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Títol

Vertical Farm Façade

First approach to the energetic savings applied to the Seagram Building in New York.

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VERTICAL FARM FAÇADE:
First approach to the energetic savings when applied to the Seagram Building in New York.

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ABSTRACT

Today, the use of natural resources, the increasing need for energy, and the rise in pollution are becoming matters of concern for developed nations. Although today's buildings are more efficient than those from the last century, they continue to waste tremendous amounts of energy and water. Furthermore, 80% of the land available for agriculture on the Planet is already farmed. The agricultural footprint can be catastrophic if we take into consideration that the world´s human population could reach 10.6 billion people in less than 40 years; an increase of almost 40%.

Thus, becoming sustainable is something that is mandatory for subsequent decades. Sustainability is becoming an important priority in architecture as well as across many organizations and governments.

Aside from an improved aesthetic, the presence of urban plant life positively affects an area's ecological, economic and social functions. The combination of a Green Wall and a Double-Skin Façade can be an advantageous solution with substantial potential and still in its early stages of research. The GW and DSF can work together as an approach to the Vertical Farms solution.

Vertical Farms are a new concept and philosophy for the way humanity thinks about agriculture. A goal for Vertical Farms is the eventual ability to grow produce in city centers in order to avoid transportation issues and to preserve existing natural life by slowing deforestation.

Working in this direction and with benefits of these three fields (Green Walls, Double-Skin Façades and Vertical Farms), the main purpose of this Thesis is to develop and quantify an improvement for a famous building in New York based on the Sustainable Building philosophy. The chosen building is the Seagram Building; it is a large office building designed by the German Architect Mies Van der Rohe in 1954-58. The goal for this improvement is to replace the entire main façade of this building with a green solution. More specifically—the improvement will replace the totality of the original façade window to a new Vertical Farm Façade.

By approximating the benefits of improving the main façade of the famous Mies Van der Rohe Seagram Building, researching the benefits of the use of new irrigation technologies, and understanding the benefits of vegetation in Double-Skin façades, this Thesis intends to define an initial approximation of the energetic benefits resulting from implementation of a Vertical Farm Façade.

Keywords: Green Walls (GW), Double-Skin Façades (DSF), Vertical Farms (VF), Living Walls (LW), Vertical Farm Façade (VFF)

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This Thesis marks the end of one of the most important stages of my life. I want to dedicate this work and the title of Enginyer de Camins Canals i Ports to my late grandfather Josep Villanova. He taught me by his example that with hard work, but also with love, you can overcome the greatest obstacles. *Gràcies avi.*

Marc Prades Villanova

TABLE OF CONTENTS

TABLE OF FIGURES

1. INTRODUCTION

The beginning of the 20th century marks a revolution in modern architecture that changed the way people think about and build structures. New lines and shapes appeared at the hands of great masters like Ludwig Mies van der Rohe, Louis Sullivan, Walter Gropius, Le Corbusier, Alvar Aalto, Frank Lloyd Wright, Oscar Niemeyer, and so on. In addition, new materials and construction systems have made possible the implementation of these innovations.

Today, most of the buildings designed by these famous architects are still open and operating, which makes it is possible to examine them and the thought that went into them. Despite the progress that these ideas represent for the architectural world, these buildings weren't designed with sustainability in mind.

More than thirty years ago, architectural critic and social commentator Lewis Mumford noted that "…the modern architect has produced the most flagrantly uneconomic and uncomfortable buildings…which can be inhabited only with the aid of the most expensive devices of heating and refrigeration. The irrationality of this system of construction is visible today in every city from New York to San Francisco: glass-heated buildings without any contact with fresh air, sunlight, or view."

Although today's buildings are more efficient than those from the last century, they continue to waste tremendous amounts of energy and water. Sited and designed with little regard for the local climate, new buildings are far more expensive to heat or cool than necessary.

Today's buildings have to be well designed from a sustainability-centered perspective. Architects and building designers must consider the environment, the weather, orientation, materials, sunlight, health, etc.

There are many advantages of sustainable design. Although green buildings are significantly more expensive than conventional ones, the initial inversion pays for itself over time. Sustainable buildings are much cheaper to heat, cool, and light; so considering the constant growth of the planet's energy debt, sustainable buildings eventually earn money when compared to conventional buildings. Furthermore, because of their low energy consumption, green buildings produce correspondingly less pollution which contributes to a healthier working and living environment—an appreciable impact considering that the typical American spends 80 percent of their time indoors.

Taking into consideration these variables, it is obvious that promoting sustainability of structural designs is a need. Fortunately, many architects and civil designers have been working on developing sustainable buildings during recent decades. Technology has been advancing exponentially and has become a powerful tool for architects, designers and engineers to reach sustainable building goals. More efficient systems, materials with better proprieties, and new cooling strategies have debuted thanks to much of the recent work and effort by researchers and professionals

The main purpose of this Thesis is to develop and quantify an improvement for a famous building in New York according to the Sustainable Building philosophy. The chosen building is the Seagram Building; it is a large office building designed by the German Architect Mies Van der Rohe in 1954-58. The goal for this improvement is to replace the entire main façade of this building with a green solution. More specifically—the improvement will replace the totality of the original façade window to a new living wall panel in a double skin façade.

Whereas space is limited, Green Walls and Green Roofs add a unique and more interesting visual to the city scene. Aside from an improved aesthetic, the presence of urban plant life positively effects an area's ecological, economic and social functions. According to the publications of Heidt and Neef (2008) the functions of the Green Walls can be summarized on the following diagram:

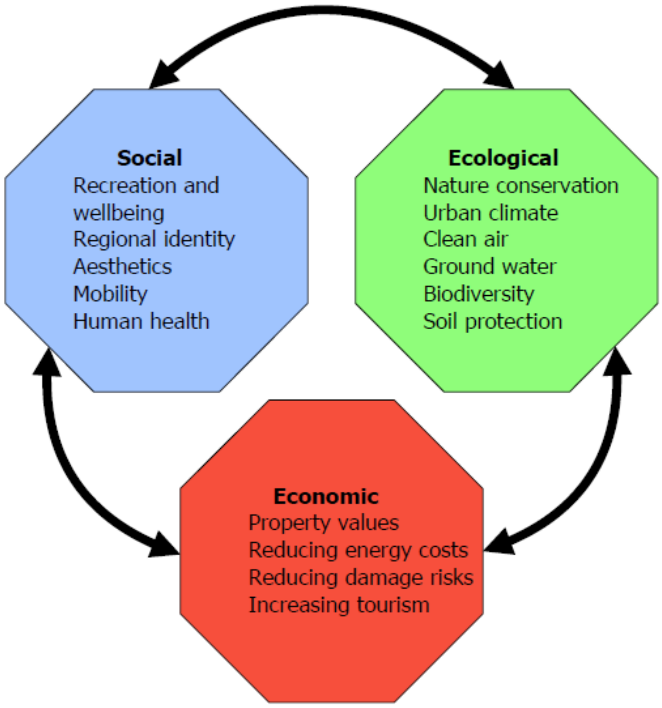

Figure 1. Social, economical and ecological functions and objectives of urban green and sustainability. (Heidt and Neef, 2008)

Green walls have become an important new research field as people have begun to understand the benefits of installing plants on building facades. Among these advantages are the following:

- Reduced urban heat island effect: The temperature increase in urban areas caused by the replacement of natural vegetation with inorganic material. This results in the conversion of sunlight to heat. Vegetation cools buildings and the surrounding areas through the processes of shading, reducing reflected heat, and evapotranspiration.

- Improved exterior air quality: Elevated temperatures in modern urban environments with increasing numbers of vehicles, air conditioners, and industrial emissions have led to a rise in pollution. Plants are able to reduce this by capturing airborne pollutants and atmospheric deposition on leaf surfaces. Plants also work as filters for noxious gases and particulate matter.

- Improved energy efficiency: Improves thermal insulation capacity through external temperature regulation. This can impact both cooling and heating.

- Aesthetic improvement: Green walls provide aesthetic variation in an environment in which people carry out their daily activities. Numerous studies have linked the presence of plants to improved human health and mental wellbeing.

- Improved indoor air quality: For interior projects, green walls are able to filter contaminates that are regularly flushed out of buildings through traditional ventilation systems. The filtration is performed by plants, and in the case of bio-filtration, micro-organisms.

- Noise reduction: The growing media in living wall systems will contribute to a reduction of sound levels that transmit through or reflect from the living wall system.

- Marketing: Improved aesthetics may help to market a project and provide valuable amenity space.

Green walls are a key component of living architecture and they will become increasingly important fixtures in our cities in the years to come. Green wall technologies provide a wide range of options for designers who are interested in using the building envelope to accomplish multiple objectives and to provide new free standing design features on the interior and exterior of buildings.

As well as Green Walls, Double-Skin Façades have also become an important field in Building Systems. Many researchers have been working on developing DSFs in order to provide a better solution to building envelopes. An effective DSF design has notable advantages:

- Thermal insulation: DSFs provide better thermal insulation than traditional façades

- Solar protection: cavity space allows the placement of solar shading devices which improves shading coefficients and, as a result, reduces direct head loads.

- Energy savings: as a result of the benefits in insulation and solar protection.

- Acoustic insulation: reduction of noise levels inside buildings. Some authors stand that acoustic insulation is one of the most important advantages of the Double-Skin Façades.

- Transparency: people who spend time inside appreciate natural light. This natural light also allows for the reduction of energy consumption in buildings.

- Aesthetics: Double-Skin Façades multiply the creative possibilities for designers and architects.

- Economics: The money saved over time from energy conservation more than makes up for the higher initial investment.

- Wind protection: the external façade works as a barrier between wind and the cold air that gets let into the cavity. This reduces the cooling effect of wind in winter.

- Rain protection: the external façade provides a shield to the building which improves its durability.

Vertical Farms are a new concept and philosophy for the way humanity considers agriculture. The planet's growing human population already uses 80% of available land on for agriculture. A goal for Vertical Farms is the eventual ability to grow produce in city centers in order to avoid transportation issues and to preserve existing natural life by slowing deforestation. Despite being new and not fully understood, Vertical Farms are clearly advantageous:

- Preparation for the future: an increasing quantity of people living off of a limited amount of agricultural surface space poses an evident problem for the future. Vertical Farms will provide one sustainable alternative to this issue.

- Increase of crop production: Vertical Farms are imagined as food factories where plants can be growing 24 hours a day, 365 days a year.

- Water sustainability: by recycling the dark water by plants' evapotranspiration.

- Protection from weather disasters: Vertical farms reduce potential vulnerability to natural disasters like floods, drought, tornados, etc.

- Sustainable environments for urban areas: placing Vertical Farms in city centers will reduce the dependency of cities on farmlands.

- Conservation of natural resources: more Vertical Farming means less traditional agriculture—which is translated to less stress on the environment and less deforestation.

- Organic crops: A safer farming environment inside buildings enables easier production of organic produce—which is healthier and more valuable for consumers.

- Healthier workplace: reduction of the traditional farming risks.

- Reduction of fuel consumption: avoiding transportation from the field farms to the city the fuel consumption is reduced.

- Energy production: Vertical Farms could produce energy from the biogas by using the organic waste. Placing solar panels and wind turbines in the building allow the Vertical Farms to be energetically independent.

- Flexibility with placement: Vertical Farms can be located creatively in myriad areas.

A combination of a Green Wall and a Double-Skin Façade can be a great solution with many advantages and it is a field with a lot of projection and which is still at an initial stage of investigation. This GW and DSF can work together as an approach to the Vertical Farms solution.

Dr. John Zhai, PhD graduate from MIT and extensive researcher with honors from the University of Colorado at Boulder, along with his graduate research team has made recent and substantial development in this field. Participating researchers include Matthew Kincaid, Michael Gartman, Marc Prades and Tamzida Kahn.

One of the most impressive focuses of Zhai´s proposed improvements on the Seagram Building is directly related to a green double-skin panel that the team is developing. With that said, this document is going to show a whole view of the green façade field, also an approximation to the behavior and advantages of a double skin façade, as well as demonstrate the research done around the Living Wall panel; then, in the second part of this document, there’s going to be demonstrated how the Living Wall panel has been tested on the Mies Van der Rohe Seagram Building main façade using some commercial software (Energy Plus, Open Studio and SketchUp). These softwares allow for the measurement and quantification of the improvements in terms of heating system savings using the new Double-skin Living Wall Panel.

1.1. APPROACH TO SUSTAINABLE BUILDINGS

According to the World Commission on Environment and Development we can define *environment* as “The place where we all live” and *development* as “what we do in attempting to improve our lot within that abode.” Originally “Sustainable Development” was used as a way to reach a balanced economic growth while maintaining the resources for future generations. Today, the use of natural resources, the increasing need for energy, and the rise in pollution are becoming a matter of concern for developed nations. Being an important industrial sector, the building industry has to minimize the level of pollutants released into the atmosphere and the energy used by the building during its life cycle. All of these concerns are being introduced in the architectural design of structures.

The term “bioclimatic architecture” was first used by Victor Olgyay in the early 1950s. Many factors and stages are analyzed during the process of turning the abstract idea of a building into a real one. It is during this process the aesthetical, functional and technological factors are taken into account. Victor Olgyay included human psychology, climatology and building physics into the equation in order to develop a strong relationship between the building and its environment.

Today the role of the built environment and whether it is or is not sustainable is the main issue in every environmental policy. The necessity of adapting the buildings to the occupants’ ever- changing needs while minimizing the use of non-renewable resources is what drives the building designers. One has to take into account that of the overall amount of energetic cost of a building, about 15% is used for construction and 5% for demolition. This leaves 80% of the total amount expended during its operation. This leads to a growing demand for thermal, naturally lit and ventilated buildings. This is the direction in which future projects are headed. However, the concept of efficiency is very complex and many strategies have to be applied to many different fields. The key elements the functional and formal design are construction technologies, the occupants’ health and comfort, and the ecological impact on the environment. Taking these criteria into account, we can improve the energetic efficiency of all elements that constitute a building—resulting in the recognition that the building envelope is one of the key elements in achieving this model.

1.2. OBJECTIVES

The main purpose of this Thesis is to implement a sustainable improvement to a famous skyscraper in New York (The Seagram Building). This old building was raised in the beginning of the second half of the twentieth century when sustainability was not a priority.

Improving the main façade of the famous Mies Van der Rohe Seagram Building is a symbol of modern architecture. Mies Van der Rohe and many other architects have revolutionized concepts of architecture with their ideas and beliefs; they changed the conception of previous architecture using new materials and shapes.

Becoming sustainable is something that is mandatory for subsequent decades. Sustainability is becoming an important priority in the architecture field as well as in many organizations and governments. This will revolutionize architecture the way Mies Van der Rohe did.

Influencing the public's mentality to believe in sustainable projects and actions by improving the main façade of the Seagram Building is the most important objective of this Thesis.

1.2.1. Specific Objectives

By approximating the benefits of improving the main façade of the famous Mies Van der Rohe Seagram Building, researching the benefits of the use of new irrigation technologies, and understanding the benefits of vegetation in Double-Skin façades, this Thesis intends to define the energetic benefits from implementation of the Vertical Farm Façade.

Objectives based on informing people's perceptions of sustainability:

- Studying and researching the advantages and disadvantages of Green Walls, analyzing the different types of Green Walls, and discussing the best option to be applied to the Seagram's Building Vertical Farm Façade.

- Double-Skin Façade research: understanding different types of DSFs and the benefits of using them on buildings. Different Double-Skin Façades have been studied and researchers around the world are working on understanding the thermal behavior of these systems. This provides very useful information to consider later in the computational analysis.

- Researching the field of Vertical Farms is also essential to better understand the implementation of the Seagram Building Vertical Farm Façade. Vertical Farm technology is trending around the world and could be the first step in filling the space. Knowing more about these technologies and current studies is very important to understand the benefits of implementing Vertical Farms in Manhattan.

- To make sense to the implementation of the Vertical Farm Façade in the Seagram Building, some prior calculations are necessary. One of the goals of this Thesis is to do an overall calculation of the energetic benefits of the implementation of this Double-Skin Vertical Farm Façade.

2. GREEN WALLS

2.1. INTRODUCTION

Since the beginning of time, humanity has worked to protect itself from nature. From the use of fire and caves to the construction of more sophisticated tools and structures, humans have managed to survive in the wild. Spanning the many theories about the beginning of architecture is one common denominator: man's will to domesticate the natural environment.

Most early man made constructions were short-lived and built with raw materials found nearby. As methods of production became more complex, societies began to develop stable infrastructures and long-lasting settlements. For thousands of years, the global population has increased. The majority of this population growth has taken place in large cities and urban areas—places where humanity's sense of isolation from nature is at its highest. As this physical gap between humanity and nature grows, humanity's ability to appreciate and resonate with the natural world shrinks. Today, some modern cities seem entirely disconnected from nature; metropolises of concrete and asphalt where machines and factories reign.

Figure 2. Myth of the hut, Leon Battista Alberti

Despite the existing distance from the wilderness, humans do not want to lose contact with nature. After all, the natural world is our original home, our natural habitat. During the last decades, societies have tried to maintain contact with nature in urban areas. Garden cities and public parks give people space to get fresh air, play, hold social gatherings, and basically escape from city life. According to research done by Givoni in 1991, visual and physical contact with plants can directly benefit health.

Despite the implementation of green getaways in cities, the effects that these provide to the population are insufficient and sporadic. According to Santamouris (2001), public parks do manage to lower temperatures within their vicinity but are incapable of thermally affecting the concentrated structures where people live, work and spend most of their urban lives.

Recently, Wong (2009) indicated that the outer surfaces of buildings offer a substantial space for vegetation in urban cities. As a result, planting on building roofs and walls has become one of the most innovate and rapidly developing fields in ecology, horticulture and built environment.

It is obvious that vegetation will improve the quality of city environments. Properly implementing plant life in urban areas will positively affect heating and transportation processes as well as the welfare and health of the city's inhabitants.

Among the most promising options for improving the urban environment is incorporating nature within the vertical surfaces of a building—otherwise known as a Green Wall.

A Green Wall is a wall-- either built into the facade of a building or freestanding—that hosts vegetation and occasionally soil or an inorganic growing medium. The earliest and most similar instance of a Green Wall was the 600BC roof gardens of the Hanging Gardens of Babylon. From the Roman Empire to Scandinavia to Japan, various cultures have made use of types of Green Walls for their structures. During the Renaissance, for example, estates and monastery gardens were covered with fruit walls, which warmed the structure and promoted the growing process. In Pompeii, shopkeepers introduced vines to climb along their shop balconies. From the mid 17th century for nearly 200 years—peaking with their representation in the Louis XIV's palace gardens of Versailles in France—fruit walls could be found in abundance all over the world.

Figure 3. Hanging gardens of Babylon. (quevuelenaltolosdados.blogspot.com)

As Marc Ottelé (2011) explains in his research studies, over the centuries, various techniques were used to let plants grow along façades and walls. Lambertini (2007) asserts that the beginning of Green Walls came from people who obtained plants from the ground and put them into planter boxes. In 1984, a project led by Paul-Lincke-Ufer in the Kreuzberg neighborhood of Berlin was the first inner-city residential eco-project (Köhler, 2006). His project examines the potential for inner-city greening. His team planted various plant species in flowerpots along the façade and at the base of the façade (Peters, 2011).

"Bringing nature under the interest of city dwellers was one of the characteristics of the famous artist and architect Friedensreich Hundertwasser. Hundertwasser designed in 1986, an accommodation complex of 52 houses with undulating façades and roofs." (Ottelé, 2011). There were more than 200 trees and shrubs growing on the roof, the balconies, and in planter boxes (Lambertini, 2007).

With a tangible increase in air pollution, cities have grown more and more responsive to green initiatives. Unfortunately, most large cities do not have enough space to introduce parks or other alternative green areas. During the 1900's Ebenezer Howard from the UK worked to satisfy that need by developing the "Garden City" concept. During the 1970s, an extension of concepts developed by Frank Loyd Wright-- and directly contradicting the modern, industrial efforts of the time— led to the progressive notion of Green Architecture. This movement was based on marrying ecology with urban developments. (Lambertini, 2007).

'Beside for architectural reasons people became increasingly aware that green is indispensable in the urban environment' (Ottelé, 2011). In the early 1980s, the German government began to incentivize green city efforts. (Köhler, 2008).

Green Walls were particularly important in the Arts & Crafts and Modern style movements in Europe. At the beginning of the 20th century, some movements like the 'Jugendstil Movement' used different climbing plants on building façades in an effort to merge buildings with their gardens. In England, Garden Cities are excellent examples of Green Walls. William Robinson and Gertrude Jekyll designed outdoor vegetated rock walls used for screens and boundaries in gardens.

The use of Green Walls and climbing plants declined after the 30's as a consequence of new building techniques and people's fear about compromises of wall durability.

Stanley Hart White (University of Illinois Urbana-Champaign) invented the modern Green Wall with integrated hydroponics in 1931-1938. White holds the first known patent for a green wall, or vertical garden—conceptualizing this new type of garden as a solution to the problem of modern garden design.

On the other hand, a large-scale living wall with a hydroponic system was created in the 1930s by a cooperation of the well-known architects Burle Marx, Lucio Costa and Le Corbusier. These architects designed and created a hanging garden for the Ministry of Health and Education in Rio de Janeiro (Brazil) where they hung plants without access to the natural soil on the ground (Lambertini, 2007).

Figure 4. Ministry of Health and Education, Rio de Janiero, 19543. (www.greekarchitects.gr)

Figure 5. Ministry of Health and Education, Rio de Janiero, 1943. (www.studyblue.com)

Patrick Blanc is often credited as having developed the concept in the late 1980s. The French botanist is seen as the first to design the 'modern' structure of Green Walls with a full hydroponic system, an inert medium and numerous exotic species. However, the actual inventor is Stanley Hart White, a Professor of Landscape Architecture who patented a Green Wall system in 1938.

Presently, Green Walls are again a point of interest in bringing nature back to dense urban areas. To clarify the variations, several researchers have defined an overall Green Walls classification system based on structure, plant species, watering system, and growth sustainability.

2.2. GREEN WALL CLASSIFICATION

The term *Green Wall* refers to the growing of plants on, along, or against a wall or façade of a building. Dunnet and Kingsbury (2004) define Green Walls as “a living and therefore a self-regenerating cladding system for buildings, with traditional use of climbing plants to cover the surface of a building. Green walls can be created by the use of climbing plants directly at the façade or also with the assistance of a supporting system to create a space between façade and the plant structure.”

In 2005, Hermy proposed the following definition for Green Walls: “Green cover on vertical surfaces by plants rooted on soil. This can be rooted in the soil ground level of the façade or also in planter boxes placed on the façade.”

In 2008, Köhler defined Green Walls as “typically covered with woody or herbaceous climbers either planted into the ground or in planters in order to cover the building with vegetation. Living wall systems involve planters or other structures to anchor plants that can be developed into modular systems attached to walls to facilitate plant growth without relying on rooting space at ground level. Supplemental irrigation or hydroponic systems are necessary for these systems. Living walls systems can be used outside a building as well as inside a building.”

In his Master Thesis, *Green Façades and Building Structures*, M.A. Mir (2011) proposes that Green Walls be separated in three main categories: Wall vegetation, Green façades, and Living walls systems.

2.2.1. Wall vegetation

Wall vegetation is characterized by a spontaneous and irregular growing of plants in a natural way. These plants usually grow on wall surfaces like joints and cracks, as well as along the top of some walls.

Wall vegetation can also be divided in two categories: Naturally grown vegetation and Concrete prefabricated panels with vegetation.

2.2.1.1. Naturally grown vegetation:

The main characteristic of this type of Green Wall is the natural growth of vegetation on old or damaged structures. Naturally grown vegetation is common on old walls, historical monuments, and other old structures with disintegrated mortar or building material that enables plants to root. These plants grow naturally in an irregular and unplanned way because of the nonexistent human intervention.

Figure 7. Naturally grow vegetation. (www.freestockimages.org)

Figure 7. Naturally grow vegetation. (www.123rf.com)

Concrete prefabricated panels with vegetation:

Green concrete is a prefabricated panel basically made with concrete that offers structural strength as well as a base for vegetation—allowing for quick and spontaneous plant colonization on a wall. One of the concrete proprieties is the porosity; a special design using coarse aggregate (lava stone, D32) and adding air to the mixture during the setting creates concrete panels with large pores that can be covered and filled with a specific soil concoction. To provide structure, this layer rests atop another layer of self-compacting concrete. In this way, vegetation is allowed to grow between the large concrete pores where some soil has been accumulated. In order for these platforms to absorb water naturally, the panels are tilted slightly vertically in order to collect water from outdoor precipitation. A downside to this method is a result of high pH levels in the concrete and low levels of water: scalability. Only a small quantity of plants can flourish on these panels.

Figure 8. Concrete prefabricated panels with vegetation. (Ottelé 2011)

2.2.2. Green façades

According to the definition given by M.A. Mir (2011), Green façades are created by vines and climbing plants that are rooted in soil or containers, growing upwards or cascading down, that require a structure to maintain their position, develop growth, and survive seasonal exposures. Green facades are easily scalable and rely on the adaptable characteristics of a broad range of plant species. This is the most common type of Green Wall. Plants can be rooted into the soil in front of the wall or planted in artificial substrate on planters.

Types of Green façades vary depending on where the plants are located. Two locations are planted into the soil or growing from planters.

2.2.2.1. Plants planted into the soil:

This type of façade usually takes a long time to cover the whole surface. Plants grow from the floor against the façade. The main property characteristic of this kind of Green Wall is that plants take water from natural sources like rainwater and groundwater. The category can be divided into self-climbing plants, which grow directly to the wall, and plants that need a supportive structure.

Figure 9. Green façade planted into the soil. (www.selector.com)

2.2.2.2. Plants planted in planters:

Plants growing from planters can be situated in different places or at different altitudes of a façade. It is easy to find different instances of this kind of Green façades. In some cases, planters are situated on the bottom of a façade in order to allow plants to create a falling effect. They can also be distributed randomly along the wall. The main characteristic of this type of Green Wall is that this system needs a continuous watering system. Furthermore, plants have a limited space to root because of the planters, so the dimensions of planters and plant distribution define how the Green façade is going to grow. As it seems, the plants in planters need more maintenance than those planted into the soil. Additionally, this system has a slow growth time—meaning it could require years to cover the whole façade. Self-climbing plants and plants that need supporting structures to grow are alternatives to Green façades with plants planted into the soil.

Figure 10. Green façades planted in planters. Barcelona. (www.geolocation.ws)

Depending on the plant species, it is sometimes necessary to design a supporting structure. Some plants are able to grow along vertical surfaces because of their adhesive characteristics. These plants have adhesive root structures that enable them to attach directly to the façade. Many species have this characteristic and every one has it's own way to grow. This makes it important to choose the species carefully based on the desired final result. Plants without these adhesive properties generally need a supporting structure. These structures can be made with steel cables that create surfaces or three dimensional shapes.

Depending on the supporting structure design, we can also classify this kind of façade into two types of structural green facade systems:

2.2.2.3. Two dimensional systems:

As researchers from Greenscreen explain, two- dimensional solutions consist of vertical cables, horizontal cables, rods, grids, or nets fixed on a frame or a rigid structure. These cables or nets in the two dimensional systems configurations have to be in tension. As a consequence, the connectors and the attachment points to the building structure or frame is a critical factor. The tension of these cables added to the weight of the plants transmits an increasing load to the building— an important structural factor to consider. *"Cable systems and their attachment components are most often made from stainless steel that can add to durability and strength, but also increases costs"* (www.greenscreen.com).

Because of the need of a supporting structure for this solution, 2D systems are close to the buildings façades. Many materials as steel or wood can be used in 2D system components, conforming a huge variety of different configurations or solutions for building façades. To choose between these solutions is important to take in consideration some factors like how is the plants inhabit, which are the plants that will grow in the system and also the weight of the system on the building structure.

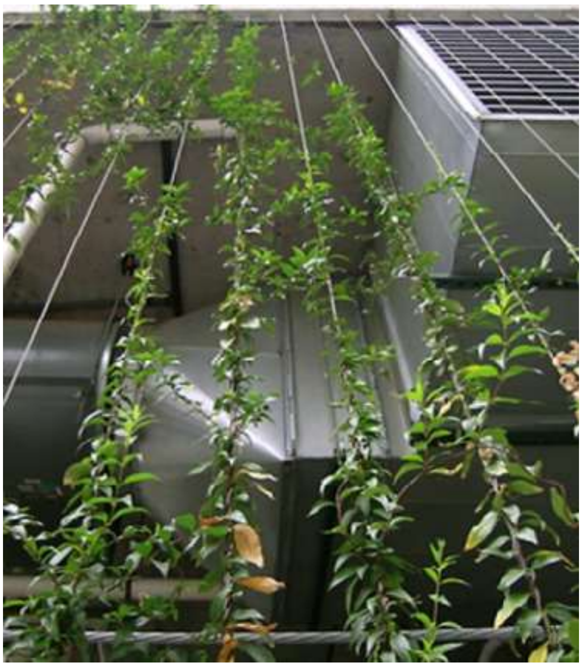

Figure 11. 2D system. (www.greenscreen.com)

2.2.2.4. Three dimensional systems:

The three-dimensional systems are basically panels that occupy a volume instead of just a surface like two dimensional systems. Furthermore, 3D systems do not necessarily need a frame or a structure for support.

There is a variety of working 3D systems in building façades around the world. According to Greenscreen.com:

"One approach uses two wire grids held apart by intermittent wires and welded to a perimeter steel frame for strength in mounting. The wire grids are either woven or welded at various spacing. Another 3D system uses a structural panel with an integral truss that does not require a surrounding frame for mounting or strength."

"This modular panel has reduced material weight and creates some unique opportunities to cover large surfaces without perimeter frames, and for creating shapes. Structural panel systems are rigid, can span openings, and can be mounted vertically, horizontally, or between structural elements as freestanding facades. Attachment details for 3D panels connect at the perimeter frame, or when using the truss panel, can alternately be located at the edge or within the panel field. Panel mounting details are available to create variable spacing off of a building surface, creating additional flexibility. 3D panels are rigid and the attachment design does not require resisting the same tension forces as 2D cable systems. Panel attachments primarily are engineered to resist weight loads and wind forces, and in some cases can be designed for limited cantilevers."

Figure 12. 3D system. (www.greenscreen.com)

One of the most notable advantages of 3D systems is the additional structure provided to growing plants. As a result of the shape of these systems, three-dimensional structures are an excellent supporting material in which plants can grow. Not to mention that this reduces the pruning maintenance.

2.2.3. Climbing plants species

Another mechanical plant attachment is leaf hooking. This involves the leaf pattern and plant strength hooking partially around a host structure until its growth advances to surround the supporting elements. Many green facade plants can be vine-like in their vertical growth characteristics, but are actually plants that are woody in nature and are runners and scramblers. This group relies on the structural host to support the plant lying upon or growing through the host. The plants tend to be long and leggy extensions, such as Bougainvillea. Within these various descriptions, some plants prefer to grow directly to the top of the supporting structure—and then take significant time to spread. Others prefer to spread early and then continue growing vertically. Ultimately, the green facade structure design should take into account the growing characteristics and growth habits of these different plants. Aerial root plants in close proximity to a building surface will migrate to the building and abandon the facade structure. Runners and scramblers may require additional maintenance to establish on a system.

As Marc Ottelé explains in his Thesis, there are different kinds of climbing plants based on their abilities to climb with or without a support. Clinging plants have a strong tendency to grow upwards toward the light (phototropism).

