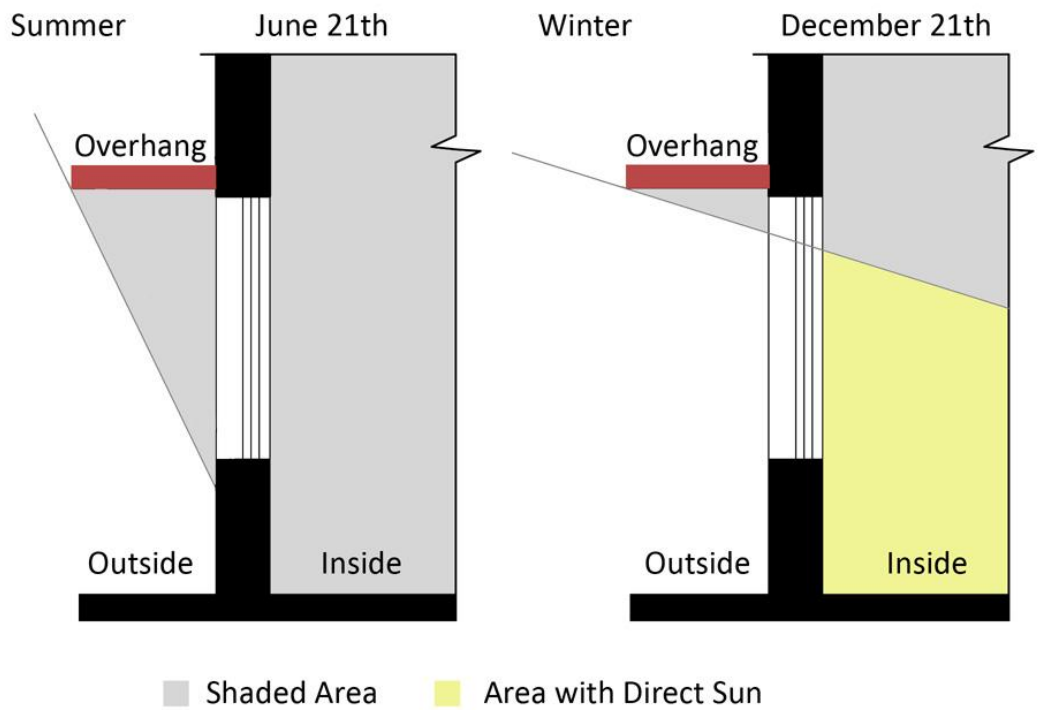


Figure 2-39. Overhangs Performance in the Summer and Winter
The figure shows how the overhangs can block the sun in the summer (the highest point here June 21th) and allow penetration in the winter (the lowest point here December 21th)

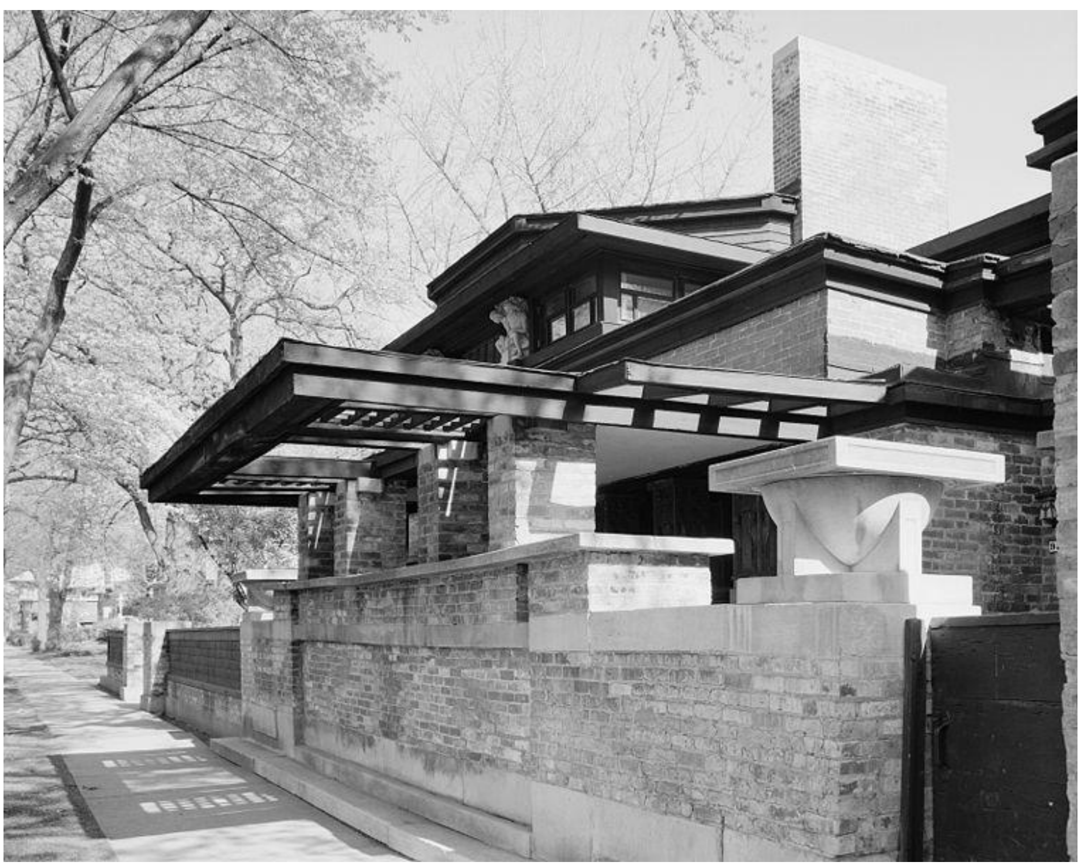


Figure 2-40. Wright's Home in Oak Park, Illinois; by Frank Lloyd Wright
Source: http://www.essential-architecture.com

- **Orientation**

The orientation of the building is one of the first steps in the passive solar design. If the building is not oriented correctly it will not work properly with PSD. The right orientation for the building is to situate as much spaces as possible to get south sun. In a very simple example which is shown in Figure 2.41 the building should face the south or with the maximum angle of 30 degrees with the south direction. In the 30 degree situation the south facing facade is still provided with 90 percent of the potential solar gain (Johnston & Gibson, 2010). Further than 30 degrees can in fact make the shading analysis hard which will be discussed in the shading analysis section. As it can be seen some windows will not have direct sun when the sun moves.

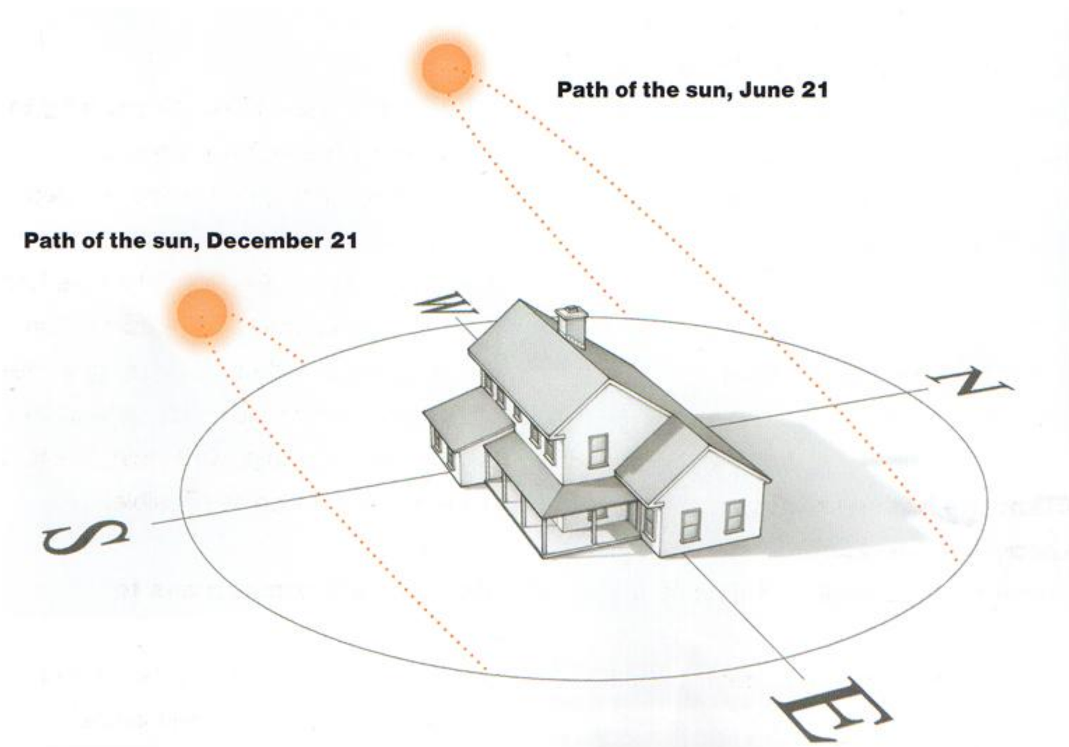


Figure 2-41. Solar Orientation
The figure shows a simple example of a correct orientation
Source: (Johnston & Gibson, 2010)

- **Shading Analysis**

Shading analysis is important to be studied with regard to the sun's movement. The afternoon sun, for instance, can create some shaded areas on a facade which means that some windows do not receive sunlight. This becomes complex when the floor plan is not as simple as the one in Figure 2.41 and there are some angled walls and volumes. Thus the architects should analyse the facade with different sun angles to find the best orientation and interior arrangement as well.

- **Openings**

There are two important aspects about openings which mainly include windows. The first is the orientation of windows, which was discussed before, and the second one is their size. As a rule, achieving the best passive solar design, the architects should put a proper amount of openings toward the south, limit windows on western and eastern elevations and avoid using windows facing the north (Johnston & Gibson, 2010). This indeed enables the building to gain southern sun that can be converted to an appropriate passive solar design by its integration with proper overhangs. Figure 2.42 shows a net-zero house that implemented the principles of passive solar design in terms of openings size.

Figure 2-42. Yannell House, Chicago.
The figure shows the example of different attributes of southern and other elevations
Source: www.theyannellhouse.com

- **Thermal Mass**

Thermal mass is the other factor that is related to solar design and passive solar design accordingly. “Thermal mass is any dense material that absorbs heat during the day and release it at night after the sun has set...Thermal mass allows for more glass and greater passive solar contribution to winter heat and a higher performance home overall”(Johnston & Gibson, 2010). Thus thermal mass is a material that has its outer surface exposed to the sun rays and inner surface inside the home (e.g. any cladding material which is not insulated thermally such as a brick wall). Using the right material at the right places is what architects can consider in their design. The important thing is that “only the first 4 inch -almost 10 cm- of thermal mass is effective in storing and releasing heat, and greater thickness yields little additional benefit” (Johnston & Gibson, 2010). Figure 2.43 shows some customary materials and their attributes in terms of thermal mass design.

Material	Btu/°F per Square Foot (4-in. depth)
Water (reference)	20.8
Brick pavers	9.0
Poured concrete	8.8
Flagstone	8.5
Concrete masonry units	8.4
Builders brick	6.5
Adobe	5.5
Hardwood	1.7

Figure 2-43. Thermal Mass Heat Storage Capability of Common Building Materials
“If the thermal mass is less than 4”, divide the listed chart figure by the thickness of the product is used. For instance a 2” of builder brick yields 3.25 Btu/Square Foot”
Source: (Johnston & Gibson, 2010)

2.8.2. Natural Lighting

Taking advantage of natural light could have a profound impact on reducing energy consumption for lighting. As it is clear, situating spaces in a way that they can gain daylight helps to decrease their dependency on artificial lighting. In houses that have limited sides with access to natural light (e.g. semi-detached houses) it is challenging to have all the interior spaces with natural light. This issue will be discussed in the third chapter through the case study.

2.8.3. Natural ventilation

Natural ventilation is one of the techniques that can help have fresh air inside the building without using mechanical air conditioners. It can also help the cooling system in the building in a sense because moving air can simulate a feeling of a cooler temperature than what its actual temperature is. It works simply with the main principle of air pressure difference: cold air has a higher pressure and goes down, and warm air has a lower pressure and rises up. Thus, with the difference between warm and cold air pressures, there will be an air movement from higher pressure zone (cold air) to lower pressure zone (warm air). In a house, this air movement will be

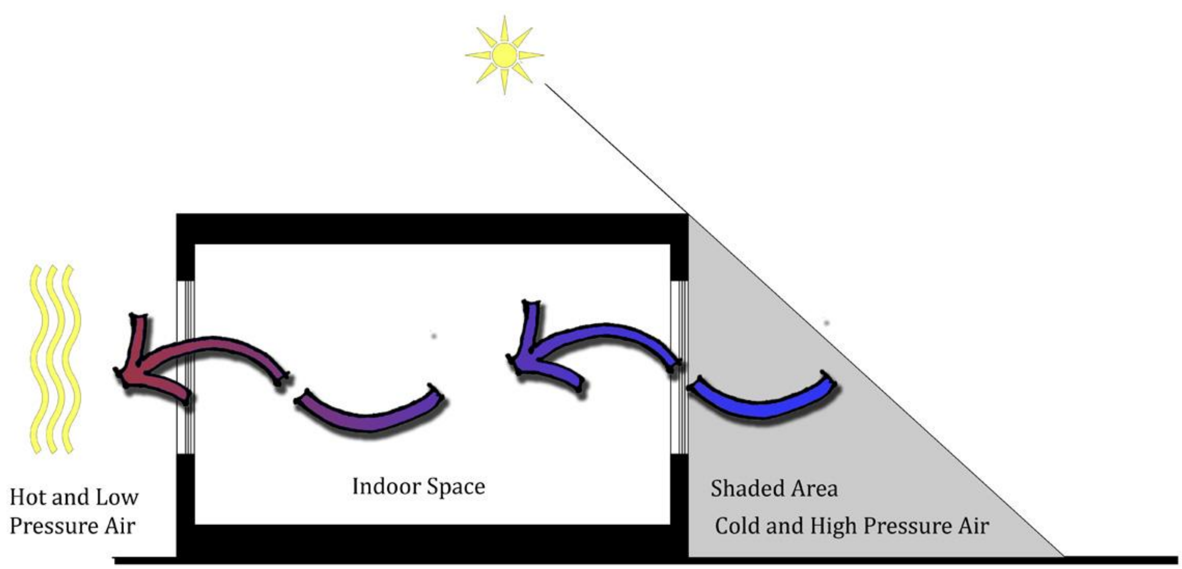


Figure 2-44. Natural Ventilation
The figure shows the simple principle of natural ventilation – the air moves from the shaded side to the other side

from the northern side which is a shaded area to the southern side which has south sun (Fig. 2.44). It also gives the designers the opportunity to work with a vertical air movement which is very helpful in multi-storey houses that have connected spaces on different floors. In this case there will be an air movement from the first floor to the next ones (Fig. 2.45).

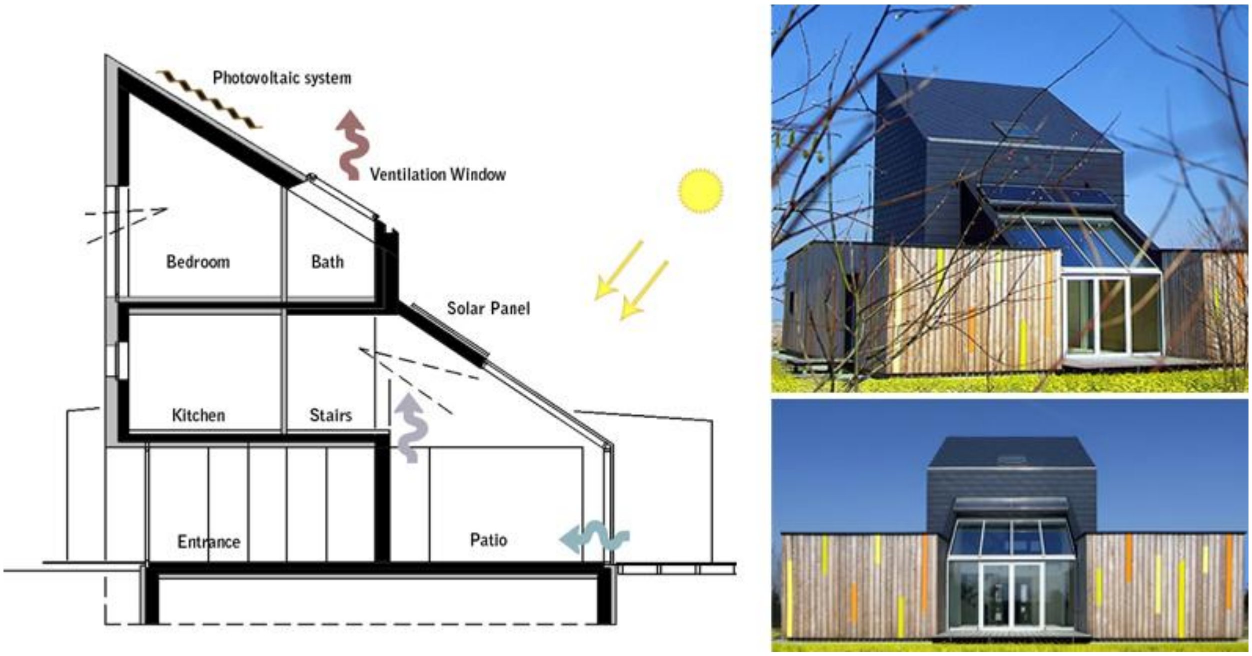


Figure 2-45. Natural Ventilation in Co2 Saver House, Poland – By PETER KUCZIA
Source : http://www.kuczia.com - www.archdaily.com
The section is created by the author based on the designer’s concept

However, in multi unit buildings that do not have two opposite open facades, natural ventilation will be more complex. In this case using vents or air shafts are very customary; “apartment buildings typically rely on a building-wide ventilation system that pulls stale air out of each apartment via bathroom and kitchen vents and ducts it to a common exhaust at the top of the building” (Johnston & Gibson, 2010). Natural ventilation in apartment buildings will be discussed in the third chapter in more detail.

2.8.4. Other Strategies

As it was mentioned before there are many design techniques that can be used in designing net-zero buildings. There are some other important techniques such as using green roofs or using doubled envelopes that have been employed by architects in different projects. Green roofs, as a very effective technique, are beneficial in terms of energy and green space, as well as environmental impact (Fig. 2.46). Green roofs indeed work as a thick insulation layer that prevents the building from being heated by sunlight and it can also create high quality spaces on the roofs. Green roofs are also environmentally beneficial in cities; absorbing the sun's heat they can reduce the "urban heat island"phenomenon in the cities. In addition, green roofs can be integrated with the concept of "urban agriculture" to produce different types of vegetables and fruits within the cities.

Figure 2-46. Green roof of a Residential Highrise Apartment Building in Downtown Portland
The green roof is a combination of intensive and extensive plants
Source: Photo courtesy of Green Roofs for Healthy Cities - http://www.msnbc.msn.com/id

Chapter 3

Case Study

Net-Zero Senior Housing Project

Vancouver Olympic Village, Canada

3.1. Introduction

This chapter discussed the case of the Senior Housing Project, an apartment building in the Olympic Village, Vancouver. The case study is based on the analysis of architectural documents, an interview with its architect[16], and visits to the project. Some other sources are also used for specific details such as related websites. In fact this research might entail more than one case to be studied; however, some factors made the author choose only one case for this study. Because of the limited length of this report, if more case studies were to be included, each case would not be done justice. The other reason being that there are not many net-zero apartment buildings around the world, which have been primarily designed to be net-zero. Many projects that do exist, or might exist, rather, are either still in the design process or under construction. Furthermore, some of the cases have been renovated later and equipped with certain features to achieve net-zero goals; as a result, they do not have considerable architectural design techniques. The chosen case for this study is the Senior Housing Project in Olympic Village, Vancouver which was selected because of its location, its importance as a model, and its considerable architectural design in comparison with the other net-zero residences.

3.2. Olympic Winter Games 2010 and the Olympic Village in Vancouver

The Olympics have always been an opportunity for host countries to demonstrate their advancement in different fields, of which architecture is primary. Designing highly advanced stadiums both in terms of technology and design is one of the examples of these demonstrations. However the legacy of the projects has been recently the other point when governments make such an investment. Canada got the opportunity in 1976 to host the Olympic Summer Games in Montreal, as well as in 1988 to host the Olympic Winter Games in Calgary[17]. Canada as one of the leaders in environmental and energy related issues had the chance again to broadcast its achievements by hosting the Olympic Winter Games in 2010. Accordingly, The Olympic Village located in False Creek area in Vancouver was designed as a

[16] On June 25th, 2010 the author conducted an interview with Mr. Stuart Lyon, from GBL Architects.
[17] Canadian Olympic Committee, http://www.olympic.ca

neighbourhood with the required facilities to host Olympic athletes during the Winter Olympic Games 2010 (Figures 3.1, 3.2 and 3.3). The Olympic Village is a very high sustainably thought of and designed project, demonstrating the future of housing projects in Canada. The buildings are planned to be sold to people after the games. Several apartment buildings were designed by different firms to create a unique neighbourhood for the Olympic Games. The Olympic Village has been a site for demonstrating the concepts, achievements and goals of the housing sector in Canada. The tendency to abovementioned environmental concerns has been embedded in some regulations of construction in Olympic Village. One of these regulations is that all the buildings within the site have to qualify for the LEED Gold certificate. All the buildings in the Olympic Village have targeted LEED Gold accordingly, while there is one building that goes for LEED Platinum. This building is an apartment building called "*Senior Housing*" Project.

Figure 3-2. Aerial Photo of the Olympic Village in False Creek Area, Vancouver
The site is marked with a black border.
Source: Bing Maps. http://www.bing.com/maps

Figure 3-1. View of the Olympic Village from the Water
Source: http://www.vancouver-real-estate-direct.com/blog/2009

Figure 3-3. Overview of the Olympic Village.

1. Southern Edge 2. Central Plaza 3. Community Centre 4. Eastern Edge

3.3. Senior Housing Project

The neighbourhood of the Olympic Village includes a community centre, and several high-rise residential buildings organized around a central plaza. In fact the net-zero building is one part of a complex that includes three towers. These three towers are connected at their first two levels above the ground as well as at two parking levels. They also have a rooftop common garden on the third floor which is the space for residents to communicate and get together. The southern tower has 6 levels above the ground, the western one has 13 levels and the northern tower which is the case for this study is a 7 storey building. The whole project is located at the southern edge of the Village and the net-zero building is located on the northern part (Figures 3.4 and 3.5). Although there are some controversial issues about the function of the building and its contrary nature to the definition of net-zero buildings, Senior Housing can be considered as the first constructed net-zero highrise apartment building in Canada which has been primarily designed to achieve net-zero goals. This project has been designed by GBL Architects who designed some other buildings for the Olympic Village as well. The project was conceptualized to initially accommodate athletes during the Winter Olympic Games 2010, and

Figure 3-4. Location of the Project in the Olympic Village
The project and net-zero tower are marked with red and yellow borders respectively.
Source: http://www.vancouver-real-estate-direct.com/blog/2009

then to be used for senior housing after the games. General description of the net-zero Senior Housing project is represented in Table 3.1.

Name of the Project:	**Senior Housing Project, Olympic Village**
Type of Building:	Multi unit Residential Building
Year of start/finish:	Start: 2007 / Finish: 2010
Architect:	GBL Architects INC
Number of Floors:	7 Floors; 5 Residential levels- 2 levels Including Townhouses and Food Store - 2 Parking Levels (under the ground)
Number of Units:	67 units (61 apartments and 6 townhouses) and 1 food store
Type of Units:	Single level and duplex Apartments
Gross Area:	5,100 m2
Structure system:	Concrete
Cladding:	Swiss Pearl, Spandrel Glass and Glass

Table 3-1. General Description of the Net-Zero Apartment Building

Figure 3-5. Net-Zero Senior Housing Project (South-East View) - GBL Architects
Two story townhouses and a food store occupied the first two levels.