2.2.3.1. Self-climbing plants:

These plants grow naturally on tree trunks or rocks so the building façade surface should be equally as rough to enable good growth and adherence. Many plants with aerial roots or suckers attach themselves so well that they find guidance on walls (the surface must have enough roughness for their microscopic root hairs to grab on). Smooth, shiny metal and glass or plastic surfaces are probably not suitable because they don't have enough adherence for the microscopic root hairs (Dunnet and Kingsbury, 2004). Façade joints are vulnerable for the penetration of aerial roots due to the negative phototropism (they grow away from the light). In order to cover façades, good plant options include deciduous or evergreen climbing species.

Figure 13. Self-climbing Hedra helix. (www.plantasonya.com.br)

2.2.3.2. Twining climber plants:

Twining plants are one of the largest groups of climbing plants. The main stem or a side stem twists itself with a helical motion around the supporting system.

These kinds of plants need a supporting structure because they are specialized to climb tree trunks and branches. Supporting systems for these plants are usually placed with a certain distance from the façade to allow optimal growth. The growing direction is mainly vertical which is important for placement of supporting systems. Some species of the twining climbers can reach a height of 30 m (Ottelé, 2011).

Figure 14. Twining climber plants. (www.physics.aps.org)

2.2.3.3. Rambler plants

Rambler plants need supporting systems to climb using a weaving method. The strategy of their growth is to hook other structures using thorns and spines. One of the characteristics of this species is that they grow in a three-dimensional space so they usually need human intervention and maintenance; which consequently involves extra costs. One of the most known species of this plant category is the winter jasmine.

Figure 15. Rambler roses. (www.davidaustinroses.com)

2.2.3.4. Tendril and leaf twining climbing plants:

These plants have special tendrils and specialized leaves that twist like a corkscrew to wrap around a climbing support.

Figure 16. Twining climber plants. (Marc Prades)

The inconvenience of this species is that tendrils do not have a long lifespan—generally amounting to several years. These plants can grow on vertical or horizontal supporting structures. This is an advantage when using this plant along walls or on roofs or pergolas.

Figure 17. Tendril and leaf twining climbing plants, Clementis. (www.davesgarden.com)

2.2.4. Living walls

Living walls systems are the last and most modern type of Green Wall. These walls are self-sufficient vertical gardens that are attached to the exterior or interior of a building. They differ from green façades in that the plants root in the structural support, which is fastened to the wall itself. The plants receive water and nutrients from within the vertical support system instead of from the ground.

The main characteristic for the living walls is the use of artificial substrates instead of soil. These artificial substrates use hydroponic technology as an irrigation system, which uses water mixed with nutrients for plants. A waterproof membrane separates the living walls from the building walls to avoid moisture transmission.

An important difference between Living Walls and Green Façades is that Living walls allow for the growth of many different species in the wall surfaces while Green façades have more limitations. Because of the irrigation systems, plants in LW don't grow outside the panels. This avoids the maintenance of pruning the plants.

"Due to the diversity and density of plant life, living wall systems require more intensive maintenance (regular water, nutrients, fertilizer) than green façades (which are rooted into the soil). Living wall systems may also use the wall structure, though they are built out of connecting pre-vegetated panels or integrated fabric systems which can be attached to a (free) standing wall" (M.A. Mir. 2011)

Living walls systems are used in several ways. LW can be found in partial walls, building façades, in civil engineering structures but also it can be used in internal spaces like building lobbies and halls.

Figure 18. Interior Living Wall . (www.greenupgrader.com)

According to the Master Thesis published by M.A. Mir (2011) we can separate the Living Walls Systems into two main categories depending on the fabrication process. Out of various existing living walls, including indoor and exterior façades, all have been prefabricated or made in-situ:

2.2.4.1. In-situ Living Wall panels:

Living walls raised in-situ are actually only partially-prepared panels. These panels still need more elements and staff installed on them. After installing the half prepared panel, additional plants are planted on them.

The systems can be composed of many different felt layers, the textile materials with growing felts. With this method, the components are stuck to a metal frame that supports their weight as well as all the other components that compose the Living Wall. After hanging the frames to the façade, the plants are allocated into the pockets.

Plants grow into the wall pockets and they are irrigated by the hydroponic system. However, the space provided by the pockets is limited so the plants can't grow indefinitely. Furthermore, plants with large roots are not able to be used in this type of Living Wall because of the limited space of these pockets. Moisture sensors are necessary to keep the optimal humidity level; these sensors are connected to the pump which pumps around 3 liters per m^2 per day depending on the climatological conditions, weather and season, as well as the orientation of the façade.

Under the panels there is a leakage profile that collects the overflowing water. This water can be pumped to the start of the water circuit with new nutrients for the plants. On average, for every square meter of Living Wall, 25 plants can; weighing—including frame, plants, etc.—around 100 kg per square meter.

This system was also used for the famous French botanist Patrick Blanc in his 'Mur Vegetal'.

Figure 19. In-situ Living Wall. (www.dorsetdesignbuild.co.uk)

2.2.4.2. Prefabricated Living Walls panels:

The main characteristic of prefabricated Living Walls is the integrated fabric systems. These systems are composed of a structural frame with plant supports in addition to the plants. The plant supports can be comprised of geotextiles or polypropylene plastic containers. All of the irrigation systems are integrated into these panels. As M.A. Mir (2011) supports in his studies "*This type of living wall system supports a great diversity of plant species, including a mixture of groundcovers, ferns, low shrubs, perennial flowers, and edible plants.*"

These prefabricated panels are designed to allow water to flow through them. Connections between panels allow the water to flow from panel to panel. As M.A Mir describes in his Master Thesis of Green Façades and Building Structures, it's common for a drip irrigation line to be installed early to provide the easiest and most effective method of watering (drainage) possible. This consists of a drip pipe that is often incorporated into the system. The drip pipe is connected to a water pump that provides the possibility for additional nutrients into the water system. Typically, nutrients are distributed in the water cycle, from the top of the wall to the bottom.

Rainwater can be used for the irrigation of the Living Walls but it always depends on the polluting substances found in that water. It is recommended to filter rainwater before using it for the irrigation. The irrigation system can be the designed for the whole wall but if there is more than one wall or if the wall has different orientations, is recommended to use separate irrigation systems for each wall. The orientation and the sunlight incidence change the plants' need for water and a unique irrigation system is at risk of providing too much water to some plants and not enough water to others.

Figure 20. Prefabricated LW panel. (www.inhabitat.com)

A variety of Prefabricated Living Walls systems are fully functioning in buildings around the world. The next lines will briefly describe each of these systems:

2.2.4.2.1. Foam Based System

Foam used in Foam-Based Living Walls is a made of aminoplast resin. This foam works as the substrate for plants. Using the Foam Based System has many advantages because of the proprieties of the foam. This material is very efficient with water so it can be irrigated by just trickling water and nutrients down the wall from the top. This method is good for a huge variety of plants because it creates a pH-neutral growing media and is also adaptable in different climates. As a result, this type of prefabricated Living Wall can be applied in both indoor and outdoor systems.

Figure 21. Fytowall Living Wall. (www.esi.info)

As M.A Mir describe in his Master Thesis of Green Façades and Building Structures:

"The growing medium is placed in steel baskets and the steel baskets are hooked on an aluminum carrier. The aluminum carrier of the system creates a cavity of 50 mm at the backside with the wall. The aluminum styles have a standard distance of 510 mm from each other. The panels of this system have the standard size of 1000 mm x 490 mm x 140 mm and the weight of a panel is about 88 kg/m 2 without plants, by maximum water saturating."

2.2.4.2.2. Planter Boxes System

Greenwave is the company that is developing this type of prefabricated Living Wall system. It consists of reinforced fiberglass plastic box modules. These boxes are filled with soil so it is possible to plant a large variety of plant species. Plants with large roots are also able to grow in this system because there is space enough for them in the boxes. The irrigation pipes are placed behind the boxes providing water and nutrients throughout the Living Wall.

Figure 22. . Greenwave System. (M.A. Mir, 2011)

Products allowed in the market are modules of 600x500x200mm with a total weight of around 30kg depending on the soil mixture and the weight of the plants themselves.

This Living Wall System can be used in outdoor conditions and indoor situations.

2.2.4.2.3. Mineral Wool-Based System

This type of Living Wall System is very extended around Europe because of the many design possibilities for the use of different plant species.

One of the main characteristics of the Mineral Wool-Based system is that the growing medium is a mineral wool. The frames of the mineral wool-based hold are made with aluminum, which reduces the overall weight. The irrigation system provides water with nutrients for the plants via a network behind the plants.

Commercial panels are provided by Wallflore with the following characteristics:

The dimensions are 75x600x1000mm and each panel weighs an average of 13kg without plants. Each panel can hold up to around 16 plants (27 plants/m^2). A dark gray felt made of PP and PE is used as an envelope around the panels. All the components that can come into contact with salts (from plant nutrition and plant acids) are manufactured from a high quality aluminum alloy.

Figure 23. Wallflore Living Walls (www.wallflore.nl)

2.3. ADVANTAGES AND DISADVANTAGES OF GREEN WALLS

During recent decades many researchers have been studying the advantages of Green Walls. It is obvious that some of the Green Walls advantages and disadvantages depend on the type of Green wall in question (i.e. Living Wall Systems in comparison to Natural Wall Vegetation). However, there is a common denominator across all kinds of Green Walls—so most of their advantages hold true across classifications with varying effectiveness.

Despite the many advantages of Living Walls, the penetration of the green technologies to the Building sector is still in its early stages.

As marc Ottelé described in The Green Building Envelope: *"A façade can be considered as a vertical garden and as an extension of nature in an ecological sense. Greening the exterior of buildings will provide ecological services like breeding and resting habitats for birds which may be enjoyed by humans. A well vegetated façade offers in each season the possibility of the transformation of the visual aspects (i.e. for example: changes in colour intensities of the leaves), on this way a green façade is always renewing."*

On the other hand, Green Walls systems have some disadvantages, which this chapter will discuss in depth. With technological improvements to Green Walls Systems, some of these disadvantages will decrease or simply disappear.

Green Walls also have consequences like falling leaves, the extra initial cost, and maintenance costs. The proliferation of insects is a positive side effect from an ecological view but is generally considered to be annoying for people, especially for indoor living walls.

There is an assumption that Green Walls can damage walls—but the reality is that plants work to protect and maintain the integrity of walls.

According to the Master Thesis done by M. A. Mir in 2011 about the Green façades and building structures, we can summarize the advantages of Green Walls in the following points:

- Building insulation improvement and moderation of the internal building temperature by the external shading from plants.
- Improve air quality by filtering air particulates.
- Reduction of the Urban Heat Island (UHI) effect.
- Provide Sound Isolation.
- Create an appropriate environment fomenting biodiversity.
- Aesthetical advantages.

2.3.1. Building insulation improvement and moderation of the internal building temperature by the external shading from plants.

Plants growing on the façade of buildings provide protection from sunlight by blocking it with the presence of leaves. This shade means that less sunlight arrives to the façades and, as a result, less radiation affects the building; decreasing the internal temperature.

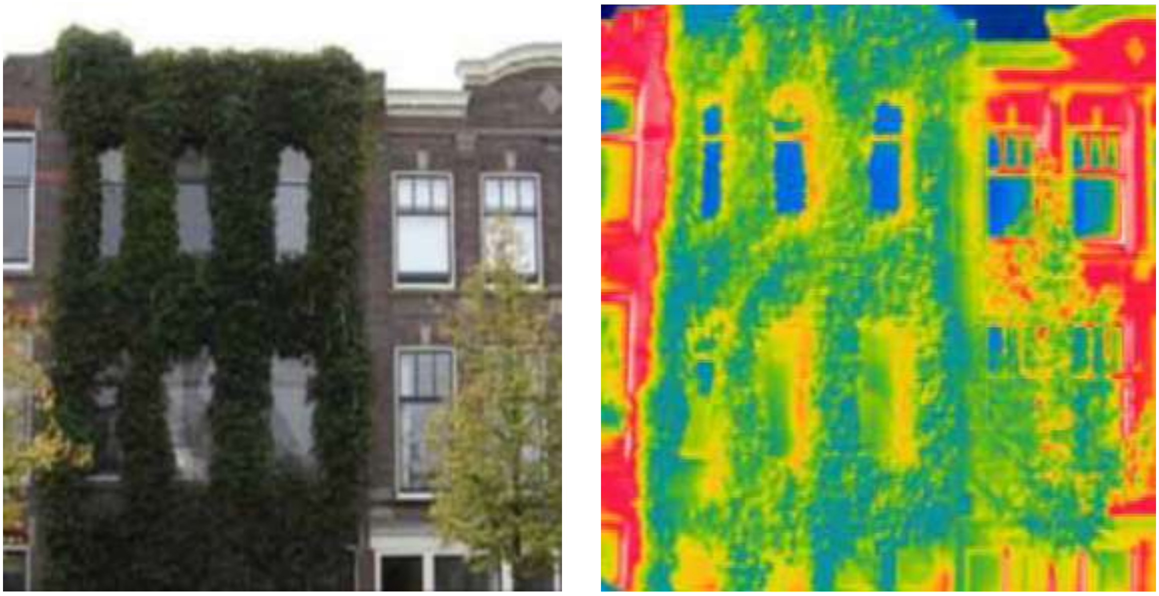

Figure 24. Picture of the same building with a regular camera (left) and an infrared camera (right); Ambient air temperature 21ºC. (Ottelé 2011)

Dense vegetation on building façades provides additional protection again wind. Wind speeds along the façades work against the insulation of the building because it cools the walls. Plants reduce the effects of wind, resulting in better insulation during winter. As a result, every decrease in the internal air temperature of 0.5 °C will reduce the use of electricity for air conditioning up to 8% (Dunnet and Kingsbury, 2004).

Roofs and Green Walls will refrigerate local air temperatures in two distinct ways. In one, walls behind greened surfaces absorb less warmth from the sun. This is clearly seen in figure 3.14 and 3.15 where uncovered parts of the façade are warmed and the parts protected with leaves are considerably cooler. Second, green walls and roofs will refrigerate warmed air through evaporation of water (Wong et al. 2009), also known as evapo-transpiration.

The majority of the sun's radiation is absorbed by bituminous materials, masonry or concrete, and are reradiated as sensible warming. Masonry, concrete or asphalt will reflect 15 to 50% of the radiation they receive (Laurie, 1977). Greening paved surfaces with vegetation in order to block radiation before it affects hard surfaces can reduce the heating of these surfaces, notably in dense urban areas. In a urban warming island effect setting, even night air temperatures are higher because of the absorption of heat and radiation behind the surfaces during the dusk hours (Getter et al.,2006)

Krusche et al., studied in 1982 how sunlight is transformed into energy on a Green Wall building façade. Out of 100% of sunlight energy a GW façade receives, evapotranspiration uses between 20% and 40%, plants photosynthesis uses from 5% to 20%, leaves reflect between 5% and 30%, and finally, heat transmission is between 10% and 50%

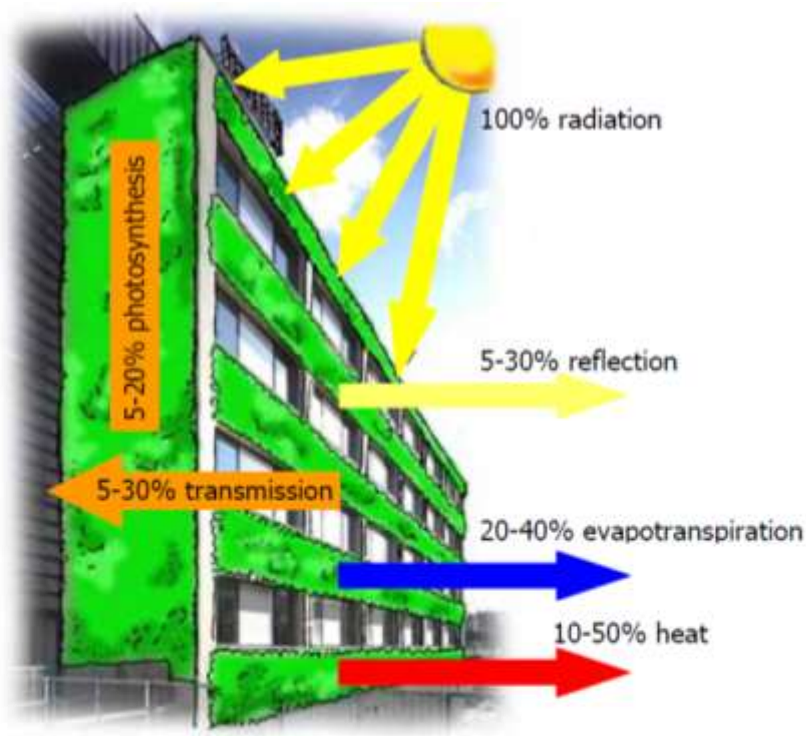

Figure 25. Schematisation of the energy balance vegetation. (Ottelé 2011)

As it is shown, the evapotranspiration of plants in Green Walls can be significant and, as a result, can reduce the head transmission of hard surfaces. UV light deteriorates materials so reducing the amount of sunlight on the building materials can increase the durability of these materials. This is beneficial for buildings and cost effective in reducing maintenance costs. Indeed: the denser and thicker the planted surfaces, the more beneficial the effects.

Insulation material lowers the impact of the temperature contrast between inside and outside. In winter scenarios the insulation material reduces the rate of heat transfer to the exterior. In summer scenarios the reverse happens: the rate of heat transfer is reduced from the exterior to the interior. The insulation level of vertical greened surfaces can be raised using several systems (Peck et al., 1999; Rath and Kießl, 1989, Pérez et al., 2011):

- By enveloping the building with greenery.
- As wind diminishes the energy efficiency of a building by 50%, a vegetation layer will work as a cushion that prevents wind from moving along a building surface.
- The thermal endurance of a construction can be diminished from 23W/m^{2}K to 12 W/m^{2}K.
- The thermal insulation implemented by greenery and substrates used.

2.3.2. Improve air quality by filtering air particulates.

Many studies claim that plants are able to reduce the quantity of particulates on the air by filtering them. According to research done by Lindberg (1982), particles of fine dust adhere to leaves' surfaces and plant stems reducing the air concentration of dust ($PM_{2.5}$, PM_{10}). This propriety of plants is a major advantage to keeping the air clean because the leaves can hold on to the particles and then, during the rainfalls, dust is cleaned and returned to the soil. The finest particles remain adhered to the leaves even after rainfall, but this dust is also going to be returned to the soil as a natural process once the leaves fall.

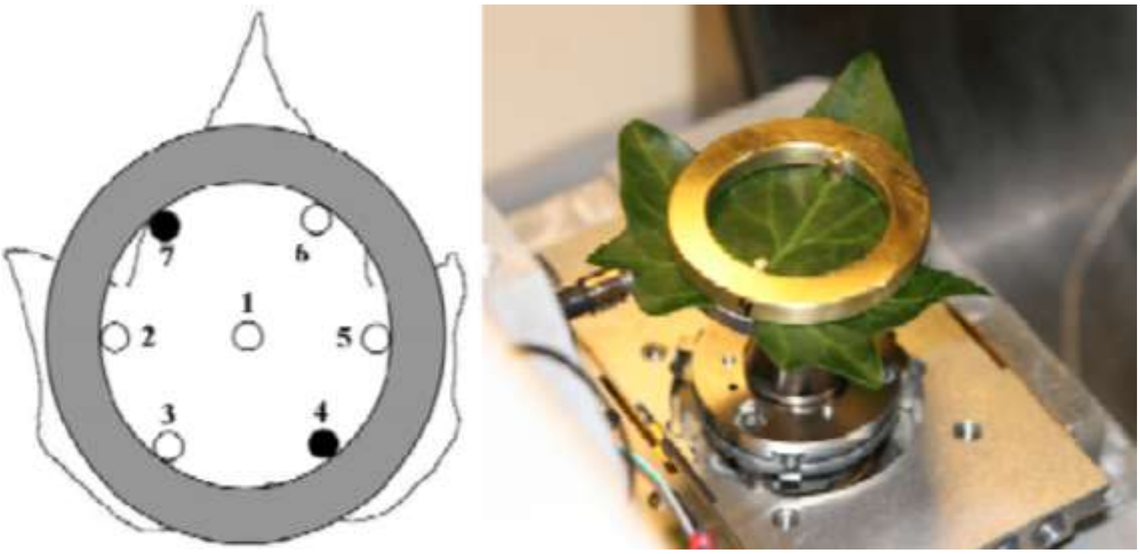

Figure 26. Sample procedure using ESEM analysis. (Ottelé 2011)

As Bussotti et al, proved in their researches in 1994 that "plant barriers immediately along a roadside (daily traffic level 20.000-50.000 vehicles) are more beneficial in capturing lead (Pb) and cadmium (Cd) particles than plants investigated in the rural area ".

Furthermore, concrete, stone, brick, asphalt and glass surfaces contribute to add more dust and particles to the air. This is due to the summer periods when these surfaces are heated, causing thermal vertical movements that elevate and spread particles into the air. Having green walls will reduce the total quantity of materials that contribute to this phenomenon.

2.3.3. Provide Sound Isolation.

After many decades of high-speed urban growth, many big cities are overpopulated. The lack of open land causes many buildings to be built close to highways or bus terminals, meaning people are in contact with severe noise pollution. It was discovered that more than 44% of the population within the European Union was in contact with road traffic noise levels of more than 55 dB in 2000 (Boer et al., 2007).

Cities that have the objective of creating new sustainable urban lifestyles have found that vegetation is a key element in resolving this noise pollution (Wong et al., 2009). According to Wong et al., (2009), not all vertical greening systems are effective at reducing noise. Most of the greening systems perform a reduction of around 5 to 10 dB for perception in the variation of sound intensity. This is noticeable for human perception as a change in sound volume. The growing media in living wall systems contributes to a reduction of sound levels that carries through or reflects from the greenery system. Factors that can change noise reduction involve the materials used as structural components of the living wall system, the depth of the growing media, and the overall coverage (Cook et al., 1974).

Plants can absorb, reflect and diffract noise; an effect that could lead to a more satisfactory environment in urban areas. The links between the greenery coverage and the sound absorption coefficient shows that the greater the greenery coverage, the higher the sound absorption coefficient becomes.

2.3.4. Aesthetical advantages.

It is widely known that people appreciate nature in cities. Urban areas lost the majority of relation with nature so inhabitants appreciate the occasional exposure to parks, trees, and other sporadic vegetation. Green walls around the world have become famous—even serving as a tourist destination in some cases. The aesthetic value of Green Walls is widely recognized; the good feelings that people have when surrounded by plants has been proven to be beneficial for physical health. These feelings also lead to better efficiency in working environments.

It can also be useful to hide partial walls. There is an example in Madrid where a partial wall next to a museum was covered by a Living Wall system; this makes the view for visitors more pleasant—it even became a famous tourist attraction.

Figure 27. Living wall in Caixa Forum Museum. Madrid. (www.inhabitat.com)

On the other hand, the presence of Green Walls can reduce the proliferation of graffiti and undesirable aesthetic on walls. In this sense, Green Walls work as an anti-vandalism shield for buildings.

2.3.5. Create an appropriate environment fomenting biodiversity.

Urbanization raises new questions about the conservation of biodiversity. As a high proportion of the world's population moves from rural to urban sites, there are alterations in the connection between human activities and biodiversity, and thus to the way we create biodiversity preservation policies. Nevertheless, little attention has been paid to understanding how to make cities more biodiversity-friendly, both within the urban fabric as well as in faraway places (Oliveira et al. 2010). Biodiversity is a key element of ecosystems and a key premise of sustainable ecosystems (Watson and Zakri, 2005).

The application of vertical greening systems to enhance biodiversity is being investigated and current research on the properties of vertical greening systems to supply this advantage is low. Large scale vertical greening projects have been developed to use inborn plant species and create habitat as urban reforestation. The design of vertical greening systems for biodiversity or ecological restoration needs that either the designers or their consultants have a close knowledge of the needs of the plants in the area where the project is developed, as well as the particular needs of the various fauna (Green roofs, 2008)

Hedra helix and several other escalating plants bring about colorful berries appreciated by birds in the winter. When we take a look at the façades or outside walls of buildings, green systems exhibit ecosystem characteristics. They will serve as a habitat, an exhibition structure, and as a mechanism for the flow of material and energy. This may also lead to ecological services like breeding and resting habitats for birds—a function that humans may appreciate. This resulting undisturbed habitat is valuable for microorganisms in addition to being adequate for small animals (bees, bats, birds, etc.

Escalating plants are especially popular by birds and bats. Green façades utilities in this case as food supply (insects) and as a nesting or breeding chance. Finally, the observation of these animals can be an origin of great delight to city dwellers too. Including nest boxes into green façade designs (linking of functions) will raise the impact of these preventive actions relatively when applied solely.

Figure 28. Butterfly in a Living Wall. (www.walterreeves.com)

2.3.6. Reduction of the Urban Heat Island (UHI) effect.

An urban heat island (UHI) is a metropolitan area that appears to be much warmer than its surrounding rural area,, significantly at winter season. To prevent confusion with global warming, scientist call this fact the “Urban Heat Island Effect”.

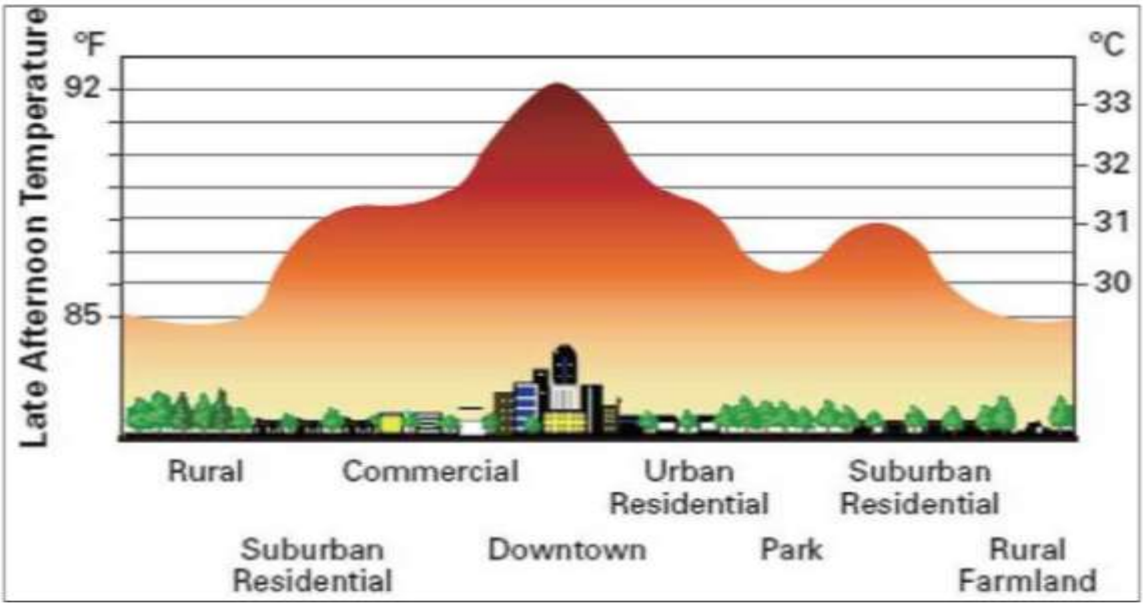

Figure 29. Heat Urban Island effect. (www.deadwidroses.files.wordpress.com)

There are few reasons that can explain the heat island effect, but the most important is the unsustainably high level of urban development. For example, to build offices buildings, a significant amount of green spaces have been replaced by asphalt and concrete, which will absorb heat during the daytime and store it. Afterward, the energy is released during the night (Lozadaa et al. 2005). In addition, heat from air conditioners, vehicles and places such as factories only add to the level of heat. Every day, cities are producing hot gasses, but there is not enough vegetation to absorb them.

Another consideration why temperatures in cities usually are higher than their surroundings is because of diminished amounts of evaporation. When water evaporates, the process of changing from a liquid to a gas, there is a simultaneous consumption of latent heat—a process that cools surrounding areas. Nonetheless, to have more land, cities are being filled with ponds and lakes, leaving the countryside with more evaporation than the cities. With asphalt and concrete acting as humongous heaters, factories, vehicles and air conditioners producing heated gasses, and the grave lack of vegetation and water, the urban heat island effect is getting progressively serious in over-populated cities (Yu-Peng yeh, 2010).

Green façades and living walls form their own specific microclimates that are quite different from surrounding climates. Because of this, specific microclimates around the building are affected.

The interior climates are affected by the Green Walls as well as the outer climate. This is because greened façades absorb less heat than non-greened façade, and contributes to less heat radiation during the night. Therefore a greened façade contributes to the mitigation of the urban heat island phenomenon. As shown in the graph to the right, there are different effects on different surfaces based on temperature changes over twenty-four hours. Water surfaces such as lakes show lower maximum temperatures arise more slowly because of the evaporation of water. Woodlands containing plants and vegetation that contain water also show this characteristic.

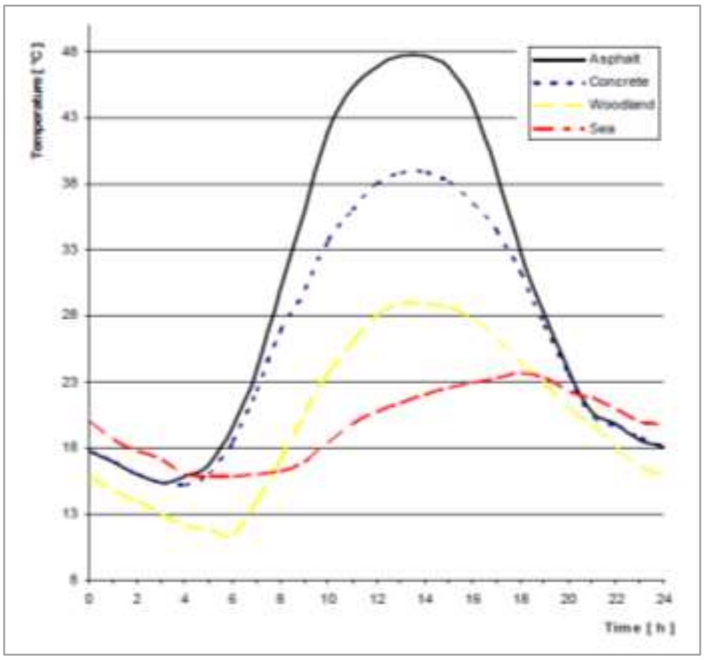

Figure 30. Temperature development of different surfaces on summer day. (Krusche et al. 1982)

Hard surfaces like glass and concrete contribute to runoff of rainwater into the sewage system. Plants buffer water on their leaf surfaces for more time than building materials and the processes of transpiration and evaporation can contribute to the presence of water in the air. This results in a more sustainable climate in the urban area

3. DOUBLE-SKIN FAÇADES

3.1. INTRODUCTION

Humanity has been evolving since the beginning. People have been continually improving their quality of life with new technologies and ideas. From the early huts to the most modern and intelligent buildings, humans tirelessly transform their shelters. There has been a continuous evolution to reach the goal of protection from the weather—and more recently, to satisfy the comfort demands of the building's inhabitants.

A comfortable temperature—warm enough during winter and cold enough during summer—is probably the greatest demand by the building's users. During the beginning, fire heaters and posterior heating systems that run on electricity or oil have satisfied this demand. Architects, designers and builders have been raising buildings without being particularly watchful of the heating gains or losses of their building envelope.