3.3.1. Design Process and Alternatives

This project was not planned originally to be a net-zero project. Thus the orientation of the building had been fixed before the decision to make it net-zero was taken. However because this building was oriented towards the south, it was chosen to be net-zero (Recollective Report, 2007). Three design options were proposed for this building and finally one of them was selected to be developed. The three options are compared below regarding their annual energy consumption costs, initial costs and embodied energy test which is assessed by lifecycle cost analysis. The basic design is a typical double-loaded conditioned corridor which has a five centimetre insulation layer outside of its structure (Fig.3.6). This formed the basis for observing the performance of the three options.

Figure 3-6. Basic Design (preliminary Design): Double-Loaded Corridor Building
Source: Recollective Consulting report to Canada Green Building Council, 2007

- **Option A**: Single-Loaded, Unconditioned Corridor

In this option, natural ventilation is considered for a corridor which is single loaded with the major number of units arranged along the south-facing facade (Fig.3.7).

- **Option B:** Double-Loaded Interior Corridor with Increased Envelope Articulation and Ventilation Chimneys

This option targets reducing the envelope area while benefiting from natural ventilation. The disadvantage of this option is that some units do not have direct sun, thus passive solar energy would not be received by these units, consequently increasing the heating demand. However, the use of natural light for the corridors is an advantage in this option (Fig.3.7).

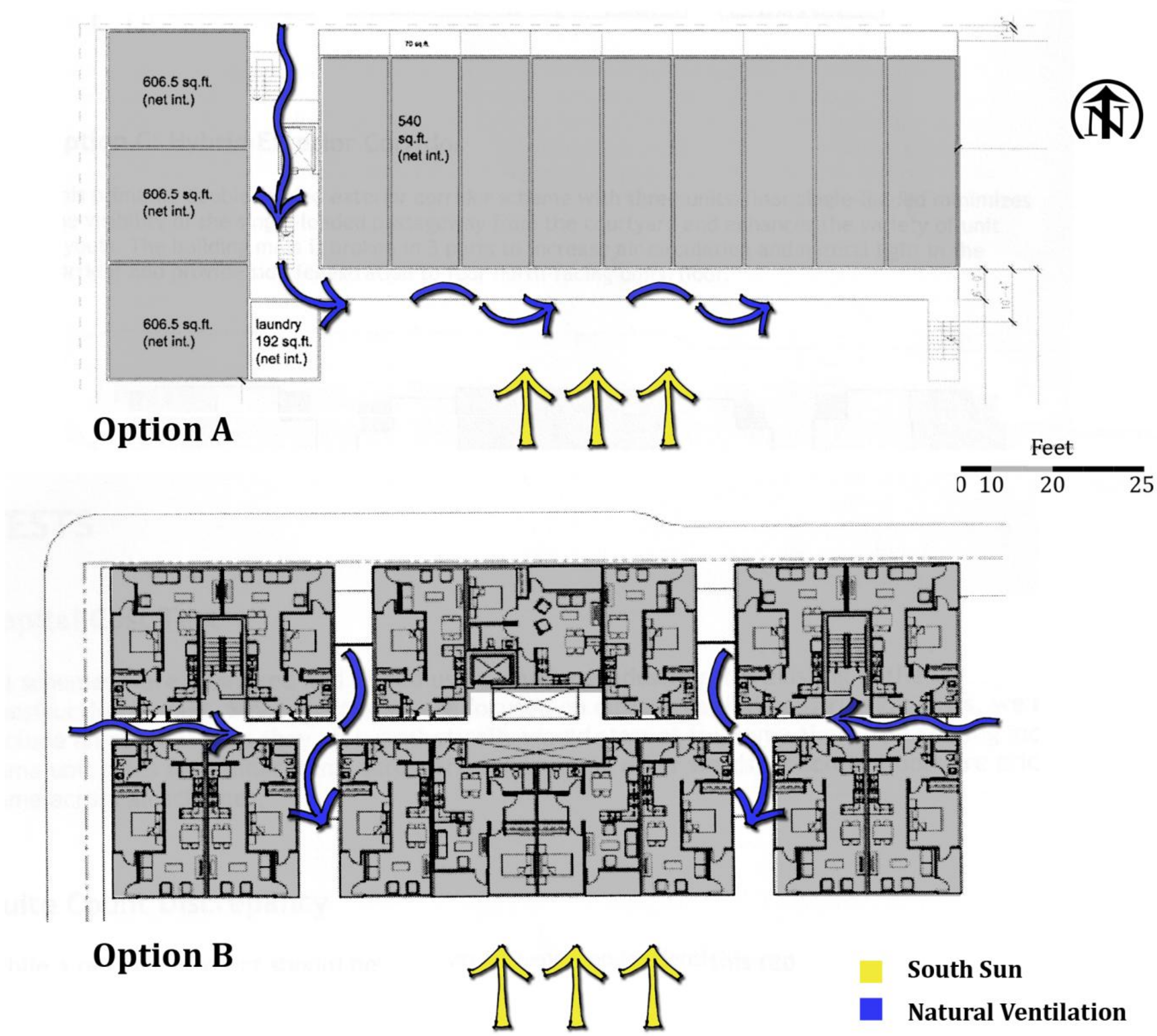


Figure 3-7. Option A and Option B
Paying attention to natural light and ventilation is shown in these options.
Source: Recollective Consulting report to Canada Green Building Council, 2007

- **Option C and C Prime** : Hybrid Exterior Corridor

This option tries to create a balance between economic aspects, architectural values and energy design; however, there are some disadvantages within this scheme. It minimizes the use of natural light and ventilation in comparison with Option A; it utilizes more area at each level which leads to some units without direct sunlight (Fig.3.8). It provides only north-south ventilation which can be more functional and lesser turbulence in the corridors. This option was developed during the design section and it led to another option. The other option which is Option C was finally chosen to be developed as the Senior Housing project due to its attributes and positive points which will be discussed (Fig. 3.8).

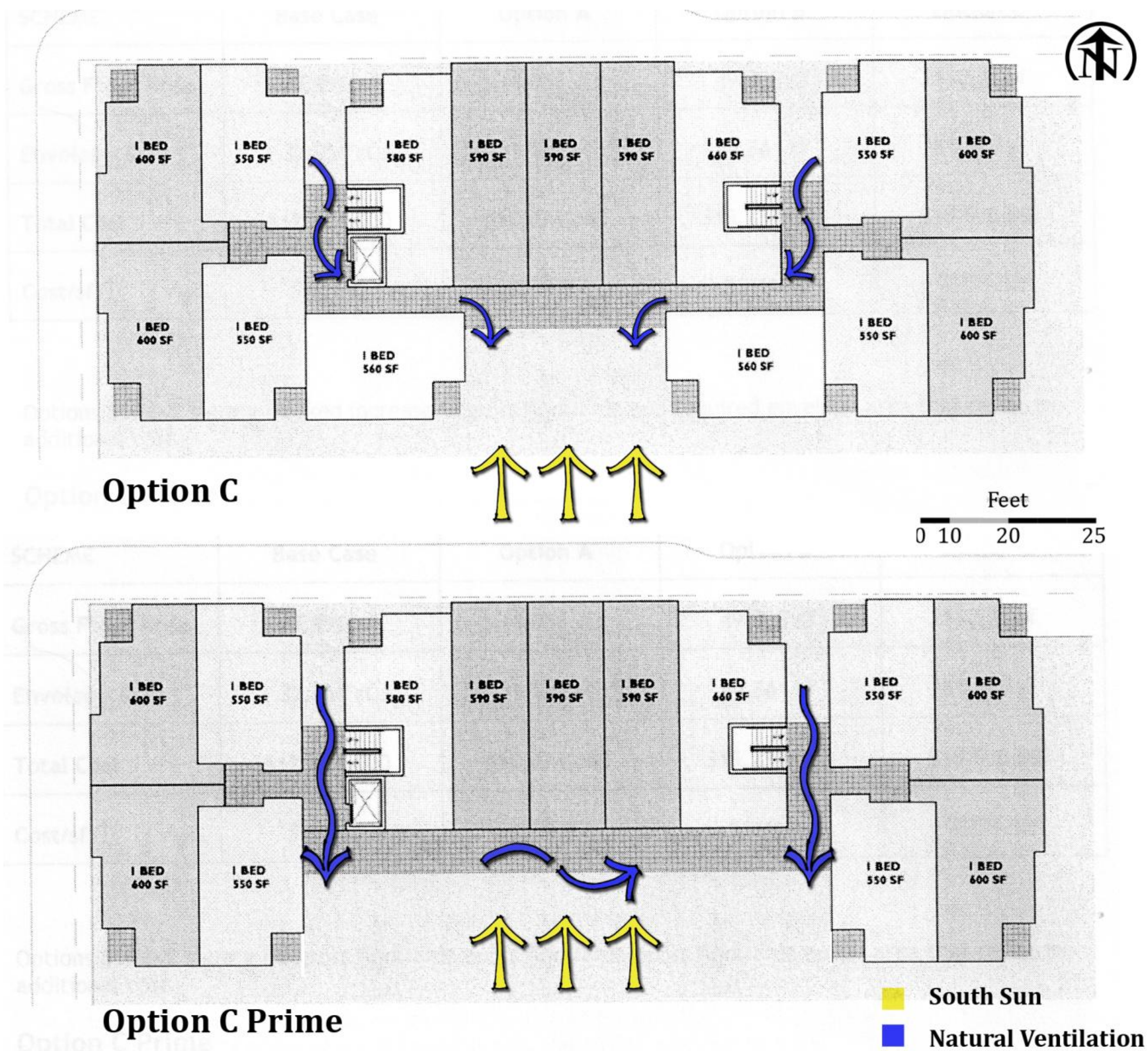


Figure 3-8. Option C and Option C Prime
Paying attention to natural light and ventilation is shown in these options.
Source: Recollective Consulting report to Canada Green Building Council, 2007

- **Analysing the Options**

The options were simulated and analysed in terms of energy matter by the designers and the results of the tests are represented in the tables below (Tables 3.2, 3.3 and 3.4). All the options are considered with the same materials and R values for walls, roofs and windows.

The initial cost is one of the most controversial issues in net zero buildings. As mentioned in chapter one of this study, the cost of adding facilities for generating energy on-site increases the initial expenses of these buildings compared to traditional ones. Table 3.2 represents the total cost of the options based on their gross floor and envelope areas. In fact required utilities for producing energy are not considered in this table. A true comparison can only be done by comparing the cost per unit area (in the table cost per foot). In this view the base option has the best cost per unit area but Option A has an additional cost of $30/square foot which is not significantly high.

Capital Cost Summary

SCHEME	Base Case	Option A	Option B	Option C	Option C Prime
Gross Floor Area	53,990 sf	48,056 sf	49,038 sf	51,231 sf	46,590 sf
Envelope Area	32,057 sf	35,942 sf	44,861 sf	51,620 sf	39,070 sf
Total Cost	$12,414,000	$12,474,000	$15,234,000	$15,030,000	$12,817,000
Cost/sf	$229 93	$259 57	$310.66	$293.38	$281 31

Table 3-2. Total Cost of the Options without Considering Utilities
The base case and the closest option which is Option A are marked with red boundary
Source: Recollective Consulting report to Canada Green Building Council 2007

As shown in Table 3.2, initial costs, excluding utility costs, can be estimated by the total floor area and envelope area. In this comparison, the basic design seems to be more economic in terms of initial costs but Option A and C Prime are still close to the base option. By analysing the required annual energy, which is represented in Table 3.3, the efficiency of option A, C and C Prime is understood. These three options reduce the required annual energy to almost one third of the basic design. Besides, the important factor defining the real cost of the building is not the initial cost; it is the cost of the building during its life cycle including maintenance fees, which is represented in Table 3.4. As this table shows Option A and Option C Prime have respectively the lowest life cycle cost for a period of 30 years. After all, Option A and C Prime are very efficiently close but Option C Prime was selected to be developed for the next phase. In fact Option A has better performance levels, lower costs and maintenance fees, so it is not clear why the architects selected Option C Prime. An increased number of units per level, increased accessibility of units because of two staircases, and probably design qualities could be some of the reasons that made the team continue with Option C Prime.

Annual Energy Expenditure

OPTION	BASE CASE	OPTION A	OPTION B	OPTION C	OPTION C PRIME
Total Energy Consumption(kWh/suite)	8,664	2,727	7,165	2,792	2,792

Table 3-3. Annual Energy Expenditure of the Options
Source: Recollective Consulting report to Canada Green Building Council, 2007

NPV Results

OPTION	BASE CASE	OPTION A	OPTION B	OPTION C	OPTION C PRIME
NPV:30 years	$17,037,000	$13,363,000	$18,656,000	$15,998,000	$13,696,000

Table 3-4. Life Cycle Cost of the Options (NPV) for 30 Years
Source: Recollective Consulting report to Canada Green Building Council, 2007

Some Basic Key Points primarily in the design section which lead to reducing energy consumption as well as reducing initial costs of the project are as follows:

- Reducing the gross floor area by minimizing waste spaces and common areas
- Reducing the envelope area by using shapes with less envelopes area and more floor area
- Reducing the non south-facing openings
- Increasing natural ventilation and natural lighting usage for common areas

3.3.2. What Type of Net-Zero is this Building?

The first step in analysing the building is to identify that what type of net-zero the building is according to the designer's claim. As mentioned in the report submitted to Canada Green Building Council (Recollective Report, 2007), the main focus of the challenge in designing this building is zero energy consumption.

The basic formulation for a net-zero building according to net-zero definition is:

Annual Consumption Loads = Annual On-Site Energy Production

This building cannot produce electricity because the option of photovoltaic panels has been replaced by evacuated tubes which produce hot water. In this condition, the building buys electricity from the grid and sells hot water to the neighbourhood utility system. Thus the cost of purchased energy should be equal to the income by selling the surplus:

Supplied energy (Lighting + Heating + Electricity) costs from the grid = Exported energy Price

The imported energy is in "Mega Watt Hours" (MWHrs); therefore, the exported energy is calculated in the sane unit to allow for comparison of amounts. The total produced energy is 434.81 MWHrs (which will be studied in detail later) and the required energy is 374.37 MWHrs, thus the building has a positive energy balance annually, at least on paper (Fig. 3.9). However the real situation can be different from calculations on paper and that positive balance which is about 60 MWHrs could be considered as the changes in energy usage by different users.

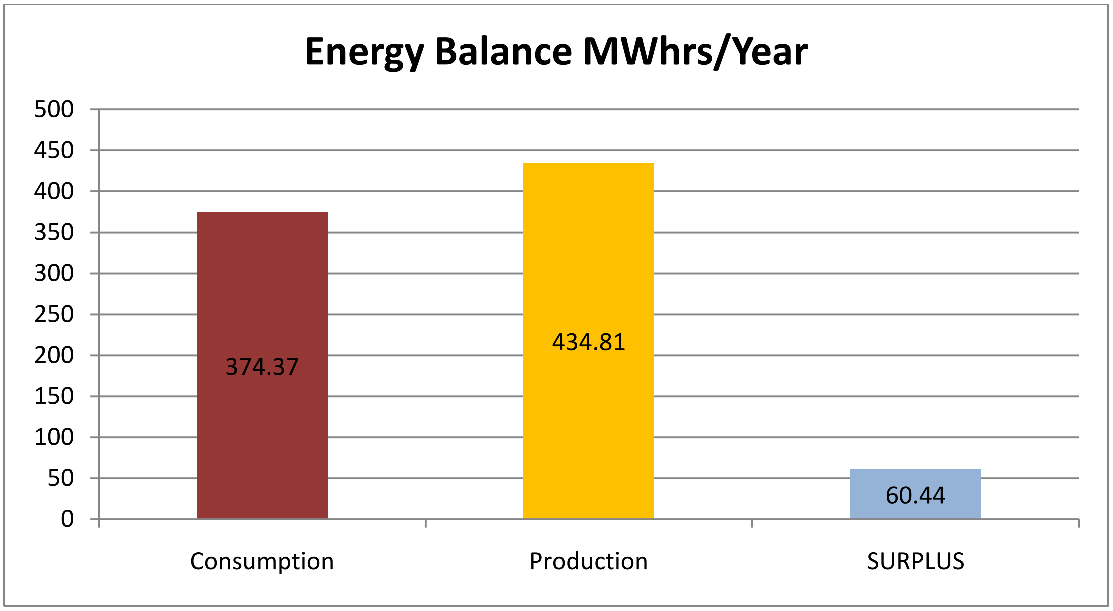


Figure 3-9. Annual Energy Balance
The figure shows that produced energy is more than the consumed energy thus the project is a net-zero building
Source of Information: Recollective Consulting report to Canada Green Building Council, 2007

In fact this building cannot produce as much energy as it consumes in terms of its required electricity. But it sells energy to the other buildings and buys some amount of electrical energy it requires. According to the definitions presented in chapter one of this study, it is not an off-grid net-zero building, thus it can be considered as a “net-zero energy cost” building. This feature entails a particular grid system that can enter the energy supplied by this building to the grid, which can measure the energy too. In this case the sold energy is “hot water” which can be used for heating system or hot water usage. In this sense the neighbourhood energy utility in the Olympic Village has a new perspective towards energy. “We’re accustomed to thinking of heat in terms of what it does in our daily lives. We purchase energy to heat our food and warm our homes. We don’t often think of heat as a form of energy that can be captured and transferred, replacing the need to purchase other forms of energy”[18].

[18] The Challenge Series Booklet. http://www.thechallengeseries.ca/get-the-challenge-series-booklet

Figure 3.10 shows four different building typologies from the perspective of energy systems, and how they are all connected to the district heating system. As it can be seen, the net-zero project is considered as a building that contributes to the neighbourhood energy utility system by producing hot water. This is not in fact a feasible feature for all net-zero buildings (selling energy) but in this case, it has contributed to the goal of the project.

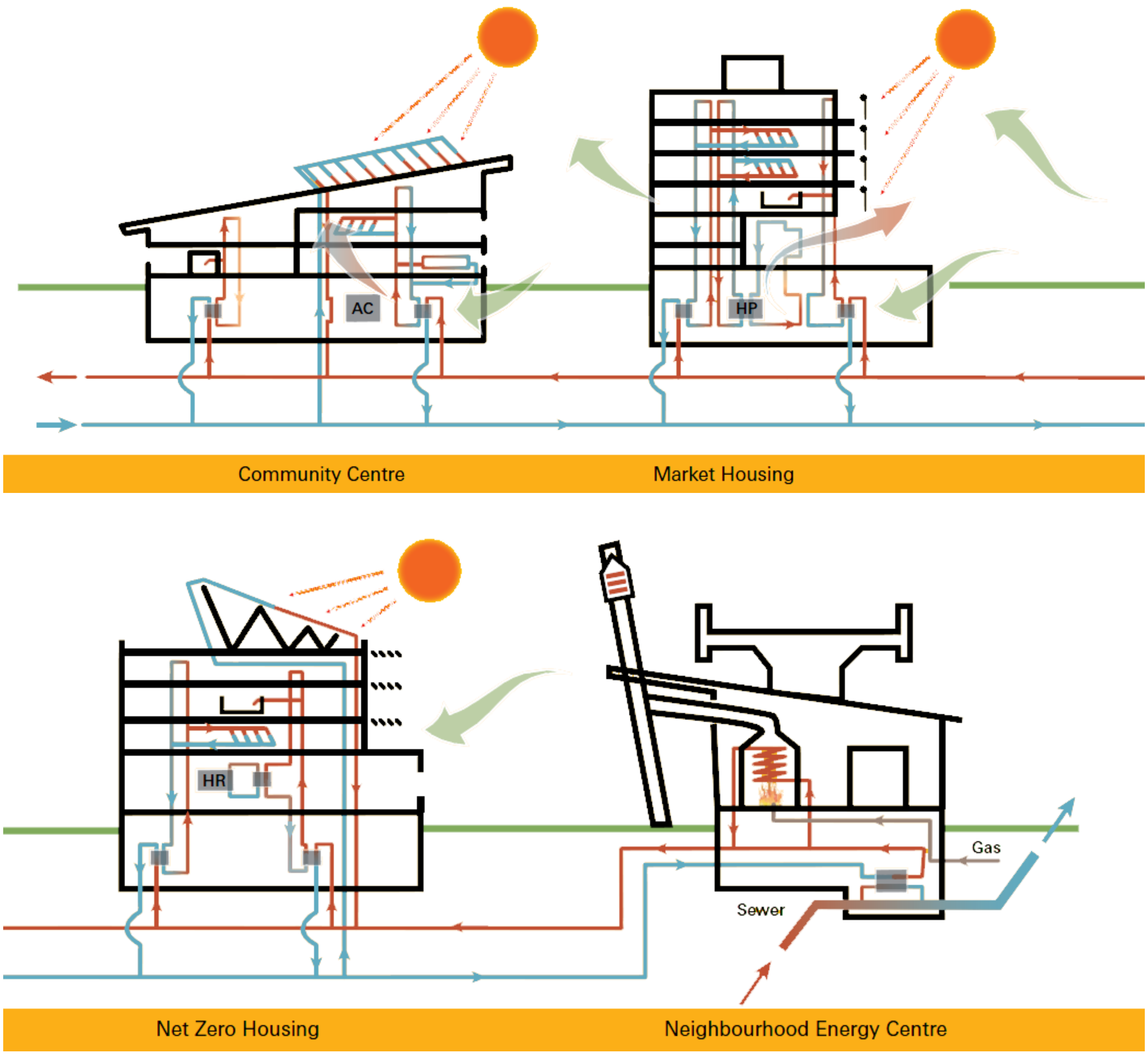


Figure 3-10. Four Types of Buildings and Their Relation to the Neighbourhood Heating System
Source: The Challenge Series Booklet. http://www.thechallengeseries.ca/get-the-challenge-series-booklet

3.4. Design Strategies

Before observing the design strategies in the Senior Housing Project, there are some important points to be considered. The first is to realize that when there is a shift from single family dwellings to multi unit buildings, the design techniques can be analysed at two scales: the building (common areas) and the units. The reason is that in apartment buildings the common area is completely separated from the unit; consequently, the energy analysis is done for units independently. The analysis represented in this chapter is done at both the aforementioned scales. Moreover, there are particular conditions that helped this project take advantage of certain design techniques. One of these is Vancouver's mild climate. This allows architects to use design techniques such as open corridors that are not appropriate for other climate conditions. In fact the "open corridor", which is the base concept in designing this apartment building, has some beneficial attributes of energy related matters and of spatial qualities (Figures 3.11, 3.12, 3.13, 3.14 and 3.15). In fact the open corridor basically rectifies the need for air conditioning of corridors by bringing natural ventilation, and reduces electricity usage during the day by providing daylight to the corridors. Besides allowing for natural light

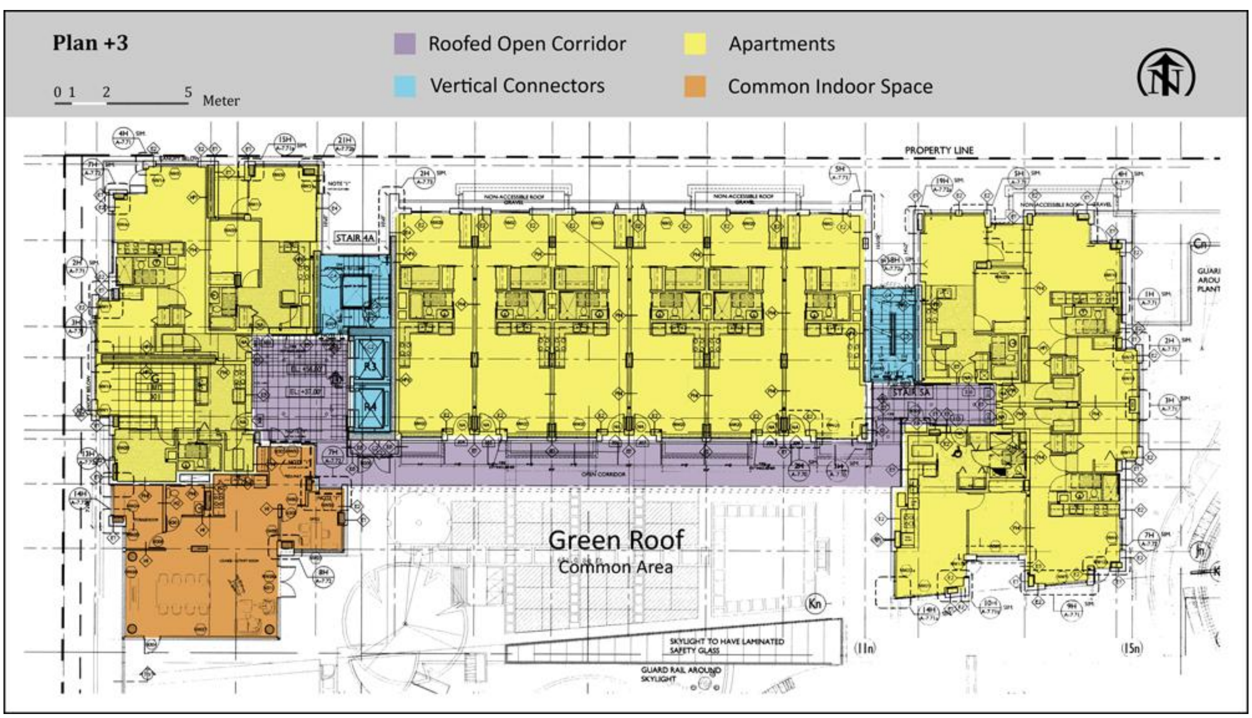


Figure 3-11. 3rd Floor Plan
The Arrangement of the open corridor and other areas

from two opposite sides, it also ensures cross ventilation within each unit. Detailed analysis of each feature will be discussed in the following sections.