Full glass facades became very popular in the last century. Curtain wall technology allows architects to raise impressive skyscrapers with more than 50% glass of the facade surface. Improvements in glass technology as well as the popularization of glass as a distinctive feature on façades of commercial buildings, contributes to the huge number of buildings with fully glazed facades around the world. Large glazed areas in office buildings are very common in order to satisfy the natural lighting demand in the workplace. However, glazed façades also contribute to significant thermal loses or gains to the total energy used for cooling or heating the buildings. Heating systems running with gas are the most common in these buildings. Nowadays the global fuel consumption seems to be unsustainable. Fuel prices are rising every year so a certain measure of electricity depends on this. Therefore, the consumption maintenance of these buildings has become an important goal.

High rise buildings with lower consumption and maintenance are currently a reality thanks to the effort of some researchers and architects who have been working on better ways to protect buildings to the weather changes. Specifically, Double-skin Facades is one of the most important fields to reach higher efficiency and lower energy consumption, as well as some other advantages to be exposed in this document.

Maurico Hernández Tascón stands in his report Experimental and computational evaluation of thermal performance and overheating in Double-Skin Façades: "*It has been suggested that the correct selection of materials and an understanding of the climatic conditions resolve most of the issues regarding thermal instability. The conscious assessment of the appropriate materials according to the climatic and functional requirements has nowadays become a key element in the design process of any building.*"

Nowadays, people are more aware with everything related to sustainability and environmental preservation and, as a consequence, there is a growing concern about the sustainability of buildings

The use of materials in construction is becoming a focus for designers and architects because of the indirect effect on the environment. Fortunately, the concern about the repercussions of inefficiently performing buildings is growing. The interest in energy-efficient buildings is also growing and, every day, more people are choosing Sustainable buildings. Reducing the environmental impact and also creating a healthy environment in which to live (and at the same time, saving money on the energy bill) is one of the goals of sustainable buildings and structural elements like Double-Skin Façades.

Double-Skin Facades are a growing trend in skyscrapers and office buildings. DSF enable improved transparency and natural lighting without big losses in energy use—something that lets architects design buildings with aesthetically-pleasing glass façades while prioritizing the sustainability of the building.

This chapter is going to explain the definition and the historical evolution of the Double- Skin Façade as well as its origin, Curtain walls. This will be followed by a classification based on different studies about the different types of Double-Skin façades. The final part of this chapter will offer a technical description of Double-Skin Façades followed by a discussion of the advantages and disadvantages of the different kinds.

3.2. DOUBLE-SKIN FAÇADE DEFINITION

During the existence of Double-Skin Façade different authors defined this building envelope. In order to give to the lector an overall view of these definitions and the authors, some definitions are exposed in this section:

- According to the Source book of the Belgian Building Research Institute [BBRI], (2002):

  "An active façade is a façade covering one or several stories constructed with multiple glazed skins. The skins can be air tighten or not. In this kind of façade, the air cavity situated between the skins is naturally or mechanically ventilated. The air cavity ventilation strategy may vary with the time. Devices and systems are generally integrated in order to improve the indoor climate with active or passive techniques. Most of the time such systems are managed in semi-automatic way via control systems."

- Harrison and Boake, (2003) Tectonics of the Environmental Skin:

  "Essentially a pair of glass 'skins' separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. Sun-shading devices are often located between the two skins. All elements can be arranged differently into numbers of permutations and combinations of both solid and diaphanous membranes".

- Saelens, (2002):

  "An envelope construction, which consists of two transparent surfaces separated by a cavity, which is used as an air channel. This definition includes three main elements: (1) the envelope construction, (2) the transparency of the bounding surfaces and (3) the cavity airflow."

- Claessens and DeHerde:

  "A second skin façade is an additional building envelope installed over the existing façade. This additional façade is mainly transparent. The new space between the second skin and the original façade is a buffer zone that serves to insulate the building. This buffer space may also be heated by solar radiation, depending on the orientation of the façade. For south oriented systems, this solar heated air is used for heating purposes in the winter time. It must be vented in order to prevent overheating in other periods."

- Kragh, (2000):

  "A system that consists of an external screen, a ventilated cavity and an internal screen. Solar shading is positioned in the ventilated cavity. The external and internal screens can be single glass or double glazed units, the depth of the cavity and the type of ventilation depend on environmental conditions, the desired envelope performance and the overall design of the building including environmental systems".

- Arons, (2001):

  "A façade that consists of two distinct planar elements that allows interior or exterior air to move through the system. This is sometimes referred to as a twin skin."

- Uuttu, (2001):

  "A pair of glass skins separated by an air corridor ranging in width from 20 cm to several meters" According to the author "the cavity is connected with the outside air so that the windows of the interior façade can be opened, even in the case of tall buildings subject to wind pressures; this enables natural ventilation and night time cooling of the building's thermal mass. In winter the cavity forms a thermal buffer zone which reduces heat losses and enables passive thermal gain from solar radiation. All types of double-skin façades offer a protected place within the air gap to mount shading and daylight enhancing devices such as venetian blinds and louvers. Sheltered from wind, rain and snow, these shading devices are less expensive than systems mounted on the exterior.

  When solar radiation is high, the façade cavity has to be well ventilated, to prevent overheating. The key criteria here are the width of the cavity and the size of the ventilation openings in the outer skin. The air change between the environment and the cavity is dependent on the wind pressure conditions on the building's skin, the stack effect and the discharge coefficient of the openings. These vents can either be left open all the time (passive systems), or opened by hand or by machine (active system). Active systems are very complicated and therefore expensive in terms of construction and maintenance. Further criteria in designing a double-skin façade are regulations concerning fire and noise protection. Using these factors as a basis, various solutions have been developed for double-skin façades."

- Compagno, (2002):

  "The term of Double Skin Façade refers to an arrangement with a glass skin in front of the actual building façade. Solar control devices are placed in the cavity between these two skins, which protects them from the influences of the weather and air pollution, a factor of particular importance in high rise buildings or ones situated in the vicinity of busy roads".

- Hendriksen, Sørensen, Svensson and Aaqvist:

  "The transparency is often seen as the main architectural reason for a double skin facade, because it creates close contact to the surroundings. This in fact is also derived from a client's point of view saying that physical transparency of a company gives a signal of a transparent organization with a large degree of openness. Double skin facades affect a lot of aspects of indoor climate and to some extend energy consumption. Transparency, view to the outside and daylight levels are increased when double skin facades are used compared to the use of traditional window facades. An increased glazing area will also lead to increased glare problems and this is crucial for open plan offices, where disability glare might occur in depth of the rooms".

- Lee, Selkowitz, Bazjanac, Inkarojrit and Kohler, (2002):

  "The foremost benefit cited by design engineers of EU double-skin facades is acoustics. A second layer of glass placed in front of a conventional façade reduces sound levels at particularly loud locations, such as airports or high traffic urban areas. Operable windows behind this all-glass layer compromise this acoustic benefit, particularly if openings in the exterior layer are sufficiently large to enable sufficient natural ventilation. […] Double-skin facades allow renovation of historical buildings or the renovation of buildings where new zoning ordinances would not allow a new building to replace the old with the same size due to more stringent height or volume restrictions".

  "Heat extraction double-skin facades rely on sun shading located in the intermediate or interstitial space between the exterior glass façade and interior façade to control solar loads. The concept is similar to exterior shading systems in that solar radiation loads are blocked before entering the building, except that heat absorbed by the between-pane shading system is released within the intermediate space, then drawn off through the exterior skin by natural or mechanical ventilative means. Cooling load demands on the mechanical plant are diminished with this strategy.

  This concept is manifested with a single exterior layer of heat-strengthened safety glass or laminated safety glass, with exterior air inlet and outlet openings controlled with manual or automatic throttling flaps. The second interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Within the intermediate space are retractable or fixed Venetian blinds or roller shades, whose operation can be manual or automated. During cooling conditions, the Venetian blinds (or roller shades) cover the full height of the façade and are tilted to block direct sun. Absorbed solar radiation is either convected within the intermediate space or re-radiated to the interior and exterior. Low-emittance coatings on the interior glass façade reduce radiative heat gains to the interior. If operable, the interior windows are closed. Convection within the intermediate cavity occurs either through thermal buoyancy or is wind driven. In some cases, mechanical ventilation is used to extract heat".

Despite the differences between these definitions, it is possible to find a common denominator definition. Double-Skin Façades are basically two (or more) glazed surfaces that create an air cavity between them. This cavity can be naturally or mechanically ventilated, or can be just closed without allowing ventilation. As it is explained in followings chapters, it could be possible to do a classification based on the ventilation system provided by the Double-Skin Façade openings.

By definition, Double-Skin Façades do not have to be necessary related with Shading Systems. However, it is known that Shading Systems can improve the quality and the benefits of the Double-Skin Façade.

In conclusion, a definition of Double-Skin Façades should talk about glazed surfaces (transparency), cavity (ventilation) and also shading devices (sun radiation).

3.3. HISTORY

Before starting with the history of the Double-Skin Façades it should be appropriate to first introduce the glass. Nowadays, glass is one of the most researched and applied building material and is one of the key elements in a window and in a glass façade as Seagram Building.

3.3.1. Glass

WorldReference dictionary defines Glass as:

"*A hard britte transparent or translucent noncrystalline solid, sonsisting of metal silicates or similar compounds. It is made from used mixture of oxides, such as lime, silicon dioxide, etc, and is used for making windows, mirrors, bottles, etc.*

The Schott Glaslexicon defines glass as:

"A material which structure resembles a liquid whose viscosity at normal ambient temperatures is so high that it can be considered to be solid. More strictly, the term 'glass' is applied to all inorganic compounds having this basic property. This distinguishes glass from the plastics family, all of which have an organic base and for this reason should not be referred as glass even if they are transparent"

According to Mauricio Hernández Tascón (2008) the main component of glass is silica sand (Silicon Dioxide SiO_2). It is an inorganic product of fusion that has been cooled in controlled methods and develops into a transparent rigid state solid without crystallizing. Normal float glass contains 71-75% of silica sand (SiO_2), 12-16% soda (Na_2O_2), 10-15% lime (CaO) and also a small percentage of other materials such as FeO_3 , which are used to give some different colour effects. Some different elements could be used for glass production and the most common are: Oxides of Silicon (Si), Boron (B), Germanium (Ge), Phosphorus (P) and Arsenic (As).

Glass is nowadays a very common building material. There are some evidences that Romans used glass for windows and mosaics, as well as glasses and cups. By then glass was a luxury product because of the production difficulties. Glass became very popular in the Gothic Cathedrals since the end of the 12th Century. One example of the magnificence of this style is Le Sainte Chapelle in Paris (XIII Century), where anyone can appreciate which probably are the most famous and ancient gothic glasses.

Figure 31.Sainte Chapelle, Paris, XII century. (www.wikipedia.org)

Figure 32. Sainte Chapelle, Paris, XII century. (www.wikipedia.org)

It was not until the XIX century, that glass started to be applied in architecture as an important functional and aesthetic feature, when it was mainly employed for palm houses and greenhouses. There are various examples of conservatories built during this time, some of the most known being the Royal Botanical Gardens, designed and built by Richard Turner and Decimus Burton at Kew, London. (Hernández Tascón. 2008)

The Crystal Palace was one of the greatest manifestations of British industrial pre-eminence. This building was designed by Joseph Paxton as a central element for the Universal Great Exhibition of London in 1851. This building war raised during the Victorian period so the engineers wanted to show the sophistication using manufacturing techniques and also various systems which was the culmination of a new typology of buildings.

Figure 33. Crystal Palace, Paxton, 1851. (www.wikipedia.org)

The exhibition building was the product of mechanization, mass production, prefabrication, standardization, modular construction, systems-integration, critical path, rapid site assembly, dismantling and ingenuity (Hix, 1974). In that time, the functionality of glass was appreciate because of the light transmittance.

The Universal Exhibition of the 1898 in Paris was the most important exhibition from the point of view of glasshouse design as well as structural engineering field. The Exhibition complex had many buildings; the most interesting was the Galerie des Machines "*which was the culmination of engineering confidence in steel structure and glass enclosure* ". (Hix 1974).

At the beginning of the XX century modern architects were influenced by the application of glass as key material in architectural language. By then, the Neues Bauen movement made glass very popular between architects because of the technological improvements on building structures. These improvements, above all structural, allowed to abandon the structural purpose of the preceding façades and made it free to open big glass surfaces and take advantage of the natural lighting and heat.

An example of the Neues Bauen movement building is the fully glazed workshop wing of the Bauhaus in Dessau designed by Walter Gropius in 1926. He uses a curtain façade with glass supported by steel frames.

Figure 34. Bauhaus, Walter Gropius, 1926. (www.bc.edu)

Since that moment, some other modern architects, such as Le Corbusier and Mies van der Rohe, used glass on their façade designs. At that time, the climatic systems inside buildings wasn't enough developed, so the glass surfaces became strong restrictions for the thermal control. *"It was after the Second World War, with the availability of climatic control air conditioning and the development of float glass manufacture by Sir Alistair Pilkington*" (Compagno, 2002), when the use of glass façade surfaces on buildings continued their development.

The use of glass in post-war architecture gave us examples of the developments of glass technology. However, these applications were single-glazed and environmentally insufficient.

The greenhouse effect created by glass and applied before by gardeners during the nineteenth century was applied in the early twentieth century to take advantage of sun's energy to heat buildings. (Hernández Tascón 2008)

Understand how a building façade works as a part of the building envelope responding to the climate is one of the most important goals that architects, engineers, designers and researchers had been chasing. The development of Double Skin Facades (DSF), as a dynamic element, was integrated into the built environment with arguments such as sustainability, ecology, free ventilation and energy efficiency.

3.3.2. History of double skin facades

As Hernandez Tascón brilliantly describe in his works (2008); Buildings have evolved from structures based and surrounded by massive walls with small openings, to the transparent enlarged glazed skins used today. As a consequence of this enlargement of glazed surface on the facade; the building has become more sensitive to climatic variations and also dramatically dependent on environmental control systems. The awareness about energy efficiency involving the building envelope started to be an important issue when modern architecture included glass as a tool of the exploration of new spatial dynamics in building design.

Many factors contribute to the rise of Double-Skin Façades; First, the natural lighting advantages of glass façades have, on the other hand, big problems with thermal losses. Then, the increased insulation levels and the optical properties of glass –which allow IR radiation to pass through but not to released- behaves the problem of overheating. Finally, the rise of the energy cost during the energy crisis in the 1970s brought the sense of urgency that made governments and industries to be more energy efficient.

The first building which has a curtain wall façade known is the Stiff Factory (1903). It was designed by Richard Stiff in the German town of Ginger. The architect was asked to rise a toy factory.

Figure 35. Stiff Factory, Richard Stiff, 1903. (www.flickr.com)

The need of natural lighting and insulation against the cold German weather as well as the strong winds registered in that region were the main characteristics of the building.

The building has three-story with a ground floor for storage. The upper floors were designated to workspaces. The Double-Skin façade of the building is basically made of steel frames and there are some additions of timber frames. Currently, the building is still in use.

Otto Wagner projected a building with Double-Skin frames in envelopes in the Post Office Savings Bank in Vienna; developed by Otto Wagner. Wagner designed a steel structure to hold the glass and aluminum skylight. In that case the Double-Skin was used on the skylight covering the main banking hall. The building is currently in use; some renovations were made to accommodate air conditioning and lighting.

Figure 36. Post Office Savings Bank in Vienna, Otto Wagner, 1906. (www.la-belle-epoque.de)

During the decade of 1920’s, the Double-Skin Façade concept became more used and also more developed. *“Moisei Ginzburg used the double skin concept on the facade of the communal housing project of Narkomfin building, designed in 1928 and finished in 1932”* (Buchli, 1998). Even being one of his most famous works and also recognized by the UNESCO as a human heritage, the building is currently in decadence and without any maintenance.

Figure 37. Narkomfin building, Moisei Ginzburg, 1928. (www.creativecommons.org)

The famous rationalist architect Le Corbusier has also studied and applied the concept of the Double-Skin Façade. His studies let him create the idea of 'Mur Neutralisant'. This concept was thought as a Ventilated Double-Skin Façade. Le Corbusier finally uses his façade design in the Cite de Refuge (1928), later he uses as well this design in the Immeuble Clarte (1930).

Figure 38. Cité de Refuge, Le Corbusier, 1928. (www.flickr.com)

Le Corbusier described the facade as *"a free facade consequence of the non-load-bearing function of the walls, since the structural frame releases the facade from this function".*

Figure 39. Immeuble Clarte, Le Corbusier, 1930. (www.wikiarquitectura.com)

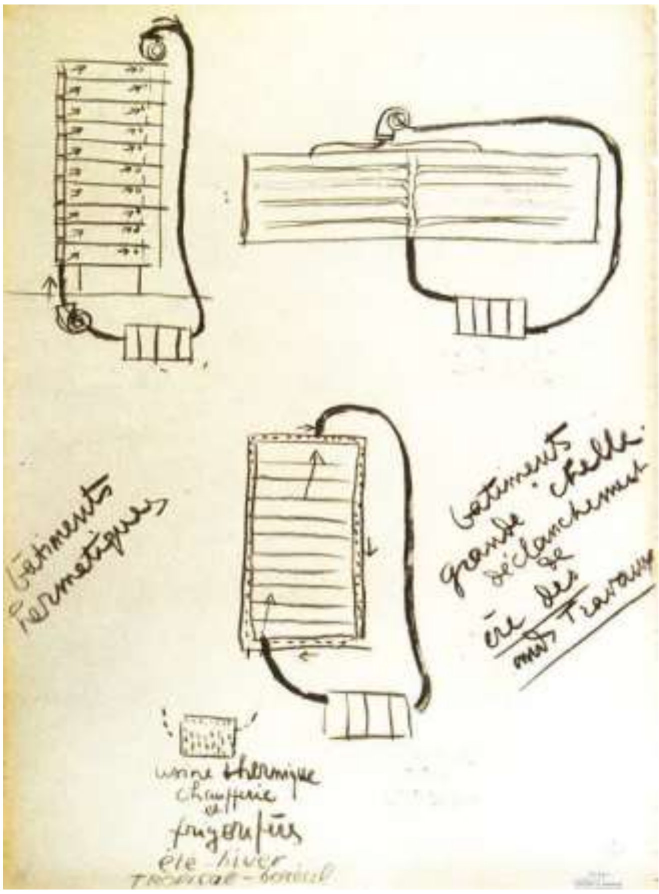

Figure 40. Le Mur Neutralisant, Le Corbusier (www.facadeconfidential.blogspot.com)

Because the freedom of the nonstructural faced, the architect was able to replace traditional windows to use a glass wall. Nevertheless, the system was not applied yet as it was considered at that time to be very expensive to build and very inefficient (Besset, 1962)

Oscar Niemeyer and Le Corbusier collaborate in the design of the Ministry of National Education in Rio de Janeiro in 1936. These architects had been developing shading systems for the façades which allow the control of the solar radiation. Le Corbusier called them 'brise-soleil'. The following pictures show some drawings of the sun movement by Le Corbusier.

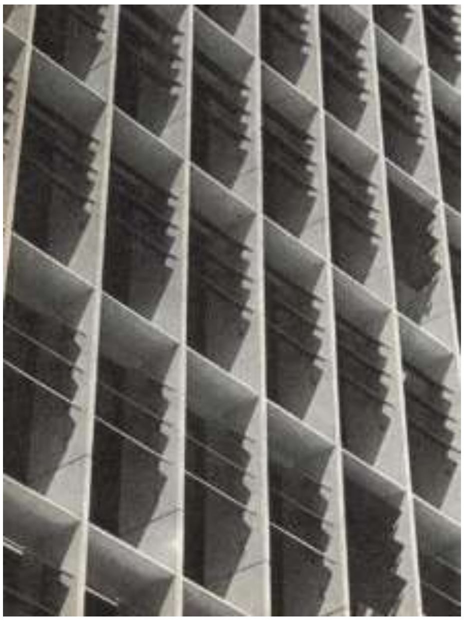

Figure 42. Education Ministry in Rio de Janeiro, 1936. (Besset, M., 1968)

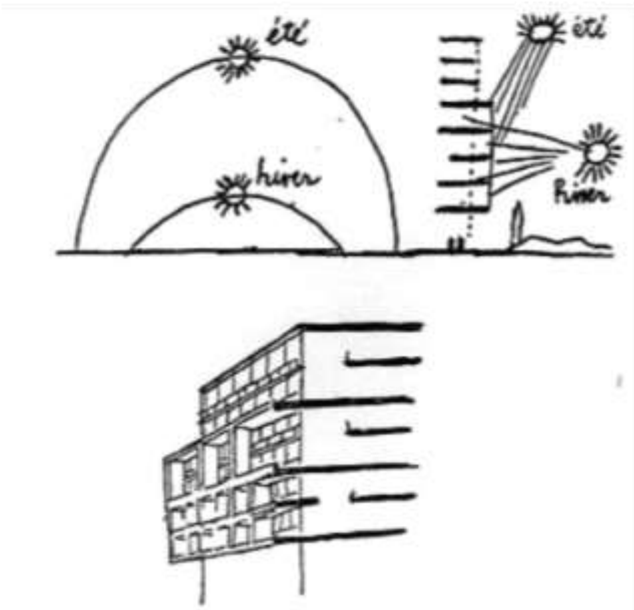

Figure 41. Brise Soleil, Le Corbusier (www.facadeconfidential.blogspot.com)

Le Corbusier also used the 'brise-soleil' concept in some other projects using a glass curtain wall; he referred again to his 'Mur Neutralisant' as the *"large glass panes set in aluminum frames; the panes would be double, spaced one foot apart; in this space there would be circulated hot air in winter and cold air in summer and would allow solar heat to penetrate in winter"*.

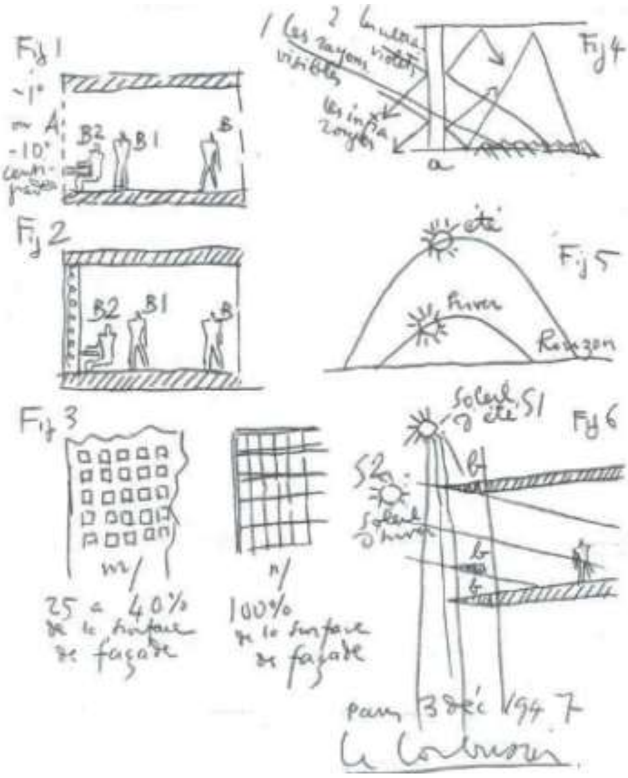

Figure 43. Brise Soleil drawings, Le Corbusier.

As the years went, the concepts that rationalist architecture stands became more accepted. One of the most common elements in this modern architecture was the curtain walls. Large American corporations wanted to project themselves using high and modern buildings as an image of the company. Some architects like Mies Van der Rohe became very famous rising tall buildings with curtain walls in cities like Chicago or New York. As an example of the use of the curtain wall glazed façade system is the IBM Headquarters in Chicago raised in 1950.

Figure 44. IBM Headquarters, Mies Van der Rohe, Chicago 1950. (www.photobucket.com)

Despite the attempts of Le Corbusier to apply his 'Mur Neutralisant', the concept of Double-Skin Façade wasn't applied with relevance until late 1970's. The Hooker Office Building in Niagara Falls was the first building which incorporated Le Corbusier's DSF concepts.

Figure 45. Hooker Office Building, 1980. (www.arquitecture.waterloo.ca)

Since that precedent, many other architects and designers decided to use the Double-Skin Façades in their buildings. In the United States but also in Europe some examples like the Briarcliff House Office building in Farnborough (UK) incorporated DSF in the building envelope.

"The growing awareness of environmentally friendly buildings motivated by corporate and political reflection influenced the proliferation of DSF concepts on high-rise office buildings". (Hernández Tascón. 2008).

Buildings like GSW Headquarters by Sauerbruch & Hutton, the Debis building by Renzo Piano, and the Commerzbank Headquarters by Foster and Partners are some of the publicized examples using Active and Interactive façades in Buildings. (Kragh, 2000).

Another example of the uses of the Double-Skin Façade in modern buildings is the Norman Foster Swiss Re building, known as 'The Gherkin'. Most architectural journals have defined this building as an example of sustainable architecture.

Figure 46. The Gherkin, Norman Foster, 2004 (www.webbaviation.co.uk)

3.4. DOUBLE SKIN FAÇADE CLASSIFICATION

It exist many different kinds of Double-Skin Façades and also the different combinations used to create this façades. That is why it is possible to find many Double-Skin Façade classifications in the literature. Depending on the criteria used by the author ventilation systems or the portioning have more importance.

For example, according to Széil (2001), it is made a first Double-Skin Façade based on ventilated mode of the building depending of if it is mechanical or natural. Then façades are classified depending on the operation mode and cavity portioning.

- Exhaust air systems.
- Façades with connected cavities / compound windows.
- Shaft window façades.
- Corridor façades.

Then Pottgiesser (2004) made another classification based on the construction and the positions of the ventilation openings as well as the divisions of the cavity.

According to the Belgian Building Research Institute in Ventilated Double Façade research project (Lancour, et al, 2004), it is possible to do a classification based on different classificatory criteria:

3.4.1. Classification based on the ventilation system

Following this criteria it is possible to distinguish three types of ventilation systems in Double-Skin Façades.

- Natural ventilation
- Mechanical ventilation
- Hybrid ventilation

Standard NBN EN 12792 defines:

Natural ventilation: "*ventilation (…) which relies on pressure differences without the aid of powered air movement components*. *The two driving forces of natural ventilation are the differences in pressure created by the stack effect and by the effect of the wind.*"

Mechanical ventilations: "ventilation with the aid of powered air movement components."

Hybrid ventilations: "C*ontrolled compromise between natural ventilation and mechanical ventilation. In general, in this type of ventilation, natural ventilation is used as far as possible. The mechanical ventilation is only triggered when the driving forces of natural ventilation become inadequate and no longer make it possible to achieve the desired performances. A control system permits the shift from one type of ventilation to* *the other in an automatic and controlled manner on the basis of a control algorithm. It should be noted that few ventilated double facades use this type of ventilation.*"

3.4.2. Classification based on the partitioning of the cavity

Before starting with this section, a first distinction between windows and façades should be made. In one hand there's a ventilated double window, and on the other hand, ventilated double façades. "*Within the ventilated double facades, numerous possibilities of partitioning are imaginable and an additional classification can be created"* (Lancour 2004)

3.4.2.1. Ventilated double window

A ventilated double window is a single opening in a façade which has two glazing surfaces split by a certain distance forming a cavity. It can be founded with many different types of glass or windows. In some literature can be also named as 'Box-window'.

Figure 47 Ventilated Double Window. (www.fimagenes.com)

3.4.2.2. Ventilated Double Façade

Double Façades are a type of façade where the cavity is physically delimited, horizontally by the floors and vertically by the walls, so the module of the façade is which imposes the dimensions on the cavity.

As Lancour (2004) and some other researchers classify in their report Ventilated Double Façades, there are different types of Ventilated Double Façades:

3.4.2.2.1. The corridor

This kind of ventilate double façade are partitioned by story. One of the great characteristic is the large cavity between the two glasses, in which it is generally possible to leave enough space to walk through. The cavity is physically limited by each level of each story, so the cavities of each story are independent. This vertically limitation contrasts with the horizontal freedom which can extend the cavities across several offices or even an entire floor.

Figure 48. The corridor Double-Skin Façade type. (www.stylepark.com)

3.4.2.2.2. The ´Shaft-box´

"*The objective of this partitioning concept is to encourage natural ventilation by adapting the partitioning of the facade so as to create an increased stack effect (compared to the naturally ventilated facades which are partitioned by story)"* (Lancour 2004).

This façades are characterized by a composition of juxtaposed façade modules. The modules are partitioned by story and also have vertical ventilation ducts set up in the cavities. These ducts are extending over several floors. Every single module is connected to one of these vertical ducts, which have the function of stimulate the conduction of fresh air between facade modules. This air is naturally drawn into the ventilation ducts and evacuated by an outlet usually located on the top of the building.

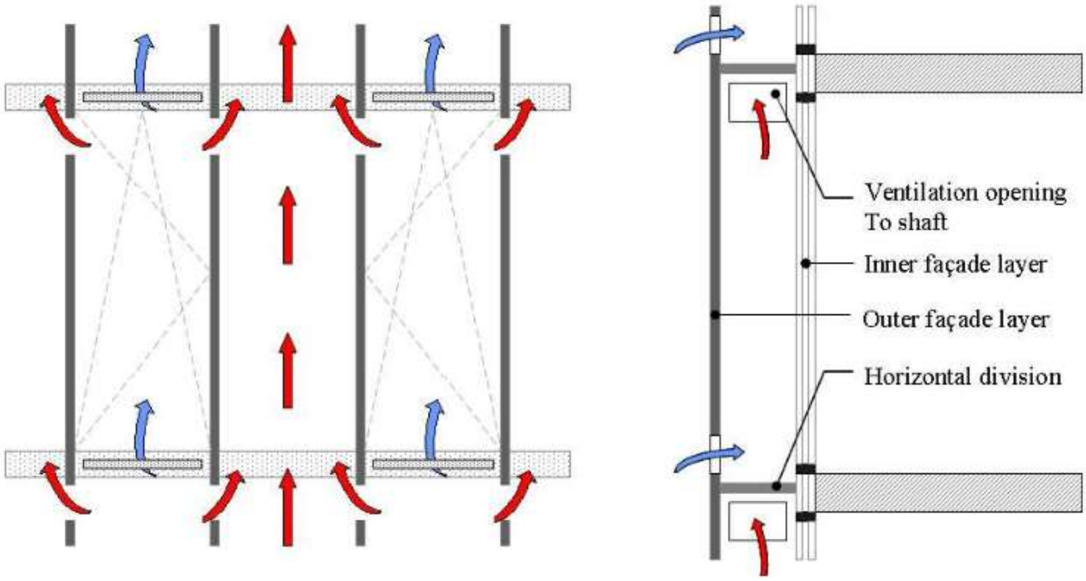

Figure 49. The Shaft Box scheme. (Lancourt 2004)

3.4.2.2.3. The multi-story

Multi-story ventilated double façade is characterized by a large cavity which connects different building levels so the air can flow in horizontal, like the Corridor type, as well as in vertical. As it happened in the Corridor type, the cavity is as big as it allows a person to walk through, which is very useful for maintenance services like cleaning. Sometimes, it is possible to find some buildings where the cavity runs all around the building without the presence of any partitioning.

"Generally, the facades with this type of partitioning are naturally ventilated ; however, there are examples of facades of this type which are mechanically ventilated. It should be noted that the facades of this type generally have excellent acoustical performances with regard to outdoor noise. This characteristic can be the reason for applying this particular type of facade." (Lancour 2004)

Figure 50 . The Multi Story System. (Lancourt 2004)

3.4.2.2.4. The multi-story louver

This type of Ventilated Double-Skin Façade is very similar to the previous one (the multi-story naturally ventilated double façade). In this case, the main difference between this two façades is that *"the multi-story facade lies in the fact that the outdoor facade is composed exclusively of pivoting louvers rather than a traditional monolithic facade equipped (or not) with openings. This outside facade is not airtight, even when the louvers have all been put in closed position, which justifies its separate classification."* (Lancomer 2004)


Figure 51 Multi-Story Lower type of Double-Skin Façades. (Lancour 2004)

3.4.3. Classification based on the ventilation modes

The ventilation modes are the different ways that air can circulate into a cavity, taking in consideration the origin and the destination of the air. At the same time a Double-Skin Ventilated Façade can only have a kind of ventilation mode. However, it does not mean that the same façade cannot have different ventilation modes in a determined time period. Indeed, the Ventilation mode is totally independent of the different types of ventilation applied in a façade (natural / mechanical / Hybrid).

"*A facade can adopt several ventilation modes at different moments, depending on whether or not certain components integrated into the facade permit it (for example, in the event of the presence of openings in the indoor and outdoor facades)*" (Lancour 2004).

In this section the different ventilation modes in a Double-Skin Façade are exposed following the criteria used by Lancourt, Deneyer, Blanco, Flamant and Wouters in The Ventilated Double Façades report.

3.4.3.1. Buffer zone

In this type of ventilation there is, actually, any kind of ventilation; that is because of the close cavity formed between the inside and the outside glasses, with any kind of ventilation being possible into the cavity.

3.4.3.2. Air supply

The characteristic of this Ventilation mode is that uses outdoor air which, after circulating into the cavity, is brought to the inside of the room or into the ventilation system.

3.4.3.3. Air exhaust

This ventilation mode is almost the opposite of the last mode described. The air comes from the inside of the building and, after circulating through the cavity, is evacuated towards the outside. The ventilation of the facade thus makes it possible to evacuate the air from the building.

3.4.3.4. Indoor air curtain

In this case the air in circulation is always from the inside of the room; ventilation system takes the air from the room and after circulating through the cavity is returned to the inside of the room. In the cavity the ventilation forms an air curtain which envelopes the whole inside facade.

3.4.3.5. Outdoor air curtain

This type of ventilation mode is almost the opposite of the Indoor air curtain. The air circulating through the cavity comes from the outside of the building and is returned to the outside as well. In the cavity the ventilation forms an air curtain which envelopes the whole outside facade.

Summarizing, the Double-Skin Façade classification has many criteria to be classified. The following chart shows a scheme which classifies the different types of Double-Skin Façades based in the three different criteria exposed before.

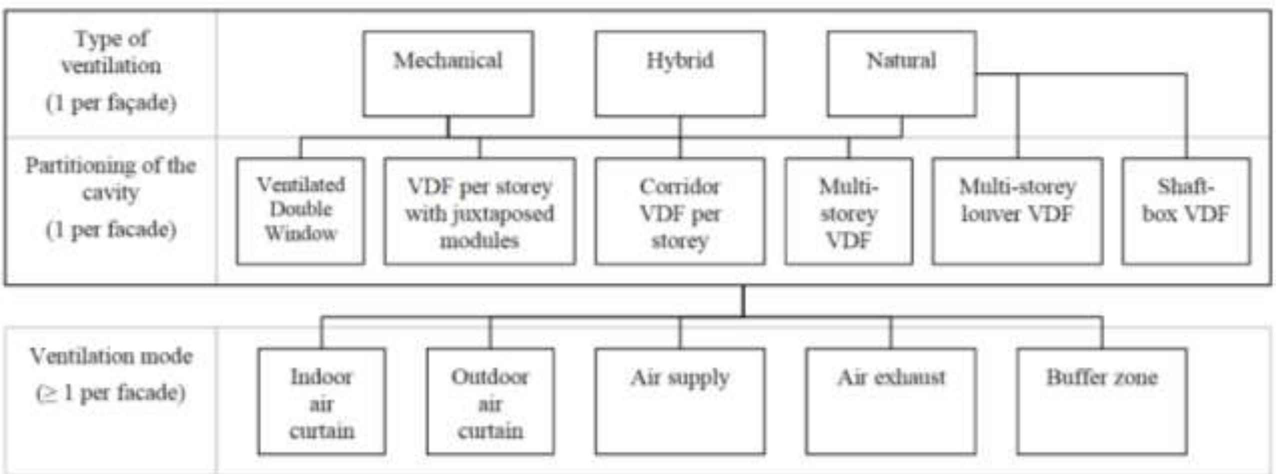

Figure 52. Overall Classification of Double-Skin Façades. (Lancourt 2004)

3.5. ADVANTAGES AND DISADVANTAGES OF DOUBLE-SKIN FAÇADES

Despite the many types of Double-Skin Façades, most of them have a common denominator when talking about advantages and disadvantages. Many researchers and authors have been developing Double-Skin Façades, from their publications and conclusions it is possible to make a list with the things that improve buildings by using Double-Skin Façades.

3.5.1. Advantages

- Thermal insulation: SDF provide a better thermal insulation than traditional façades

  "A double-skin façade also reduces heat losses because the reduced speed of the air flow and the increased temperature of the air in the cavity lowers the rate of heat transfer on the surface of the glass. This has the effect of maintaining higher surface temperatures on the inside of the glass, which in turn means that the space close to the window can be better utilized as a result of increased thermal comfort conditions" (Campagno, p.94)

- Energy savings
- Solar protection: cavity space allows the placement of solar shading devices which improves shading coefficients and, as a consequence, reduces direct head loads.
- Acoustic insulation: reduction of noise levels inside buildings. Some authors stand that acoustic insulation is one of the most important advantages of the Double-Skin Façades.
- Transparency: natural light is appreciated for building users can also allow to reduce energy consumption in buildings.

  "Good lighting of the workplace is one of the main factors of indoor comfort that can positively influence health and productivity of office personnel. Natural light, its variations and its spectral composition are of great importance for well-being and mental health. Natural light is a fundamental component of our life, helping our body to produce vitamin "D", an important anticancer element." (www.buildingenvelopes.com)

- Aesthetics: Double-Skin Façades multiplies the creative possibilities of designers and architects.
- Economics: despite the higher initial investment, energy savings can balance this with the savings in the running costs.
- Wind protection: the external façade work as a barrier between windy environment and air into the cavity reducing the cooling effect of wind in winter. But also allowing to open the windows in summer because the DSF contributes to the reduction of wind pressure.
- Rain protection: the external façade provides a shield to the building improving their durability.

3.5.2. Disadvantages

- Additional maintenance: some maintenance operations like cleaning are more difficult and also more extensive taking in consideration that glass surface has been doubled.
- Construction costs: building Double-Skin Façade takes more time, more material and, as a consequence, more initial costs.
- Fire protection: because of the connectivity through the cavity fire can be `propagated easily.
- Less useful space: DSF need a certain distance between glass surfaces which means that, into practice, buildings with DSF loses some useful area in each level.
- Acoustic problems. The cavity can work as an acoustic channel so noise can be transmitted from room to room through the cavity.

3.6. DISCUSSION

The envelope is the most important component in a building considering the thermal balance. The energy consumption became one of the primary issues for architects when they design the first approaches of a building. Glass is currently extensively used in buildings façades; natural lighting is one of the greatest advantages of using this material.

Glass as a construction material is nowadays associated with modern aesthetics and also high technology. *"Glass is now widely applied as a fashionable material associated to symbolize a 'transparent' corporate image for office buildings."* (Hernández Tascón. 2008). As this author stands in his researches, the influence of glass façades on the internal building environment has been a great object of research during the last century. However, the Double-Skin Façade development still have many uncertainties in how they should be applied by architects and designers.

The main reason of the existence of the Double-Skin Façades is the will to resolve the thermal deficiencies of single glass façades. The most appreciated benefits of DSF is the thermal and acoustic insulation, as well as the improvement of natural lighting. Nevertheless, if the DSF is not well designed it could provoke a reversal of the thermal insulation and, as a consequence, an overheating of the building.

The climate conditions, the geographic location and orientation of the building, the solar radiation, the façade design and structure, as well as the building user requirements are the most important elements to be considered during the Double-Skin Façade design process.

Understanding how the Double-Skin Façade cavity works is probably one of the most important points during the design. Many researchers have been studding the behavior and the circulation of the air into the cavity. Depending on the geometry of the cavity and also the different types of openings the results can be dispersed. The final response of the airflow and thermal performance have many variables that have to be considered in order to avoid overheating and ensure correct ventilation into the cavity.

Knowing the behavior of Double-Skin Façades is a difficult task. Many studies worked in the field of Computational Fluid Dynamics (CFD) models to make an approach of how air flows into the cavities, as well as to measure their thermal insulation. However, despite all the research done since today, the development of the CFD in Double-Skin Façades is still under-developed.

4. VERTICAL FARMS

4.1. INTRODUCTION

The domestication of plants was developed more than 10,000 years ago in Mesopotamia and later in some other parts of the planet. This domestication meant a big change in the communities allowing them to have more control and mastery of their food. Storing aliments for winter or for the next harvest was the foundation of the civilizations.

These civilizations have been evolving in parallel with agriculture techniques. Tractors and machinery is used today in large agricultural tracts. The growing population has been demanding aliments and the industry is providing them. Every single day the whole world agriculture surface is increasing. Rainforests and natural areas are being substituted by agricultural exploitations around the World. As Despommier & Ellingsen (2009) and NASA and FAO stands, 80% of the land available for agriculture on the Planet is already farmed. This also means that wild and natural extensions are decreasing in favor to agriculture areas.

Figure 53. Already farmed Earth available land. (Yasmin Rahman. 2012)

In order to support this large scale of agricultural activity, millions of hectares of hardwood and coniferous forests (temperate and tropical), grasslands, and wetlands were sacrificed, or at the very least severely reduced to fragmented remnants of their former ranges. In either case, significant loss of biodiversity and disruption of ecosystem functions on a global scale has been the result (Wilson, 1992)

The agricultural footprint can be catastrophic if we take in consideration that many experts estimated that world human population by the year 2050 will increase in 3 billion people. This means that world human population can reach the 10.6 billion people in less than 40 years which is an increase of almost 40%.(United Nations 2004).

"By the year 2050, nearly 80% of the earth's population will reside in urban centers. […] An estimated 10^9 hectares of new land (about 20% more land than is represented by the country of Brazil) will be needed to grow enough food to feed them, if traditional farming practices continue as they are practiced today." (Despommier & Ellingsen. 2009)

Figure 54. World human population estimation. (Yasmin Rahman. 2012)

In approximately 5 years, 153 of the world's 358 cities will have more than one million inhabitants, 15 of them will be in Asia (Kunzig,2011).

People living in urban centers will generate a huge alimentation demand. Following the current system it is translated to more land available but also a complex and expensive transport system from fields to cities. Preserve all the products and transport them could be an unaffordable solution to cover this demand if we consider the increasing costs of energy.

This situation requires new ideas and solutions able to satisfy the world food demand that guarantees the sustainability and preservation of the wild and natural areas.

It is therefore imperative for any innovator in the agricultural industry to learn to make do with shrinking land space. New innovations can also widen profit margins and therefore help their pocketbooks, so it is all the more reason to be able to squeeze more agricultural productivity into the same land space. (Chuck Martin. 2013)

The solution to this problem could be a Vertical Farm (VF). Vertical Farms is an evolution concept of indoor farming; using the most advanced technologies and efficient growing systems. As Despommier say in his webside:

"Vertical farms, many stories high, will be situated in the heart of the world's urban centers. If successfully implemented, they offer the promise of urban renewal, sustainable production of a safe and varied food supply (year-round crop production), and the eventual repair of ecosystems that have been sacrificed for horizontal farming." (Despommier. 2013)

Vertical Farms are thought as a skyscraper placed in an urban area able to produce enough food to provide most of the citizens. Mechanical and sustainable processes allow plants to grow fast and in a safety environment. New methods can be used to grow plants without the need of natural ground. People could visit these farm factories and be able to know all the processes of the proximity green alimentation industry.

"Indeed, the Vertical Farm is not merely about food, but about the unseen circuits of energy and materials, labor and resources, capital and infrastructure, technology and politics upon which our cities depend; food is only a single component of the Vertical Farm, the most visible part, the market and marketable part […]; food, the only part of farming which consumers see while the rest of the industrial process remaining invisible, unquestioned, absolved by sheer ignorance " (Despommier & Ellingsen. 2008)

Vertical Farms are also a real alternative to overcome the power of big food corporations that control most of the alimentation industry and also have great power and influence in politics. The current system is attempting to the individual freedoms and is polluting the air and the land with noxious elements and chemical products. (JB. Bardot. 2013). Regular application in land of herbicides and pesticides has facilitated the agriculture production; but also created many species resistant to these chemical components. Higher and higher doses are needed to counteract plants and insects polluting the environment.

According to the IFA (International Fertilizer Industry Association), Agrochemicals, especially fertilizers, are used in almost every commercial farming scheme due to the demand for cash crops that require more nutrients from the substrate that it can provide. Fertilizer use is expensive and encourages the growth of weeds, making herbicide use almost a requirement. In commercial ventures, farming involves the production of single crop species, most of which are vulnerable to attack from a wide variety of microbes and arthropods (Carson, 1962; Zupan, 2003).

Ecological and sustainable farms are possible in the Vertical Farm concept.

Nowadays big cities like Chicago, Singapore, Tokyo or New York have a high demand for local and ecological food. Some early initiatives to build Vertical Farms started around the world. Most of these examples are still in testing process but it is a clear symptom that Vertical Farms is an important trending towards a sustainable and ecological food industry.

4.2. HISTORY

The concept of Vertical Farms (VF) as it is understood nowadays is very different as the first intents or ideas of this concept.

Nowadays defenders of VF argue that, "*by allowing traditional outdoor farms to revert to a natural state and reducing the energy costs needed to transport foods to consumers, vertical farms could significantly alleviate climate change produced by excess atmospheric carbon. Critics have noted that the costs of the additional energy needed for artificial lighting, heating and other vertical farming operations would outweigh the benefit of the building's close proximity to the areas of consumption.*"

One of the first's ideas of Vertical Farms was published at the Life Magazine in 1909 where a tall building that cultivates food for the purposes of consumption.

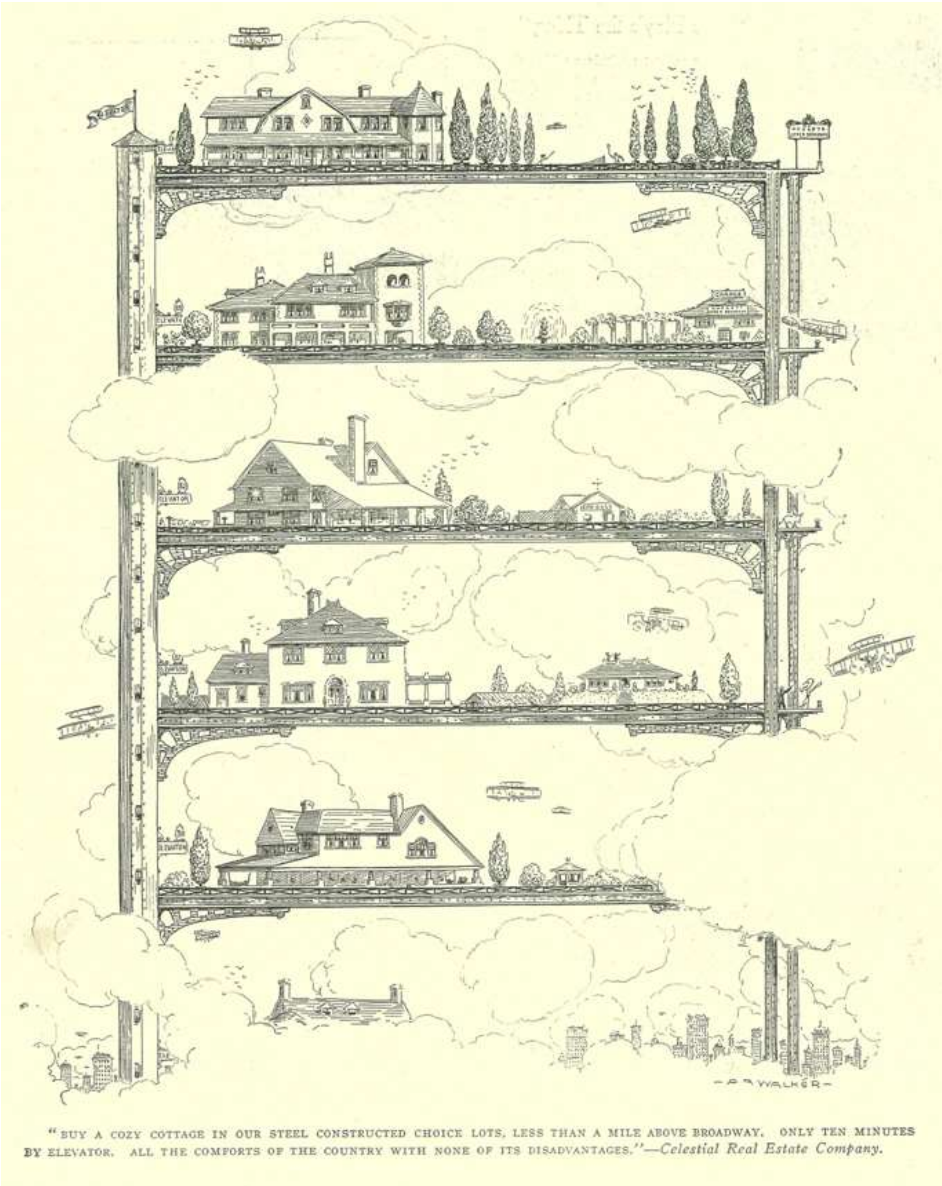

Figure 55. Steel constructed choice lots. Life Magazine. 1909. (www.architakes.com)

Architects as Le Corbusier in the Immeubles-Villas (1922) reproduce some ideas related to the Vertical Farm concept. Also SITE's Highrise of homes (1972) imagined a modern version of the 1909 Life Magazine idea placing houses with gardens in a vertical way.

Figure 56. Highrise of Homes by SITE. 1972. (www.fritzhaeg.com)

Many built examples in high buildings using hydroponics are documented in the canonical text of 'The Glass House' by John Hix. Some of them are the Vertical Farms at the School of Gardeners in Langenlois, Austria, and the glass tower at the Vienna International Horticulture Exhibition (1964). This shows that the VF concept already existed more than forty years before the currently debate about the sustainability and viability of Vertical Farms.

Despite the architectural precedents, nowadays technology is many steps upper than the one used before. The development of Hydroponic technology in greenhouses has experimented a large evolution in the last decades. These horticultural building systems evolved from greenhouse technology, and paved the way for the modern concept of the Vertical Farm.

"The British Interplanetary Society developed a hydroponic for lunar conditions and other building prototypes where developed during the early days of space exploration. During this era of expansion and experimentation, the first Tower Hydroponic Units where developed in Armenia in 1951." (www.wikipedia.org)

Mixed-Use Skyscrapers

The Malaysian architect Ken Yeang is probably the most widely known architect that has promoted the idea of the 'Mixed-Use Skyscrapers'. This is a combination of inhabits where people can live or work with Vertical Farms where food is produced.

The main characteristic exposed by Ken Yeang is that plants should grow in the open air instead of hermetically sealed mass produced agriculture. Without climate control or artificial lights to improve the productivity. The Mixed-Use Skyscrapers were proposed as a communal planting space where building habitants could grow their own food. This option requires less initial investment than the following options presented in this chapter what is a clear advantage. Mixed-Use Skyscrapers are the Vertical Farms type used in this Thesis for the Seagram Building improvement, where office work and farm production will coexist.

Figure 57. How buildings should look by Ken Yeang. (www.treehugger.com)

Despommier's skyscrapers

Dickson Despommier, a professor of environmental health sciences and microbiology at Columbia University in New York City, modernized the idea of vertical farming in 1999 with graduate students in a medical ecology class. He stands that Vertical Farms could be a sustainable option for many reasons.

"The cultivation of plant and animal life within skyscrapers will produce less embedded energy and toxicity than plant and animal life produced on natural landscapes. " (Despommier 1999)

He also claims that natural landscapes are too toxic for natural wildlife; considering the high costs of transportation in the current agricultural and alimentation production system, build skyscrapers for the simple purpose of agricultural production could be a sustainable solution despite the ecological and environmental costs of building them.

The Vertical Farm concept defended by Despommier is a skyscraper structure where plants and animals could grow 24 hours a day 365 days a year in a hermetically sealed environment where herbicides and insecticides are not necessary to guarantee the production. The renewable technology allows to produce big quantities of food without a big energy consumption taking in consideration the savings in transportation because the Vertical Farms would be placed at the city centers. Solar panels and wind turbines would produce enough energy to be energetically independent. A water capture system could reduce the amount of water demand by Vertical Farms.

Figure 58. The Vertical Farm by Dick Despommier. (www.inhabitat.com)

Chris Jacobs and Andrew Kranis from Columbia University and Gordon Graff from the University of Waterloo's School of Architecture in Cambridge, have been producing some architectural designs.

"*Together with Graff, and after disagreeing with Despommier's technical assumptions regarding energy and water balances in 2011, Tahbit Chowdhury and a multidisciplinary team from Waterloo's Dept. of Environmental Engineering and Dept. of Systems Design Engineering augmented the concepts with a focus on low-energy economically-intensive protein-production*." (www.wikipedia.org)

Chowdhury and Graff applied advanced industrial engineering design philosophies to modernize current greenhouse technology as it pertains to hydroponics and aeroponics. The results of the Waterloo team's work showed that there is sufficient technical grounds to begin implementing Despommier's ideas for skyscrapers. However, Chowdhury and Graff showed that the designs will be dramatically different from what Despommier envisioned at Columbia University.

The technology needed to make Vertical farms a reality already exists according to Despommier. The system that he raises can be effective and profitable as some preliminary research studies show.

"Developers and local governments in the following cities have expressed serious interest in establishing a vertical farm: Incheon (South Korea), Abu Dhabi (United Arab Emirates), and Dongtan (China), New York City, Portland, Ore., Los Angeles, Las Vegas, Seattle, Surrey, B.C., Toronto, Paris, Bangalore, Dubai, Shanghai and Beijing. The Illinois Institute of Technology is now crafting a detailed plan for Chicago. It is suggested that prototype versions of vertical farms should be created first, possibly at large universities interested in the research of vertical farms, in order to prevent failures such as the Biosphere 2 project in Oracle, Arizona." (Despommier, Dickson. 2009)

The Paignton Zoo Enviromental Park in the United Kingdom in 2009 is the world's first pilot production system installed. This project is working as a place where do research about the sustainable urban food production using these technology. The aliments produced are used to feed animals while the project enables evaluation of the systems and provides an educational resource to advocate for change in unsustainable land use practices that impact upon global biodiversity and ecosystem services.

In 2010, the Green Zionist Alliance proposed a resolution at the 36th World Zionist Congress calling on Keren Kayemet L'Yisrael (Jewish National Fund in Israel) to develop vertical farms in Israel.

In 2012, the world's first commercial vertical farm building was opened in Singapore.

Figure 59. Singapore Vertical Farm. 2012. (www.edition.cnn.com)

The characteristics of Singapore are suitable to place the first Vertical Farm building in the world. Singapore has only 710 square kilometers and most of the land is urbanized. The dependence of this country of imported food is handicap that this Vertical Farm wants to minimize producing more than 0.5 tons of vegetables per day. Furthermore, the main goal of the company is to reach the 2 tones in few years.

Figure 60. Vertical Farm in Singapore. 2012. (www.cbc.ca)

At the end of the 2012 a Canadian company announced the formal opening of its first fully commercial Vertical Farm.

This Vertical Farm is placed in Vancouver using the rooftop of a car park in downtown. The success of this enterprise is that provides fresh vegetables to a number of local restaurants through an online grocery delivery service.

The immediate commercial potential of this Vertical Farms is the easy integration to existing urban spaces being a beginning step to reach the Despommier idea of a Vertical Farm Skyscraper.

Originally developed in the Paignton Zoo Enviromental Park, the Vancouver VF is using the same system which uses a low-power conveyor to move a series of stainless steel racks holding 24 vertically stacked (1x0.5m) hydroponic trays.

Figure 61. Vertical Farm in Vancouver. Canada. (www.theengineer.co.uk)

The company's latest facility consists of 120 individual racks, covers 4,000ft^2 of growing space, and will produce 68 tons of leafy green vegetables per year. The Vertical Farm uses just the 10% of the water required in traditional agriculture while is producing higher yields. (www.vancouverfoodster.com)

Some other companies like the Swedish Planagon are drawing up plans to raise larger Vertical Farms that are closer to the Despommier's VF concept.
(http://www.theengineer.co.uk)

Many other Vertical Farms are designed around the world including new technologies. Vertical Farms are just starting and the existent ones are providing crucial information to avoid errors and improve the technology and methodology. One example is the Mardi Vertical Farming Agricultural Research and Development Institute in Malaysia designed by Yasmin Rahman.

Figure 62. Mardi Vertical Farm Building. Malaysia.

4.3. ADVANTAGES AND DISADVANTAGES OF VERTICAL FARMING

Vertical Farms are being developed on their firsts steps providing some important information about their functionality and sustainability. The numerous advantages of the Vertical Farms are still balancing the disadvantages of the initial investments.

The following pages are dedicated to analyze the different advantages and disadvantages of the Vertical Farms.

4.3.1. Advantages

Vertical Farms has many potential advantages which have been discussed by Despommier. Many of these benefits are obtained from scaling up hydroponic or aeroponic growing methods in skyscrapers.

4.3.1.1. Preparation for the future

As it is presented in the introduction, the world human population is increasing exponentially while the percentage of already used land at the earth useful for agriculture is estimated around the 80%. Adding to this the future trend of migration to the cities Vertical Farms are probably one of the most realistic and sustainable alternatives to solve this future and also our planet.

Thanks to the Vertical Farms cities could be, if not totally self-supplied, at least less dependent to the food importations. This is a key concept for the future cities taking in consideration that the United Nations estimates that in the next five years the world will have more than ten cities with more than a million people population.

Figure 63. Vertical Farm. (blogs.yorkschool.com)

The future also involves the conquest of the space. Developing Vertical Farms is probably the first step to learn how to optimize indoor farms on the Earth to then launch this technology to the hypothetical space colonies.

4.3.1.2. Increase of crop production

Traditional farming has the limitation of the seasons and most of them produce only once a year. Vertical Farming could be possible to grow plants in all seasons which multiply the productivity of the farmed surface. Despommier (2009) stands that the productivity factor could be around 5 times higher in comparison to the traditional systems. In some crops, like strawberries, the factor could be as high as 30.

Despommier suggests that, if dwarf versions of certain crops are used (e.g. dwarf wheat developed by NASA, which is smaller in size but richer in nutrients), year-round crops, and "stacker" plant holders are accounted for, a 30-story building with a base of a building block (5 acres (20,000 m^2)) would yield a yearly crop analogous to that of 2,400 acres (9.7 km^2) of traditional farming.

Figure 64. Vertical Farm in Vancouver. Canada. (www.theengineer.co.uk)

Indoor farming also gives an extra protection against plagues or any other natural phenomena that affect the productivity in traditional farming fields. Vertical Farms have more production and also more reliability and safety

4.3.1.3. Water sustainability

One of the challenges that Vertical Farms have to overcome is the water consumption. Placing these farms at the city centers the water consumption could be a problem to supply the population as well as the Vertical Farms.

To avoid this problem many sophisticated systems allow to convert black and grey water into drinking water by collecting the water of evapotranspiration. Is also possible to control the agricultural runoff by recycling black water.

4.3.1.4. Protection from weather disasters

Crops grown in traditional outdoor farming suffer from the often suboptimal, and sometimes extreme, nature of geological and meteorological events such as undesirable temperatures or rainfall amounts, monsoons, hailstorms, tornadoes, flooding, wildfires, and severe droughts.

The protection of crops from weather is increasingly important as global climate change occurs. “Three recent floods (in 1993, 2007 and 2008) cost the United States billions of dollars in lost crops, with even more devastating losses in topsoil. Changes in rain patterns and temperature could diminish India’s agricultural output by 30 percent by the end of the century.” (Michael Pollan. 2009)

Figure 65. Drought. (www.grist.org)

On the other hand, Vertical farms provide a controlled indoor environment whose productivity does not depend on these weather phenomena’s. This independence is a key concept if we take in consideration the increasing instability of the weather in many places in the World because of the Global Warming.

4.3.1.5. Sustainable environments for urban areas

Placing Vertical Farms at the city centers also means a rupture with the duality city-farmlands. Vertical Farms could have multiple purposes in addition to growing plants; a big grocery store could be places at the buildings, as well as restaurants. Also Vertical Farms could be a place where to install your company in office floors or any other activity.

4.3.1.6. Conservation of natural resources

Each unit of area in a vertical farm could allow up to 20 units of area of outdoor farmland to return to its natural state ("A Farm on Every Floor", The New York Times. 2009). Using VF instead of traditional farming a recuperation of the forests and rainforests as well as grassland and natural habitats nowadays used for agriculture reasons.

Figure 66. Deforestation for agriculture causes. (www.earthfirstnews.wordpress.com)

As it was commented previously, the diminution of fuel consumption has the consequence of a reduction of air pollution and the carbon dioxide emissions. This means a healthier environment and more preserved ecosystems.

4.3.1.7. Organic crops

Vertical Farms have a controlled indoor environment where plants can grow. This protected environment reduces the need of any kind of pesticides or herbicides as well as any other kind of chemical product.

As well as people take more consideration about their health through the aliments organic food is being more valued. The perception of a healthy and sustainable product by the customers and clients is changing and concepts like ‘food miles’ matter. Knowing where the food comes from is becoming important and as closer as better. The demand of local products have increased because the sustainability and the quality associated to these products.

4.3.1.8. Healthier workplace

Traditional farming could be a hazardous occupation with some particular risks such exposure to infectious diseases like malaria, as well as schistosomes and exposure to toxic chemicals commonly used in agriculture as pesticides or fungicides. Also dangerous situations in confrontations with wildlife like venomous snakes or some other animals. Severe injuries can happen with the use of large industrial farming equipment.

Vertical Farming reduces the exposure to most of these risks providing a safer working place for workers and employees.

4.3.1.9. Reduction of fuel consumption

Vertical Farms placed in the city centers does not need any transportation of the aliments because they are already at the same place where consumers are. This means that all the fuel and gas used to transport food but also the energy used to keep aliments fresh like refrigerators or freezers are not necessary. This suppose a dramatically reduction of the fuel use.

As a consequence of this fuel consumption reduction fewer emissions are expelled to the atmosphere, which is yet another reason to rely on the environmentally friendly vertical farms.

Avoiding transportation it also results in less spoilage and infestation. Research has shown that 30% of harvested crops are wasted due to spoilage and infestation, though this number is much lower in developed nations. (Despommier. 2009)

4.3.1.10. Energy production

The energy production is probably one of the key elements to understand and to guarantee the viability of Vertical Farms.

The energy independence of the Vertical Farms could be reached thanks to use an extremely efficient system but also producing energy by the combustion of biogas made from the organic waste of the Vertical Farm (non-edible parts of plants and animals). This gas is generally composed of 65% methane along with other gases.

It could be also possible to equip the Vertical Farms with wind turbines and solar panels to leave even less of carbon footprint.

4.3.1.11. Flexibility with placement

"Such a farmscraper in Antarctica could grow food normally grown in Florida, while another section grows what is seen in Central Europe, and other parts of the building could grow a myriad of food indigenous to many countries. Sometimes, temperatures, humidity and other conditions ideal for one type of food may not be ideal for another, which is why rooms and sections must have sealed double-doorways apart from one another, to ensure an "airlock effect" of not letting one room's artificial climate enter another and alter the growth of certain crops." (Chuck Martin. 2013)

Vertical Farms can remain producing the 24hours per day, every day in a year thanks to the energy equipment. While the day light would take care of the light need of the plants, during the night a highly efficient LED lights could illuminate the plantation to keep going with the production.