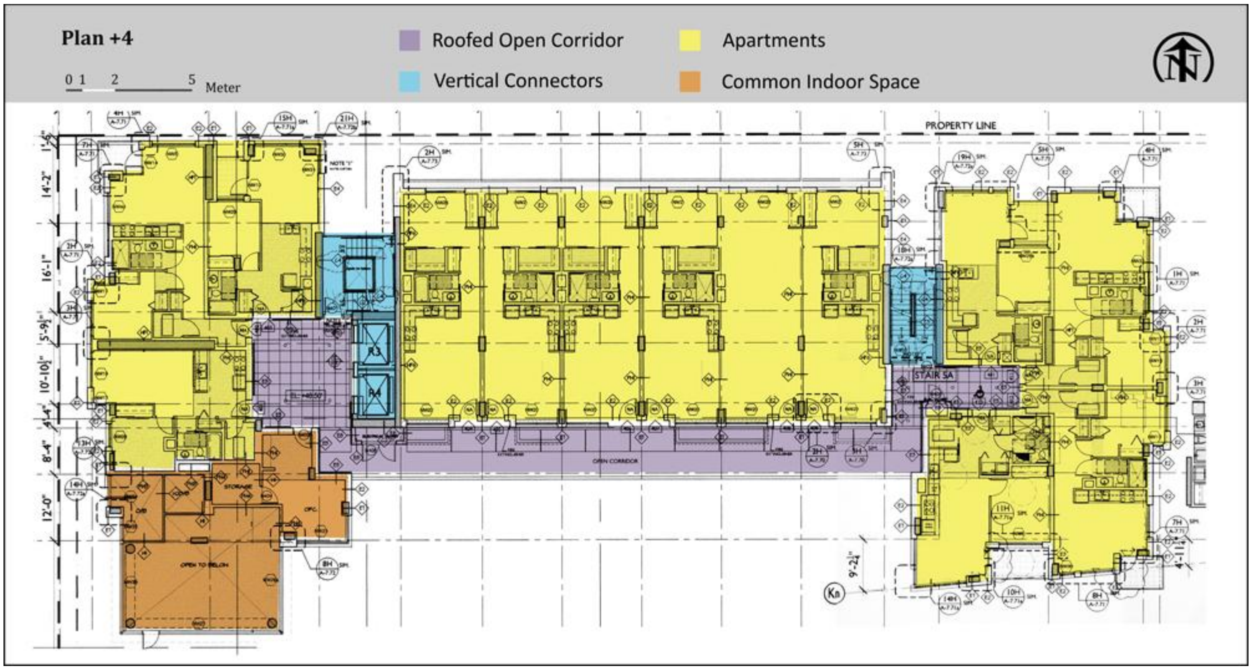


Figure 3-12. 4th Floor Plan
The arrangement of the open corridor and other areas

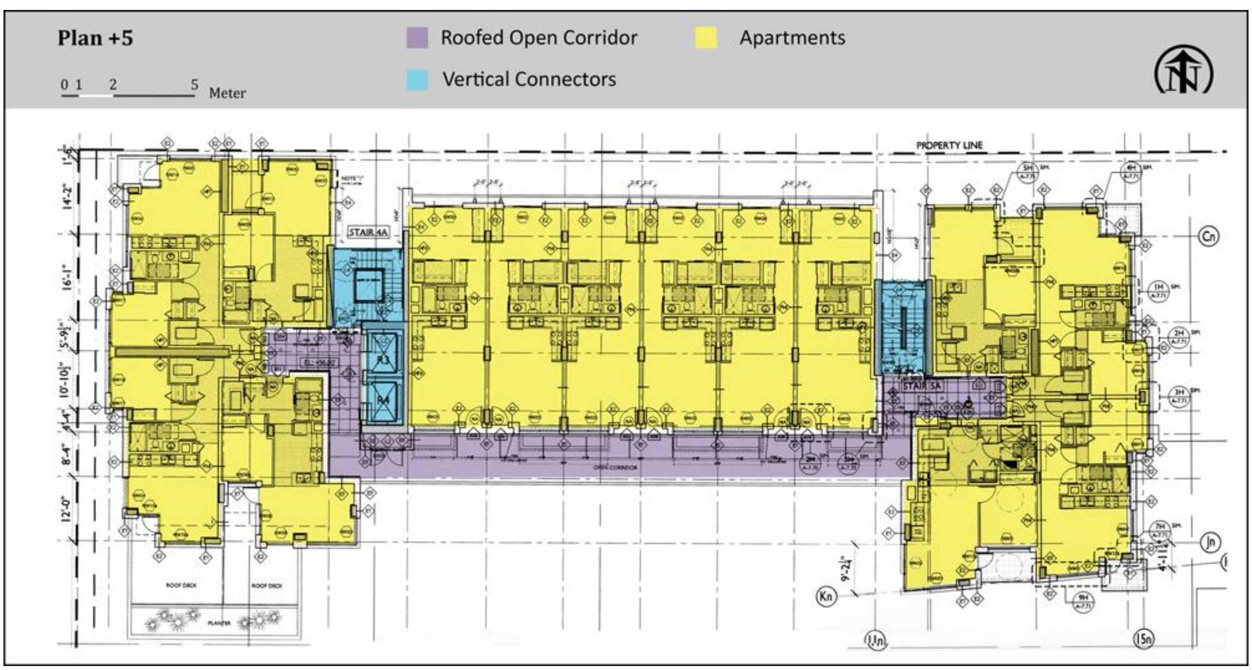


Figure 3-13. 5th Floor Plan
The arrangement of the open corridor and other areas

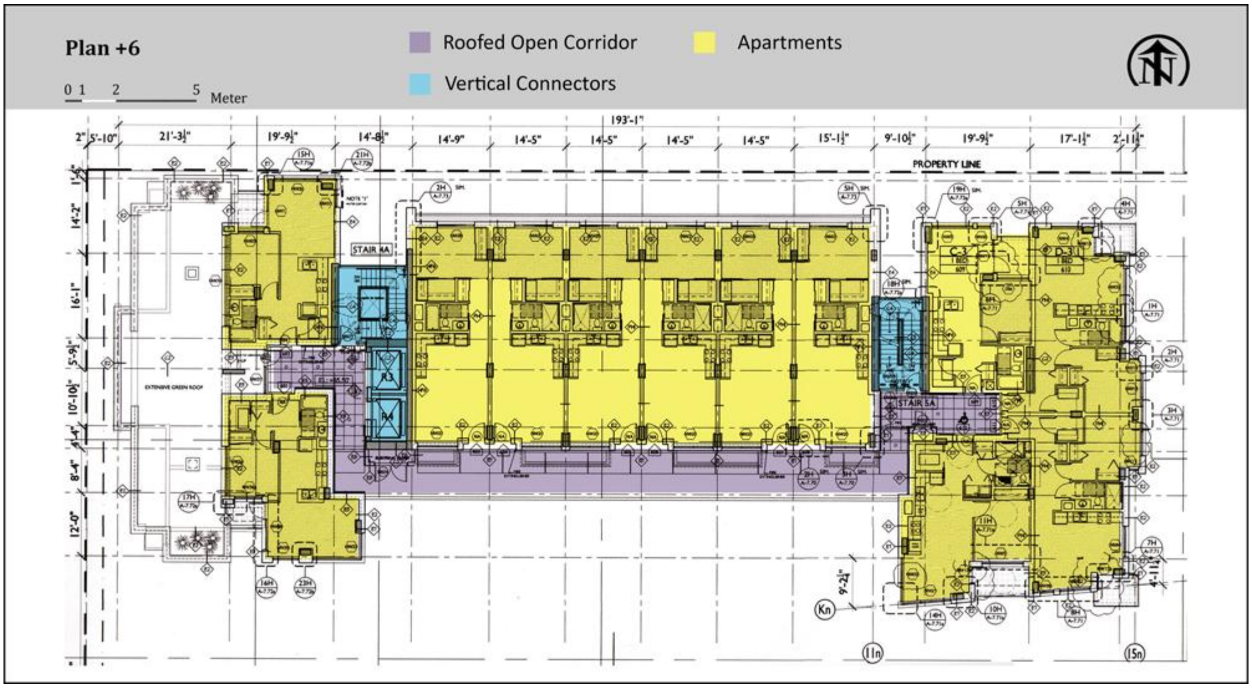


Figure 3-14. 6th Floor Plan
The arrangement of the open corridor and other areas

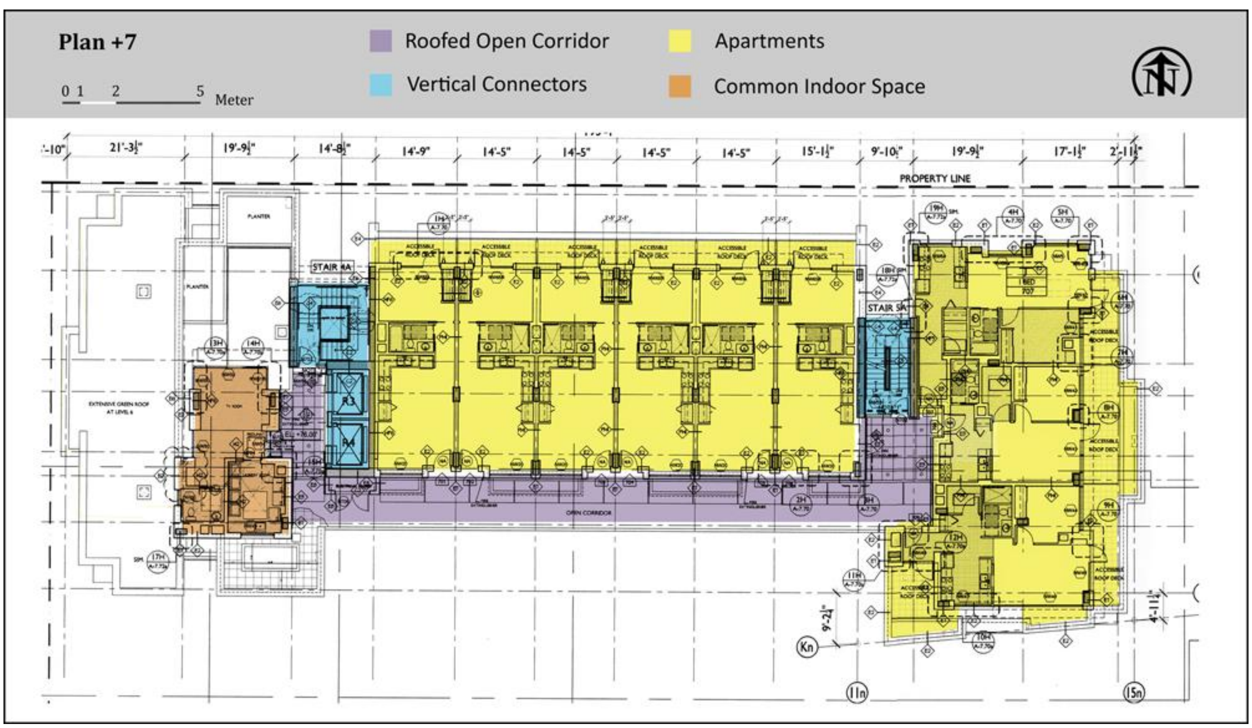


Figure 3-15. 7th Floor Plan
The arrangement of the open corridor and other areas

3.4.1. Passive Solar Design

Passive solar design has a very important role in this project as far as no cooling system is considered for the building. In fact it can prevent the units from overheating during the summer. The passive solar design depends basically on the sun's angle as discussed in chapter two. The maximum and minimum angles of the sun's rays (which occur on 20th June and 20th December respectively) for Vancouver are approximately 64.16 and 17.39 degrees respectively[19]. Passive solar design have been applied through different techniques in this building , one of which is using overhangs, but the most noteworthy one is the use of the single loaded corridor which services the units (Fig.3.16). According to the calculations in the Figure

Figure 3-16. Open Corridor and its role in Passive Solar Design – Section f-f will be analysed in the Figure 3.18.

[19] http://www.susdesign.com/sunangle

3.17, the open corridor enables the units to have direct sun light during the winter, and does the contrary in the summer (Fig.3.18).

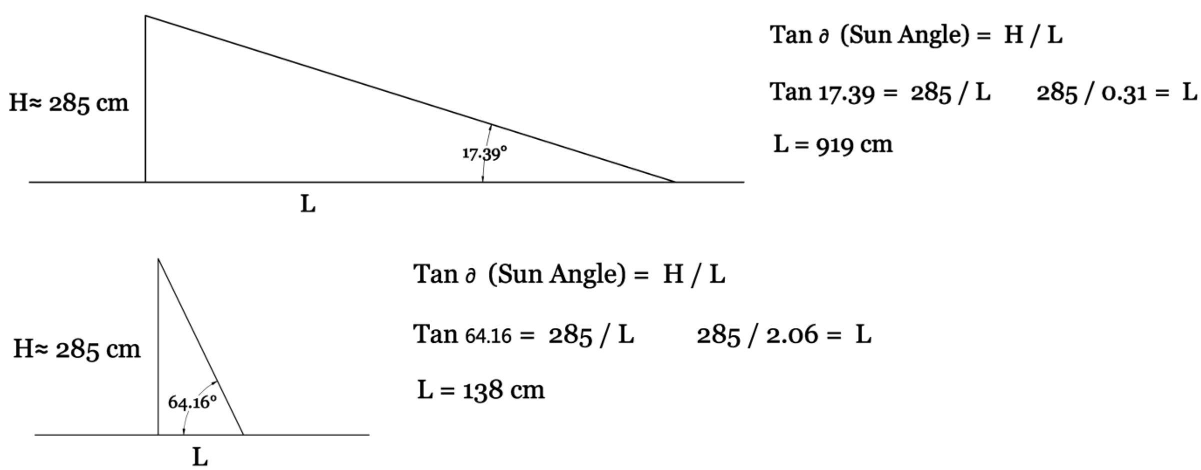


Figure 3-17. Penetration of Sun - The calculation above is related to the lowest angle of the sun's rays during the winter (on 20th December); while the bottom calculation is related to the highest angle of the sun's rays (on 20th June)

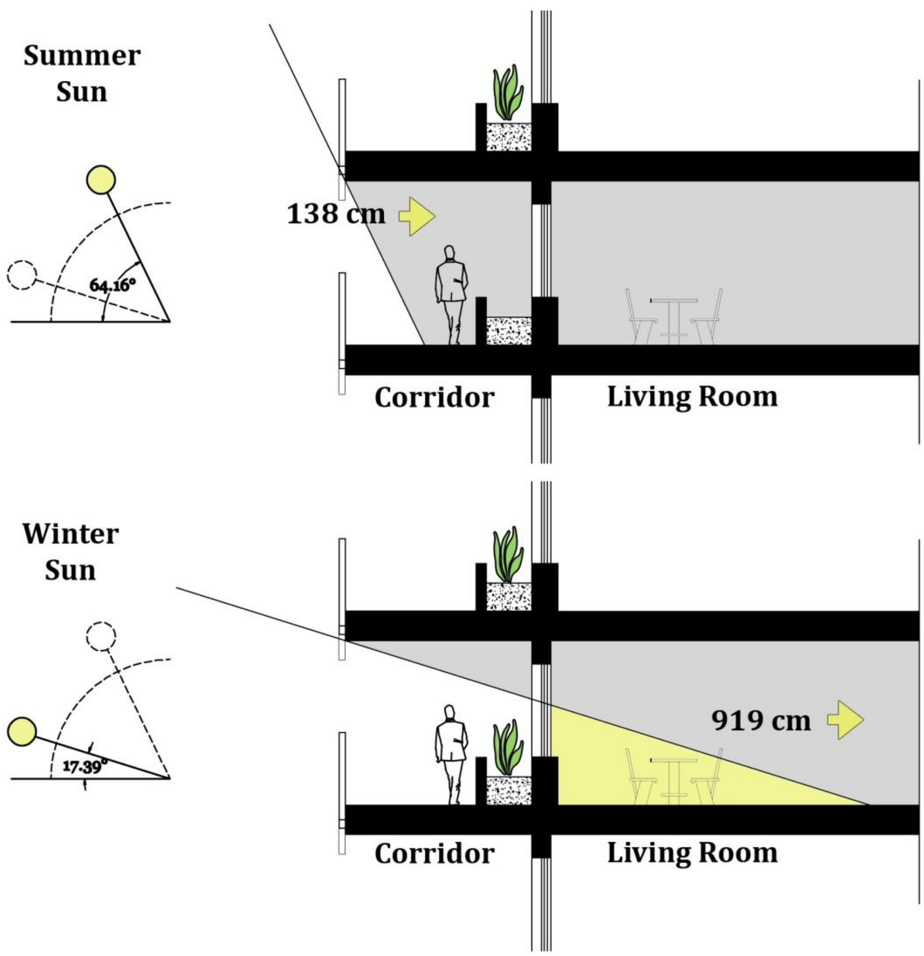


Figure 3-18. Penetration of Sun into the Units – Section F-F
The Figure shows how sun rays penetrate the units in the winter

- **Opening Size**

One of the basic rules in solar design is to have maximum openings located on the south, which is done to a great degree in this project. Openings in eastern and western facades should be less than the number on the southern facade -windows facing the east are preferred over those facing the west- and finally openings on the north should be avoided or at least be very limited. In fact, there is no noticeable difference between western, eastern and northern elevations in terms of openings size (Figures 3.19 and 3.20). This negative aspect is in fact made up for by using overhangs on the south, west and east facades. The main reason for why the architect used this technique is that some units are oriented toward the east and the west, thus they could not have limited openings because they need proper amount of natural light.

Figure 3-19. Western Elevation
There is no meaningful difference in opening sizes in the elevations; the difference is only in using overhangs

Figure 3-20. Top: Northern Elevation - Bottom: Southern Elevation
There is no meaningful difference in opening sizes in the elevations

- **Overhangs (Sun Visors)**

Overhangs in different facades need different design standards according to the sun's angle at different times of a certain day. It means overhangs on the east side, for instance, should be designed for a lower degree of sun by considering the sun angle diagram. Figure 3.21 shows two types of overhangs with different attributes which will be analysed in Figures 3.22 and 3.23.

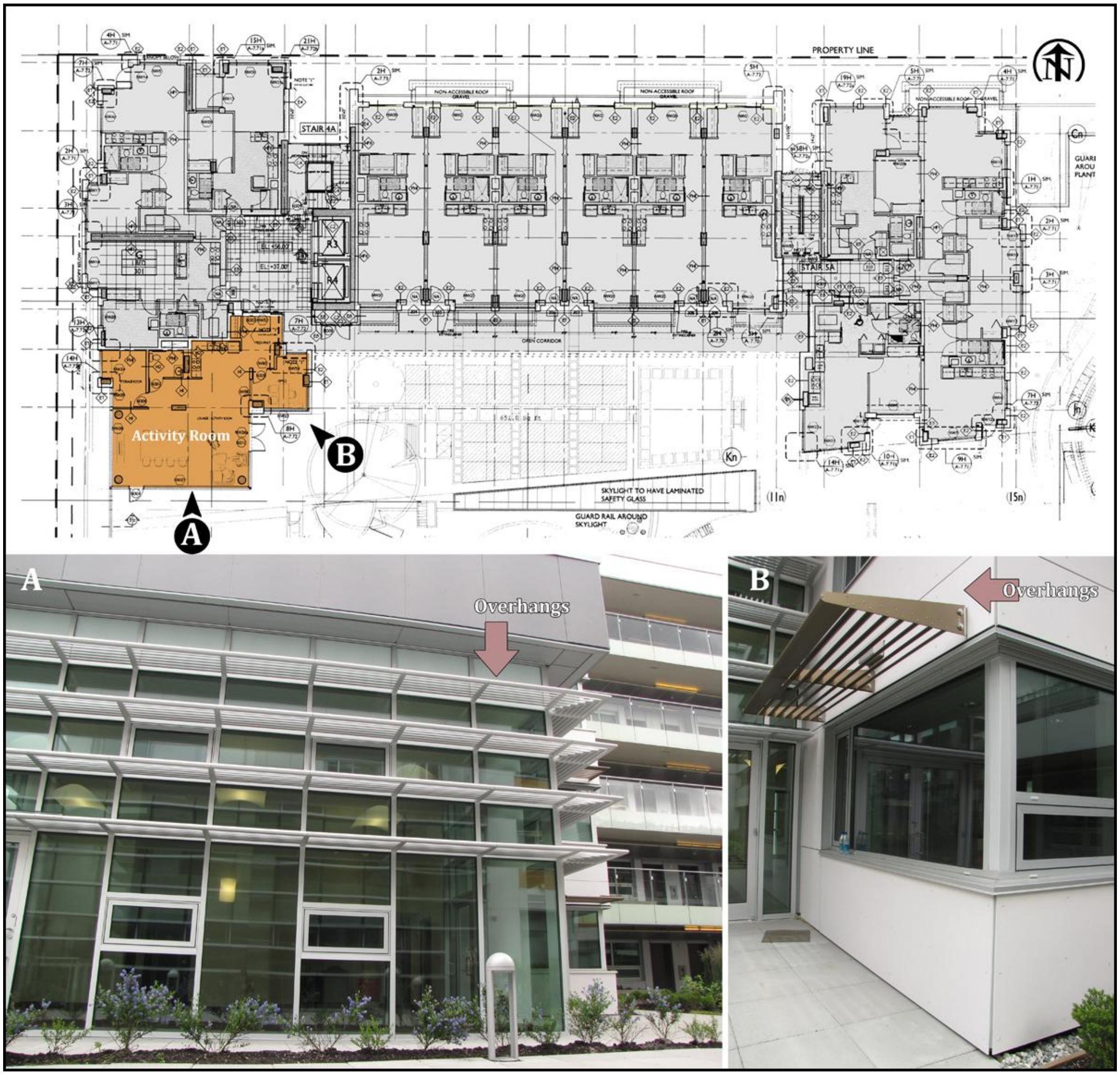


Figure 3-21. Passive Solar Design - Using Different Overhangs

A: Overhangs protecting Activity room on the third floor – B: Southern elevation overhangs

Figure 3.22 simulates the overhangs used on the southern elevation which are shown in Figure 3.21-B. It demonstrates that these overhangs are to protect the units in the summer and allow penetration of sunrays during the winter. To predict the period of time for which the overhangs protect the units, the angles of the sun on different days and months are analysed. The figure also shows that they completely protect the units from May 1st to August 1st. (The angle of the sun on these two days is about 56 degrees at 12:00 pm[20]).

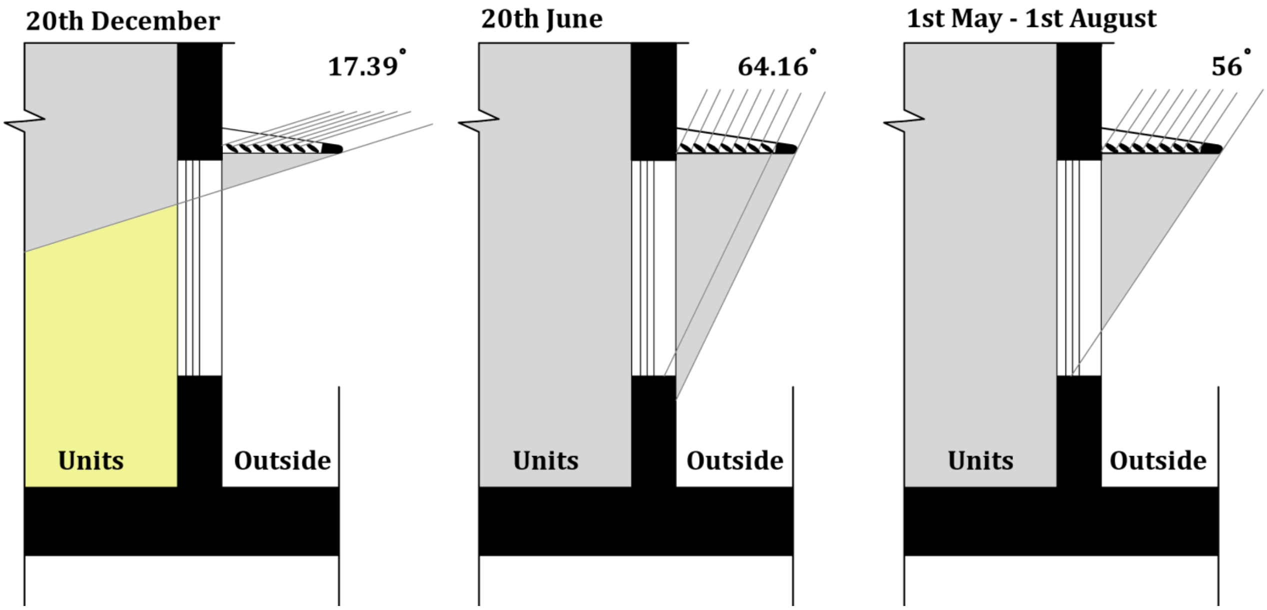


Figure 3-22. Southern Facade Overhangs
The figure shows that the overhangs completely protect the units from May 1st to August 1st and the sunrays can enter the units during the winter (20th December is the date for the lowest sun angle)

Although the food store on the first two levels is not part of these calculations for the net zero building, it still contributes to the goal. Hence the overhangs which are located on the western facade are analysed (Fig.3.23). The analysis shows that on 20th of June these overhangs do not completely block sun light while they work properly on the southern elevation. The reason is that the sun angle on that date -when the western overhangs are exposed to sun- is different from 12:00 pm. For this case 4:00 pm has been selected as a sample evening time, thus the sun angle is 39 degrees allows for direct sunlight inside the food store on this date and at that time. In fact the overhangs in this side do not work properly according to the analysis.

[20] http://www.susdesign.com/sunangle/

Figure 3-23. Overhangs of the Food Market - Western Facade
Sun angle: 39 degrees, 20th June, 4:00 pm

The other technique used in this building for high ceiling areas such as the activity room - with approximately 6 meters height- is using several small overhangs at different levels rather than creating a long overhang (Fig.3.24). In fact a long overhang needs a considerable structure; moreover it occupies a large space. In this case if the architect needed to replace an overhang, he would have to use a 2.55 meter long overhang instead of four 0.9 meter overhangs (Fig.3.24). The small overhangs work properly and allow the sunrays to penetrate the interior space almost before 1st May and after 1st August as shown in Figure 3.25. They block sunrays during the summer and keep the activity room cool and hopefully without the need for a cooling system.

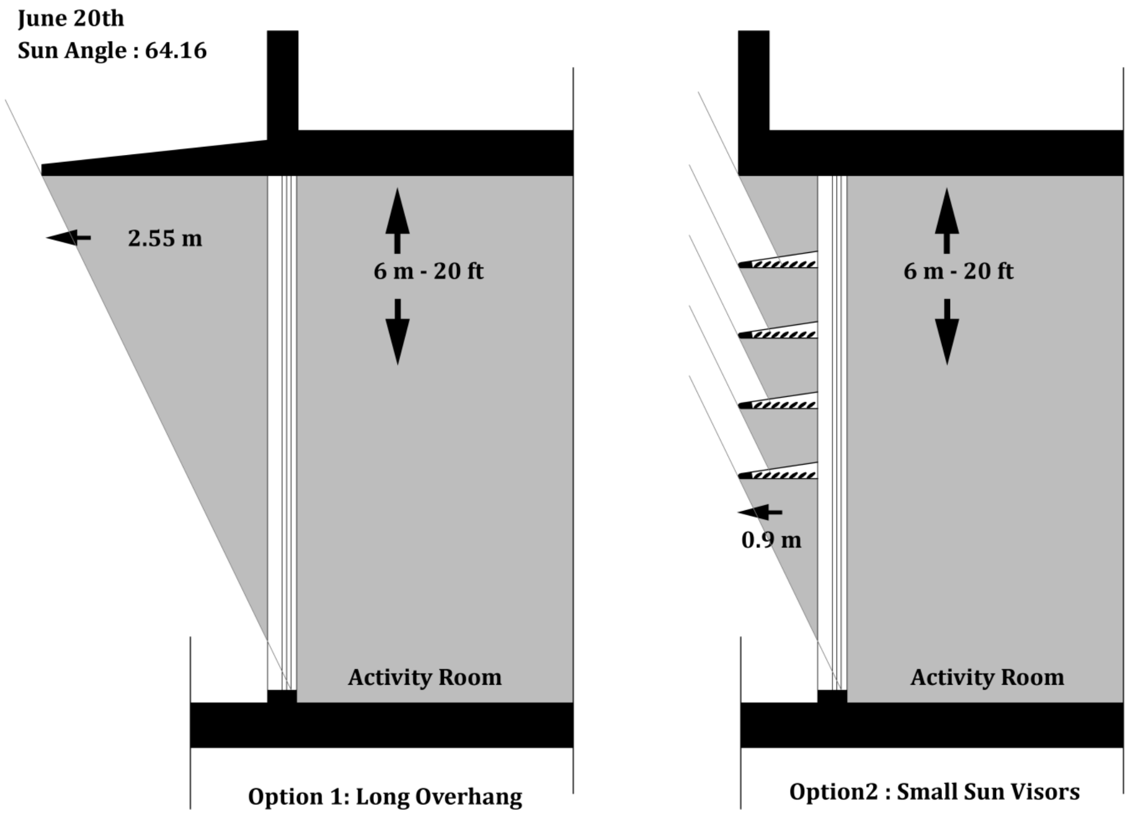


Figure 3-24. Comparing one long overhang with many small overhangs (Sun Visors) in the Activity Room (Fig.3.21-A)

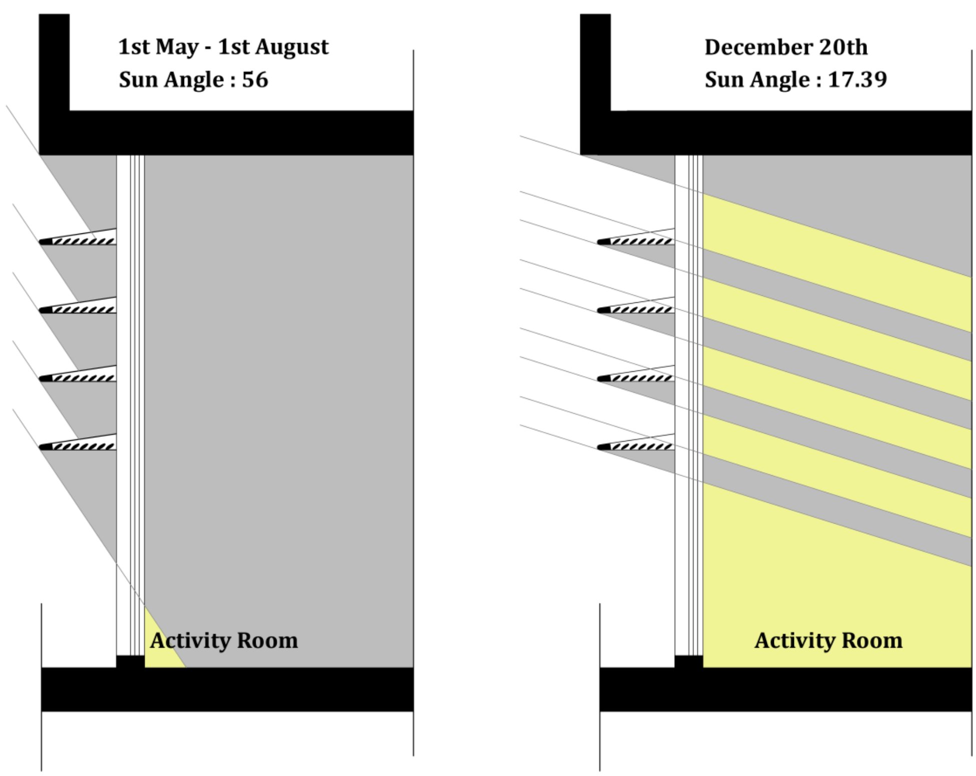


Figure 3-25. Performance of Activity Room Overhangs during Different Months
They block the sunrays from 1st May to 1st August

3.4.2. Natural Ventilation

When the cooling system is eliminated from the equation owing to Vancouver's climate and market, the role of natural ventilation becomes critical. In fact cooling systems are commonly avoided in Vancouver especially for housing that is not high end. If designed well, natural ventilation can compensate for, if not, be better than a mediocre cooling system. Natural ventilation has been utilized for common spaces such as corridors and staircases, as well as for the individual units.

- **Common Areas ; Open corridors and Staircases**

Open corridors, as is clear, are directly connected to the outside and thus outdoor air (Fig.3.26). Associated with passive solar design, this openness brings about air circulation in the space (Fig.3.27). It is almost the same for staircases where a porous steel surface separates the stairs from the street (Fig.3.26).

Figure 3-26. Natural ventilation for Common Areas
The picture on the left shows the open corridor, while the one on the right shows the open staircase

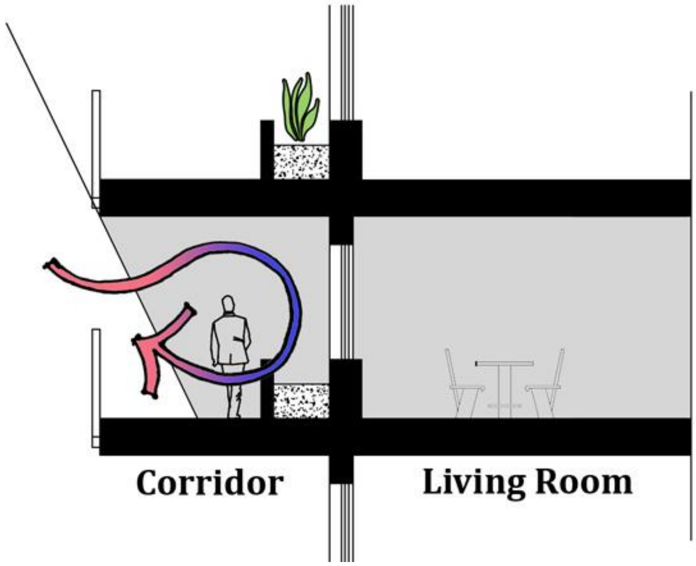


Figure 3-27. Air Circulation in the Open Corridor

- **Cross Ventilation**

Cross ventilation, as a technique, has been used innovatively in this building. It has been so done by using an open corridor on one side and open staircases on the other. According to site conditions, there is an air movement from the northern side (staircase) to the southern side because of the difference in air pressure between these two sides (Fig.3.30).

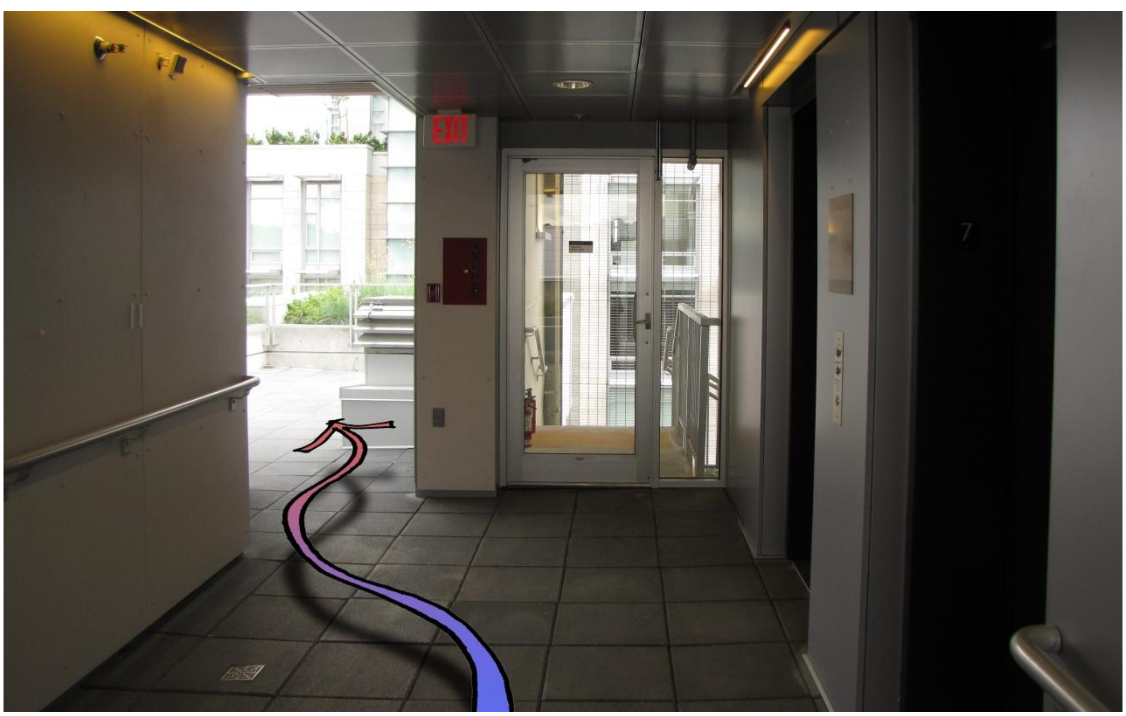


Figure 3-28. Cross Ventilation through the Small Lobbies

There are certain areas among those that are common, however, where the air does not circulate naturally within them. These areas are located on the small lobbies on the third, fourth, fifth and sixth floors, where the depth of the space does not allow the air to circulate. These spots are shown with a green circle on each floor (Fig.3.30, see appendix for other levels). This problem was noticed during a visit to the project in the summer. There was in fact an uncomfortable air condition in these areas. The best air circulation is on the seventh floor where there are less barriers and the air has an almost clear path to move through (see appendix for 7th level).

There is one crucial fact that hinders the efforts of the designer in terms of cross ventilation. The fact is that as per guidelines, the builder was compelled to put a fire door between the staircase and the lobby; as a result, the air cannot flow from one side of the building to the other side unless this door is kept open (Fig.3.29). If “Option C” in the primary design section was chosen to be developed, this problem would not appear. Putting the staircase at the end of the corridor has disadvantaged the project from this vital feature. This concern in fact intensifies the abovementioned unpleasant air condition in the small lobbies. This demonstrates one of the challenges in designing these buildings that should be considered while designing the section.

Figure 3-29. The Fire Door Separates the Staircase and the Lobby

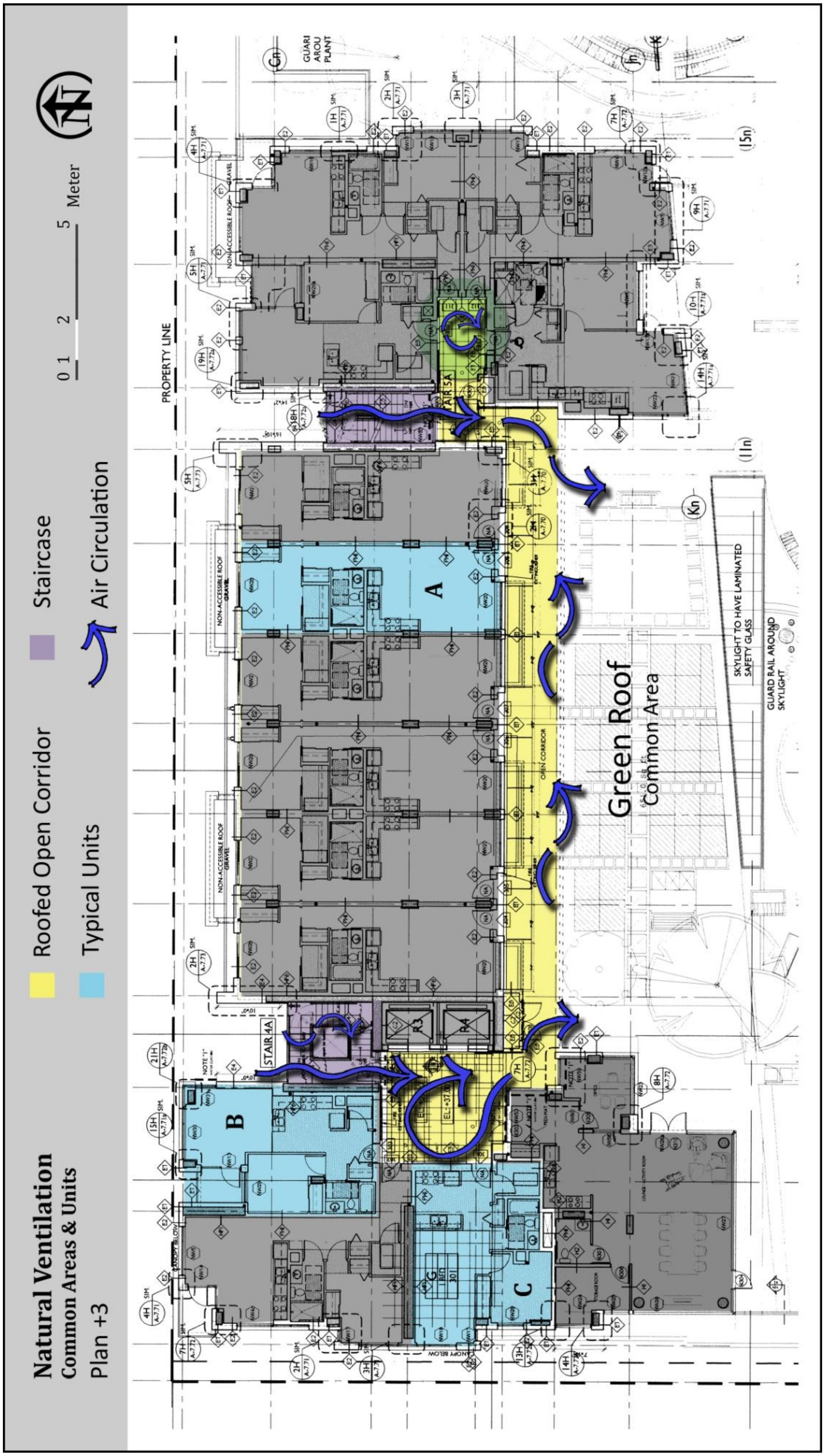


Figure 3-30. Natural Cross Ventilation - 3rd Floor
The green circle shows the space where the air does not circulate naturally

- **Natural Ventilation in Units**

At the scale of the unit, the general rules of the techniques are the same those used in the common space, but the barriers and opportunities are different. In fact, individuals can control the air circulation within each unit by opening or closing windows and doors, even those that separate each room. As mentioned before, one of the other important contributions of the open corridor to this building is that it leaves two sides open for units that are located beside it (Fig.3.31 -Unit Type A). It allows the units to take advantage of the difference in air pressure between the northern and southern sides and thus be naturally ventilated. The best condition for such air circulation is the units with two opposite facades which promote air circulation, but sometimes two windows on the same side can somehow simulate that condition if one of them