The Vertical farms technology could be also used into refugee camps in order to provide livelihood to people with needs.

This solution has some other consequences such the reduction of the need of water or agricultural land in territories where these needs could be the origin of many armed conflicts.

Figure 67. Water shortage. (www.thefuturescompany.com)

4.3.2. Disadvantages

4.3.2.1. Economics

One of the biggest obstacles that Vertical Farms have to overcome is the economical side. These buildings are too expensive; the high technology required, the terrains in a city center, etc. It is translated to an enormous start-up costs that without the help of the administration are not possible to effort.

The maintenance of Vertical Farms is also a handicap. The extra cost of lighting (even using LED systems) but especially the energy required to heat the Vertical Farm are not as much higher than the transportation costs that VF saves. This balance could be decanted to the VF side if governments and administrations make laws and efforts to punish the environmental friendly industries.

"The initial building costs will be easily over $100 million, for a 60 hectare vertical farm. Office occupancy costs can be very high in major cities, with cities such as Tokyo, Moscow, Mumbai, Dubai, Milan, Zurich, and Sao Paulo ranging from $1850 to $880 per square meter, respectively." (Pocket World in Figures, The Economist, 2011 ed. pg. 64)

4.3.2.2. Energy use

If one of the goals of Vertical Farms is the possibility to grow different species during the whole year, because of the different inclination of the sunlight depending on the seasons it is necessary a supplementary artificial light. Bruce Bugbee (2009), a crop physiologist at Utah State University, believes that the power demands of vertical farming will be too expensive and uncompetitive with traditional farms using only free natural light. The scientist and climate change activist George Monbiot (2010) calculated that the cost of providing enough supplementary light to grow the grain for a single loaf would be almost $10 (although his calculation has not considered LED growing lights, which are somewhat more efficient - around 1/2 to 1/5 of the cost).

The energy issue is also a big obstacle for Vertical Farms. Heating the entire building could be very expensive and energetically not sustainable. Even using biofuels from the organic debris it is not enough energy to supply the needs of a Vertical Farm.

To address this problem, The Plant in Chicago is building an anaerobic digester into the building. This will allow the farm to operate off the energy grid. Moreover, the anaerobic digester will be recycling waste from nearby businesses that would otherwise go into landfills.

4.3.2.3. Pollution

Without taking in consideration of the energy used by the food transportation, a Vertical Farm produces more greenhouse gases than a traditional field. VF require more energy per kilogram of production.

"As plants acquire nearly all their carbon from the atmosphere, greenhouse growers commonly supplement CO_2 levels to 3-4 times the rate normally found in the atmosphere. This increase in CO_2, which has been shown to increase photosynthesis rates by 50%, contributes to the higher yields expected in vertical farming. It is not uncommon to find greenhouses burning fossil fuels purely for this purpose, as other CO_2 sources, like from furnaces, contain pollutants such as sulphur dioxide and ethylene which significantly damage plants."(Blom, T.J.; W.A. Straver; F.J. Ingratta; Shalin Khosla; Wayne Brown (2002-12)."Carbon Dioxide in Greenhouses")

This means that even if the rest of the farm is powered by sustainable or green energy, VF requires a CO_2 source. Also, through necessary ventilation, much CO_2 will be leaked into the city's atmosphere.

Light pollution could be also a problem in the city centers. A 40 story Vertical Farm in a residential area lighting all the night could be annoying for the neighbors.

A huge amount of water is used in Vertical Farms. This water could contain organic particles that could smell bad and also could pollute the water. If the VF do not take care of the recycling of their waters this could be also a big problem for the future of this systems.

4.4. DISCUSSION

Vertical Farms are a new concept that is still in a developing process. Little steps have been done by many researchers and companies, as well as some governments. VF is a future solution to the issues that our planet is going to effort.

Many problems have appeared and the technology is still in a developing process but it seems that any other idea is facing the future as well as Vertical Farm concept is doing.

Vertical Farms could be a future solution but it needs a slow process to awareness people and the whole society to believe in this possibility. Traditional farmers could be against this idea so it is also important to think in a progressive ways to show to the society the many advantages of the Vertical Farms without hiding the problems related.

5. SEAGRAM BUILDING AND MIES VAN DER ROHE

5.1. INTRODUCTION

During the early years of this century there was a revolution in the field of architecture. New materials and new construction techniques came to the hands of the well-known architects such as Frank Lloyd Wright, Walter Gropius, Le Corbusier, Louis Sullivan, Oscar Niemeyer, Alvar Aalto and Ludwig Mies van der Rohe.

These new techniques allowed the architects to build in a different way. For example, they substitute the bearing walls by the columns. Using this new approach, they were able to break with the traditional vertical shapes and start a completely new way to work with the forms.

An important architect, Ludwig Mies Van der Rohe, designed the Seagram Building in New York in 1958.

Figure 68. Seagram building. Mies Van der Rohe. (credithisttheoarchii.blogspot.com)

5.2. THE ARCHITECT

Figure 69. Mies van der Rohe. (www.arqhys.com)

5.2.1. Early career

Mies Van der Rohe was born in the German city of Aachen, newt to the border with Nederland. He started working as an apprentice in the Peter Behrens's architecture from 1908 to 1912. (www.wikipedia.org)

Mies had always been attracted to the techniques of Karl Friedrich Schinkel. He particulary was interested in the way that the Prussian Neo-Classical architect used the so simple cubic shapes. During his first job as an independent professional, Mies designed some upper-class homes and he tried to implement the Germanic domestic style from the early nineteenth century that he took from Karl Friedrich Schinkel.

5.2.2. Traditionalism to Modernism

After World War I, Mies started a new project. He joined some of his own companions in terms to find out a new style that could fit into the modern industrial age. This new project was due to the fact that traditional styles had been under attack by progressive theorists since the mid-nineteenth century.

Years after the World War I, the new path took by the culture was strongly counter to the historical styles. This fact was because the World War I was seen as a crash of the old world order represented by the leadership of Europe. The artistic current that took place was the aristocratic classical revival architecture style. The idea of this new movement was to conceptualize the architecture in a more rational way in terms of design and execution. The architect should became a person with a more problem-solving trait and a person with a great knowledge of the use of the modern materials and structures.

Although most of the projects developed by Mies were not built, he became a very important figure in the field of architecture because of his capability to fit his projects with the spirit of the modern society. One of the most important moments in the Mies's career was in 1921, when he presented the so called Friedrichstraße skyscraper in the 1921, followed by a taller curved version in 1922 named the Glass Skyscraper. (Arthur Lubow's "The Contextualizer". New York Times. April 6, 2008)

Years later, he design and execute two of his most known projects in Europe: the temporary German Pavilion for the Barcelona Universal Exposition in 1929 and the Villa Tugendhat in Brno (Czech Republic) in 1930.

Figure 70. German Pavillion, Barcelona, 1929. (www.worldarchitecturemap.org)

In July 1923, he started working on the magazine "G". He also played a good role in the field of architecture which was completed with the naming of Mies as director of the association "Der Ring". Later, he became also the director of the "Bauhaus DesignSschool" where he had the opportunity to influence the school with his particularly approach in terms of simple geometric forms and in the design of useful objects. (Farnsworth House. "History" Retrieved March 2012)

Mies based his architecture on the idea of the declining of the traditional styles. In some of his project, he adopted theoretical ideas such as the aesthetic credos of Russian Constructivism with their ideology of "efficient" sculptural assembly of modern industrial materials. He developed his idea of simple forms using rectilinear and planar forms.

Mies found particularly interesting the approach followed by Adolf Loos, who replaced artistic ornament with the straightforward display of visual qualities of materials and shapes. One of the main proposals made by Loos was the fact that he believed architecture and art should be completely independent. This idea matched very well in the mind of Mies, who completely agreed. (www.wikipedia.org)

At that time, European architects admired the work of American ones. In the exhibition of Frank Lloyd Wright's Wasmuth Portfolio, Mies found a new concept in the disposition of the interior space. The free-flowing space with inter-connected rooms were fascinating for Mies who particularly paid attention in the open floor plans, typical from American engineering structures.

5.2.3. Significance and meaning

One of the goals of Mies was to create a new language for architecture in terms that could be used to describe the new era of technology. He realize the need of a new current that was in harmony with the his time. His work was characterize by a rational approach. He considered the configuration and arrangement of an architectural element as two of the most important characteristics that one must consider.

Mies studied the most important philosophers and thinkers of his time and past time in terms to increase his understanding of his own time. As a pioneer of modernism, Miles influence the culture of his own days with the ideas that were relevant to his architectural mission. *“Mies architecture was guided by principles at a high level of abstraction, and his own generalized descriptions of those principles intentionally leave much room for interpretation. Yet his buildings are executed as objects of beauty and craftsmanship, and seem very direct and simple when viewed in person.”* (www.wikipedia.org)

The modern age were well described by Mies from the overall to the smallest concept. Beyond the esthetic qualities, which are remarkable, Mies filled his work with so much sense that has pushed the contemporary philosophers to still talk about his architecture.

5.2.4. Emigration to the United States of America

At the beginning of the worldwide depression, Mies served as director of the faltering Bauhaus. In 1932, due to the increasing power of the Nazis, Mies decided to move it to Berlin. Few years later, the Gestapo made impossible to continue with the normal operation of the society and it had to closed.

Later, he decided to move to USA and he accepted to run the department of architecture in the Illinois institute of technology in Chicago. He influenced the way to educate and train the students. His ideas became very important and influence in the following years in USA.

Due to the fact that he was working at the IIT (Illinois institute of technology), he was able to design and build the new master plan of the campus. Nowadays we can still see in the IIT all the buildings that Mies left to the campus. One of the most “Miesian” projects can be found in the IIT campus, where we can find out the S.R. Crown Hall as the perfect representation of the Mies's work and way to think.

The projects developed in the IIT campus changed the way to think of the American citizens. The Mies's architecture, clearly with German Bauhaus and western European influence, became immediately accepted by the society.

Later, in 1944, he obtained the permission to become a citizen of the United States. During the following 30 years, Mies dedicated his work to project in a more structural and rational way. His new goal became the enclosing of open and adaptable spaces and, in terms to achieve this objective, he used modern material and construction techniques as prefabricated steel shapes or the use of large sheets of glass.

5.2.5. American work

During the 31 years spent as an architect in United States, Mies developed very remarkable projects, some examples are: : the residential towers of 860–880 Lake Shore Dr, the Chicago Federal Center complex, the Farnsworth House, Crown Hall and other structures at IIT; and the Seagram Building in New York.

5.2.5.1. Farnsworth House

During 4 years, between 1946 and 1951, Mies developed a private project for the Dr. Edith Farnsworth. In that project, Mies was able to explore the relationship between humans and nature, which was reflected in the glass pavilion next to the Fox River, surrounded by forest.

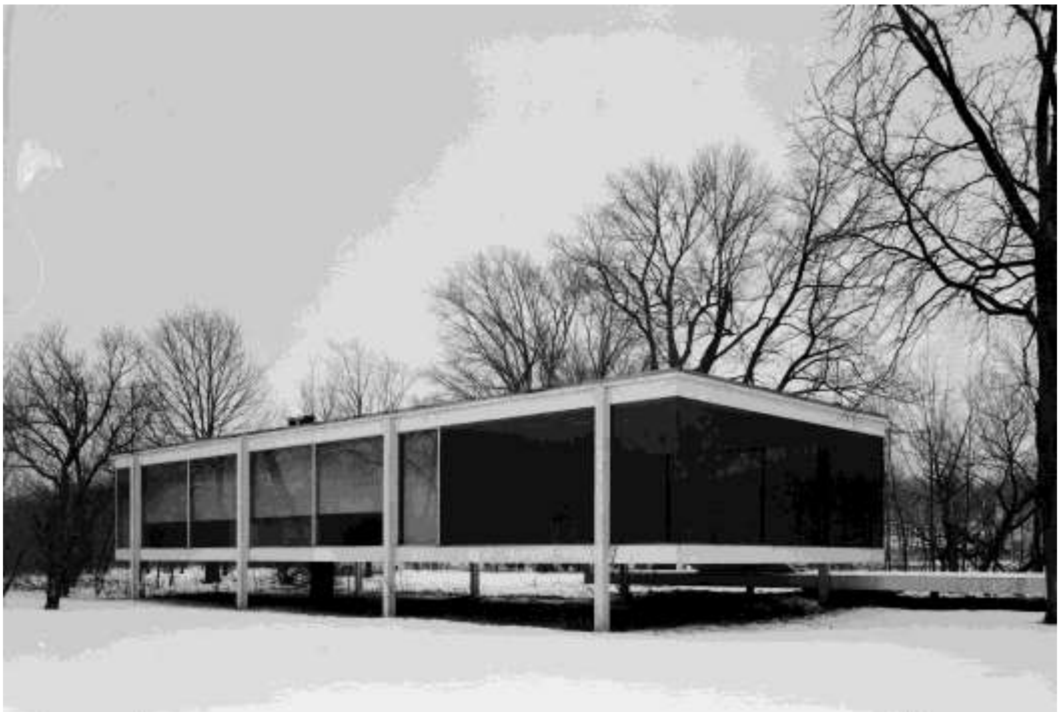

Figure 71. Farnsworth House. Illinois, 1951. (www.wikipedia.org)

The structural frame with all the walls made of glass allows the light to come inside and envelop the interior space. Instead of walls, Mies used wood-paneled in terms to define sleeping and living spaces. Full-height draperies provide the privacy required when needed. The houses is one of the best accomplishments of Mies and is considered a temple between heaven and earth. The house is a clear example of modern architecture, a structure without bones or skin framework. The idea of simplicity is quite present in the project. (Farnsworth House. “History” Retrieved March 2012)

5.2.5.2. 860–880 Lake Shore Drive

Around 1950, Mies designed 4 apartment buildings for Herb Greenwald: the 860–880 (which was built between 1949 and 1951) and 900–910 Lake Shore Drive towers on Chicago's Lakefront. The buildings, made with glass and metal, were advanced to its time. Following the traditional approach of Mies, he designed the towers as simple rectangular blocks.

Figure 72. 860-880 Lake Shore Drive, Chicago, 1951. (www.streetervillehomes.com)

The simple approach used by Mies, created a feeling of light, openness and freedom of movement that would be copied in many other towers produced by Mies of his followers. Years later, the spirit of America would be well described with the openness and freedom of movement that the work of Mies transmitted. (www.wikipedia.org)

Mies created interior flowing spaces in flat surfaces in terms to represent oasis in the middle of the chaos of the city. The nature was truly represented in his work by combined space of pavement and nature soil where the plants where able to grow up.

5.2.5.3. National Gallery, Berlin

Mies projected his last work for the Berlin National Gallery. This building is considered the maximum statement of his architecture and the one which best fits his principles. The building is supported by steel columns and a cantilever roof plane. The flexible space inside the building, surrounded by a unique glass wall is a quite reflexion of the Mies's approach.

Figure 73. National Gallery Museum, Berlin, 1968. (www.repeatingislands.com)

In terms of volume space, the glass pavilion is small in comparison to the total building. A big podium building is used to place most of the museum in an area without windows. (http://www.plataformaarquitectura.cl)

5.2.6. Furniture

Mies used new industrial technologies to perform furniture pieces that have become popular things. Some examples are: Barcelona chair and table, the Brno chair, and the Tugendhat chair. The furniture developed by Mies have some relevant characteristics; as a separation between supporting frames structures and the supported surfaces, employ of the cantilevers in terms to transmit the lightness and delicate look of the frame structures. During this period, he collaborated closely with interior designer and companion Lilly Reich.

Figure 74. Barcelona Chair, 1928. (www.icollector.com)

5.3. SEAGRAM BUILDING

In 1958, the Seagram Building of the New York City was designed. This project is considered as the pinnacle of the modernist architecture and Mies was the one chosen to perform the work. He worked with Phyllis Bronfman Lambert, one of the most known architectures of the period.

"The Seagram Building has become an icon of the growing power of the corporation, that defining institution of the twentieth century. In a bold and innovative move, the architect chose to set the tower back from the property line to create a forecourt plaza and fountain on Park Avenue." (www.wikipedia.org)

Figure 75. Seagram building, New York, 1958. (www.designkultur.wordpress.com)

During the procedure of design, Mies had to defense his project again the Bronfman's bankers. His design of an useless open space at the bottom of the building did not seem very efficient by the client and they did not see that it would give presence and prestige to the building in the future. Phillip Johnson took care about the selection and implementation of the materials and he designed the Four Seasons Restaurant, that has been remained unremodeled until today. ("Seagram Building" Academic. Retrieved 2012-06-18)

The building stands 515 feet tall with 38 stories, and was completed in 1958. This structure, and the International style in which it was built, had enormous influences on American architecture. One of the style's characteristic traits was to express or articulate the structure of buildings externally. It was a style that argued that the functional utility of the building's structural elements when made visible, could supplant a formal decorative articulation; and more honestly converse with the public than any system of applied ornamentation. A building's structural elements should be visible, Mies thought. ("Seagram Building" A View On Cities. Retrieved 2012-06-18)

Mies constructed the Seagram Building as a steel frame structure. Despites Mies preferred the idea of making the frame structure visible to the public, the American building codes imposed to cover all the steel with a fireproof material. Because of the fact that Mies did not like concrete at all, he decided to use non-structural bronze-toned I-beams to suggest structure instead of concrete. This allow to accomplish the idea of making the support structure visible to the public, because the I-columns run vertically surrounding the large glass windows. This new approach, the idea of a non-structural element supported by an internal mix structure, has become commonplace.

Figure 76. Seagram Building lobby. (www.archdaily.com)

On completion, the construction costs of Seagram made it the world's most expensive skyscraper at the time, due to the use of expensive, high-quality materials and lavish interior decoration including bronze, travertine, and marble. The interior was designed to assure cohesion with the external features, repeated in the glass and bronze furnishings and decorative scheme. ("New Skyscraper on Park Avenue to be First Sheadthed in Bronze"; The New York Times March 2, 1956 p.25)

Figure 77. Seagram Building lobby. (www.blog.archpaper.com)

Another interesting feature of the Seagram Building is the window blinds. As was common with International style architects, Mies wanted the building to have a uniform appearance. One aspect of a façade which Mies disliked, was the disordered irregularity when window blinds are drawn. Inevitably, people using different windows will draw blinds to different heights, making the building appear disorganized. To reduce this disproportionate appearance, Mies specified window blinds which only operated in three positions – fully open, halfway open/closed, or fully closed. (www.wikipedia.org)

Figure 78. Seagram Building façade.

In terms to increment the lateral stiffness, in the 38 floor Mies putted a structure made of steel moment frame and reinforced concrete. The concrete core shear walls extend up to the 17th floor, and diagonal core bracing (shear trusses) extends to the 29th floor. ("Structure and Design" G.G. Schierle)

According to Severud Associates, *"the structural engineering consultants, it was the first tall building to use high strength bolted connections, the first tall building to combine a braced frame with a moment frame, one of the first tall buildings to use a vertical truss bracing system and the first tall building to employ a composite steel and concrete lateral frame."* (www.wikipedia.org)

As Mies wanted, all the area around the building was remodeled in terms to match with the look of the building. Mies has the idea that the area around all his construction had to be in harmony with the building itself. As Antoni Gaudi did in most of his projects, Mies he designed a completely new gathering area around the building. ("The Social Life of Small Urban Spaces")

Figure 79. Seagram Building plaza. (www.flickr.com)

5.4. DISCUSSION

The Mies Van der Rohe Seagram Building is an icon of Modern Architecture and a symbol of the first skyscrapers in Manhattan. This building is considered a monument and a historic building that is necessary to preserve.

Changing the whole façade of this famous building would be controversial, likely generating some rejection. The loss of authenticity is one of the criticisms that this project would need to overcome.

The main goal of this implementation is to show the benefits of becoming sustainable—In this particular case, by using Vertical Farms and Double-Skin Façades. The economic benefits of the implementation of Vertical Farm Façades are not the only source of significance; other benefits already presented in previous chapters are also very important.

The fact that a Vertical Farm Façade on the Seagram Building would be controversial is good for the interests that this Thesis defends. Events with higher controversy result in more impactful repercussions via debate and media. As a result, this means more public knowledge related to the benefits of becoming sustainable for companies and people.

Losing the authenticity of the Seagram Building is something unaffordable. That is why the Vertical Farm Façade should be a temporary implementation to demonstrate the benefits of Sustainability for a number of years without being a permanent action.

This would represent an extra effort— but is something necessary in order to preserve the aesthetic of this iconic building and to disarm the critiques.

6. COMPUTATIONAL ANALYSIS

6.1. INTRODUCTION

The previous chapters have been analyzing different building concepts and also trends to effort the future challenges. Many of these ideas previously exposed are represented and used in this study. The Vertical Farm Façade takes the some advantages of Green Walls, Double Skin Façades and also Vertical Farms and tries to reproduce a model that could be reproduced in existing buildings and skyscrapers.

The Vertical Farm Façade exposed in this Thesis follows the idea to improve the west façade of the Mies Van der Rohe Seagram Building in New York. To improve this façade is proposed a change of the existent façade and replace it with a Double Skin Façade where, between the two glass surfaces, many plants could grow by the Living Walls hydroponic system. These plants could be just decorative but following the philosophy of the Vertical Farm many plants to eat could be planted in this façade giving an extra value to this concept and giving to this the name of Vertical Farm Façade.

To get an initial overview of this concept and the advantages associated to them it is necessary to do some calculations and measurements. In this chapter some results about the efficiency of the implementation of this Vertical Farm Façade are shown. To get those results some software and programs are used. EnergyPlus, OpenStudio and SketchUp are the three main programs and interfaces used in this Thesis.

These programs allow drawing a specific geometry defining all the characteristics of the building (materials, uses, etc.) and then calculate an estimation of the energy consumption of the Building considering the ventilated heating and cooling systems installed as well as the definition of the climate where the building is placed and also the schedules of the building depending on the uses.

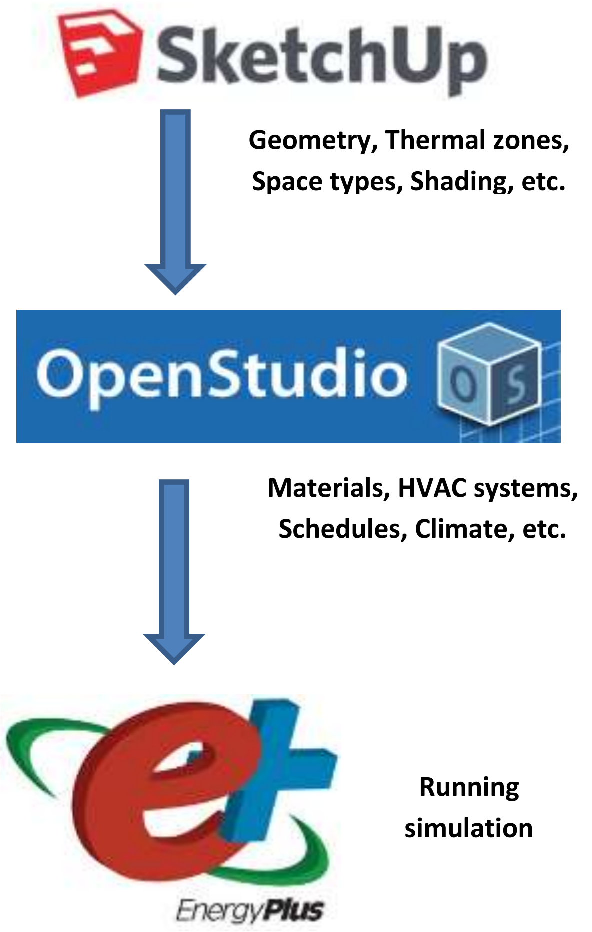

Figure 80. Software used scheme. (Marc Prades. 2013)

Using these programs it is possible to get an approximated result about the advantages of changing the main façade of the Seagram Building. This chapter presents and explains how these programs have been used and which parameters have been took in consideration to calculate the thermal and energetic changes of the façade.

On the other hand, all the changes done in the Seagram Building in order to calculate an approximation result are explained and discussed in this chapter. All the assumptions and simplifications performed in order to use the software are also represented in the following points.

6.2. GEOMETRIC MODELLING

6.2.1. Sketchup

"Google SketchUp is the first FREE (along with a Pro/paid version) and open source software to design professional 3D and 2D models with ease simplicity. It's major advantage is that the learning curve of Google SketchUp is very small and most users can learn how to operate the program within hours of first using."

"Google SketchUp is open source, meaning that it is a platform is open for Rubyscript programmers to develop plugins for this software. Allowing it to have versatility seen by no other design program. With the open source comes an immense amount of plugins available for the software." (www.sketchuppluginreviews.com)

As it is said, SketchUp is an open source what means that it allows the possibility to create plugins that combine SketchUp with other software or programs like OpenStudio.

Figure 81. Logo. (openstudio.nrel.gov)

6.2.2. Geometry

For this Thesis SketchUp has been used to create the entire geometry of the Seagram Building. As it has been explained on previous chapters, Mies Van der Rohe designed this building in 1958. The building stands 515 feet tall with 38 stories mainly harboring offices but also a restaurant in the top floor.

Seagram Building has many special characteristics that have been tried to reproduce designing the geometry in SketchUp.

Starting for the building's plan, the main characteristic is the existence of a building core that harbors the elevators and also the stairs. This core has the same dimensions in all the levels.

Figure 82. Seagram Building plan. (www.selldorf.com)

As it is shown in the following picture, the simplification done at the plan section is reducing the entire level in five spaces respecting the presence of the core in the center. In this way each façade has their own space which is an advantage, as it will be explained in the following points.

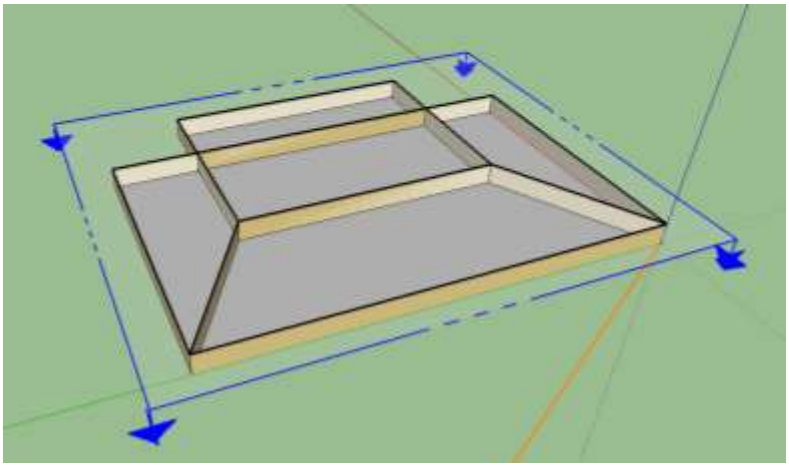

Figure 83. Plan geometry

This geometry in the plan is reproduced in most of the levels. Multiplying this for the 38 levels it is possible to build the entire skyscraper.

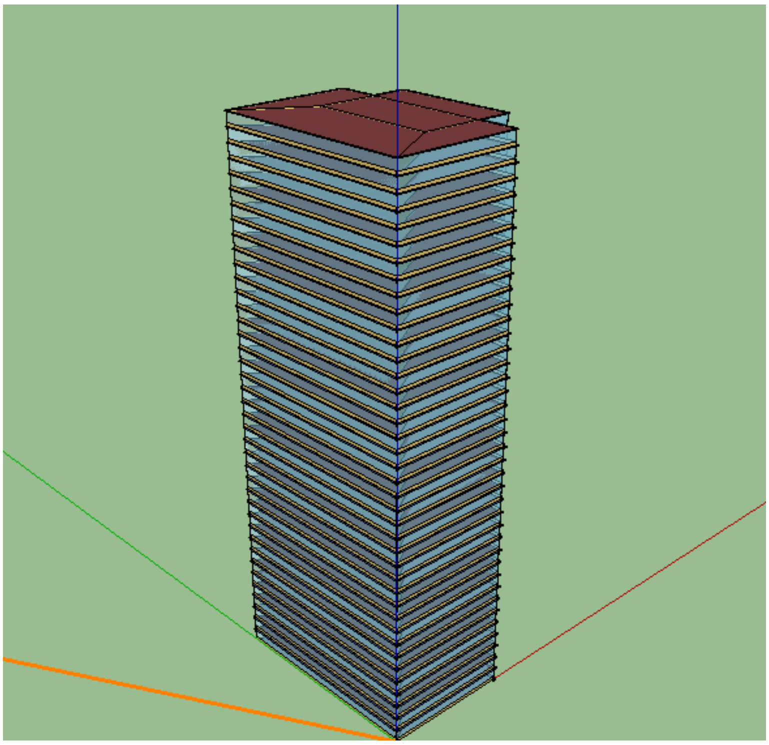

Figure 84. Entire building geometry

6.2.3. Shading

Shading is very important when considering thermal gains and losses. Depending on the inclination of the Sun, the surrounding buildings, or the shading devices, the energy balance calculated could be very different.

Taking into consideration the different trajectories of the sun during the year it is important to define all the possible effects to the building in terms of shading. The surrounding buildings produce larger or shorter shadows to our building that affect it.

Seagram Building is placed in Manhattan (New York) where skyscrapers are really abundant. Many other tall buildings exist next to it, some of them even taller than The Seagram. Depending on the season or the day these buildings project different shadows on the Seagram Building façade. That is why surrounding buildings are also represented in the geometry as it is shown in the following figure

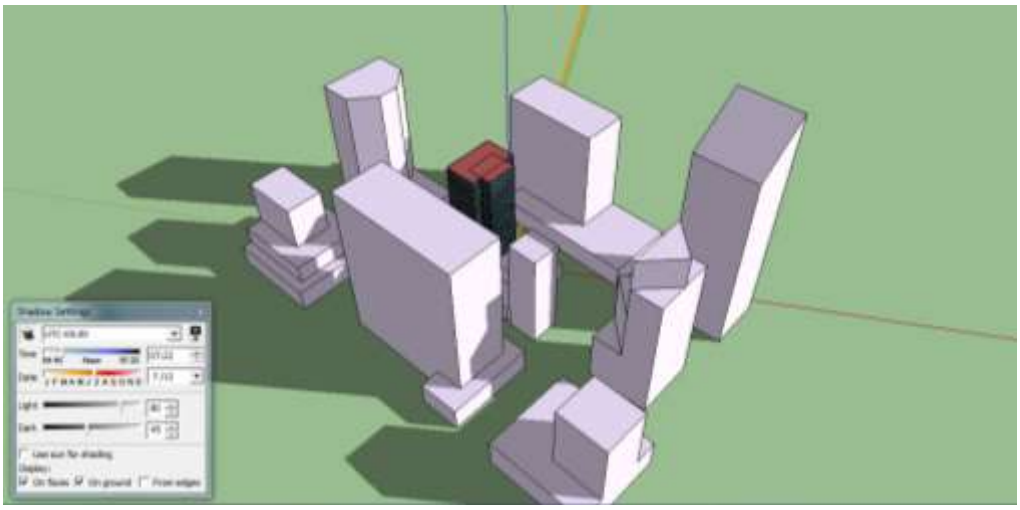

Figure 85. Surrounding buildings shadow in the morning.

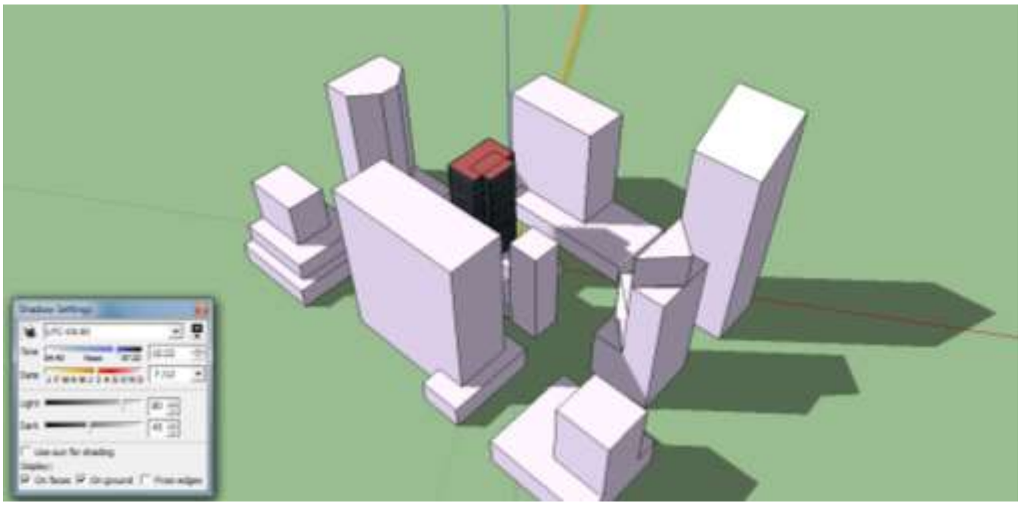

Figure 86. Surrounding buildings shadow in the afternoon.

With the goal of creating a less heavy geometry of the surrounding buildings and in order to have more flexibility in subsequent calculations, some of the sides that do not project any shadows onto the Seagram Building have been deleted. This way, the file is lighter and has the same effect on our building. The following pictures show this simplification.

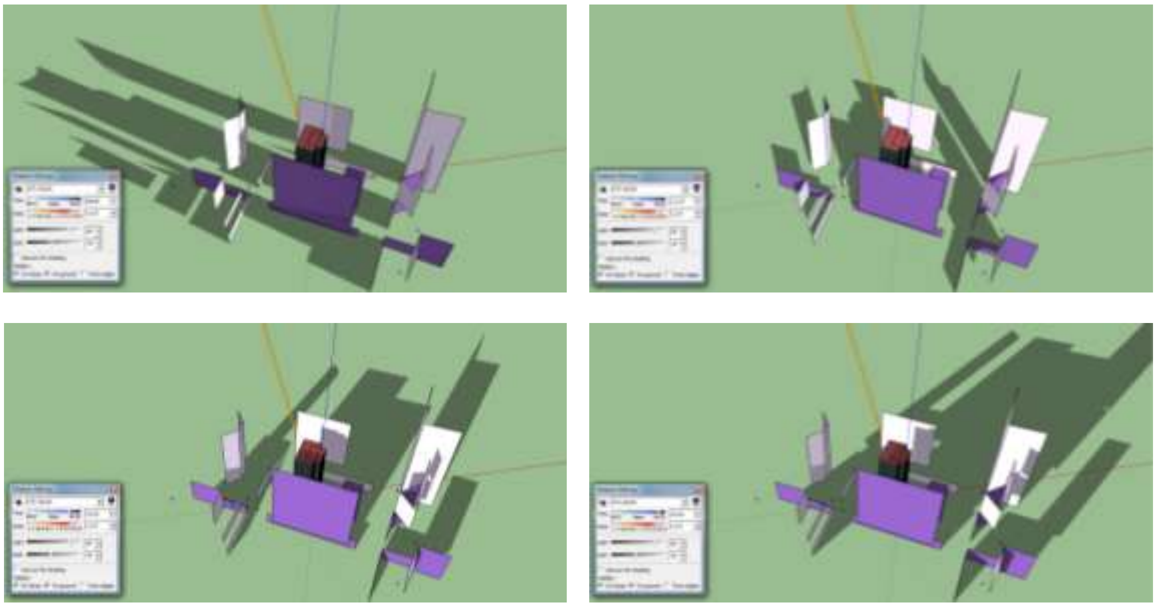

Figure 87. Shading simplification in different moments of the same summer day

6.2.4. Thermal zones

To calculate how the temperature fluxes work in the building is necessary to define thermal zones. Every space can have multiple thermal zones or vice-versa. A thermal zone is a volume (could be a room, could be an entire floor, etc.) that works as a unique air sharing area where are flows freely and maintains consistent temperature proprieties.

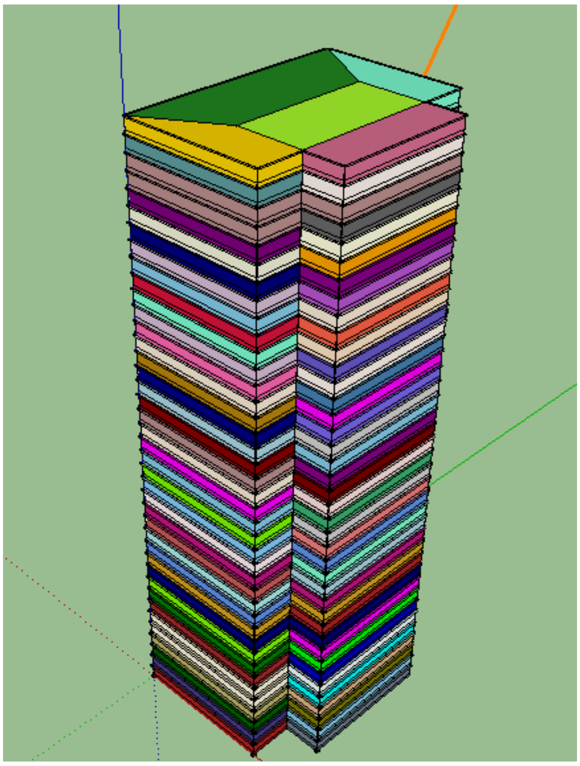

Figure 88. Thermal zones

Then, working with the OpenStudio interface, it is possible to assign a ventilated heating and cooling system to each thermal zone.

Applying this concept to our simulation, every zone (five for each floor) has been assigned a thermal zone. As shown in the following picture, a different color is assigned to each thermal zone.

6.2.5. Space types

Space types are very important in defining the uses of each zone within the building. Depending on how a zone is used, the energy needed to heat or to cool that zone varies. The Seagram Building has many different spaces like the lobby, the attic, the restaurant, the core, the office rooms, the restrooms, etc. The restaurant kitchen does not need the same energy or light as does a restroom or an office room.

These different uses of the spaces are defined in the SketchUp plugin. The main lobby on the first floor has special parameters provided by ASHRAE; the restaurant in the top floor is also defined, the restaurant kitchen on the back (East) of the building and also the attic has a differentiation that impacts the subsequent calculation. The entire building core has been defined as a corridor.

The following picture shows the different space types defined in the computational model. As seen, most of the levels are office zones.

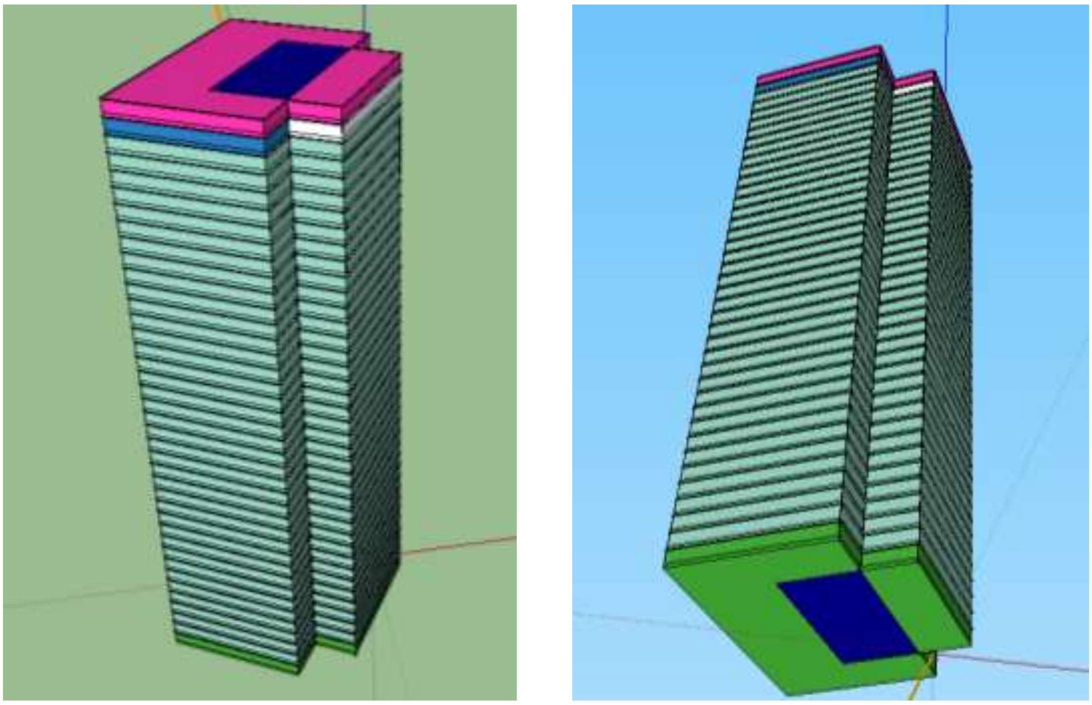

Figure 89. Space types defined in the model

6.3. ENERGY SIMULATION INTERFACE

6.3.1. OpenStudio

"OpenStudio is a cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance. OpenStudio is an open source project to facilitate community development, extension, and private sector adoption. OpenStudio includes graphical interfaces along with a Software Development Kit (SDK)."

Figure 90. Logo. (openstudio.nrel.gov)

"OpenStudio allows building researchers and software developers to quickly get started through its multiple entry points, including access through C++, Ruby, and C#." (www.openstudio.nrel.gov)

This program makes it possible to work in a friendly interface that combines the geometry from the SketchUp Plugin and also runs simulations from EnergyPlus.

Defining the climates and geographic situations, the sun trajectories and heat are specified. Then the materials used in each surface have to be defined as well. OpenStudio also makes it possible to specify different schedules in each zone depending on its use.

6.3.2. Weather data

Open studio uses weather files from the weather data library of the EnergyPlus Energy Simulation Software in an EnergyPlus format.

"Weather data for more than 2100 locations are now available in EnergyPlus weather format — 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. The weather data are arranged by World Meteorological Organization region and Country." (www.eere.energy.gov)

These data are derived from hourly observations in specific locations done by the US National Weather Service. Illumination and radiation are necessary to simulate buildings. Because of this, starting in 1999, many measurements are taken every 5 minutes or hourly.

"The data include basic location identifiers such as location name, data source, latitude, longitude, time zone, elevation, peak design conditions, holidays, daylight savings period, typical and extreme periods, ground temperatures, period(s) covered by the data and space for descriptive comments. The time step data include dry bulb and dew point temperature, relative humidity, station pressure, solar radiation (global, extraterrestrial, horizontal infrared, direct, and diffuse), illuminance, wind direction and speed, sky cover, and current weather." (www.eere.energy.gov)

Accurately defined weather data is crucial to the performance of an accurate computational model. In the case of the simulation of the Seagram Building, the weather data is particularly important because it analyzes the differences between two different façades with different behaviors and different elements—each with a particular response to weather changes

The Sun trajectory during the year has different inclinations and radiance power. The presence of plants is a big challenge that this Thesis is trying to manage using the information provided by the experimental results from Matthew Kincaid and Michael Gartman's model.

6.3.3. Materials

As explained in previous chapters, The Seagram Building has many special characteristics in terms of material used. These special materials like marble or bronze are placed in the interior walls. What we are trying to model is the difference between the existent façade and a new façade typology. This means that the two compared models have the same partitions and interior walls. That is why the materials used in this computational analysis are the ones defined by default.

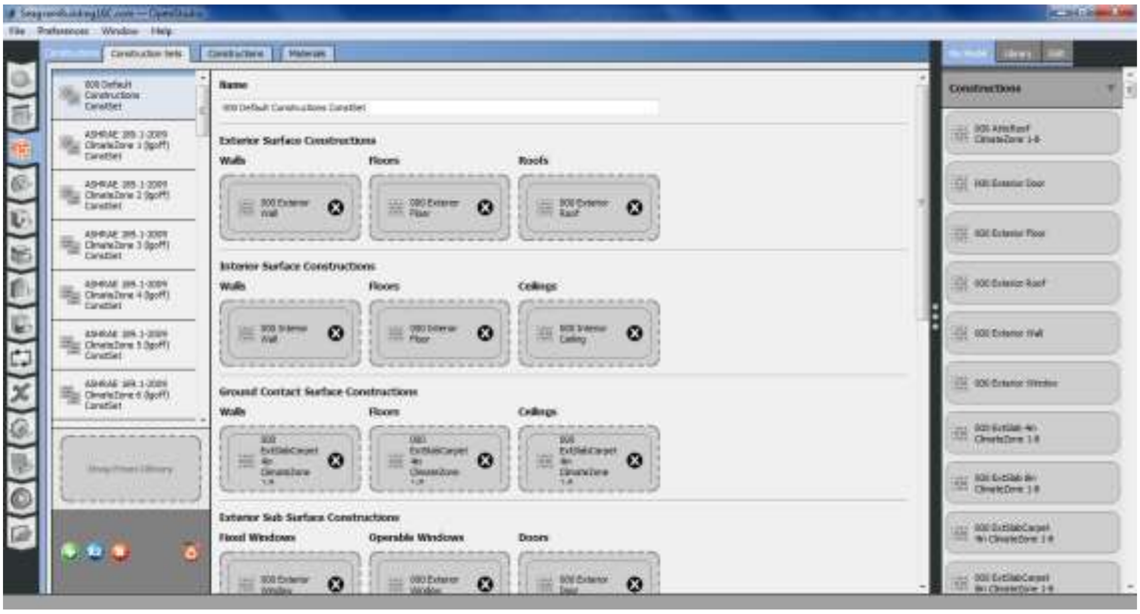

Figure 91. OpenStudio interface. Materials and constructions

On the other hand, the materials used for the main façade are really different between the studied cases. OpenStudio is able to use many different materials from the Building Component Library (BCL).

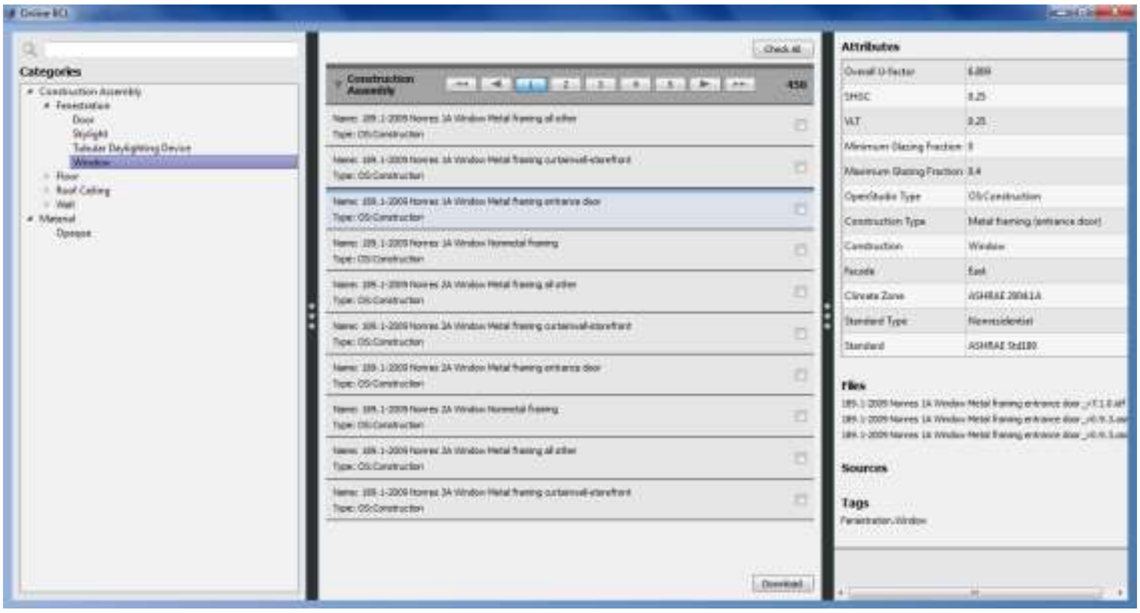

Figure 92. OpenStudio interface. Building Component Library (BCL)

One advantage of using OpenStudio is that it allows users to define special materials or systems by combining library materials.

6.3.4. Schedules

The presence of people has an important repercussion on the energy consumption in a building. As was exposed previously, every single zone has its own functionality, so the energy consumption of a restaurant is not the same as the consumption of a conference room.

Just like the uses are different depending on the spaces within the same building, the schedules are also different. A conference room might be used only once a day while people could be at the cafeteria all day, especially during rush hour. The difference of occupancy and activity in zones affects the energy consumption.

These schedules are defined by the EERE website. EnergyPlus technique manual describes the schedules as:

"This group of objects allows the user to influence scheduling of many items (such as occupancy density, lighting, thermostatic controls, occupancy activity). In addition, schedules are used to control shading element density on the building. […] Schedules are processed by the EnergyPlus Schedule Manager, stored within the Schedule Manager and are accessed through module routines to get the basic values (timestep, hourly, etc.). Values are resolved at the Zone Timestep frequency and carry through any HVAC timesteps." (www.eere.energy.gov)

OpenStudio use these schedules created for each special space type.

Figure 93. OpenStudio interface. Schedules sets

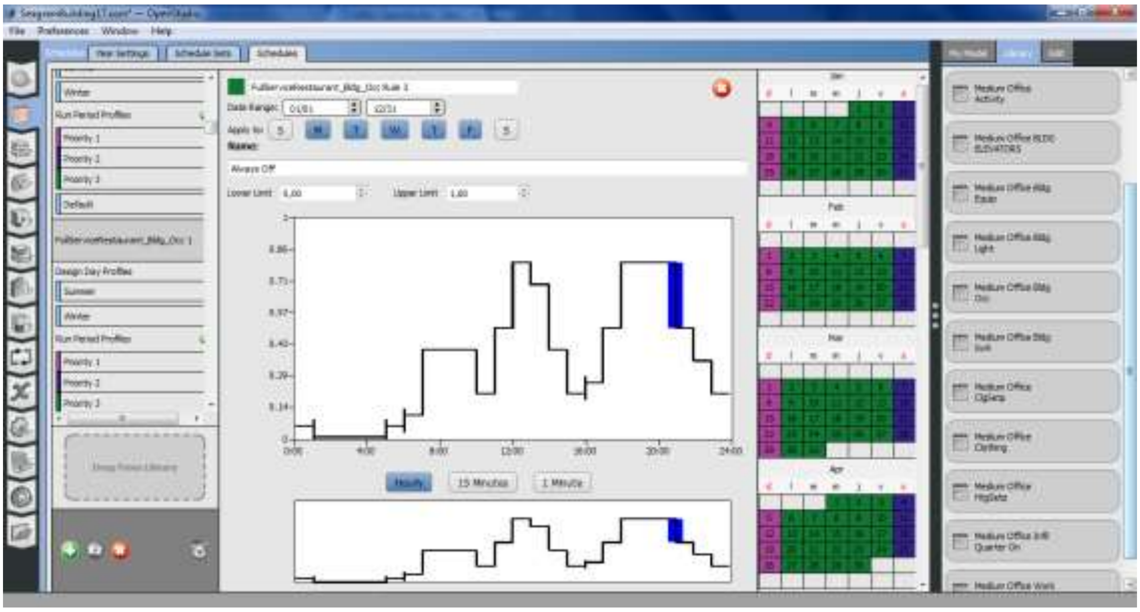

Figure 94. OpenStudio interface. Schedules

6.3.5. HVAC performance

HVAC systems are a Heating, Ventilation and Air Conditioning technology. Installing a HVAC in your building provides an environmental comfort for building users by the regulation of thermal comfort as well as acceptable indoor air quality. HVAC systems reduce air infiltration, provide ventilation, and are able to maintain pressure relationships between spaces.

"HVAC is important in the design of medium to large industrial and office buildings such as skyscrapers, where safe and healthy building conditions are regulated with respect to temperature and humidity, using fresh air from outdoors." (www.wikipedia.org)

As fast as technology has been improving, HVAC systems have adapted new methods of modernization and become more efficient. Nowadays, many different kinds of HVAC systems are available in the market.

Much research has been done to simulate the HVAC system used in the Seagram Building in order to be consistent with reality. US Department of Energy website provides much information of current buildings and also idealistic models. After many unproductive trails to determine which HVAC system is used in the Seagram Building it was decided to use the information provided by US Department of Energy. A large office building built before 1980 has been chosen as a representative model with an HVAC system used then in large office buildings like Seagram Building.

The HVAC system used there is a Variable Air Volume (VAV) system. This simple system could use one supply duct that distributes approximately 13ºC (55ºF) in cooling mode. Because the supply air temperature in this simple VAV system is constant, the rate of air flow must vary to meet the rising and falling heat gains or losses within the thermal zone served.

"There are two primary advantages to VAV systems over constant-volume systems. The fan capacity control, especially with modern electronic variable-speed drives, reduces the energy consumed by fans, which can be a substantial part of the total cooling energy requirements of a building. Dehumidification is greater with VAV systems than it is with constant-volume system, which modulate the discharge air temperature to attain part load cooling capacity."
(www.wikipedia.org)

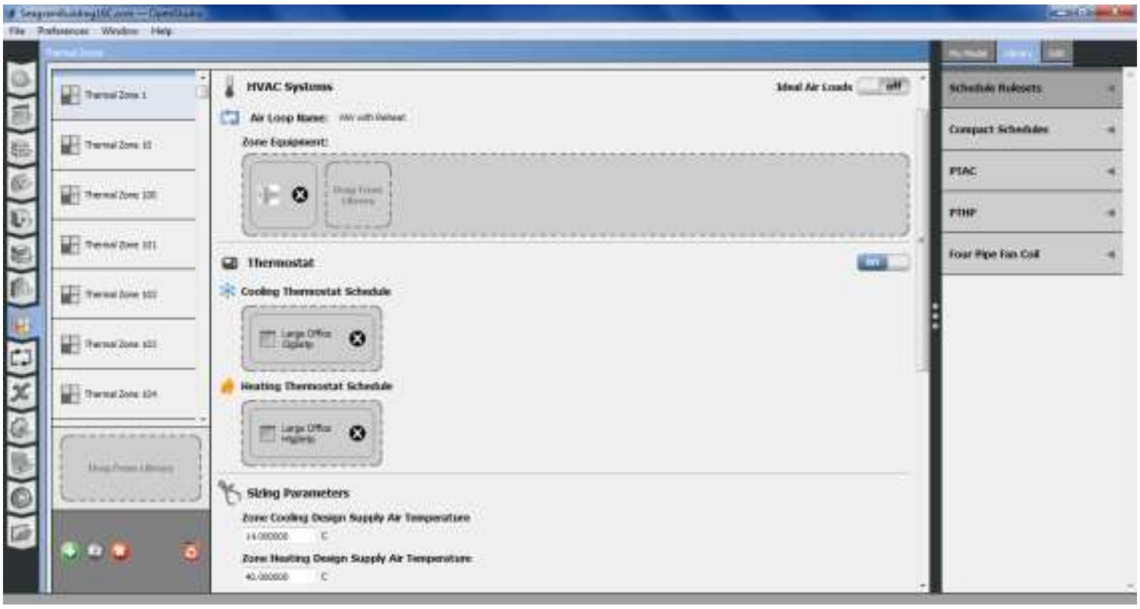

Figure 95. OpenStudio interface. HVAC and Thermostat for each Thermal Zone

6.4. ENERGY SIMULATION PROGRAM

6.4.1. EnergyPlus

"EnergyPlus has its roots in both the BLAST and DOE–2 programs. BLAST (Building Loads Analysis and System Thermodynamics) and DOE–2 were both developed and released in the late 1970s and early 1980s as energy and load simulation tools. Their intended audience is a design engineer or architect that wishes to size appropriate HVAC equipment, develop retrofit studies for life cycling cost analyses, optimize energy performance, etc. Born out of concerns driven by the energy crisis of the early 1970s and recognition that building energy consumption is a major component of the American energy usage statistics, the two programs attempted to solve the same problem from two slightly different perspectives. Both programs had their merits and shortcomings, their supporters and detractors, and solid user bases both nationally and internationally."

"Like its parent programs, EnergyPlus is an energy analysis and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc., EnergyPlus will calculate the heating and cooling loads necessary to maintain thermal control setpoints, conditions throughout an secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would. Many of the simulation characteristics have been inherited from the legacy programs of BLAST and DOE–2."
(Getting Started with EnergyPlus. April 2013)

6.4.2. Running simulations

As it is explained at the introduction, the model designed and defined in SketchUp and OpenStudio is later calculated by EnergyPlus.

OpenStudio is able to launch a simulation using EnergyPlus without opening the software as a user. Running the simulation in the OpenStudio interface means that OpenStudio is using the EnergyPlus software.

All the items modified and designed in OpenStudio are used in the calculations. Running the model studied in our case could take around two hours to process.

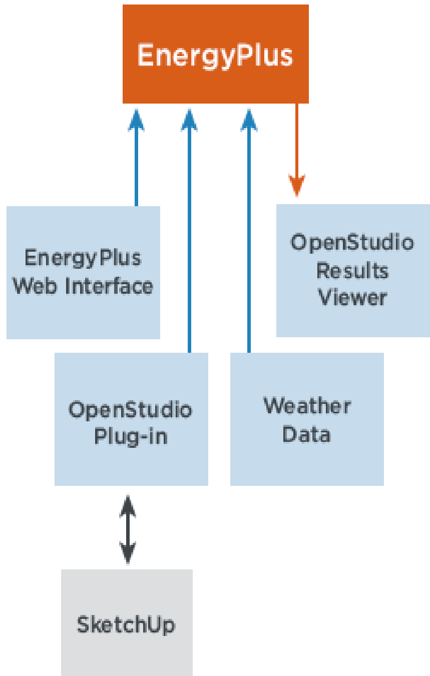

Figure 96. EnergyPlus Add-Ons. (www.eere.energy.gov)

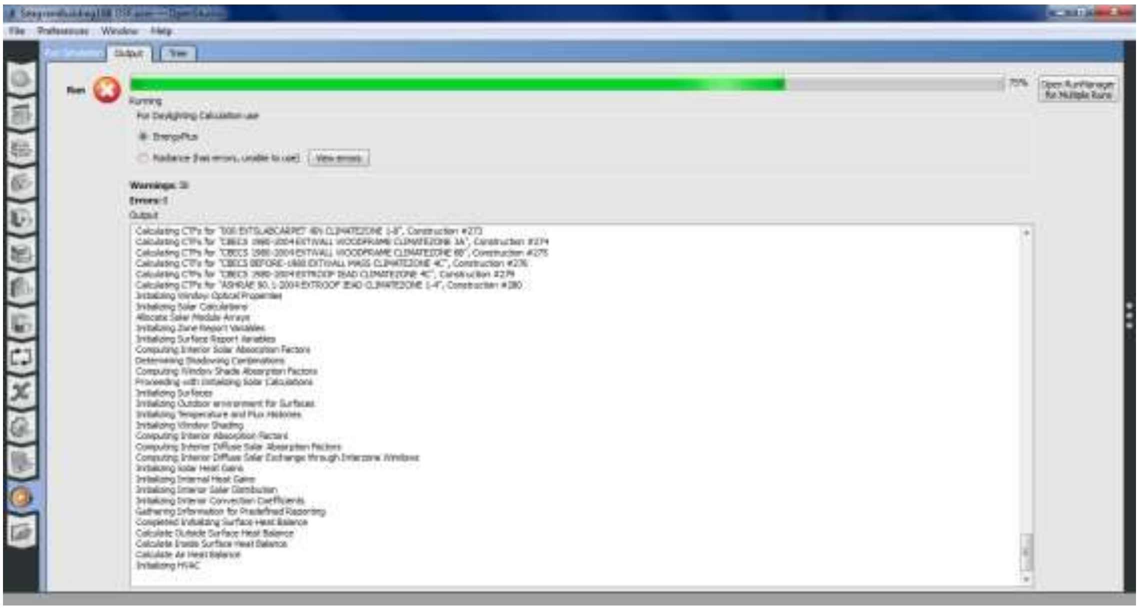

Figure 97. OpenStudio interface. Running simulation

After the simulation in EnergyPlus, much information was gained about all the processes calculated in the model—Electricity consumption, Natural Gas consumption, District Heating consumption, District Cooling consumption,, etc.

To more easily visualize these results, OpenStudio provides the OpenStudio Results Viewer. This software is very useful to find the interesting numbers in the enormous charts that EnergyPlus provides.

6.4.3. Equations used

EnergyPlus is a complex software that is able to calculate heat balances in buildings. Many equations and complex calculation methods are used and considered.

Weather, sun inclination, wind, shadows and many other elements define the variables used by EnergyPlus equations and systems. The window geometries and the materials used are also determinant elements to be considered.

As explained, EnergyPlus is a complex software that uses many equations and equation systems. All of these are well explained in the EnergyPlus manual, *EnergyPlus Engineering Reference: The Reference to EnergyPlus Calculations* (2013)

For further inquiry, follow the link below:

http://apps1.eere.energy.gov/buildings/energyplus/pdfs/engineeringreference.pdf

6.5. CALCULATIONS AND RESULTS

The main purpose of this Thesis is to calculate the improvement resulting from the application of the previously described Double-Skin Façade as a Green Wall using farm plants to create a Vertical Farm Façade.

To compare the benefits between the new façade and the existing one, the first step was calculating a model of the current Seagram Building (with the original façade). The next step was redrafting the building with the new Vertical Farm Façade (VFF). The design of the VFF can vary based on the different classifications of Double- Skin Façades.

This chapter will compare the calculations that correspond with the different models in order to get an overall conclusion about the benefits or disadvantages associated with using the Vertical Farm Façade.

6.5.1. Current Seagram Building calculation

To calculate the current Seagram Building energy balance, the previously detailed modeling process (with the different software) was used.

The materials used are the ones given by default from the information provided by US Department of Energy

The shading coefficient is an approximation of the shadows projected by the existent steel beams on the Seagram Building façade.