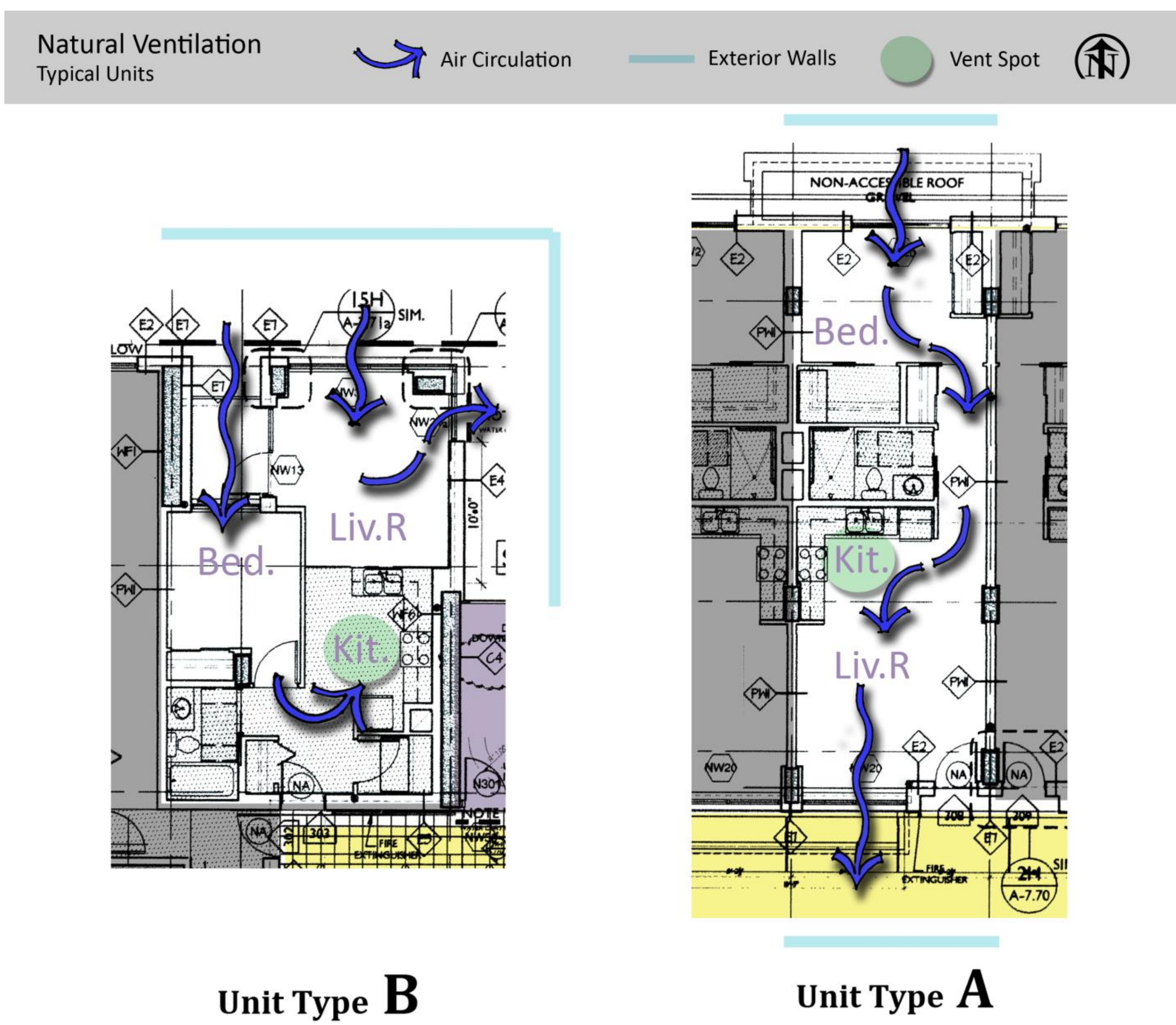
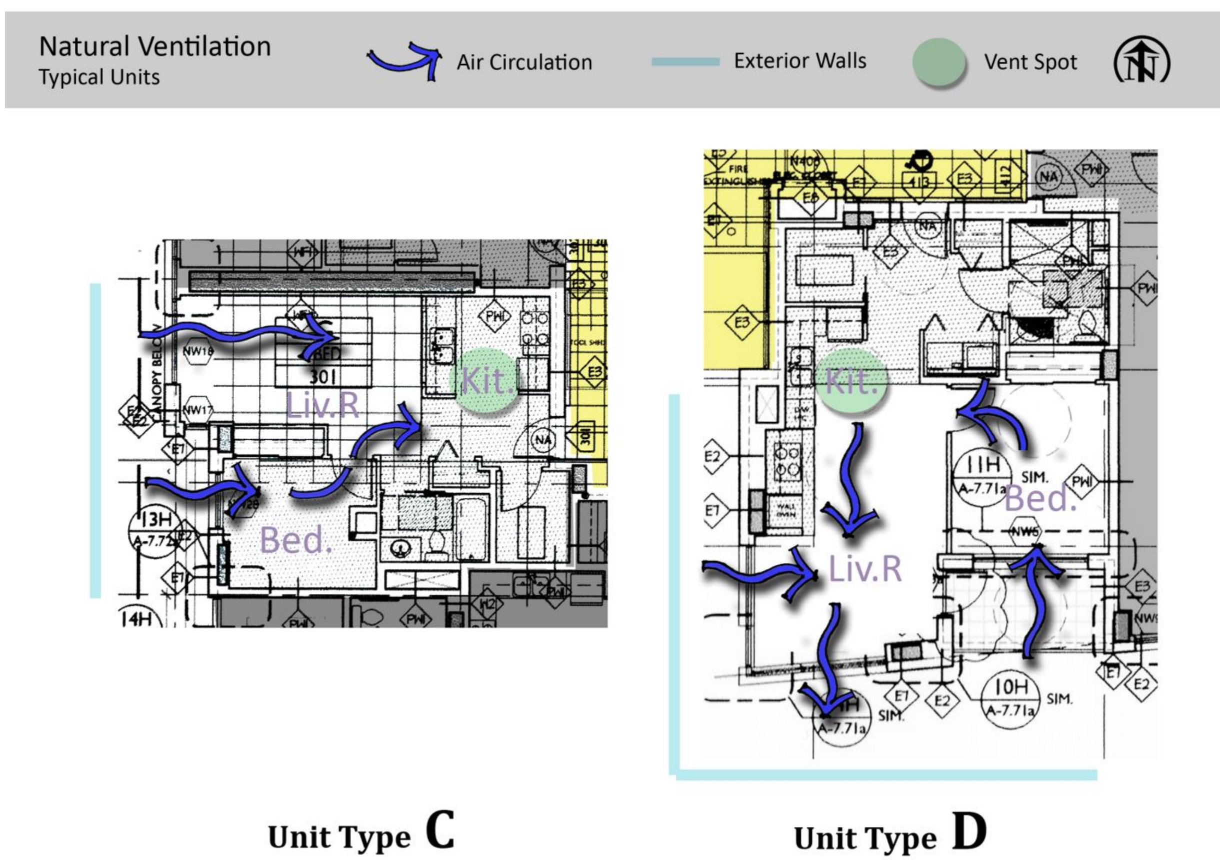


Figure 3-31. Interior Air Circulation - Unit Types A & B

is in shadow (shadow can be made by a deep terrace) as is shown in some units (Fig.3.31 – Unit Type B, Fig. 3.32 – Unit Type D and Fig.3.34 – Unit Type G). The other way is by placing a vent or air shaft at the right place within the apartment, which is the small kitchenette in this case. It can work even with natural air flow according to the different air pressures inside and outside the apartment. In fact the air can even be drawn out to the space above the roof where it is hot during the summer. Subsequently the air coming inside from the windows replaces the air which is going out through the vent or the air shaft. The vent placements in the units show a good central position for them that increase the area that the air is flowing through (these places are shown with green circles in Figures 3.31, 3.32, 3.33 and 3.34).

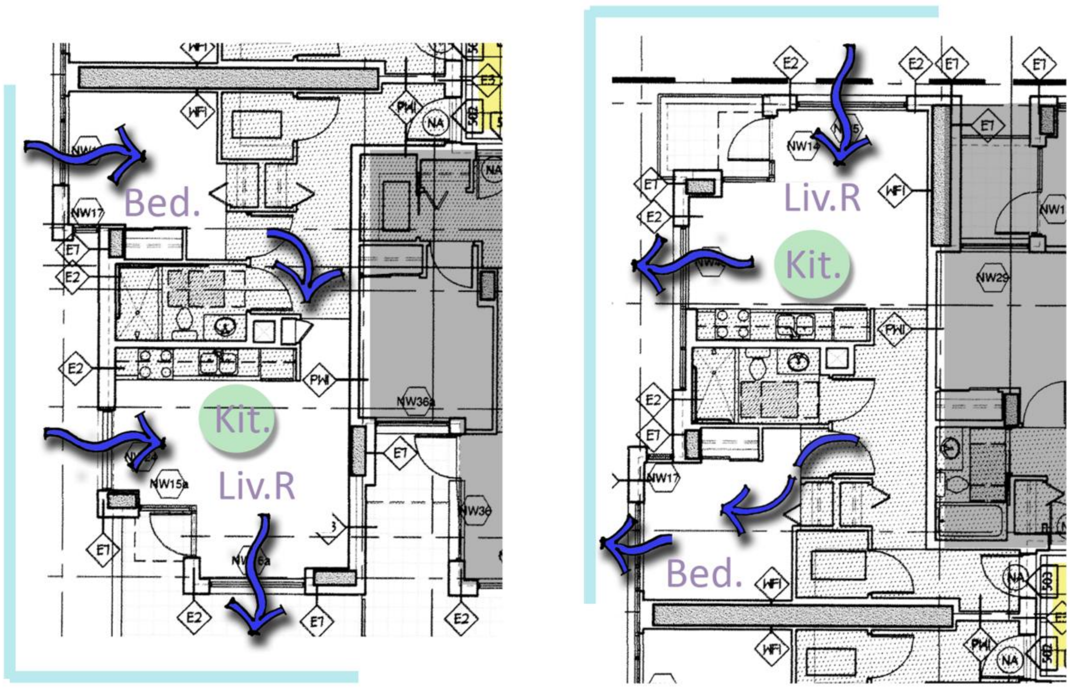
In some units (e.g. Fig.3.32 – Unit Type C), air circulation is achieved only through those vents, and thus the performance of the vents is very important. The size and the location on the roof is also effective. The vents should be situated in a place with direct sunlight to be able to make the air move through the vent. However the units that benefit from natural air circulation on their level still have better ventilation.



3-32. Interior Air Circulation - Unit Types C & D

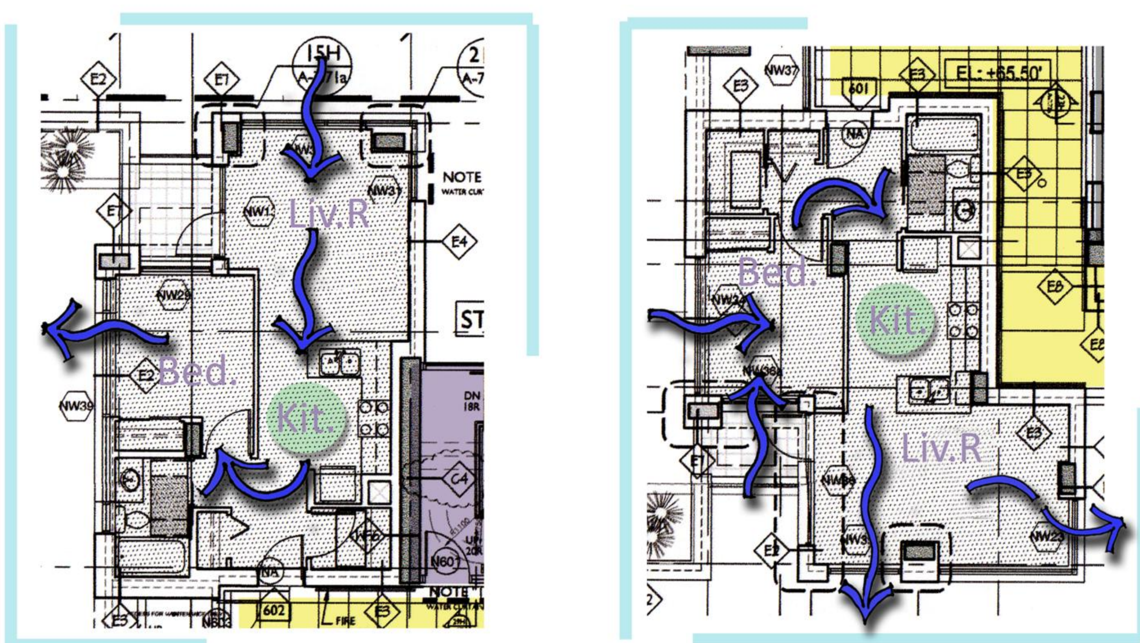
Natural Ventilation
Typical Units

Air Circulation | Exterior Walls | Vent Spot



Unit Type E **Unit Type F**

3-34. Interior Air Circulation - Unit Types E & F



Unit Type H **Unit Type G**

3-33. Interior Air Circulation - Unit Types G & H

3.4.3. Natural Light

- **Common Areas**

Using natural light is very important in net-zero apartment buildings because it can greatly reduce the required lighting energy. In fact, common spaces in apartment buildings should always be lit; as a result, they consume lots of energy. Open corridors again have a main role in common spaces; they obviously do not require lighting during the day thus a huge amount of electricity is saved in this regard. In addition the open corridor allows the light to penetrate to the lobby where the elevators are located (Fig.3.35). Correspondingly, staircases benefit from natural light thus the staircases do not require lighting during the day. This significant feature decreases the energy consumption noticeably during the life cycle of the building. In addition it reduces the initial expenses on lighting and maintenance as well.

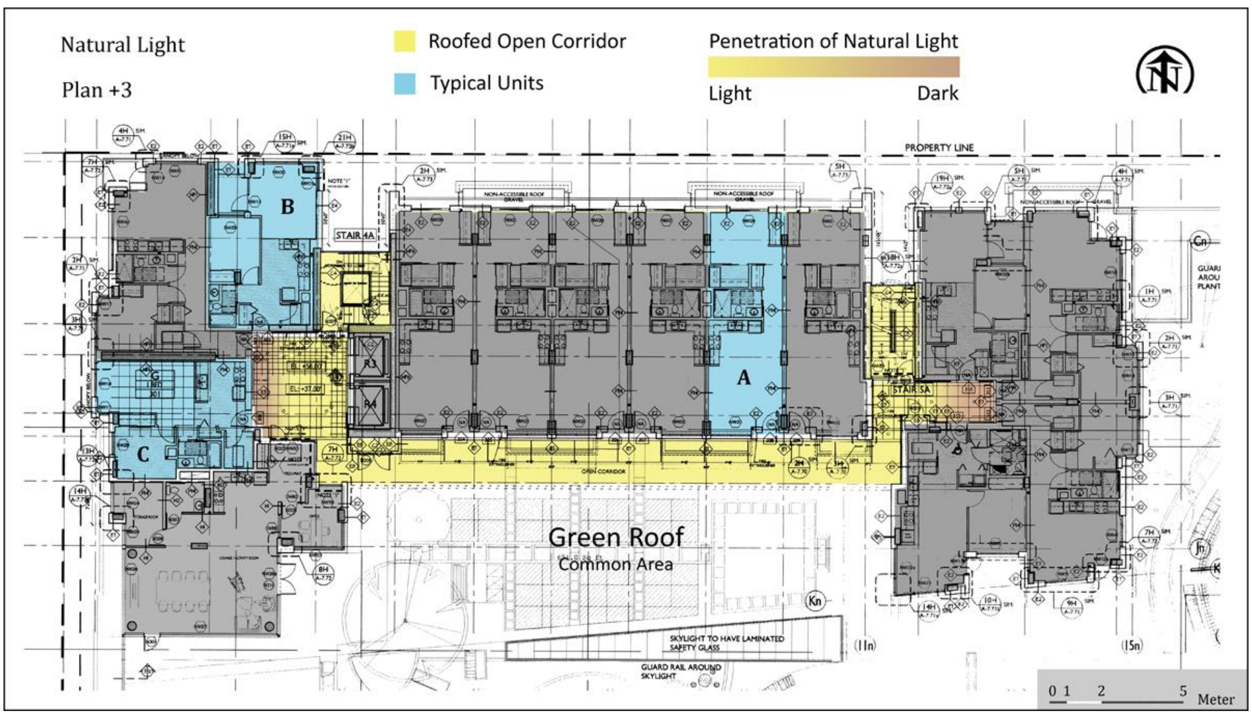


Figure 3-35. Natural Lighting for Common Spaces
The figure schematically shows that only two small areas that do not have natural light

The disadvantage here is the depth of the lobbies, especially the eastern ones which do not receive enough light on cloudy days, hence they resort to be lit artificially (Fig. 3.35). This problem becomes less important on higher levels where the corridors are shallower and there is more amount of daylight.

- **Units**

Units as the major part of an apartment building can thus save energy significantly. Due to the fact that this building will be occupied by the elderly, the usage of the apartments during the day is more than the standard range. This intensifies the role of natural daylight in designing interior spaces. As mentioned before, the sunlight from the southern side is better suited for this purpose as compared to that from the east and west. In fact, facing south, the units have longer and better daylight. A single loaded open corridor enables the units (Fig.3.36 – Unit Type A) to acquire natural light from two sides in contrast with double loaded corriors -which are very common in apartment buildings- that only allow the units natural light from one side. In this case open corridors bring light from the south to the units as shown in Figure 3.36 (Fig.3.36 – Unit Type A).

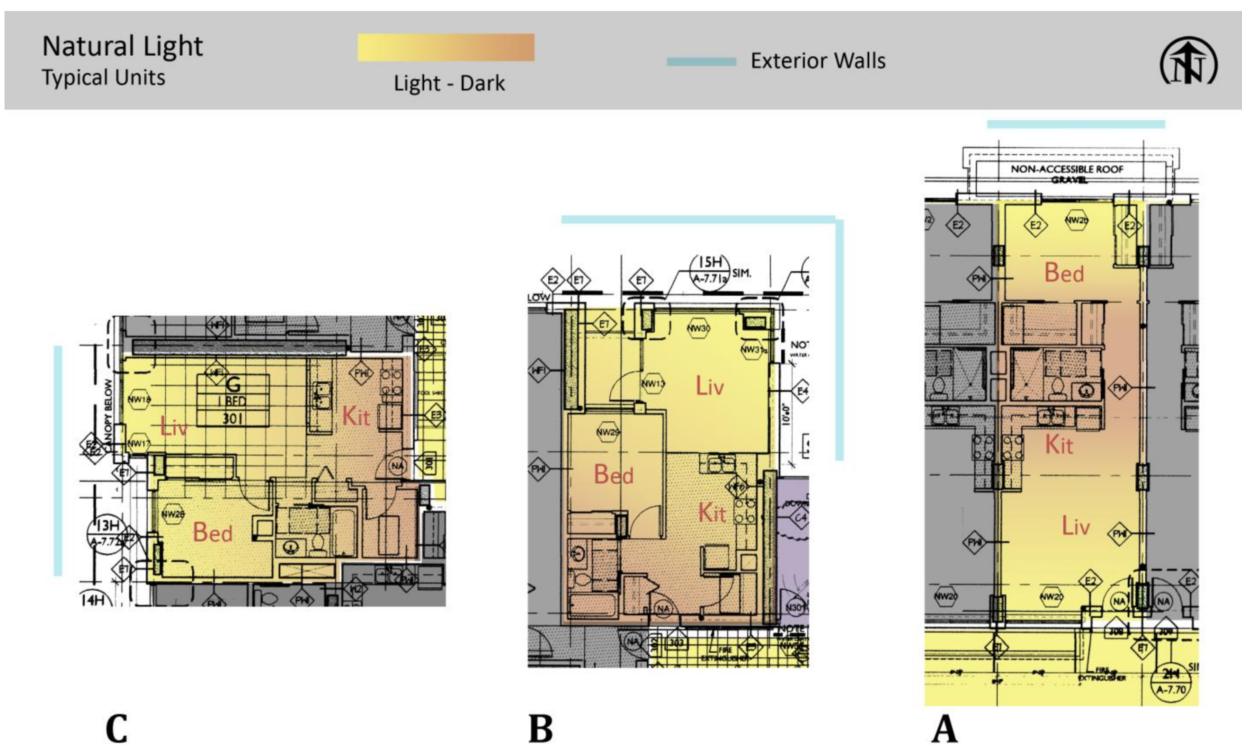
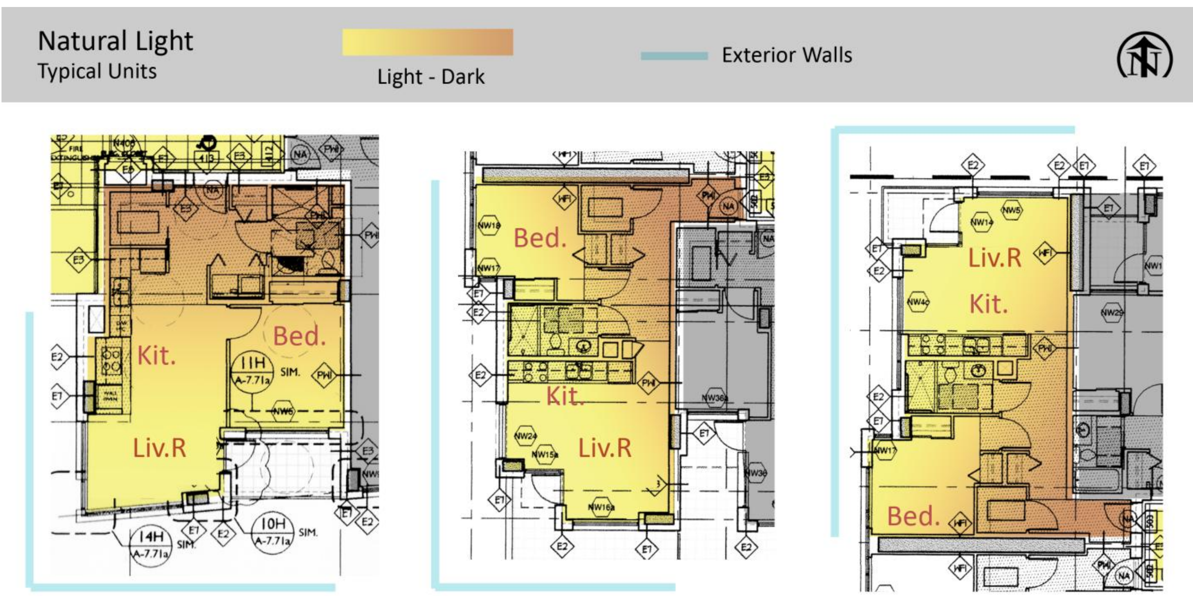


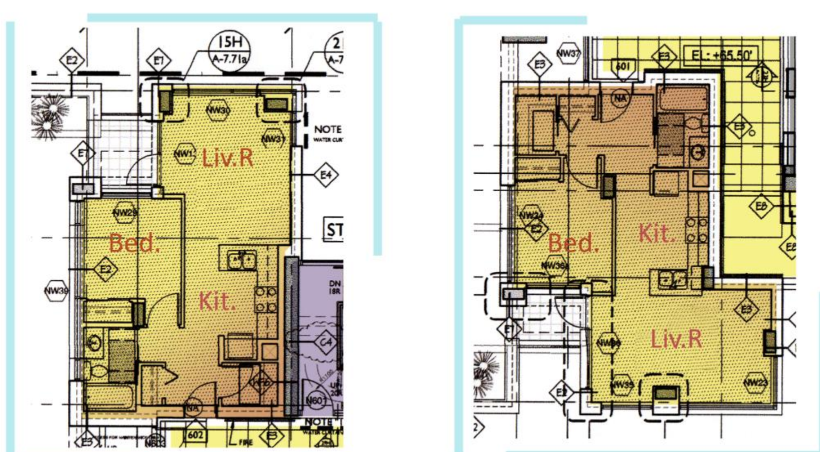
Figure 3-36. Natural Light in Units - Unit Types A, B & C - The figure does not show the light penetration and only shows the attention of the designer in locating different spaces with regard to natural light

Typical units are analysed in terms of natural light in the Figures 3.36, 3.37 and 3.38. It is noticed that the architect has conciously designed some spaces to be on the rear and spaces which continiously require light during the day are placed in the front. In this regard living rooms and beds have natural light, and spaces like bathrooms and entrances have been put in darker areas. Moreover, open kitchenettes contribute to this idea and allow the light to penetrate deep into the units. There are afew units that are not oriented towards the south and they have natural light from one side that make them practically darker than the other units (Fig. 3.36 – Unit types B and C).



Unit Type D **Unit Type E** **Unit Type F**

Figure 3-37.Natural Light in Units - Unit Types D, E & F –
The figure does not show the light penetration and only shows the attention of the designer in locating different spaces with regard to natural light



Unit Type H **Unit Type G**

Figure 3-38. Natural Light in Units - Unit Types G & H

There are also some roof windows that allow the light to enter the central spaces that do not have natural daylight. The advantage about these widows is that they face the north so they do not have a negative effect on passive solar design principles (Fig.3.39). The negative point is that any roof window or non south-facing window can contribute to heat loss.

Figure 3-39. North-Facing Roof Windows

3.4.4. Green Roofs

The other design technique which has been used widely in this project is using vegetation on the roofs. This feature highly reduces the amount of energy absorbed by the roof and reduces the energy that enters the building from the ceiling. Indeed the green roof works as a thick insulation layer. In this project a particular type of extensive vegetation has been used that does not require a great soil depth; as a result, the structure will not be affected by any added weight (Fig.3.40). Green roofs can be seen on all terraces, especially on the roof of the second floor where the common roof top garden is located between the three towers (Fig.3.41). In fact, according to the project designer, the green roof on the third floor is a place that is designed to be converted into a community garden by the residents in the future. Green roofs not only benefit the building but also reduce the urban heat island within the city area.

Figure 3-40. Extensive Vegetation on the Roof
This type of extensive vegetation does not need a thick soil layer underneath which is beneficial both in terms of imposed weight on the structure and easy irrigation

3-41. Green Roofs and Terraces
The picture on the bottom shows the common Rooftop Garden in the third floor

3.5. Utilities and Technologies

Technological facilities form the other part of the project contributing to produce energy or preventing from loosing energy. There are several technologies employed by the architect to achieve the net-zero goals in this project. There have been also many other options to be used but different reasons led to have a limited number of them which will be introduced accordingly.