6.5.1.1. Model characteristics:

- Total surface: 65,000m^2
- Shading coefficient: 0,2
- Window material: Default
- Weather: Central Park. New York
- Calendar simulation: Full year
- Timesteps: 1 hour

6.5.1.2. Results

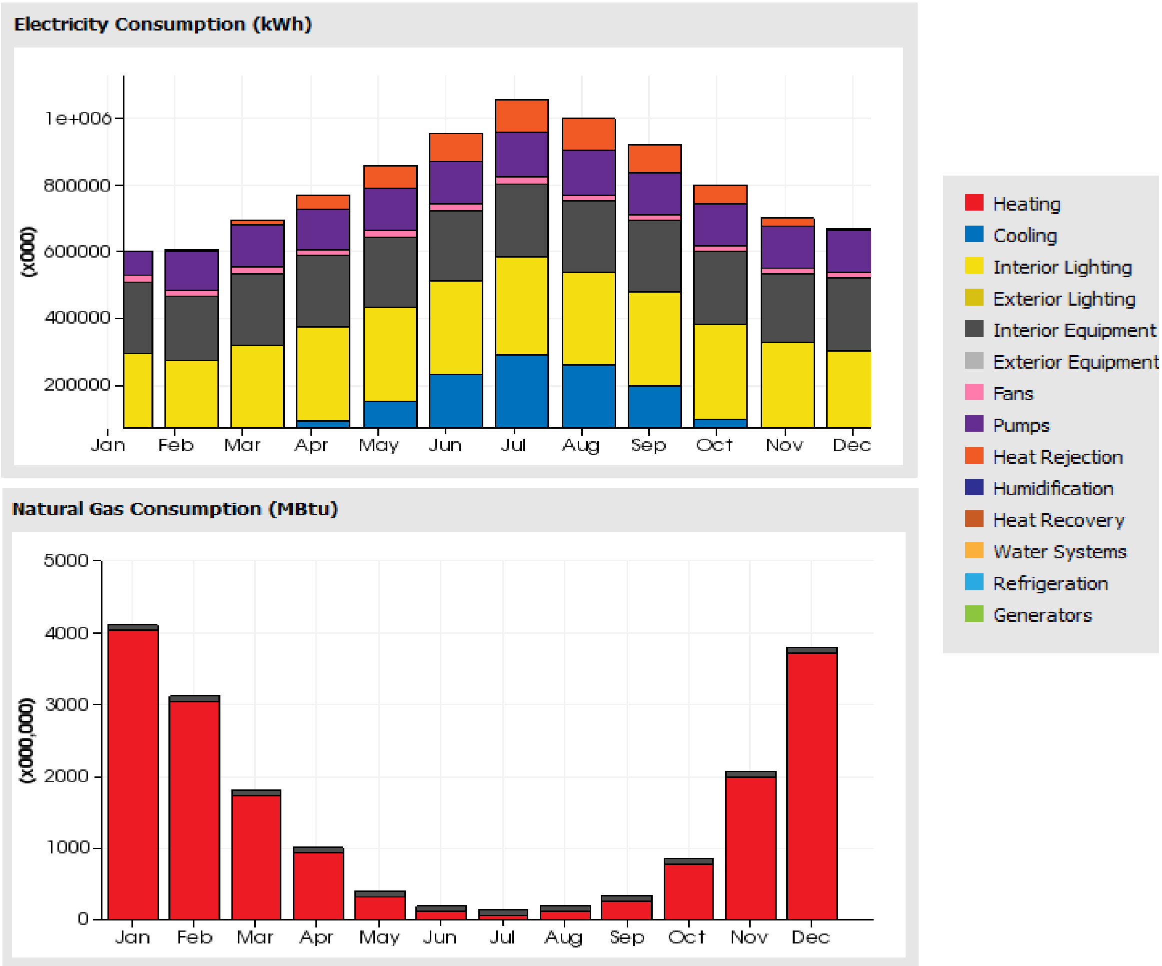

Figure 98. Electricity and Natural Gas consumption diagram of the current Seagram Building

Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	3555	1.08e+04	3.289e+04	8.084e+04	1.509e+05	2.281e+05	2.863e+05	2.587e+05	1.963e+05	9.288e+04	5.228e+04	4335	1.408e+06
Interior Lighting	2.885e+05	2.603e+05	2.857e+05	2.834e+05	2.763e+05	2.834e+05	2.95e+05	2.792e+05	2.834e+05	2.885e+05	2.741e+05	2.95e+05	3.396e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.188e+05	1.957e+05	2.158e+05	2.118e+05	2.128e+05	2.118e+05	2.198e+05	2.128e+05	2.118e+05	2.188e+05	2.079e+05	2.198e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.78e+04	1.596e+04	1.746e+04	1.754e+04	1.852e+04	1.898e+04	2.092e+04	1.942e+04	1.79e+04	1.755e+04	1.694e+04	1.77e+04	2.163e+05
Pumps	7.394e+04	1.117e+05	1.268e+05	1.244e+05	1.302e+05	1.289e+05	1.363e+05	1.342e+05	1.274e+05	1.283e+05	1.238e+05	1.276e+05	1.478e+06
Heat Rejection	1133	4029	1.524e+04	4.228e+04	6.621e+04	8.11e+04	9.842e+04	9.318e+04	8.543e+04	5.625e+04	2.542e+04	1233	5.746e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	6.015e+05	6.83e+05	6.94e+05	7.782e+05	8.577e+05	9.544e+05	1.057e+06	9.994e+05	9.221e+05	8.081e+05	7.005e+05	6.658e+05	9.625e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4024	3036	1732	928.7	315.3	117.5	66.26	120.6	263.8	772.4	1987	3719	1.709e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4102	3109	1809	1004	393.3	192.8	144.1	198.4	339.1	850.2	2062	3797	1.8e+04

Figure 99. Electricity and Natural Gas consumption chart of the current Seagram Building

6.5.2. The corridor DSF Seagram Building calculation

To calculate the current Seagram Building energy balance, the previously detailed modeling process was used. In this case, a Double-Skin Façade is modeled to recreate the Corridor type of DSF. Every single story has its own cavity equal to the width of the whole façade.

The materials used are the ones given by default from the information provided by US Department of Energy

The shading coefficient is an approximation of the shadows projected by pipes and also the plants that grow on them. This information is provided by the study realized by Matthew Kincaid, Michael Gartman.

The following picture shows the Corridor DSF as well as the shading element situated between the two glasses.

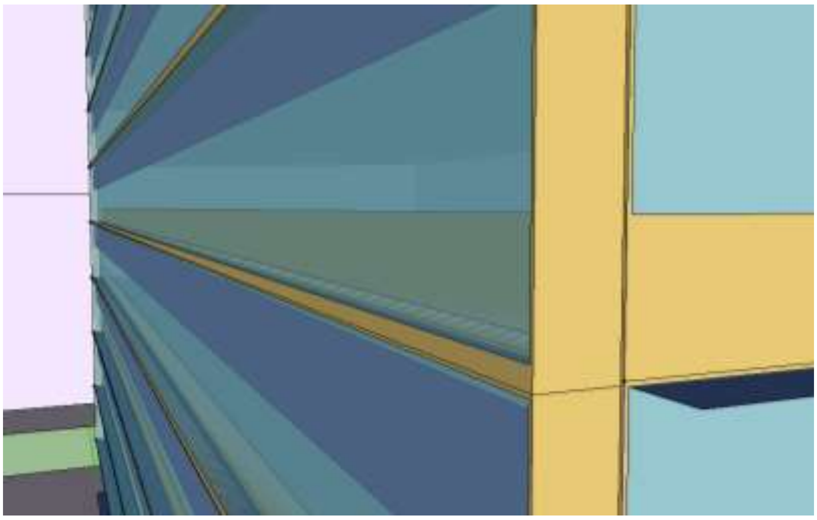

Figure 100. The corridor DSF

6.5.2.1. Model characteristics:

- Total surface: 65,000m^2
- Shading coefficient: 0,35
- Window material: Double-Skin window with full glass on the exterior and the existent façade on the inside. Default glass.
- DSF type: The corridor (one cavity for each story)
- Weather: Central Park. New York
- Calendar simulation: Full year
- Timesteps: 1 hour

6.5.2.2. Results

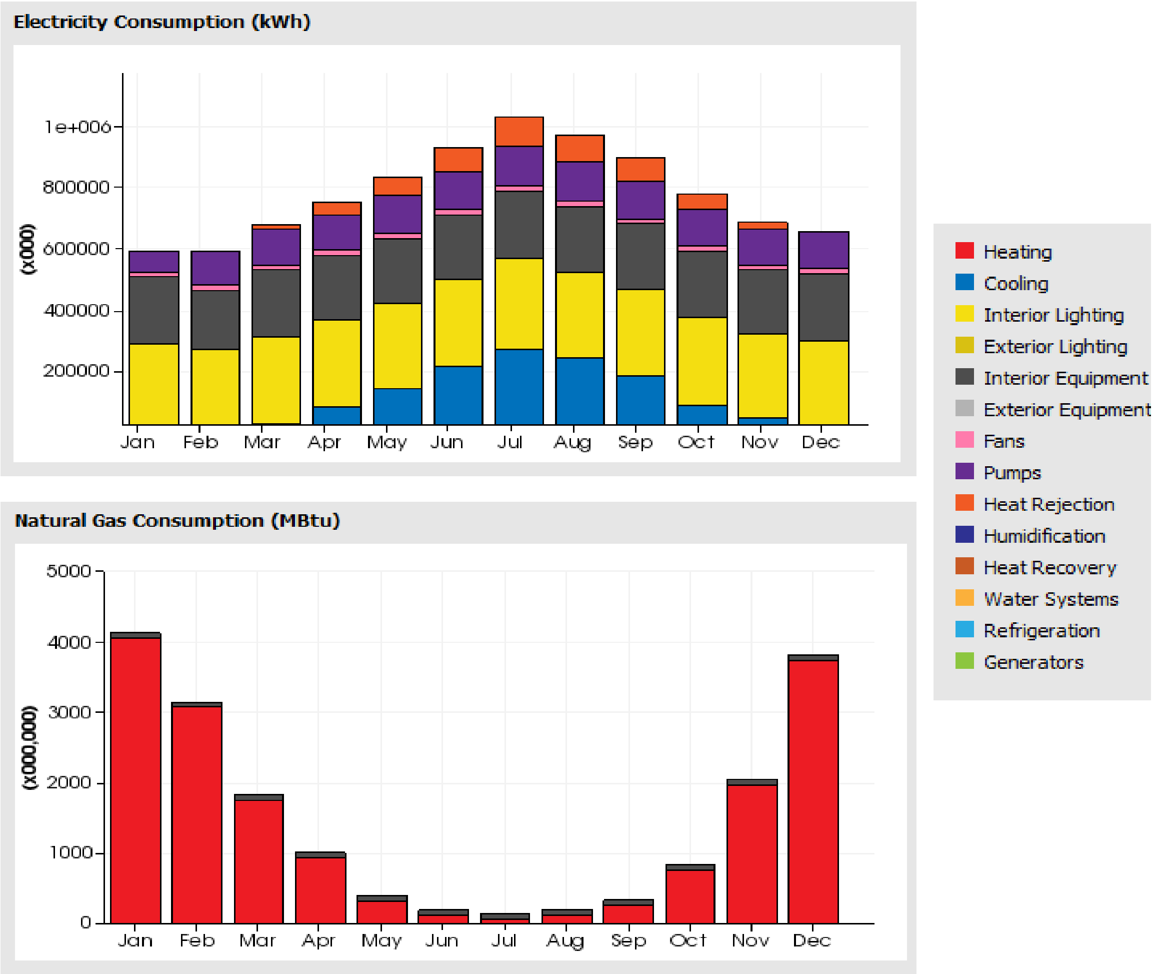

Figure 101. Electricity and Natural Gas consumption diagram of the Corridor DSF Seagram Building

Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2255	8360	2.776e+04	8.279e+04	1.403e+05	2.156e+05	2.719e+05	2.452e+05	1.855e+05	8.962e+04	4.743e+04	2658	1.315e+06
Interior Lighting	2.885e+05	2.403e+05	2.817e+05	2.834e+05	2.702e+05	2.854e+05	2.95e+05	2.792e+05	2.834e+05	2.88e+05	2.741e+05	2.95e+05	3.396e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.166e+05	1.957e+05	2.108e+05	2.108e+05	2.128e+05	2.116e+05	2.196e+05	2.128e+05	2.116e+05	2.166e+05	2.079e+05	2.196e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.69e+04	1.515e+04	1.659e+04	1.67e+04	1.768e+04	1.826e+04	2.022e+04	1.873e+04	1.721e+04	1.669e+04	1.607e+04	1.68e+04	2.07e+05
Pumps	6.801e+04	1.093e+05	1.196e+05	1.173e+05	1.227e+05	1.217e+05	1.288e+05	1.268e+05	1.203e+05	1.209e+05	1.169e+05	1.209e+05	1.393e+06
Heat Rejection	359.1	3868	1.236e+04	3.875e+04	6.175e+04	7.866e+04	9.326e+04	9.001e+04	8.559e+04	5.214e+04	2.353e+04	1028	5.373e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5.926e+05	5.928e+05	6.788e+05	7.506e+05	8.344e+05	9.293e+05	1.029e+06	9.727e+05	8.987e+05	7.805e+05	6.859e+05	6.56e+05	9.401e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4046	3069	1745	932.3	317.2	115.1	62.22	115	252.1	752.2	1973	3737	1.712e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.6	70.27	77.6	75.29	77.6	75.29	77.6	77.6	75.29	77.6	75.29	77.6	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4126	3140	1823	1008	395	190.4	140	192.8	327.4	830	2049	3815	1.803e+04

Figure 102. Electricity and Natural Gas consumption chart of the Corridor DSF Seagram Building

6.5.3. Multi-Story DSF Seagram Building calculation

To calculate the current Seagram Building energy balance, the previously detailed modeling process (with the different software) was used. In this case a Double-Skin Façade is modeled to recreate the Multi-Story type of DSF. This means that several stories are connected by the same cavity. In this case the Multi-Story DSF is simulated by using a five-story cavity.

The materials used are the ones given by default from the information provided by US Department of Energy

The shading coefficient is an approximation of the shadows projected by pipes and also the plants that grow on them. This information is provided by the study realized by Matthew Kincaid, Michael Gartman.

The following picture shows the Multi-Story DSF as well as the shading element situated between the two glasses

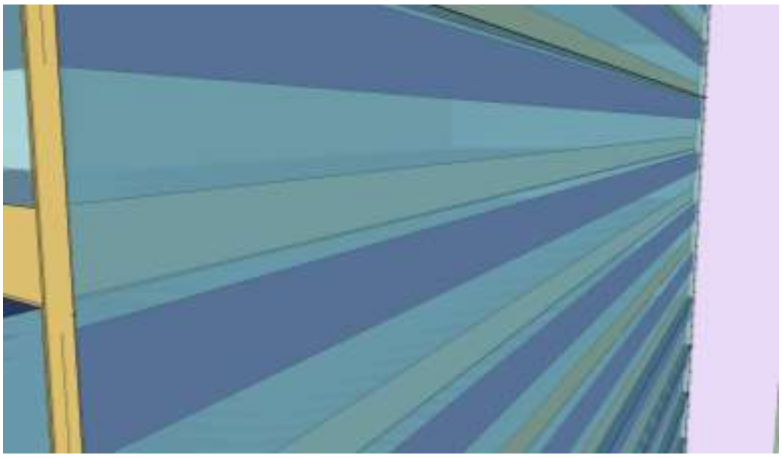

Figure 103. Multi-Storey DSF

6.5.3.1. Model characteristics:

- Total surface: 65,000m^2
- Shading coefficient: 0,35
- Window material: Double-Skin window with full glass on the exterior and the existent façade on the inside. Default glass.
- DSF type: The Multi-Story (one cavity for each five story)
- Weather: Central Park. New York
- Calendar simulation: Full year
- Timesteps: 1 hour

6.5.3.2. Results

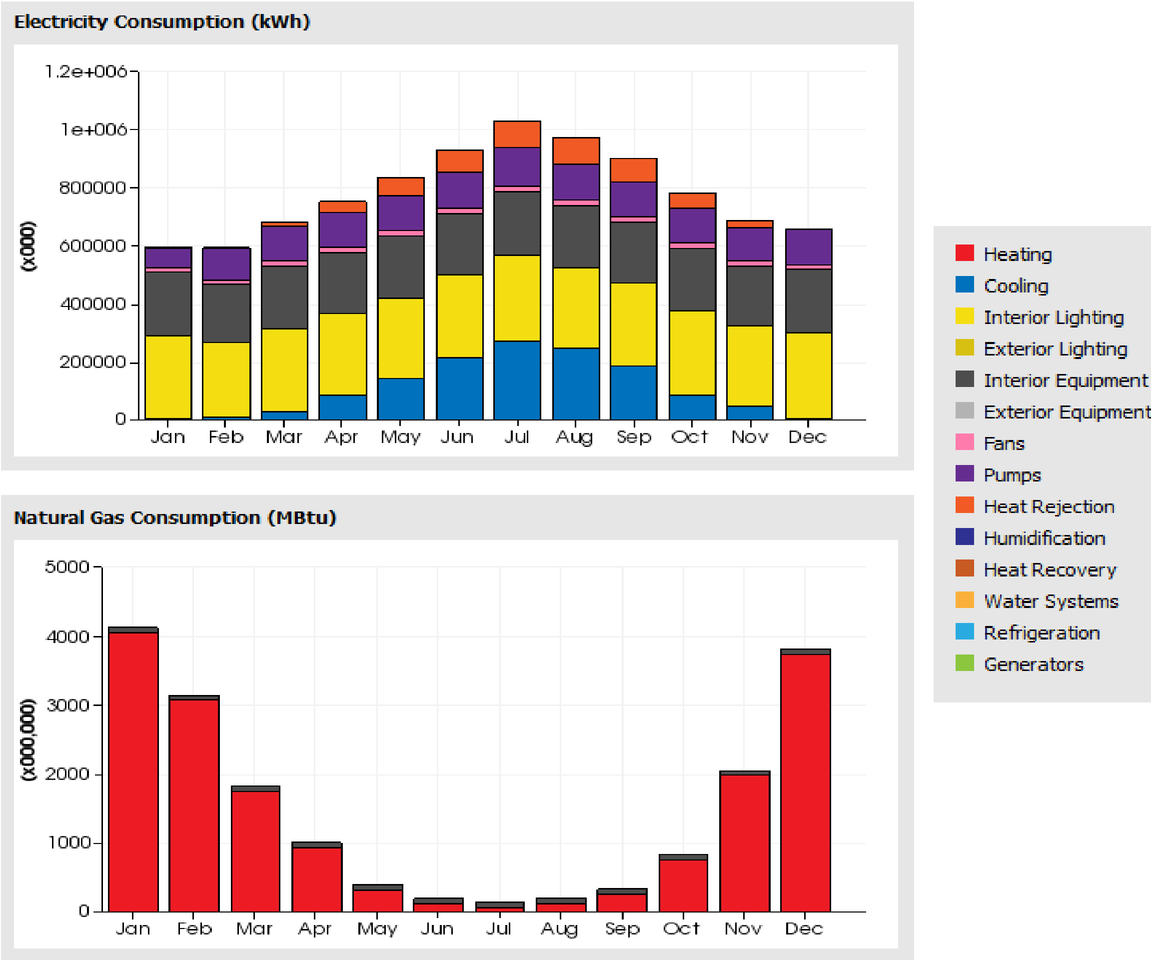

Figure 104. Electricity and Natural Gas consumption diagram of Multi-Story DSF Seagram Building

Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2208	8431	2.791e+04	6.304e+04	1.406e+05	2.119e+05	2.723e+05	2.496e+05	1.858e+05	8.384e+04	4.757e+04	2696	1.218e+06
Interior Lighting	2.865e+05	2.603e+05	2.857e+05	2.824e+05	2.792e+05	2.834e+05	2.95e+05	2.763e+05	2.834e+05	2.865e+05	2.745e+05	2.95e+05	3.366e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.166e+05	1.957e+05	2.158e+05	2.116e+05	2.128e+05	2.116e+05	2.166e+05	2.128e+05	2.116e+05	2.166e+05	2.079e+05	2.166e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.693e+04	1.518e+04	1.662e+04	1.675e+04	1.773e+04	1.828e+04	2.024e+04	1.879e+04	1.725e+04	1.671e+04	1.61e+04	1.682e+04	2.075e+05
Pumps	6.825e+04	1.005e+05	1.186e+05	1.175e+05	1.229e+05	1.219e+05	1.29e+05	1.27e+05	1.205e+05	1.211e+05	1.171e+05	1.211e+05	1.398e+06
Heat Rejection	384.1	3874	1.341e+04	3.885e+04	6.185e+04	7.86e+04	9.34e+04	9.02e+04	8.075e+04	5.227e+04	2.358e+04	1030	5.384e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5.829e+05	5.83e+05	6.792e+05	7.512e+05	8.351e+05	9.3e+05	1.03e+06	9.735e+05	8.993e+05	7.81e+05	6.863e+05	6.583e+05	9.407e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4047	3069	1742	932.4	317.1	115.2	62.33	115.2	252.4	752.8	1974	3737	1.712e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4125	3139	1820	1008	394.9	190.4	140.1	193	327.7	830.6	2049	3815	1.883e+04

Figure 105. Electricity and Natural Gas consumption chart of Multi-Story DSF Seagram Building

6.5.4. Shaft Box DSF Seagram Building calculation

To calculate the current Seagram Building energy balance, the previously detailed modeling process (with the different software) was used. In this case a Double-Skin Façade is modeled to recreate the Shaft Box type of DSF. This means that every single window in the Seagram Building has a cavity.

The materials used are the ones given by default from the information provided by US Department of Energy

The shading coefficient is an approximation of the shadows projected by pipes and also the plants that grow on them. This information is provided by the study realized by Matthew Kincaid, Michael Gartman.

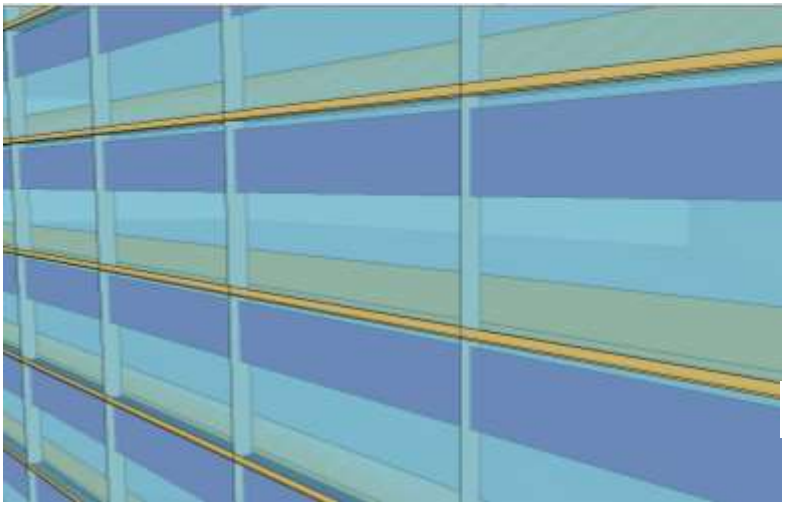

Figure 106. Shaft Box DSF

6.5.4.1. Model characteristics:

- Total surface: 65,000m^2
- Shading coefficient: 0,35
- Window material: Double-Skin window with full glass on the exterior and the existent façade on the inside. Default glass.
- DSF type: The corridor (one cavity for each story)
- Weather: Central Park. New York
- Calendar simulation: Full year
- Timesteps: 1 hour

6.5.4.2. Results

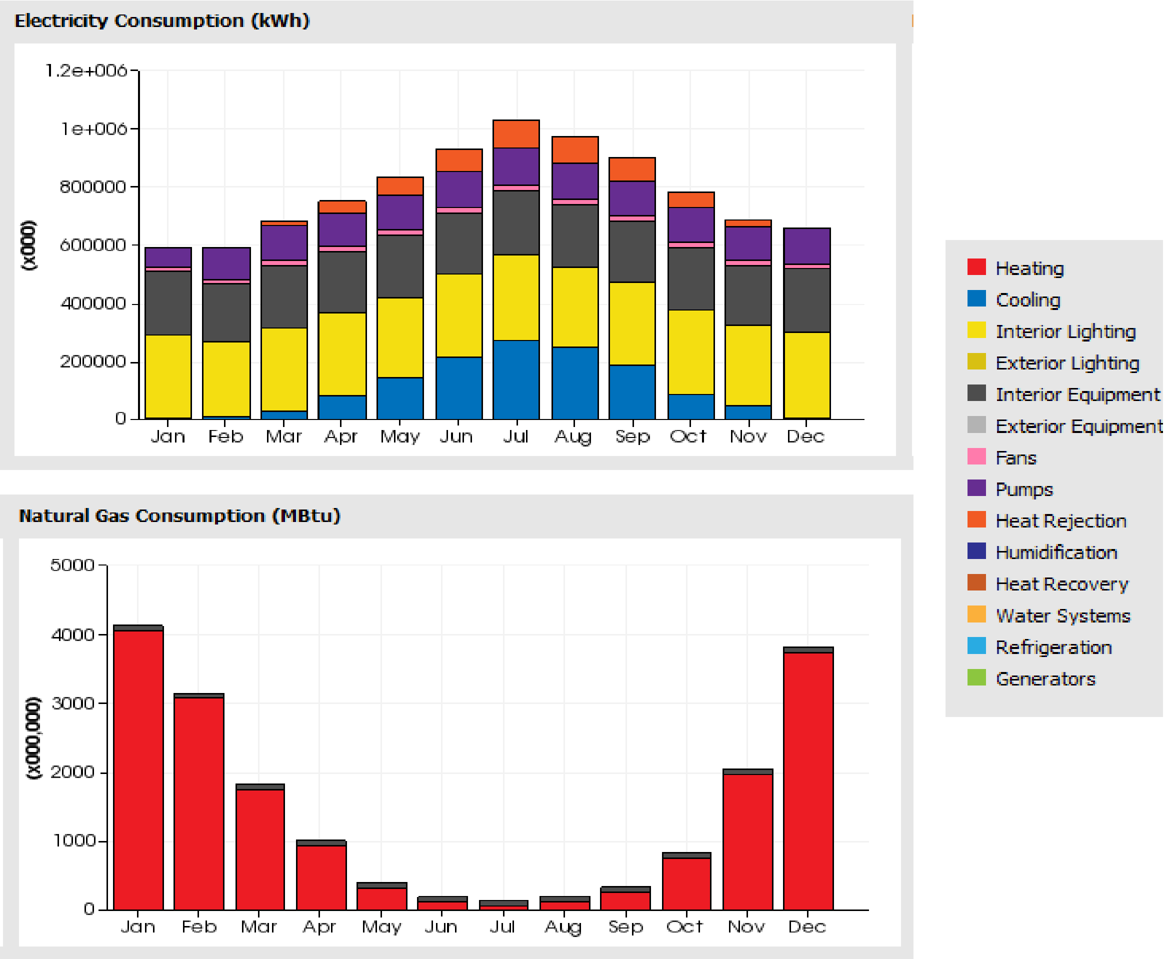

Figure 107. Electricity and Natural Gas consumption diagram of Shaft Box DSF Seagram Building

Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2254	8360	2.774e+04	8.279e+04	1.403e+05	2.156e+05	2.719e+05	2.452e+05	1.855e+05	8.562e+04	4.743e+04	2658	1.315e+06
Interior Lighting	2.883e+05	2.603e+05	2.857e+05	2.834e+05	2.752e+05	2.834e+05	2.93e+05	2.792e+05	2.834e+05	2.883e+05	2.792e+05	2.93e+05	3.396e+06
Exterior Lighting	–	–	–	–	–	–	–	–	–	–	–	–	–
Interior Equipment	2.366e+05	1.957e+05	2.158e+05	2.118e+05	2.128e+05	2.118e+05	2.196e+05	2.138e+05	2.118e+05	2.166e+05	2.079e+05	2.196e+05	2.552e+06
Exterior Equipment	–	–	–	–	–	–	–	–	–	–	–	–	–
Fans	1.69e+04	1.515e+04	1.659e+04	1.67e+04	1.788e+04	1.828e+04	2.022e+04	1.872e+04	1.721e+04	1.669e+04	1.607e+04	1.68e+04	2.07e+05
Pumps	6.803e+04	1.093e+05	1.196e+05	1.173e+05	1.227e+05	1.217e+05	1.288e+05	1.268e+05	1.203e+05	1.209e+05	1.169e+05	1.209e+05	1.383e+06
Heat Rejection	109	3853	1.336e+04	3.875e+04	6.175e+04	7.868e+04	9.326e+04	8.303e+04	6.056e+04	5.214e+04	2.353e+04	1026	5.375e+05
Humidification	–	–	–	–	–	–	–	–	–	–	–	–	–
Heat Recovery	–	–	–	–	–	–	–	–	–	–	–	–	–
Water Systems	–	–	–	–	–	–	–	–	–	–	–	–	–
Refrigeration	–	–	–	–	–	–	–	–	–	–	–	–	–
Generators	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	5.926e+05	5.927e+05	6.788e+05	7.506e+05	8.344e+05	9.293e+05	1.029e+06	9.727e+05	8.987e+05	7.805e+05	6.859e+05	6.56e+05	9.401e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4048	3069	1743	932.5	317.2	115.1	62.22	115	252.1	752.2	1973	3737	1.712e+04
Cooling	–	–	–	–	–	–	–	–	–	–	–	–	–
Interior Lighting	–	–	–	–	–	–	–	–	–	–	–	–	–
Exterior Lighting	–	–	–	–	–	–	–	–	–	–	–	–	–
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	–	–	–	–	–	–	–	–	–	–	–	–	–
Fans	–	–	–	–	–	–	–	–	–	–	–	–	–
Pumps	–	–	–	–	–	–	–	–	–	–	–	–	–
Heat Rejection	–	–	–	–	–	–	–	–	–	–	–	–	–
Humidification	–	–	–	–	–	–	–	–	–	–	–	–	–
Heat Recovery	–	–	–	–	–	–	–	–	–	–	–	–	–
Water Systems	–	–	–	–	–	–	–	–	–	–	–	–	–
Refrigeration	–	–	–	–	–	–	–	–	–	–	–	–	–
Generators	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	4126	3140	1821	1008	395	190.4	140	192.8	327.4	830	2049	3815	1.803e+04

Figure 108- Electricity and Natural Gas consumption chart of Shaft Box DSF Seagram Building

6.6. RESULTS ANALYSYS

The results obtained by modeling and computing the Seagram Building using different assumptions and geometries in its main façade are analyzed in this section. Many of the most important results and conclusions are commented and argued here in order to determine the validity of the results obtained.

All the results obtained and provided by OpenStudio Results Viewer are included in the Computational Annex at the end of this document.

Another important point of this section is a series of directions and suggestions to reach more accurate models and results in later studies.

6.6.1. Discussion

The first result that needs to be verified is the annual electrical energy consumption for the Seagram Building. The benefits and savings derived by the influence of the Vertical Farm Façade will be compared with this annual consumption.

The annual electricity consumption of the current Seagram Building is $9.625 \cdot 10^6$ kWh. To validate this result obtained from the computational analysis for the current Seagram Building, the Empire State Building in New York is used as a reference.

A recent study made by the Rocky Mountain Institute, Jones Lang LaSalle, Johnson Controls Inc. and Clinton Climate Initiative provide an estimation of the annual energy consumption of the Empire State Building. This famous New York's skyscraper icon costs in terms of energy $11.4 million per year. This means an annual consumption around $55 \cdot 10^6$ kWh. (considering the average cost of the kWh in the March of 2013. (0.18$/kWh)).

Considering the 50,000 m^2 of the Seagram Building and the 200,000 m^2 of the Empire State Building, the relation is around 1:4 while the consumption relation is around 1:5,5. The difference of these two relations is comprehensive because the energy consumption also depends on some other variables such as the materials used, the building's orientation, the HVAC system, etc. The purpose of this comparison is only to get a reference point with which to compare the results obtained knowing that the consumption of the Seagram Building calculated in this Thesis is realistic.

Once the results of the overall consumption of the Seagram Building have been validated, the difference tested between the Double-Skin Façades can be analyzed and compared to its current energy consumption.