3.5.1. Evacuated Tube Collectors

The most important technology that has been used in this project to make it net-zero is "evacuated tube collectors" which produces hot water more than this building consumes itself (Fig.3.43). Surplus of the produced hot water as it was mentioned before is sold to the other building. As the architect of the project says these vacuum tubes have a very high degree of efficiency that makes them preferable to the other technologies such as photovoltaic panels. This attribute caused eliminating solar panels and replacing them with these vacuum tubes. The designer believes that "Hot water tubes compensate for the other times of the year that we need to take some power from the grid". These tubes have a particular type of liquid in the centre which evaporates when it is exposed to sun rays. Then this vapour rises and warms up

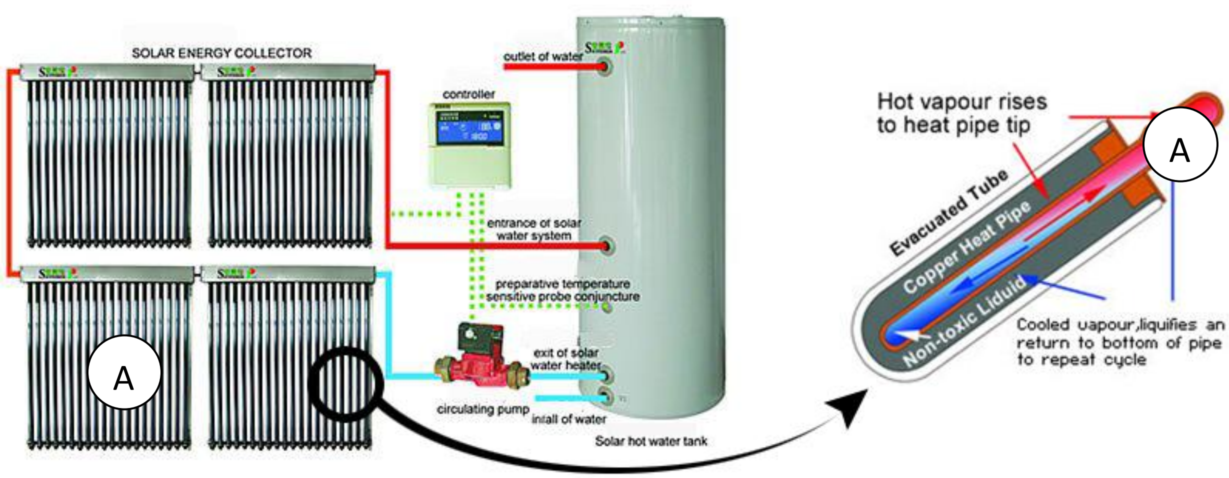


Figure 3-42. Evacuated Tube Collectors
The liquid evaporates and rises by sun's heat and warms up the water in the part A and then cools down, condenses and goes back to the evacuated tube
Source: http://www.savoiapower.com/heatvac

the water which is moving in the pipes. Afterwards the vapour cools down, condenses and comes to the evacuated tube again (Fig.3.42).

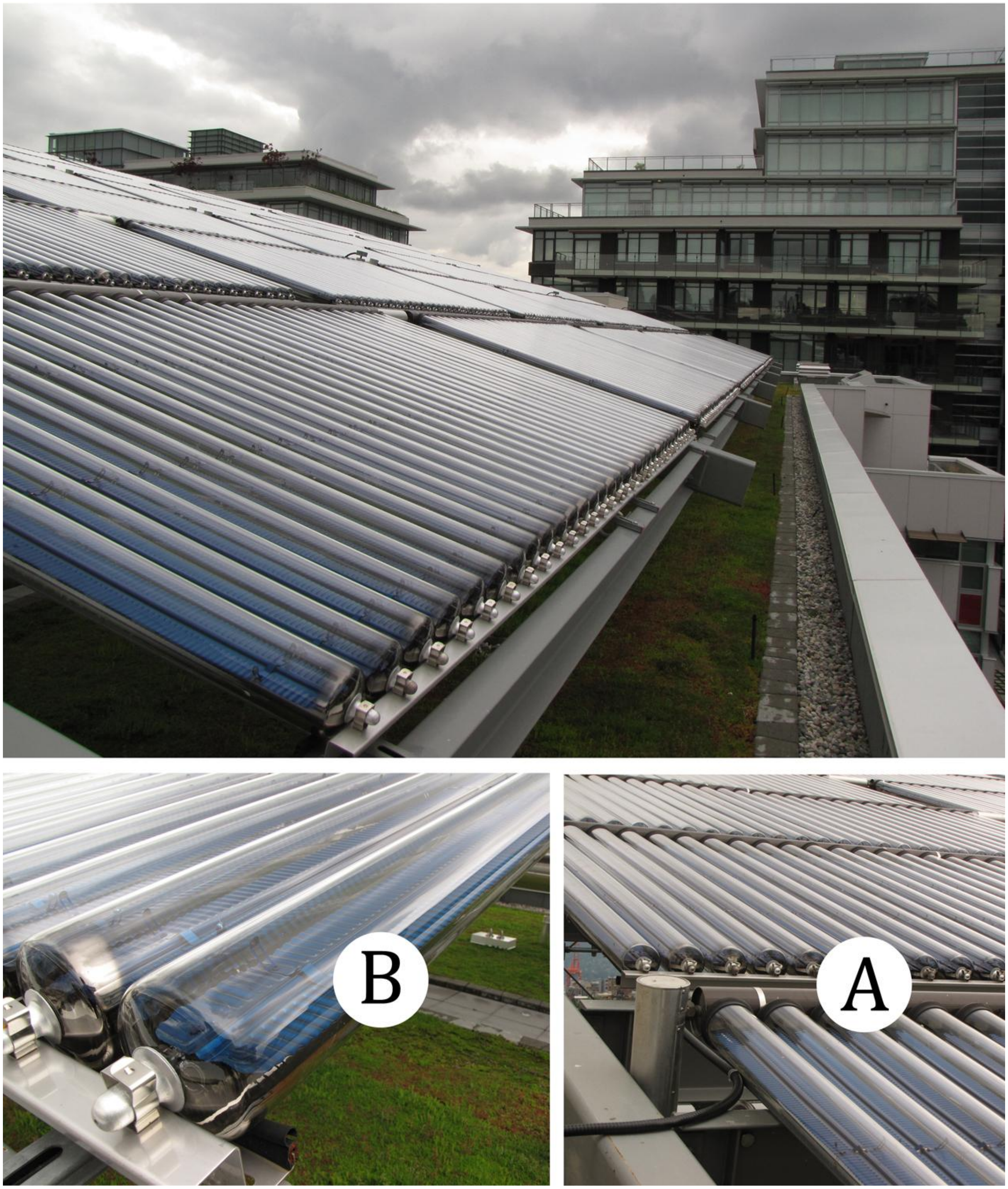


Figure 3-43. Evacuated Solar Tubes Located on the Roof
Water moves through the small tanks (marked with A), and is warmed up by the liquid which rises from the evacuated tubes (marked with B) to this tanks

These evacuated tubes have different performance and efficiency in different times of the year. The performance depends on many factors but their angle is very important. In fact they should be situated in a way that has the best overall production annually. This analysis has been done in this project and two parcels of these vacuum tubes have been considered with two different angles (Tables 3.5 and 3.6). As it is represented in Table 3.5, tubes with 45 degree angle have the best performance in August. Regarding the Figure 3.6, the performance of the panels with 15 degrees angle reaches the top in July. Comparing these two parcels reveals that the performance of the 15 degree parcel is totally better than the units with 45 degrees angle. This fact can be inferred by comparing the number in the "Output / Panel" column in these tables; the highest output per panel for parcel 5 is 1.04 MWhrs during July and August (Table 3.5) while the highest output per panel for parcel 9 is 1.78 during July (Table 3.6).

PARCEL 5: SOLAR HW PANELS CALC 45 deg

MONTH	Output/panel	#Paneles	Total GJ	MWhrs/year
Jan	0.25	44	11.00	3.06
Feb	0.42	44	18.33	5.09
Mar	0.70	44	30.89	8.58
Apr	0.83	44	36.30	10.08
May	1.03	44	45.10	12.53
Jun	0.98	44	42.99	11.94
Jul	1.04	44	45.56	12.66
Aug	1.04	44	45.65	12.68
Sep	0.81	44	35.75	9.93
Oct	0.57	44	25.03	6.95
Nov	0.28	44	12.28	3.41
Dec	0.23	44	9.99	2.78
	Total			**99.69**

PARCEL 5: HOT WATER TANK CALCULATION

	# Panels	Total M2	Total Lt
Approximate Tank capacity Parcel 5 installation	44	176	**13,167**

Table 3-5.Evacuated Tubes Parcel 5- Calculations of Energy Production in Different Months
The best performance of the parcel is during May, June, July and August
The highest output per panel is 1.04 during July and August
Source: Recollective Consulting report to Canada Green Building Council, 2007

PARCEL 9: SOLAR HW PANELS CALC 15 deg

MONTH	Output/panel	#Paneles	Total GJ	MWhrs/year
Jan	0.26	72	19.00	5.28
Feb	0.49	72	35.00	9.72
Mar	0.94	72	67.60	18.78
Apr	1.26	72	90.90	25.25
May	1.72	72	123.60	34.33
Jun	1.71	72	122.80	34.11
Jul	1.78	72	128.10	35.58
Aug	1.64	72	118.10	32.81
Sep	1.13	72	81.30	22.58
Oct	0.68	72	48.90	13.58
Nov	0.30	72	21.90	6.08
Dec	0.23	72	16.20	4.50
	Total			**242.61**

PARCEL 9: HOT WATER TANK CALCULATION

	# Panels	Total M2	Total Lt
Approximate Tank capacity Parcel 9 installation	72	287	**21,546**

Table 3-6. Evacuated Tubes Parcel 9 - Calculations of Energy Production in Different Months
The best performance of the parcel is during May, June, July and August

The highest output per panel is 1.78 during July

Source: Recollective Consulting report to Canada Green Building Council, 2007

3.5.2. Reuse of Discarded Heat (from the Food Store and Airshafts)

One of the innovative techniques that has been implemented in this building is reusing the heat which is produced by different devices in the building. The most important one is using the released heat from the refrigerators and cooling systems in the food store during the winter. The discarded heat is utilized to heat the units in the cold seasons. The other system is called "passive air shafts". Passive air shafts draw air from the units and utilize that heated air for heating system (Fig. 3.44). This heated air is in fact produced by stoves, washer-dryers and other appliances in the units. This system is not as efficient as evacuated tubes because the busters consume electricity to reuse heated air; however, it is still an innovative system that can be developed in the future. This system obviously works more effective in a cold climate and with more number of units that produce a noticeable amount of heated air.

Figure 3-44. Passive Air Shaft on the Roof
The turbine only works in the winter and takes the heated air back to the units after that air is cleaned

3.5.3. Lighting system

Some technologies are used to reduce energy consumption in the building. One of these technologies is using low-consumption lights. LED lights are one of the best and most energy efficient lights which are widely used for corridors and common spaces in this building to reduce the energy consumption at night. LED lights are used in two different forms, spot lights - as used in lobbies- and linear ones such as the type used in open corridors (Fig. 3.45).

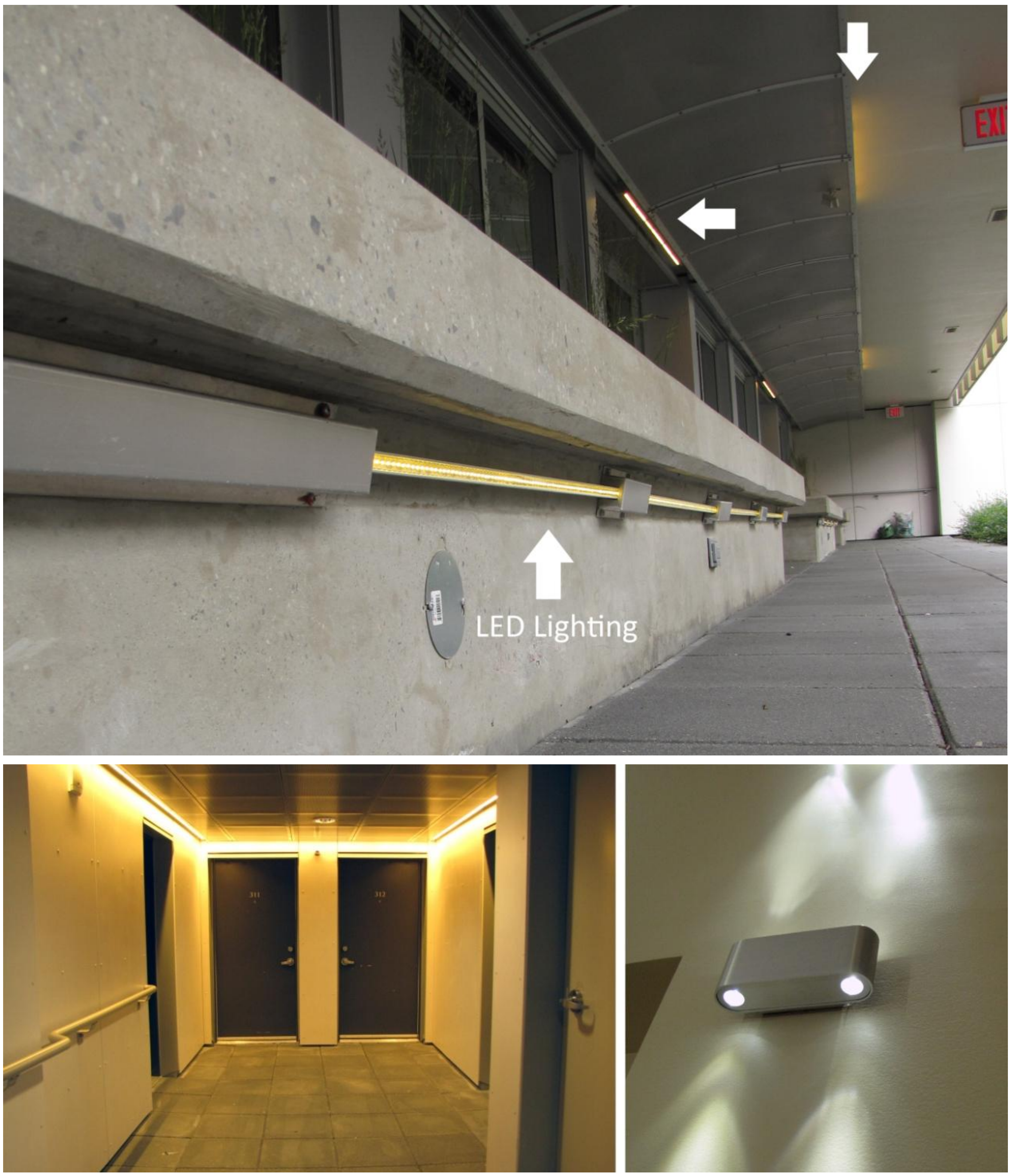


Figure 3-45. LED Lighting in the Indoor and Outdoor Areas
On the top: LED lighting in open corridors – At the bottom: LED lighting in the lobbies

Regarding the original calculated consumption loads, the common areas individually consume 67.24 MWhrs annually which is a huge amount of energy (see Appendix). Using LED lighting in these common areas significantly decreases the total energy consumption. The negative aspect of LED lights is that they are more expensive than the CFLs (compact fluorescent lamps) or regular ones; however, comparing the lifetime of these three types and their consumed energy during this time reveals that LED lights are the most efficient type (Fig.3.46). Figure 3.46 shows that the lifetime of an LED light is approximately 25,000 hours. The lifetime of CFL and regular (Incandescent) lamps are 10,000 and 1,000 respectively, thus LED lamps also have lower maintenance fees as compared to the other two types.

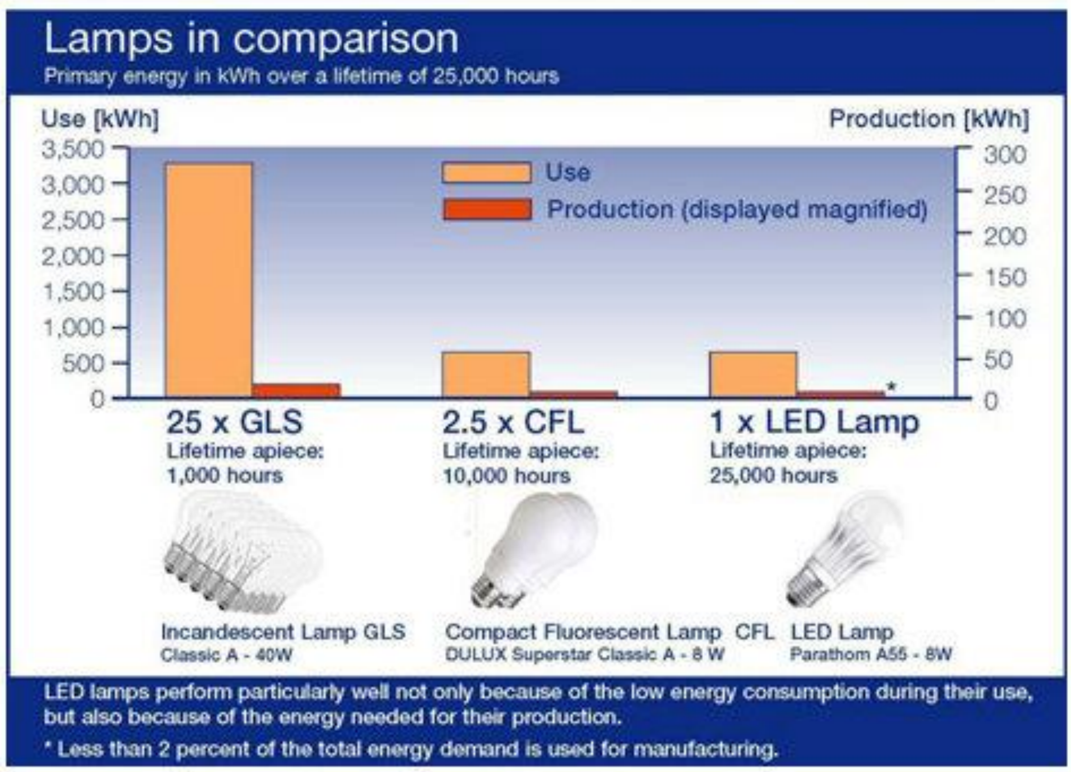


Figure 3-46. Comparison of Incandescent, CFL and LED Lights
This figure reveals that with the same lighting power, after 25,000 hrs the LED lamps have the lowest consumed energy.
Source: http://www.ecorob.com

3.5.4. Insulation

Insulation, according to the designer, was the highest priority of this project. The materials and insulation systems which have been used in this building are not customary in Vancouver. A highly sealed envelope prevents the building from overheating in the summer and losing heat in the winter. This tightly sealed envelope is gained with R40 outer walls and R50 roofs and triple glazed windows. Triple glazed windows are not a usual feature for the buildings in Vancouver, according to the designer of the project; however, this building benefits from these high performance windows even on the southern facade (Fig.3.47).

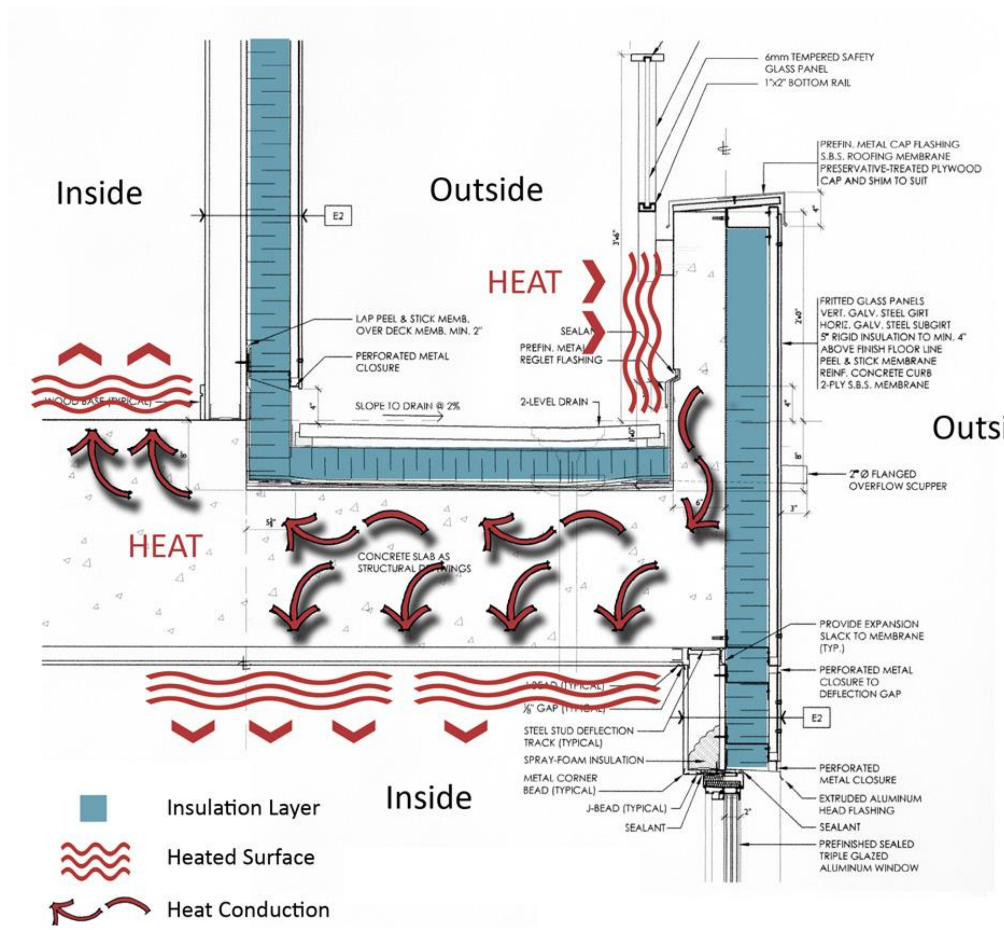
Figure 3-47. Triple-Glazed Windows

The interior walls between units are not insulated in this building which allow the units to share heat. On the other hand it has a negative aspect which is heat loss if some units are not occupied for a while.

Cladding material for the interior facades (facades which face the common rooftop garden) is a type of cement board which has a thick insulation layer behind (Fig.3.48). The insulation layer is completely outside the structure hence it can be checked or fixed easily in the future.

3-48. Cement Boards - Cladding Material
The insulation layer is located right behind the panels outside the structure

The other cladding material is “Swiss Pearl” which has been used for the street facades. The insulation technique is the same for this part and the insulation layer is located outside the structure. There are some points in this highly sealed building where the design details are not that protective and enable thermal bridging. Although the insulation layer has been put outside the structure to eliminate thermal bridging, there are certain spots where the structure –which is concrete – is exposed to the outside air (Figures 3.50 and 3.52). In fact the transferred heat from these spots is very low; however, for such a highly sealed building this is a negative point. Figure 3.51 on the other hand represents the perfect insulation with almost the same condition.



3-50. Terrace Detail – Thermal Bridging

The figure shows that the heat can enter the building during the summer – Red arrows show the heat movement

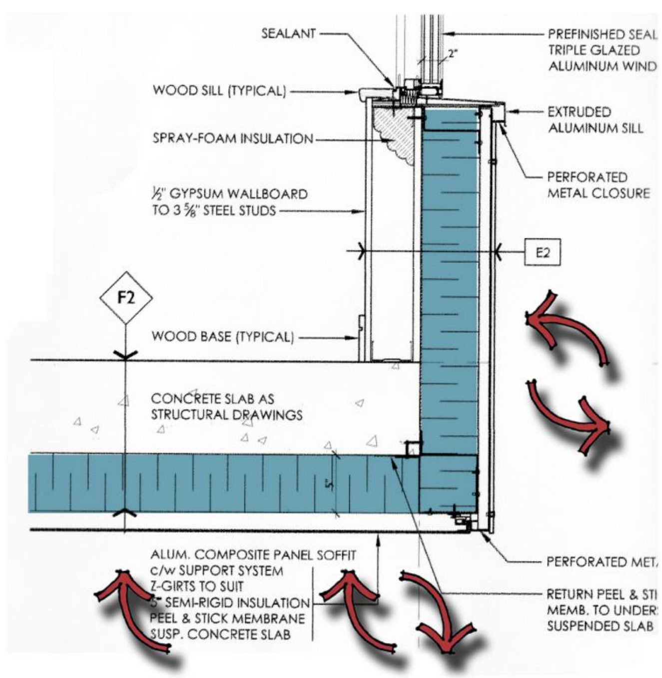
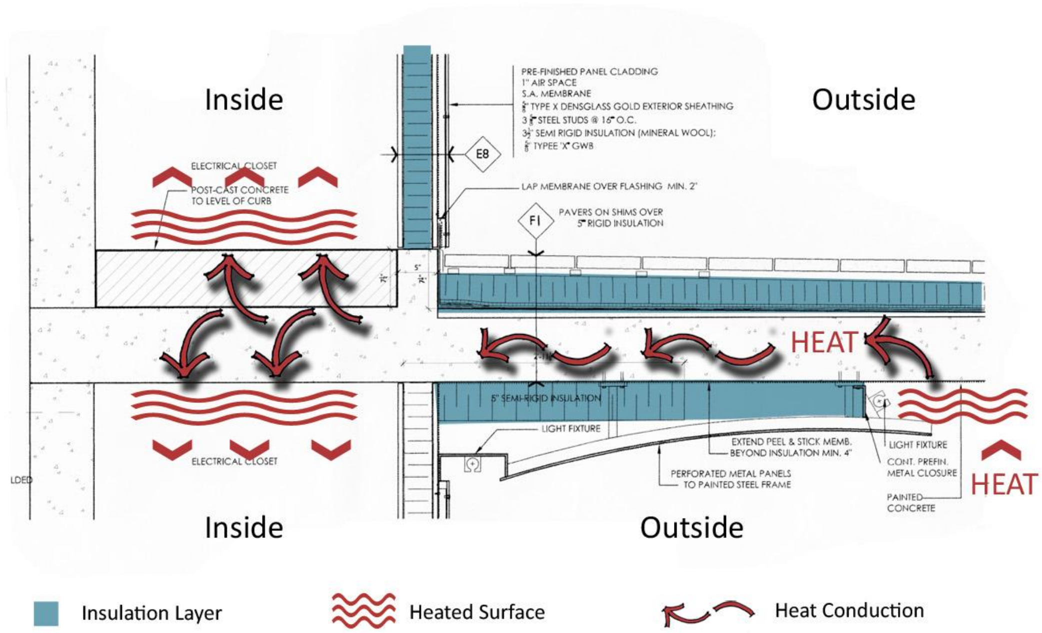


Figure 3-51. Overhang Detail

The figure shows a sample of complete insulation that does not allow the heat to enter the building in the summer



3-52. Open Corridor Insulation Detail (A) – Detail A is shown in Figure 53
The figure shows that the heat can enter the building in the summer – Red arrows show the heat movement

Figure 3-53. Detail A - Open Corridors
The figure shows the spot which is analysed in Figure 3.52

3.5.5. Energy Measurement System

One of the other technologies that has been used in this building is a system that shows the current energy consumption of the units. The panel called “PowerTab™” that indicates the amount of used energy is installed in the units (Fig.3.54). The PowerTab™ ES System provides residents real-time, wireless information about their energy use, including hot and cold water, heating, cooling, electricity, and gas. Consisting of a sleek, user-friendly monitor and a transmitter, the PowerTab™ ES System displays usage data and costs that help homeowners and building residents make better choices about their energy use[21]. This system simply makes the residents aware whether they are using the energy properly by three small lights. The green one indicates the good range; the yellow and red ones indicate critical and bad ranges respectively. Thus the residents should basically keep their consumption within the green range. Although this system cannot force the users to consume energy in its best way, it can hopefully bring cautiousness for the residents after a while.

Figure 3-54. Energy Consumption Indicator
Source: http://www.energy-aware.com/

[21] http://www.energy-aware.com

3.5.6. Appliances

Using energy saving appliances which can be recognized by some particular standards as mentioned before can noticeably reduce the energy consumption during the operation of the building. In this project because the architecture team did not continue supervising the project till installing appliances, it is not clear exactly what type of standard they would have. But as the designer says, they have considered the factor of using energy efficient appliances with the "energy star" standard. These appliances include both those in the units -such as stove, washer-dryer and fridge- and those for public usage (Fig.3.55). This issue becomes more important when we know the building is meant for senior housing. In fact the time that residents spend in their apartment is generally more than typical residents in the other buildings.

Figure 3-55. Washer-Dryers in the Laundry Room

3.6. Integration of Design and Technology

Design techniques and technologies were analysed separately in this chapter; however, the integration of design and technology is a feature that is brought to the project by its architect. In this case, utilities not only are not considered as barriers to the architecture of the building but they also improve architecture quality. One good example is the way that evacuated solar tubes are used in this building (Fig.3.58). These solar tubes have been installed on an elevated steel structure which is relatively costly in comparison with being installed directly on the roof (Fig.3.56). The space under these tubes is covered by extensive vegetation that creates a very unique and pleasant space. Thus the architect has kept both green roof and vacuum tubes. This elevated structure of vacuum tubes also gives an apt end to the northern elevation (Fig.3.57).

Figure 3-56. Evacuated Solar Tubes on a steel structure
The picture shows how the architect has used both evacuated tubes and green roof in his design

Figure 3-57. Northern Elevation
The figure shows how evacuated tubes close the elevation – Evacuated tubes are marked with the red boundary

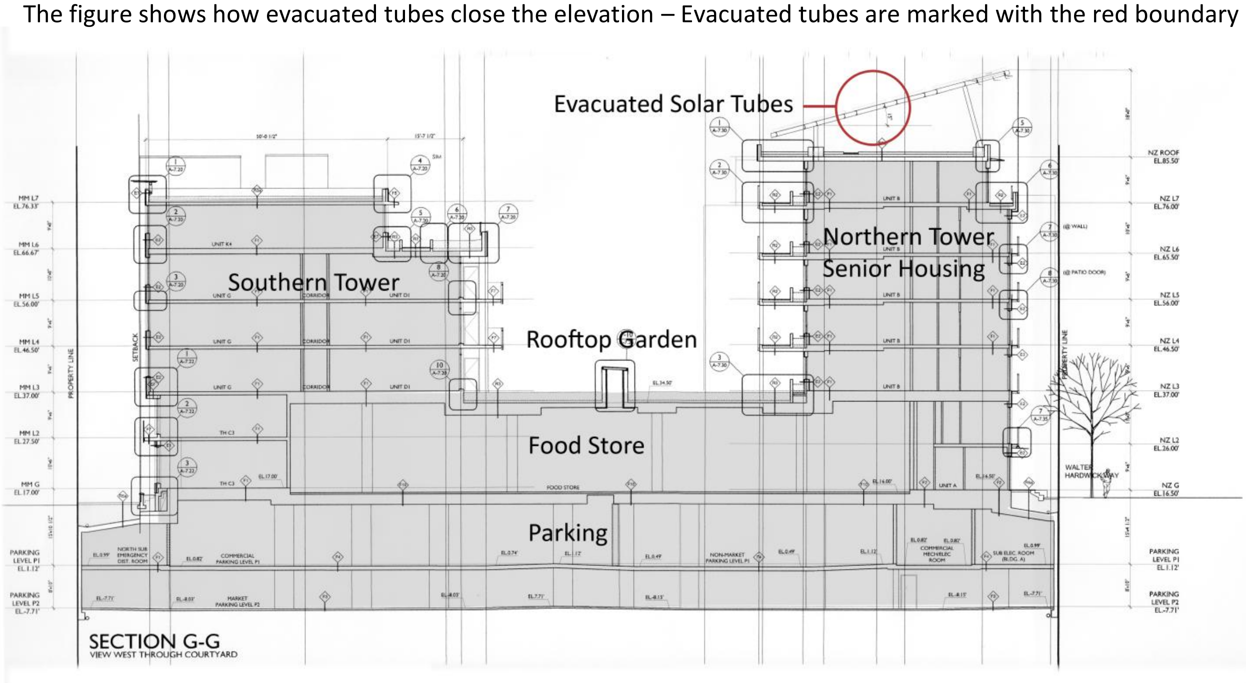


Figure 3-58. Section G-G - Location of Evacuated Solar Tubes
Evacuated tubes are marked with the red boundary

3.7. Challenges

There are some particular aspects that make this project challenging. Firstly, the building reuses the heat from the food store thus some amount of energy is taken from an external source that affects the energy calculations of the building. In addition some of the evacuated solar tubes are located on the other towers' roof; consequently, the building has used the area of other towers to produce energy on-site. The second aspect is the particularly mild climate of Vancouver which has enabled the architect to eliminate the cooling system. Eliminating the cooling system from the energy equation can highly reduce the amount of energy consumption and contribute to the goal of the project accordingly. The architect of the project does not believe that only in Vancouver's climate would he be able to design this net-zero building. As he claims, they could take advantage of some other technologies to increase the energy production such as geothermal heating system (which was avoided because of the existing neighbourhood energy utility), photovoltaic panels and wind turbines. Considering all these aspects, the author believes although some certain conditions helped this project to achieve net-zero goals –the other projects could not have these advantages- there are some other factors that have taken some good opportunities from this building as mentioned before.

After all the Senior Housing project in the Olympic Village, in the author's opinion, took advantage of the minimum design techniques and some known technologies. It is not also clear which attributes of Option C Prime made the designers develop that particular one, while in all cost and energy related aspects Option A had the best features. In terms of utilities, the building only makes use of different heating systems; however, the heating systems it benefits from are very effective and efficient. Reusing heat is indeed an innovative system that has been utilized in this apartment building. This new heating system can be considered as the most important feature that this building introduced as the pioneer of high-rise net-zero apartment buildings in Canada.

Chapter 4

Conclusion

Future of Net-Zero Apartment Buildings

4.1. Net-Zero: Goal or Challenge?

Contrary to what is believed by some professionals, buildings cannot be net-zero. As it is defined, a building is net-zero when the produced energy on-site is equal to consumed energy annually. But all the factors in the equation of produced and consumed energy can change; weather condition, performance of installed utilities, user demands and many other factors might vary and thereby alter the produced or consumed energy. This change indeed can be either negative or positive. Negatively, all the above mentioned factors could cause the consumed energy to be more than the produced energy annually and lead to changing the net-zero projects to only very efficient buildings. In fact there will never be an actual equivalence between the required and generated energy. It is an ongoing challenge to find ways to create a balance between produced energy and consumed energy.

- **Net-Zero: Destination or Starting Point?**

On the other hand, the state of being net-zero is only when the produced energy is equal to the consumed energy; going over or under this condition can give the building significant attributes or disregard it from being net-zero. Positively, it is a starting point for positive energy buildings that can sell energy to the grid. It is also the point that designers can think about working off the grid. The ability of working off the grid is a feature which will be discussed in the last part of this chapter. Not only are net-zero buildings a destination in this sense but also they are a starting point to new fields in architecture.

4.2. Challenges in Net Zero Apartment Buildings

4.2.1. Climate

It is true that climate can be highly effective in energy consumption as well as in initial costs of the buildings. If located in a cold climate, the units consume a significant amount of energy annually only for heating purposes; correspondingly, buildings in long hot summers entail powerful cooling systems -in addition to all design techniques that can be applied- which consume a huge amount of electricity. In fact heating systems (e.g. solar hot water, geothermal heating) with current technologies are generally more efficient than cooling systems. In this sense, cold climates with long cold and freezing winters are relatively preferable for achieving net-zero goals compared to hot climates with long hot summers. On the other hand the Sun as the major source of energy for buildings is more beneficial for direct heating systems than in generating electricity with photovoltaic panels according to current technologies (based on the energy report of the case study). Moreover photovoltaic panels are expensive and consume a lot of space in comparison with the amount of energy they produce. Thus, even in places with long warm seasons that have direct sun, it is more economic to produce hot water rather than electricity. According to these two aspects (efficiency of heating systems and feasibility of heating with available recourses), generally cold climate is easier to deal with to create a net-zero apartment building. This is while mild climate is obviously the best for this reason; it imposes less energy consumption both, in terms of cooling and heating.

4.2.2. Complex Design Techniques

Some fundamental differences appear in net-zero residences when they shift from “single unit” to “multi unit”. Basically in apartment buildings there are two different and separate types of areas that should be designed almost individually in terms of energy. Hence different techniques can be applied for these two parts independently; however, an innovative design tries to integrate these two together. There are several design techniques that can be beneficial for both units and common areas. For instance, one of these techniques, which is using “open corridors”, was introduced in the Chapter Three. Although the concept of open corridor has had some negative effects on the units in regard to their views, it can be still considered as a technique that contributes to both units and common areas at the same time.

Some design techniques which are very economic and effective in single family dwellings are not that practical and influential in apartment buildings. One example of these techniques is burying some parts of the buildings to use the soil as a thick insulation layer. In this example the scale of that technique is very important because burying one level in a two storey house is a lot more effective than burying two levels in a twenty storey apartment building. The other issues that come about in this case are those of natural light and views. In addition, by being buried, the units may lose some vital architectural qualities.

However two of the most effective design techniques that can be easily applied to the projects in any scale are passive solar design and green roofs. Passive solar design whose principles were described before can have a profound impact on energy consumption, especially in cold climates. It can simply make use of the sun's heat when required. Unlike passive solar design, green roofs are a lot more effective in hot climates where they can absorb the sun's heat (Fig.4.1). Green roofs indeed can prevent the roof and consequently the indoor space from heating up during the day. In a wider sense green roofs are beneficial not only for the architecture of buildings, but also for the city while lessening the heating island phenomenon within the city area.

Figure 4-1. Green Roofs Widely Used in Buildings in the Olympic Village.
Green roofs can be used to enhance the architectural quality of the space as well as to help the building to avoid sun's heat.

4.2.3. Monitoring the Operation

One of the other challenges in net-zero apartment buildings is that they need to be constantly supervised for their energy consumption. All the systems should be regularly checked and monitored to ensure that they work properly. In fact in a single family house, the residents can almost handle the efficient operation of utilities (e.g. turning the heating system off when it is not required), but in an apartment building central controlling is needed because of the complicated systems usually used. Lack of a controlling sector in apartment buildings can lead to wasting energy and losing the balance between the produced and consumed energy.

In addition, some utilities need regular control to be more efficient and to perform better. For instance, photovoltaic panels can be installed on adjustable structures that enable solar tracking in different seasons. If these adjustable structures do not work automatically, they will need to be adjusted manually. In the case of apartment buildings where there could be a huge number of these cells, adjusting the panels needs professional teams.

4.2.4. Cooling Systems

One of the challenges for apartment buildings emerges when a powerful cooling system is required, because it consumes a huge amount of energy. Current technologies that utilize alternative energy sources -as described in Chapter Two- for cooling systems are very limited. Geothermal cooling system as a cooling system that is not based on electrical energy is not very effective especially in hot weather. It is, in fact, more efficient and practical for heating systems because it works based on the temperature of the Earth's crust. The other cooling systems applicable for net-zero apartment buildings work with electricity in different ways, but the common negative aspect is that they all consume a noticeable amount of electrical energy. This required energy is usually supplied by photovoltaic panels (if not with wind turbines or water turbines) which are not very efficient compared to their cost. Photovoltaic panels in apartment buildings also entail a vast surface with clear sun. Thus cooling systems that work with electricity are challenging either economically or practically.

- **Natural Ventilation: Opportunity or Threat?**

Although natural ventilation can cool a building, it is still not a cooling system and cannot be reliable for hot climates. Even for mild climates, as seen in Chapter Three -for Vancouver-natural ventilation is not feasible for high-end housing. As learnt from the architect of Senior Housing project, there are certain days of the year that really need cooling systems to ensure a comfortable temperature inside the apartments. In the units, for instance, benefiting from natural ventilation, the residents have to leave the windows open; that by itself lets the heat come inside. In addition, by opening the windows, the residents would be disturbed by street noises if the building is located in a noisy district. It also lets the polluted air come in if the building is located in a polluted district such as downtown areas (Fig.4.2).

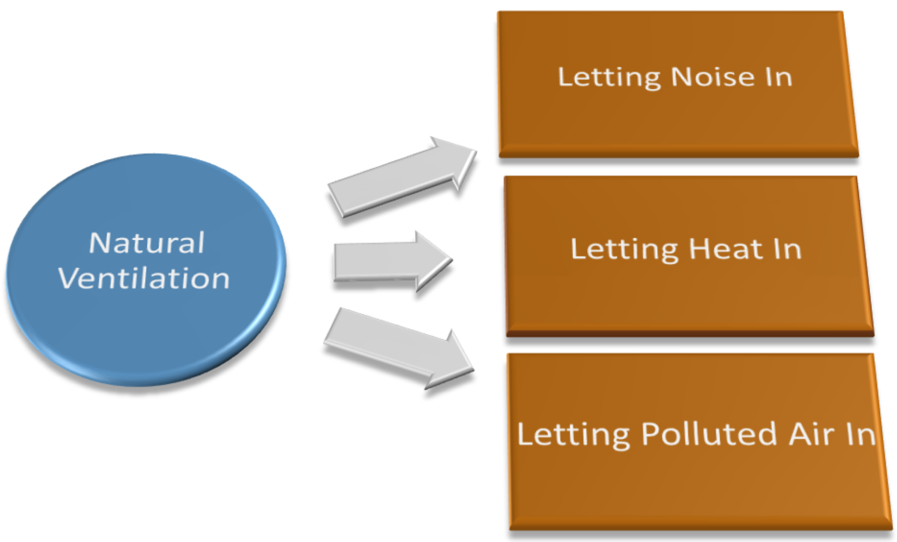


Figure 4-2. Disadvantages of Natural Ventilation
The diagram shows the disadvantages of natural ventilation in crowded areas

The other issue of natural ventilation is that it is not feasible in any elevation; in high elevations the difference between inside and outside air pressures does not allow the air to enter the building (inside air pressure is higher than outside air pressure). Moreover, generally the wind speed becomes very high in higher elevations; consequently the windows in many skyscrapers are fixed and do not allow for natural ventilation. In addition, the high speed of the air reduces its pressure, thus the wind intensifies the difference between air pressures in high elevations accordingly.

4.3. Suggestions

There are some key factors that can help develop net-zero apartment buildings as a housing prototype. These factors that directly affect the typology of feasible net-zero apartment buildings are introduced as follows.

4.3.1. Scale

The scale of the project is a very important factor in developing net-zero apartment buildings. As a simple fact, the capital investment on the project generally rises when the total gross area of a project increases. This simply assets the design process of the project, and enables the design team to invest more time and money on analysing different options and technologies. In the case of using wind turbines, for instance, the design team should analyse wind attributes before utilizing them. Wind analysis in fact entails different observations and simulation of the air movement and the environment with particular software. One example of this is the case study of this research in which, according to its designer, wind energy was eliminated from the potential utilities for the project due to its complexity and high analysis costs. The design team preferred to continue with common technologies which are easier analyse and calculate, such as evacuated solar tubes, in that particular case. However, there are several examples that could utilize wind turbines thanks to the large scale and huge investment of the project, such as World Trade Centre in Bahrain (Fig.4.3). This building is not a residential building but it shows how the scale and huge investment have enabled the architect to analyse and make use of wind turbines in a very architecturally sophisticated way.

Therefore net-zero apartment buildings are such projects that should be defined in a large scale to allow designers to work on innovative techniques and technologies. Otherwise, these types of buildings will go toward standard and prefixed options. A good example is the current situation of net-zero houses built in Canada. There are a noticeable number of net-zero small-scale houses in Canada, but the quality, innovation and richness are lacking in a majority of them (e.g. CMHC net-zero demonstration is one example of poor technologic design and lack of diversity; almost all the houses benefit from same utilities[22]).

Figure 4-3. World Trade Centre, Bahrain; by ATKINS Architects.
This building utilizes huge wind turbines that produce some part of the required energy of the building. Wind turbines are located on huge beams between the two towers.
Source: www.atkinsdesign.com

4.3.2. The Ratio of Gross Area to Footprint

The ratio of gross area to foot print is very important in net-zero apartment buildings with regard to the area and space that current technologies of producing energy require (e.g. photovoltaic panels and solar hot water systems). In the neighbourhoods within high density districts, this issue becomes more important because of the increased land prices buildings try to utilize available ground area to the maximum. Similarly to F.A.R., this ratio in a sense, represents density of the building and shows how tall the building is (the number of floors). Moreover this ratio shows the available outdoor area per indoor area unit. In fact, using this ratio, designers can understand for what amount of indoor area each outdoor area unit has to provide energy. For example, if the total gross area of a building is 6400 square meters and the footprint is 1600 square meters, the ratio would be 4. It means that each square meter of the

[22] See the projects on http://www.cmhc-schl.gc.ca/en/co/maho/yohoyohe/heho/eqho

outdoor area on the roof should compensate for 4 square meters of the indoor area. With the same gross area (6400 m2) if the building footprint was 400 square meters, each square meter of the roof would be used to respond 16 square meters of indoor areas (Fig. 4.4). Hence if the designers want to use photovoltaic panels or evacuated solar tubes as the main utilities for producing energy, they should keep in mind the abovementioned ratio and the amount of outdoor space they will require.

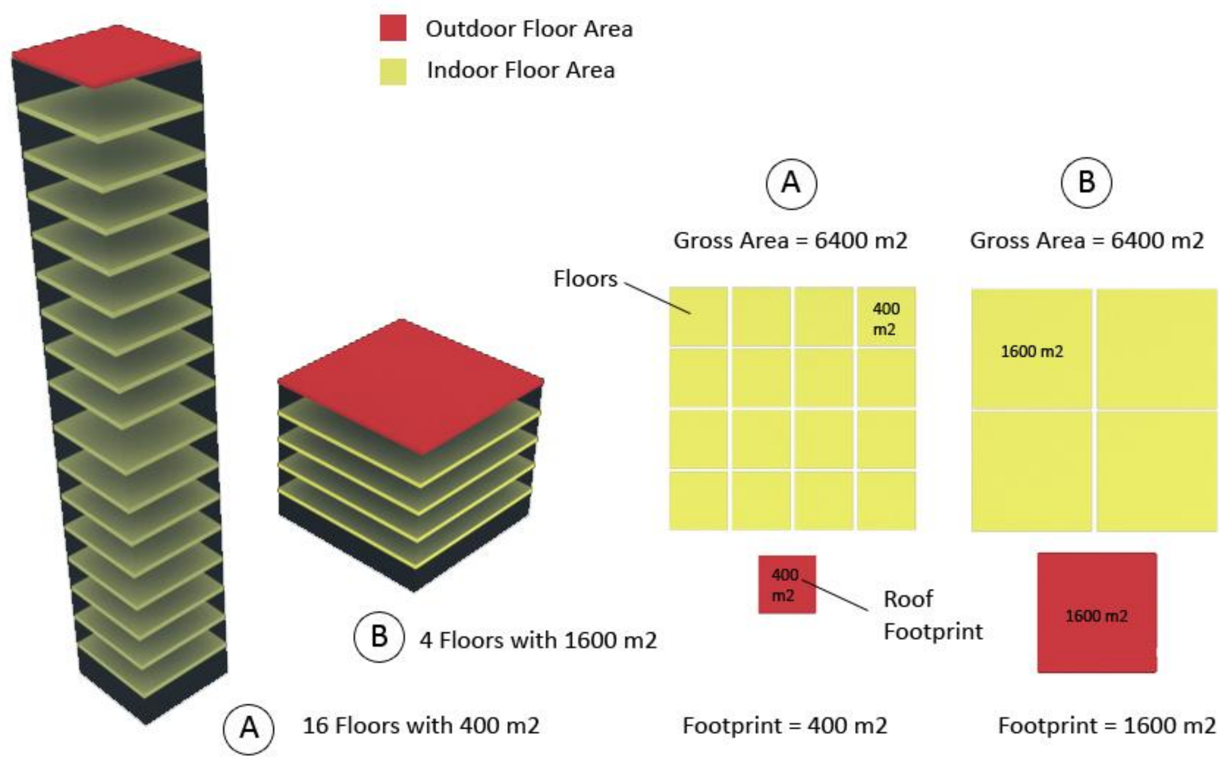


Figure 4-4. Two Different Schematic Options with the Same Gross Area
The footprint of option B which is equal to its roof area is four times greater than the footprint of option A.

In another sense, the limitation created by required space for energy utilities makes the designers look for innovative ideas of integrating technologies of producing energy with their design. For instance, one of the ways in which architects can utilize photovoltaic panels in tall buildings – where the roof area is small compared to the gross area – is to use these panels as a cladding material. This definitely entails the collaboration of the companies that manufacture these certain products. Heron Tower in London is a current example that uses solar panels as a cladding material (Figure 4.5). In fact using solar panels on the facade is the response of the architect to the limitation created by the problem of ratio. However, this technology (vertically installed solar panels) is costly and it is also not as efficient as photovoltaic panels which are installed with a particular angle to the horizon.

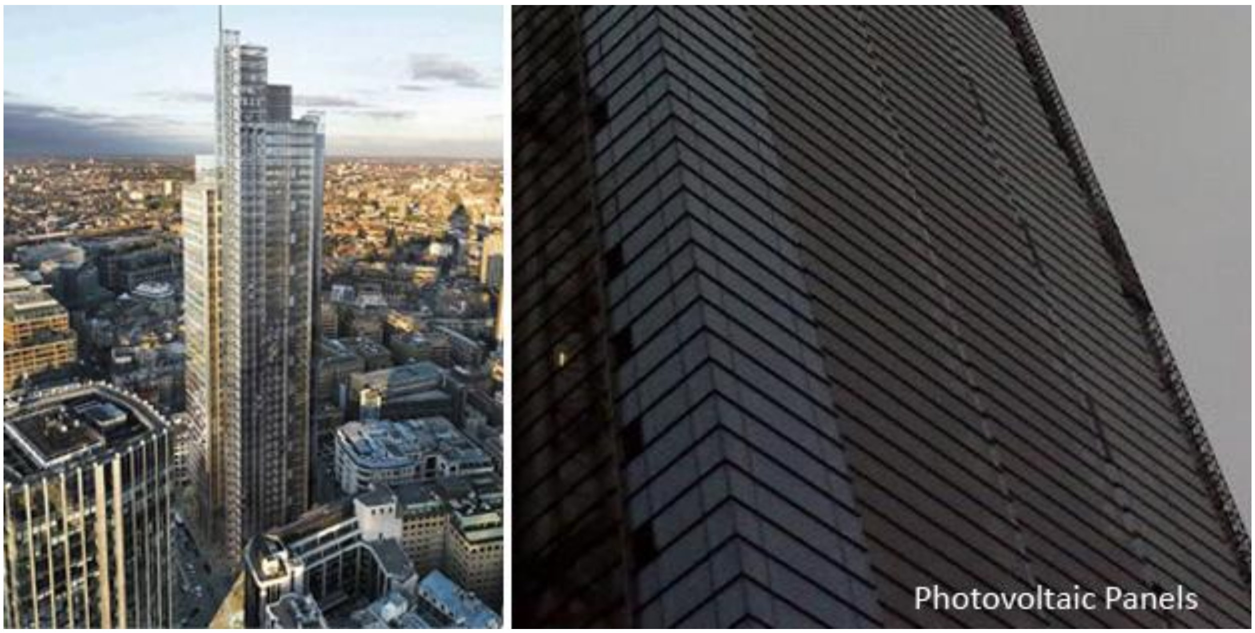


Figure 4-5. Heron Tower, London.
The picture on the right shows the photovoltaic panels on the facade.
Source: http://construction-manager.co.uk/features - http://www.skyscrapercity.com

Through this point of view, there should be a reasonable ratio between the gross area and the footprint of the building to enable the building to produce enough energy. However, some utilities such as wind turbines or geothermal heating and cooling systems do not need that much space on the building's roofs; consequently, they can be helpful when the building becomes taller. Low-rise and very tall buildings (skyscrapers) are not proper building prototypes for developing net-zero apartment buildings according to current technologies. Highrise apartment buildings that have a reasonable ratio of gross area to footprint could be the best choice.

4.4. Net-Zero Apartment Buildings in Theory and Practice

It was discussed in the first chapter that because of high initial costs of net-zero buildings compared to typical buildings, builders choose not to invest in the former. Even after the net-zero apartment buildings are built there is still an important factor in order for it to be considered as a net-zero one, which is operating with zero annual expenses on energy. In other words, the goal of the design is not achieved only by constructing the building. The goal is operating as a net-zero building as well; consequently, it starts to be achieved from the first day of operation to the end of the buildings' life. This long time goal which is achieved during the life of the building makes the role of residents very significant.

- **Energy Consciousness Culture for Users**

The significance of this culture is that if the residents as the users of the projects do not cooperate in consuming energy in the way that has been determined, the building cannot be net-zero. In the case of apartment buildings where many residents with different cultures of energy consumption are involved, achieving the goal is very challenging. Hence net-zero apartment buildings are in an endless challenge between the designed energy consumption plan and the real energy consumption condition defined by residents. This means that the users of this type of building are directly involved in assessing the success of the designers. Thus well educated users who have gained a consciousness for energy consumption can highly contribute to these particular buildings. In fact developing net-zero apartment buildings as a prototype of housing should be accompanied with raising the culture of energy consumption among their users.

4.5. Future Studies

This research, as it was mentioned before, is a starting point for further researches and studies. The fact that "net-zero" is almost a new concept means that there is not much access to many of such buildings. In the case of apartment buildings, this problem is intensified and completely keeps the research open for more case studies in the future that introduce innovative and genuine design techniques. This research also creates a ground for developing self-sufficient and unplugged housing concepts.

4.5.1. Self-sufficient Housing

Self sufficiency is a very vast field that includes many other concerns other than energy consumption. Water, for instance, is one of the serious issues in this field. However, energy is still a very important aspect in this type of building. This research provides designers who tend to work on self- sufficient apartment buildings with concise energy related concerns and guidelines.

4.5.2. Unplugged Housing

Working off the grid is an outstanding feature that some net-zero buildings can possess. But some types of net-zero buildings cannot work off-grid due to their energy production attributes. Some net-zero buildings cannot produce their energy all year round catering to particular utilities they use; consequently, they buy energy from the grid. These buildings sell energy to the grid when they produce more than their need so they annually compensate for the bought energy. Net-zero Senior Housing which was introduced in chapter three is one example of such a building. If these buildings tend to be unplugged they should be equipped with certain utilities that can store energy when there is a surplus. Although it is still a way to enable the building to work off the grid, it is sometimes impossible to store energy. Hot water, for instance, as a substance that has energy and can be easily produced in the summer cannot be stored for winters. Hence designers should think about ways of producing energy which are proper for different needs in different seasons.

Unplugged housing becomes challenging when there is a city grid in the target district. Indeed working off the grid imposes different costs to the project including the cost of analysis, adding energy storing facilities and more complex utilities. This issue brings the question of why all these costs should be incurred while the building can easily be connected to the grid.

Unplugged housing however, is one possible answer to the areas where the city grid does not exist. Such areas can be found in newly developed districts in peripheral precincts of cities, factories and mines out of towns that need some residences for their workers or even islands that do not have access to the energy grid (Fig.4.6). In these cases net-zero apartment buildings that can work off-grid are proper types of buildings to accommodate target users. In fact unplugged housing is a field which this research can definitely help but it entails a comprehensive study of the performance of buildings and the utilities at different times of the year.

Figure 4-6. Small islands are one of the target areas for unplugged and self-sufficient housing
Source: www.transportablehomesspecialist.com.au/category/transportable-homes

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EBooks:

The Challenge Series Booklet: www.thechallengeseries.ca

Zero Energy Design EBook (ZED EBook): www.zeroenrgydesign.com

Websites:

Canada Green Building Council: www.cagbc.org

Canada Mortgage and Housing Corporation: www.cmhc.ca

The Net-Zero Energy Home (NZEH): www.netzeroenergyhome.ca

Ordre des architectes du Québec (OAQ): www.oaq.com

Canadian Olympic Committee: www.olympic.ca

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A. Table of Consumption Loads: Heating, Electricity and Lighting

Source: Recollective Consulting report to Canada Green Building Council, 2007

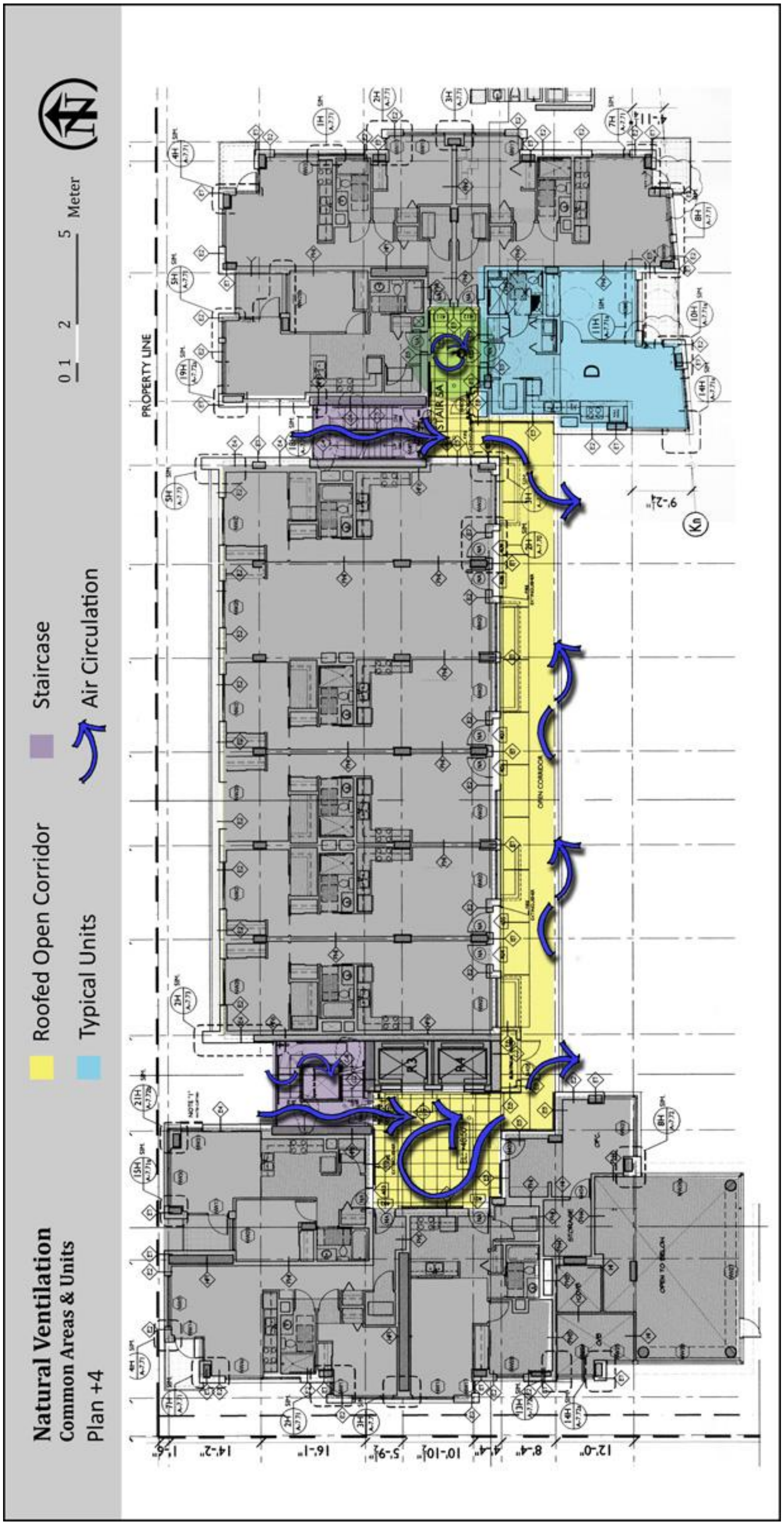
CONSUMPTION LOADS [ALL CALCULATIONS BASED ON 61 SUITE UNITS, AS PER COBALT & NEMETZ'S ESTIMATED LOAD CONSUMPTION CALCULATION TABLES]

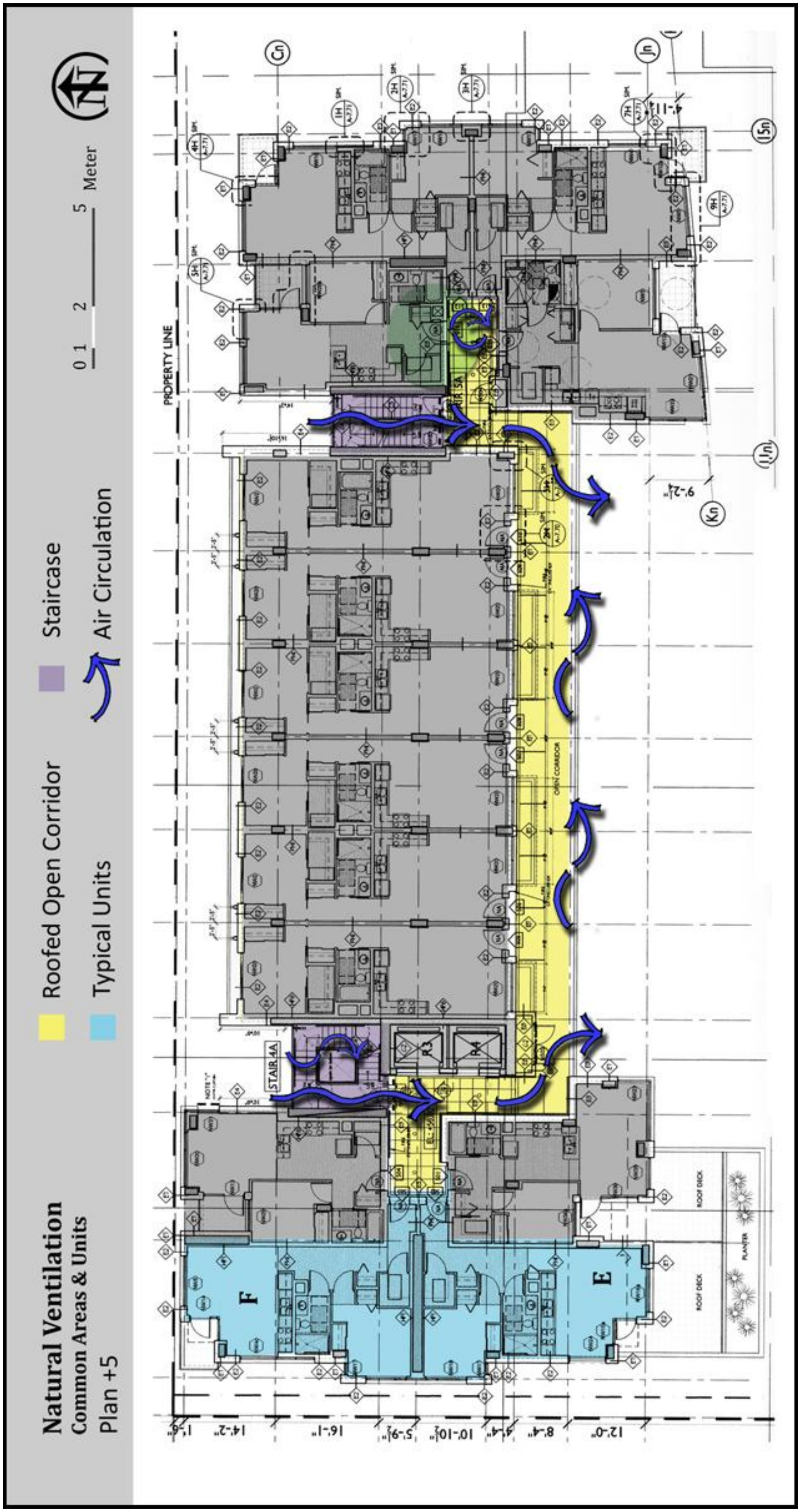
HEATING (Including DHW)	Baseline KWhrs/ unit/year	Netzero KWhrs/ unit/year	# units	Total MWhrs/ year	Previous estimate MWhrs/ year	Comments
Suites						
Total suites (space heating)	2,800	1,166	61	**71.13**	10.00	Confirmed
Total suites (Domestic Hot Water)	527	264	61	**16.10**	2.50	Confirmed
Common Areas						
Corridors	364	n/a				Confirmed
Lobby		n/a				Confirmed
Total				**87.23**		

ELECTRICITY	Baseline KWhrs/ unit/year	Netzero KWhrs/ unit/year	# units	Total MWhrs/ year	Previous estimate	Comments
Suites						
Ventilation	41.00	403.00	61	24.58	29.40	Confirmed
Refrigerators	632.00	376.00	61	22.94	22.94	Confirmed
Freezer	38.00					Included in fridge load
Microwaves	165.00	121.00	61	7.38	14.70	Confirmed. Revised as per final appliance list
Stoves	396.00	396.00	61	24.16	29.89	Confirmed. Assume BC Hydro figures
Computers	82.00	82.00	61	5.00	5.00	To be confirmed by BC Housing
TV	513.00	513.00	61	31.29	34.71	Confirmed
Others	300.00	300.00	61	18.30	60.02	Not confirmed. Assumes BC Hydro figures
Total Suites				**133.65**		
Common Areas						
Laundry/washing	28.00	29.00	61	1.77	1.77	Confirmed
Laundry/drying	255.00	200.00	61	12.20	12.20	Confirmed
Elevators	1,928.00	1,185.00	61	72.29	72.29	Confirmed as per elevator consultant
Total Common areas				**86.25**		
Total				**219.91**		

LIGHTING	Baseline KWhrs/ unit/year	Netzero KWhrs/ unit/year	# units	Total MWhrs/ year	Previous estimate	Comments
Suites	700.00	341.00	61	**20.80**	36.09	Not confirmed. Nemetz to confirmed LED loads
Common Areas						As per Nemetz estimates (issued September 26 2007). Not confirmed. BCH interested on LED. Nemetz to confirmed LED loads
Exterior		5,198.00	1	5.20	5.20	
Stairs		39,000.00	1	39.00	39.00	
Lobby/Corridors	54	24.00	61	1.46	16.197	Only load shown in Cobalt's table
Electrical Closets		8.00	1	0.01	0.01	
Amenities		499.00	1	0.50	0.50	
Laundry		237.00	1	0.24	0.24	
Common Washrooms		12.00	1	0.01	0.01	
Storage		20.00	1	0.02	0.02	
Total (as per Nemetz Estimate)				**67.24**		

B. Natural Ventilation in Common Areas : Floor Plans +4, +5, +6 and +7




Natural Ventilation
Common Areas & Units
Plan +5
Roofed Open Corridor
Typical Units
Staircase
Air Circulation
0 1 2 5 Meter
PROPERTY LINE
STAIR 4A
OPEN CORRIDOR
ROOF DECK
PLANTER
F
E

Natural Ventilation
Common Areas & Units

Plan +6

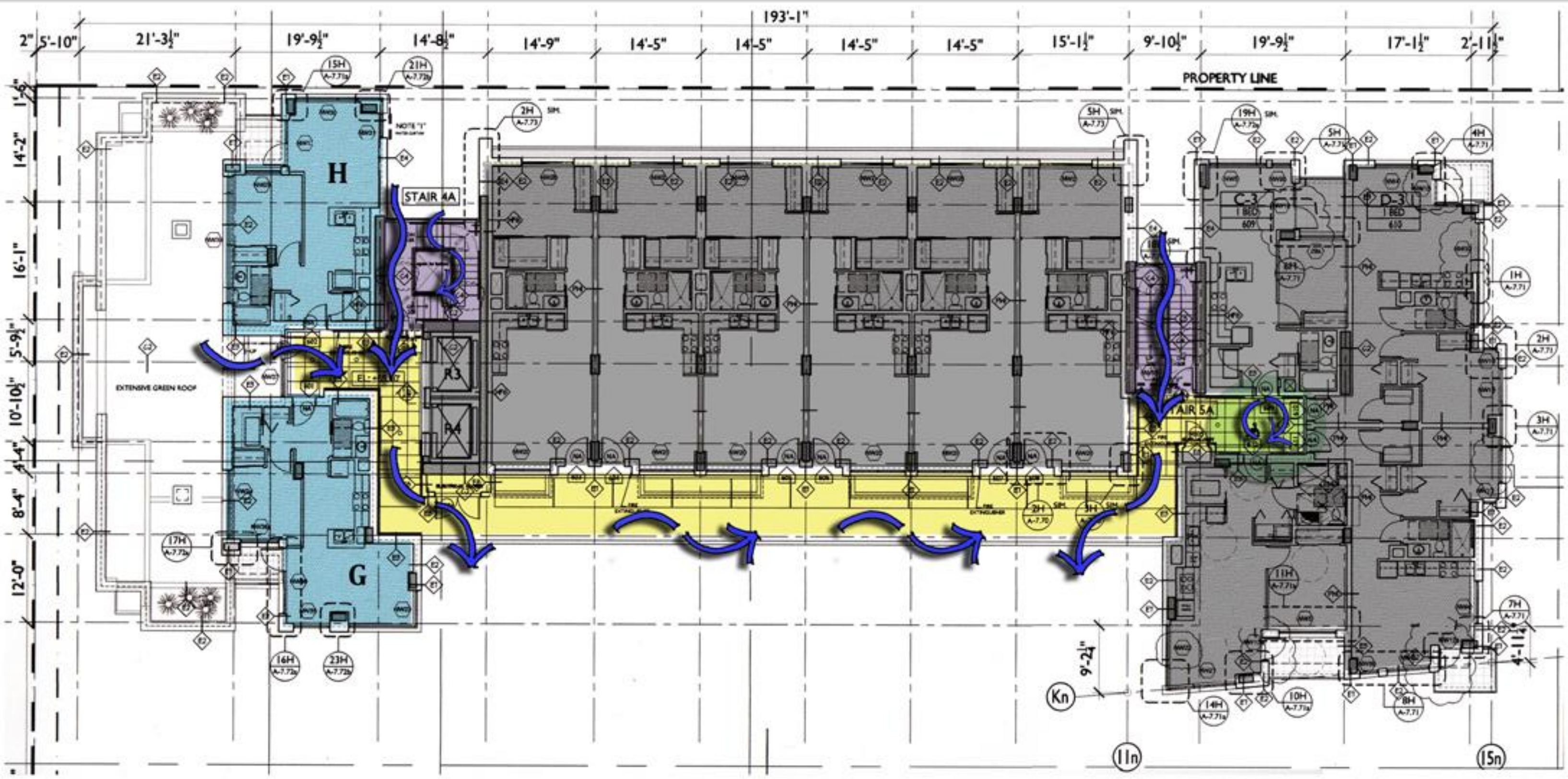
Roofed Open Corridor

Three Types of Units

Staircase

Air Circulation

0 1 2 5 Meter



Natural Ventilation

Common Areas & Units

Plan +7

Roofed Open Corridor

Staircase

Air Circulation

0 1 2 5 Meter