As it is shown in previous sections the three Double-Skin Façades tested have similar annual consumptions:

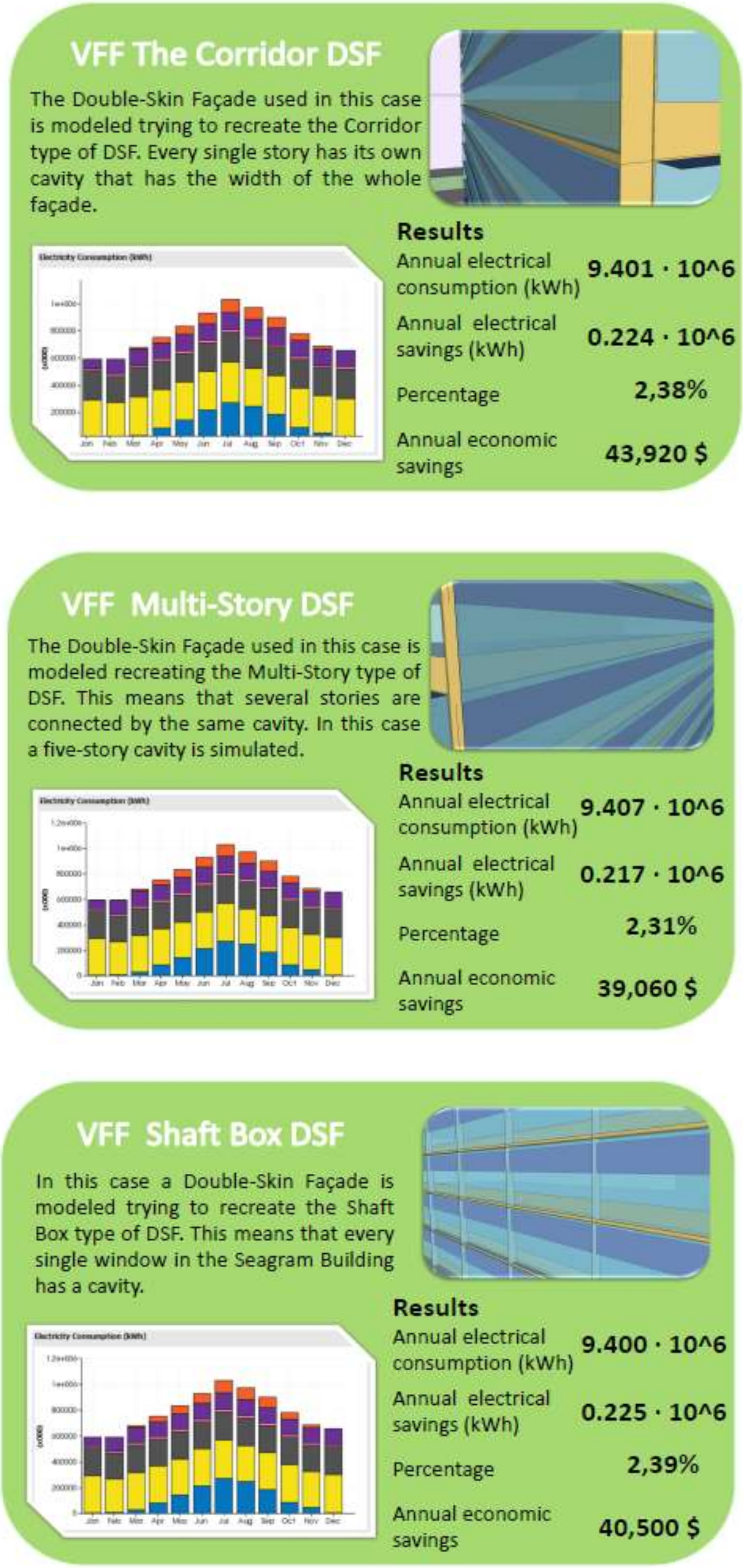

Figure 109. Main results obtained by calculating three different Double-Skin Façades

The resulting energetic benefit is at first somewhat underwhelming. In each of the three cases, the conservation is around the 2.35% —which may not seem like much.

Some reasoning behind these results:

a) Orientation
The main façade of the Seagram Building is oriented to face northwest. The heat fluxes in this façade are less important than the ones facing south. So as a consequence, the benefits associated with heat losses and gains resulting from the use of a Double Skin Façade are less dramatic.

b) Total Building Surface
The main Façade only represents the 20% of the total building surface so the benefits of improving this façade are not as substantial as would be an improvement on all of the structure's façades. Changing the totality of the Seagram Building's façades would increase the savings associated with energy conservation 4 times.

c) Shading devices
The pipes installed to harbor the plants create shadows. As a consequence of these shadows more artificial lighting is needed to keep the luminance level required for the office workspace. This means more energy is needed which counteracts the benefits of the Double- Skin Façade.

d) Surrounding buildings
The Seagram Building was raised by the end of the 1950s and was one of the tallest buildings in Manhattan. Today, many other buildings as tall as (or taller than) The Seagram Building are placed around it. The shadows projected on the Seagram Building are significant so the difference between the current Seagram Building and the building with a Double-Skin Façade may be less important because of the small amount of solar radiation on the Building façades.

e) Materials used
The materials used in all of the Double-Skin Façade models are the basic ones used by default in the Current Seagram Building model. These materials, specifically the glass, do not have any particular characteristics in terms of thermal insulation. The models calculated in this Thesis represent the least advantageous circumstances in order to indicate whether or not a DSF system would be effective without optimized variables like higher quality materials.

Comparing the three kinds of Double-Skin Façades modeled in this Thesis make it possible to analyze different values obtained in each calculation.

As a first impression, the Multi-Story Double-Skin Façade is the worst option. Analyzing the annual consumption month by month, the Multi-Story DSF has more energy consumption during the summer than the other two options. This could be because of the reduction of the shading devices due to the fusion of the cavity in five stories. Also because of the different schedules and activities of the five stories that share the cavity. This means that maybe the activity in one story has stopped while another is still working—which means having to keep warm or cold the full five story cavity only for one story's use.

Comparing the two other Double-Skin Façades calculated (The Corridor DSF and Shaft Box DSF) the results obtained are closely similar. Between the Corridor and Shaft Box there's a small difference during the winter. The Corridor DSF saves more energy in the cold months.

These differences are not conclusive enough to indicate that The Corridor DSF is better than Shaft Box DSF. But considering the higher costs of construction and maintenance of the Shaft Box system, the difference between these two Double-Skin Façades is noticeable.

6.6.2. Conclusions

The different Double-Skin Façades tested in this Thesis are an initial overall calculation of the expected behavior of a Vertical Farm Façade implementation.

This first approximation offers some valuable results. Even with suboptimal circumstances (using default window glass), the energy savings from implantation would still be substantial.

The use of a cavity and adding more shadows from the plants would still be energetically & financially beneficial despite the points explained in previous sections. A reduction of 2.35% of the electricity consumption of the Seagram Building would represent insurance worth half a million dollars in ten years.

Using better materials and more accurate calculations considering the effect of the evapotranspiration of the plants would represent a bigger proportion of this savings. Adding to this the possible use of the plants grown in the Vertical Farm to supply the local restaurants or office workers, these benefits would continually increase.

To conclude, the best Double-Skin Façade is probably The Corridor (one cavity per each story). This type of DSF saves more energy than the other two models tested and also has cheaper set-up and maintenance than the Shaft Box system.

6.6.3. Recommendations for further studies

The computational model calculated in this Thesis would be more complex but more realistic if Double Skin Façade Openings could be modeled. The openings in the DSF create different ventilations that could further improve the behavior of the façade, and as a consequence of that, would result in higher energy savings.

Determining the optimal area and location of these openings would be also interesting in order to best understand the most efficient combination is.

The Double-Skin Façades tested in this Thesis have not a HVAC system and a thermostat incorporated what means that they work as a simple Double Skin ones without ventilation and without heating system.

The materials used could be easily improved using new thermal insulation glasses. The hypothetical implementation of the Vertical Farm Façade in any existing building could be done using modern materials in order to be much more energy efficient than the models used in this Thesis. Calculating the energy savings using better materials would also be interesting, accurate, and representative of a more realistic estimation of energy savings.

Analyzing different types of glass for each skin could be also interesting in determining the optimal combination.

As explained in the introduction, John Zhai's team is working on a real model of a Vertical farm Double-Skin Façade. Matthew Kincaid and Michael Gartman are empirically developing and testing this Panel in order to determine the thermal characteristics of this window considering that inside the Double Skin Façade Cavity plants are growing using the hydroponics system.

For further studies, it would be interesting to add the characteristic values of this window to the computational model to get the benefits in terms of energy savings.

Figure 110. Kincaid and Gartman DSF model. Hydroponics system used.

Figure 111. Kincaid and Gartman DSF model. Plants growing on the pipes

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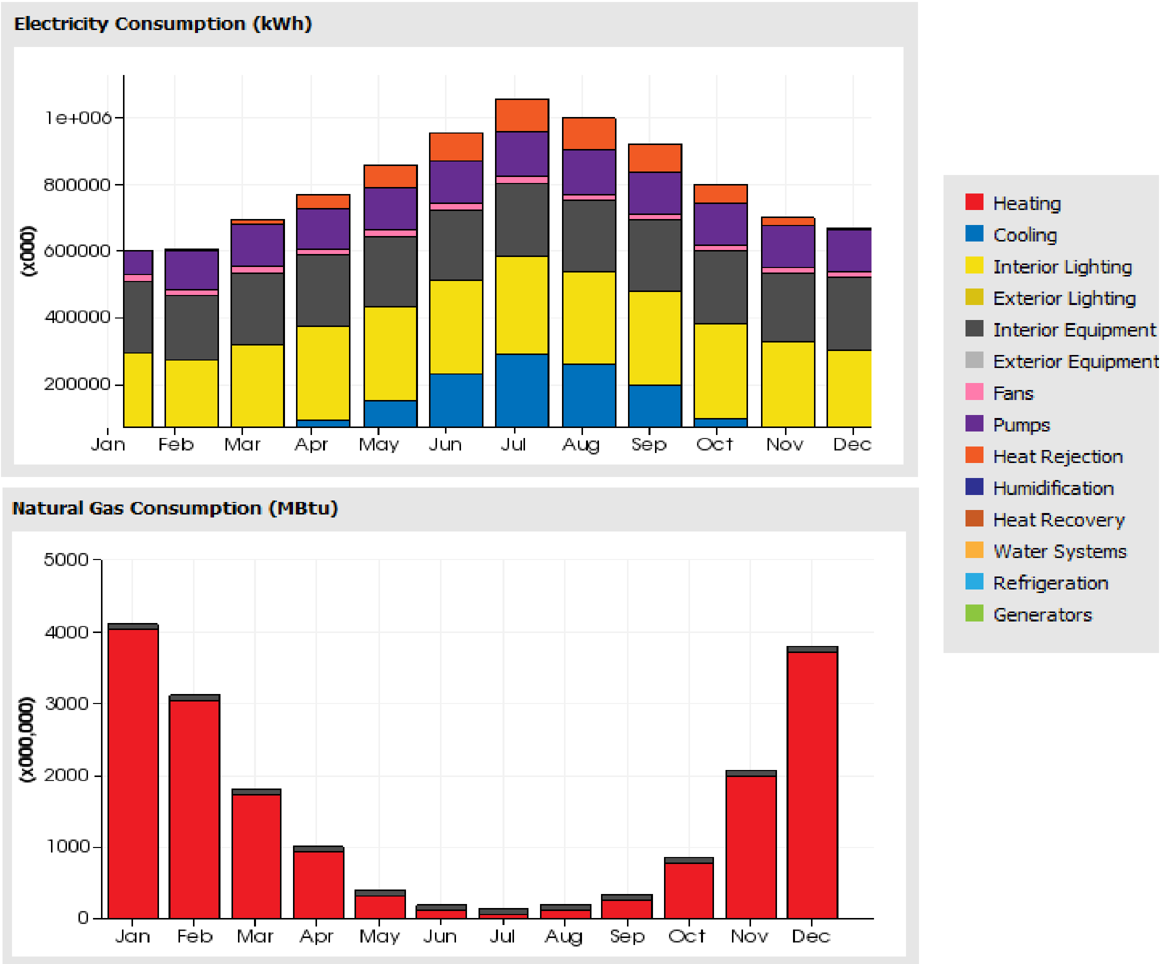
CALCULATION RESULTS ANNEX

TABLE OF CONTENTS

1. CURRENT SEAGRAM BUILDING CALCULATION



Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	3555	1.08e+04	3.289e+04	8.084e+04	1.509e+05	2.281e+05	2.863e+05	2.587e+05	1.963e+05	9.288e+04	5.228e+04	4335	1.403e+06
Interior Lighting	2.885e+05	2.603e+05	2.857e+05	2.834e+05	2.792e+05	2.834e+05	2.95e+05	2.792e+05	2.834e+05	2.885e+05	2.741e+05	2.85e+05	3.396e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.166e+05	1.957e+05	2.158e+05	2.118e+05	2.128e+05	2.118e+05	2.166e+05	2.128e+05	2.118e+05	2.166e+05	2.079e+05	2.158e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.78e+04	1.398e+04	1.746e+04	1.754e+04	1.852e+04	1.898e+04	2.092e+04	1.942e+04	1.79e+04	1.715e+04	1.694e+04	1.77e+04	2.167e+05
Pumps	7.394e+04	1.117e+05	1.268e+05	1.244e+05	1.302e+05	1.289e+05	1.363e+05	1.342e+05	1.274e+05	1.283e+05	1.238e+05	1.276e+05	1.478e+06
Heat Rejection	1133	4829	1.524e+04	4.238e+04	6.621e+04	8.33e+04	9.842e+04	9.318e+04	8.543e+04	5.625e+04	2.542e+04	1233	5.748e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	6.015e+05	6.83e+05	6.94e+05	7.702e+05	8.577e+05	9.544e+05	1.057e+06	9.994e+05	9.221e+05	8.001e+05	7.005e+05	6.658e+05	9.625e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4024	3039	1732	928.7	315.3	117.3	66.26	120.6	263.8	772.4	1987	3719	1.709e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4102	3109	1809	1004	393.3	192.6	144.1	198.4	339.1	850.2	2062	3797	1.8e+04

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 Values gathered over 8760.00 hours**

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	53642.85	834.20	834.20
Net Site Energy	53642.85	834.20	834.20
Total Source Energy	130325.99	2026.70	2026.70
Net Source Energy	130325.99	2026.70	2026.70

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050

Building Area

	Area [m2]
Total Building Area	64304.69
Net Conditioned Building Area	64304.69
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	18025.77	0.00	0.00	0.00	0.00
Cooling	5068.13	0.00	0.00	0.00	0.00	0.00
Interior Lighting	12225.14	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	9187.64	966.50	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	780.19	0.00	0.00	0.00	0.00	0.00
Pumps	5320.34	0.00	0.00	0.00	0.00	0.00
Heat Rejection	2069.13	0.00	0.00	0.00	0.00	34825.00
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	34650.57	18992.27	0.00	0.00	0.00	34825.00

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	18025.77	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	5068.13	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1512.38	0.00	0.00	0.00	0.00	0.00
	Lights	10712.76	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	919.37	966.50	0.00	0.00	0.00	0.00
	ElectricEquipment	8268.27	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	780.19	0.00	0.00	0.00	0.00	0.00
Pumps	General	5320.34	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	2069.13	0.00	0.00	0.00	0.00	34825.00
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	205.86	280.32	0.00	0.00	0.00	0.54
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	538.85	295.35	0.00	0.00	0.00	0.54

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	205.86	280.32	0.00	0.00	0.00	0.54
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	538.85	295.35	0.00	0.00	0.00	0.54

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	34650.57	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	34650.57	100.00
Total On-Site and Utility Electric Sources	34650.57	100.00
Total Electricity End Uses	34650.57	100.00

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	34825.00	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	34825.00	100.00
Total Water End Uses	34825.00	100.00

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Time Heating Setpoint Not Met	0.20
Tolerance for Time Cooling Setpoint Not Met	0.20

Report: **Input Verification and Results Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.23 20:39
RunPeriod	RUN PERIOD 1
Weather File	Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300
Latitude [deg]	41.98
Longitude [deg]	-87.9
Elevation [m]	201.00
Time Zone	-6.0
North Axis Angle [deg]	30.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	1607.62
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 End Uses**

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	16-JUL-15:00	26-JAN-22:00	-	-	-	17-APR-17:00
Heating	0.00	6104705.58	0.00	0.00	0.00	0.00
Cooling	589119.08	0.00	0.00	0.00	0.00	0.00
Interior Lighting	870572.58	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	475299.57	20151.78	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	69805.34	0.00	0.00	0.00	0.00	0.00
Pumps	200127.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	162159.57	0.00	0.00	0.00	0.00	0.01
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2367083.14	6124857.36	0.00	0.00	0.00	0.01

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	6104705.58	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	589119.08	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	42769.69	0.00	0.00	0.00	0.00	0.00
	Lights	827802.89	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	39613.84	20151.78	0.00	0.00	0.00	0.00
	ElectricEquipment	435685.73	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	69805.34	0.00	0.00	0.00	0.00	0.00
Pumps	General	200127.00	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	162159.57	0.00	0.00	0.00	0.00	0.01
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Source Energy End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 Values gathered over 8760.00 hours**

Source Energy End Use Components Summary

	Source Electricity [GJ]	Source Natural Gas [GJ]	Source Other Fuel [GJ]	Source District Cooling [GJ]	Source District Heating [GJ]
Heating	0.00	19539.94	0.00	0.00	0.00
Cooling	16050.76	0.00	0.00	0.00	0.00
Interior Lighting	38717.03	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	29097.25	1047.69	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	2470.87	0.00	0.00	0.00	0.00
Pumps	16849.52	0.00	0.00	0.00	0.00
Heat Rejection	6552.94	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	109738.37	20587.62	0.00	0.00	0.00

Normalized Metrics

Source Energy End Use Components Per Conditioned Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	303.86	0.00	0.00	0.00
Cooling	249.60	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	38.42	0.00	0.00	0.00	0.00
Pumps	262.03	0.00	0.00	0.00	0.00
Heat Rejection	101.90	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1706.54	320.16	0.00	0.00	0.00

Source Energy End Use Components Per Total Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	303.86	0.00	0.00	0.00
Cooling	249.60	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	38.42	0.00	0.00	0.00	0.00
Pumps	262.03	0.00	0.00	0.00	0.00
Heat Rejection	101.90	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1706.54	320.16	0.00	0.00	0.00

Report: **Climatic Data Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS ENTH=>MDB	31.40	10.50	79200.00	Enthalpy [J/kg]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS WB=>MDB	31.20	10.50	25.50	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG 99.6% CONDNS DB	-20.00	0.00	-20.00	Wetbulb [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN HUM_N 99.6% CONDNS DP=>MCDB	-19.20	0.00	-25.70	Dewpoint [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DP=>MDB	28.90	10.50	23.80	Dewpoint [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG WIND 99.6% CONDNS WS=>MCDB	-3.50	0.00	-3.50	Wetbulb [C]	12.40	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DB=>MWB	33.30	10.50	23.70	Wetbulb [C]	5.20	230.00

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
VAV WITH REHEAT	319.05	319.05	136.69	136.69

Report: **Object Count Summary**

For: **Entire Facility**

Timestamp: **2013-05-23 20:55:44 Surfaces by Class**

	Total	Outdoors
Wall	800	320
Floor	200	5
Roof	200	5
Internal Mass	0	0
Building Detached Shading	74	74
Fixed Detached Shading	0	0
Window	320	320
Door	0	0
Glass Door	0	0
Shading	650	650
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

HVAC

	Count
HVAC Air Loops	1
Conditioned Zones	200
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Input Fields

	Count
IDF Objects	5689
Defaulted Fields	5222
Fields with Defaults	14791
Autosized Fields	1040
Autosizable Fields	1267
Autocalculated Fields	4410
Autocalculatable Fields	4410

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY**

For: **Meter**

Timestamp: **2013-05-23 20:55:44**

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY [J]	PUMPS:ELECTRICITY [J]	HEATING:ELECTRICITY [J]	COOLING:ELECTRICITY [J]	HEATREJECTION:ELECTRICITY [J]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	0.103863E+13	0.00	0.779619E+12	0.00	0.640652E+11	0.266195E+12	0.00	0.127979E+11	0.407731E+10	0.00	0.00	0.00	0.00
February	0.937195E+12	0.00	0.704536E+12	0.00	0.574688E+11	0.418354E+12	0.00	0.388699E+11	0.163033E+11	0.00	0.00	0.00	0.00
March	0.102845E+13	0.00	0.776924E+12	0.00	0.629785E+11	0.456654E+12	0.00	0.118417E+12	0.548744E+11	0.00	0.00	0.00	0.00
April	0.102042E+13	0.00	0.761863E+12	0.00	0.631447E+11	0.447786E+12	0.00	0.327040E+12	0.152573E+12	0.00	0.00	0.00	0.00
May	0.100504E+13	0.00	0.766017E+12	0.00	0.666860E+11	0.468566E+12	0.00	0.543083E+12	0.238373E+12	0.00	0.00	0.00	0.00
June	0.102042E+13	0.00	0.761863E+12	0.00	0.683182E+11	0.464116E+12	0.00	0.821234E+12	0.299894E+12	0.00	0.00	0.00	0.00
July	0.106203E+13	0.00	0.790527E+12	0.00	0.752832E+11	0.490644E+12	0.00	0.103078E+13	0.354326E+12	0.00	0.00	0.00	0.00
August	0.100504E+13	0.00	0.766017E+12	0.00	0.699335E+11	0.483096E+12	0.00	0.931146E+12	0.342651E+12	0.00	0.00	0.00	0.00
September	0.102042E+13	0.00	0.761863E+12	0.00	0.644335E+11	0.458800E+12	0.00	0.706368E+12	0.307541E+12	0.00	0.00	0.00	0.00
October	0.103863E+13	0.00	0.779619E+12	0.00	0.631706E+11	0.461900E+12	0.00	0.334384E+12	0.202492E+12	0.00	0.00	0.00	0.00
November	0.986833E+12	0.00	0.748261E+12	0.00	0.609794E+11	0.445859E+12	0.00	0.188205E+12	0.915102E+11	0.00	0.00	0.00	0.00
December	0.106203E+13	0.00	0.790527E+12	0.00	0.637296E+11	0.460372E+12	0.00	0.156073E+11	0.451742E+10	0.00	0.00	0.00	0.00
Annual Sum or Average	0.122251E+14	0.00	0.918764E+13	0.00	0.780191E+12	0.532034E+13	0.00	0.506813E+13	0.206913E+13	0.00	0.00	0.00	0.00
Minimum of Months	0.937195E+12	0.00	0.704536E+12	0.00	0.574688E+11	0.266195E+12	0.00	0.127979E+11	0.407731E+10	0.00	0.00	0.00	0.00
Maximum of Months	0.106203E+13	0.00	0.790527E+12	0.00	0.752832E+11	0.490644E+12	0.00	0.103078E+13	0.354326E+12	0.00	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS**

For: **Meter**

Timestamp: **2013-05-23 20:55:44**

	INTERIOREQUIPMENT:GAS [J]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS [J]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	0.820863E+11	0.00	0.424557E+13	0.00	0.00	0.00
February	0.741424E+11	0.00	0.320650E+13	0.00	0.00	0.00
March	0.820863E+11	0.00	0.182683E+13	0.00	0.00	0.00
April	0.794383E+11	0.00	0.979816E+12	0.00	0.00	0.00
May	0.820863E+11	0.00	0.332852E+12	0.00	0.00	0.00
June	0.794383E+11	0.00	0.124007E+12	0.00	0.00	0.00
July	0.820863E+11	0.00	0.699082E+11	0.00	0.00	0.00
August	0.820863E+11	0.00	0.127239E+12	0.00	0.00	0.00
September	0.794383E+11	0.00	0.278329E+12	0.00	0.00	0.00
October	0.820863E+11	0.00	0.814896E+12	0.00	0.00	0.00
November	0.794383E+11	0.00	0.209629E+13	0.00	0.00	0.00
December	0.820863E+11	0.00	0.392254E+13	0.00	0.00	0.00
Annual Sum or Average	0.966500E+12	0.00	0.180258E+14	0.00	0.00	0.00
Minimum of Months	0.741424E+11	0.00	0.699082E+11	0.00	0.00	0.00
Maximum of Months	0.820863E+11	0.00	0.424557E+13	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-18 07:15:06**

	ELECTRICITY:FACILITY (Maximum) [W]	ELECTRICITY:FACILITY (TIMESTAMP)	INTERIORLIGHTS:ELECTRICITY (AT MAX/MIN) [W]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY (AT MAX/MIN) [W]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY (AT MAX/MIN) [W]	PUMPS:ELECTRICITY (AT MAX/MIN) [W]	HEATING:ELECTRICITY (AT MAX/MIN) [W]	COOLING:ELECTRICITY (AT MAX/MIN) [W]	HEATREJECTION:ELECTRICITY (AT MAX/MIN) [W]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	1754969.00	21-JAN-16:00	870572.58	0.00	475299.57	0.00	24961.38	178193.77	0.00	205941.70	0.00	0.00	0.00	0.00	0.00
February	1906304.22	11-FEB-16:00	870572.58	0.00	475299.57	0.00	27422.32	177026.02	0.00	190309.27	169674.45	0.00	0.00	0.00	0.00
March	2090031.90	27-MAR-15:00	870572.58	0.00	475299.57	0.00	30074.05	182538.77	0.00	365872.47	169674.45	0.00	0.00	0.00	0.00
April	2182566.08	16-APR-15:00	870572.58	0.00	475299.57	0.00	63502.13	194389.68	0.00	412147.66	169674.45	0.00	0.00	0.00	0.00
May	2166265.66	03-MAY-14:00	870572.58	0.00	464638.90	0.00	51704.44	200436.33	0.00	415238.97	169674.45	0.00	0.00	0.00	0.00
June	2223906.08	15-JUN-15:00	870572.58	0.00	475299.57	0.00	64068.08	196749.25	0.00	451542.15	169674.45	0.00	0.00	0.00	0.00
July	2390614.62	16-JUL-15:00	870572.58	0.00	475299.57	0.00	71713.01	204341.77	0.00	603011.24	169674.45	0.00	0.00	0.00	0.00
August	2372118.75	04-AUG-15:00	870572.58	0.00	475299.57	0.00	58822.74	203851.63	0.00	614104.54	150467.69	0.00	0.00	0.00	0.00
September	2151167.59	11-SEP-15:00	870572.58	0.00	475299.57	0.00	51104.11	191135.26	0.00	397381.63	169674.45	0.00	0.00	0.00	0.00
October	2132091.48	01-OCT-15:00	870572.58	0.00	475299.57	0.00	38637.60	186524.86	0.00	397381.63	169674.45	0.00	0.00	0.00	0.00
November	2118100.15	03-NOV-16:00	870572.58	0.00	475299.57	0.00	25946.62	183225.31	0.00	397381.63	169674.45	0.00	0.00	0.00	0.00
December	1818274.89	07-DEC-16:00	870572.58	0.00	475299.57	0.00	24688.73	175648.71	0.00	120315.87	151449.42	0.00	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00						0.00	0.00	0.00	0.00
Minimum of Months	1754969.00		870572.58	0.00	464638.90	0.00	24061.38	175648.71	0.00	120315.87	0.00	0.00	0.00	0.00	0.00
Maximum of Months	2390614.62		870572.58	0.00	475299.57	0.00	71713.01	204341.77	0.00	614104.54	169674.45	0.00	0.00	0.00	0.00

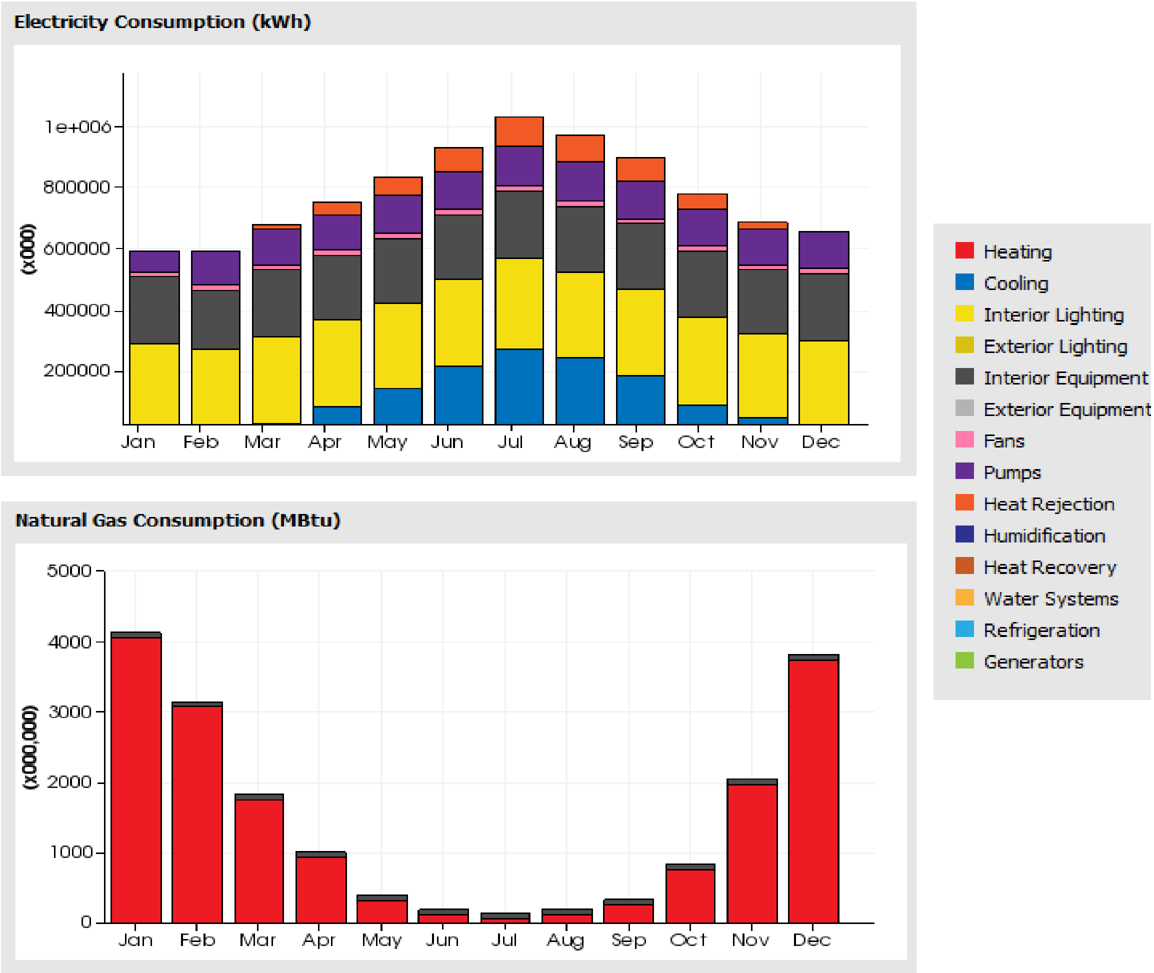
Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-23 20:55:44**

	GAS:FACILITY (Maximum) [W]	GAS:FACILITY (TIMESTAMP)	INTERIOREQUIPMENT:GAS (AT MAX/MIN) [W]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS (AT MAX/MIN) [W]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	6124857.36	26-JAN-22:00	20151.78	0.00	6104705.58	0.00	0.00	0.00
February	5568908.27	06-FEB-22:00	20151.78	0.00	5548756.48	0.00	0.00	0.00
March	3633355.70	02-MAR-06:00	20151.78	0.00	3613203.92	0.00	0.00	0.00
April	3244814.10	06-APR-05:00	20151.78	0.00	3224662.32	0.00	0.00	0.00
May	2108775.29	11-MAY-05:00	20151.78	0.00	2088623.51	0.00	0.00	0.00
June	1425068.91	24-JUN-05:00	20151.78	0.00	1404917.13	0.00	0.00	0.00
July	1037343.72	03-JUL-05:00	20151.78	0.00	1017191.94	0.00	0.00	0.00
August	1781169.60	17-AUG-05:00	20151.78	0.00	1761017.82	0.00	0.00	0.00
September	2598778.40	14-SEP-05:00	20151.78	0.00	2578626.62	0.00	0.00	0.00
October	2817145.90	19-OCT-05:00	20151.78	0.00	2796994.12	0.00	0.00	0.00
November	3786774.78	25-NOV-23:00	10075.89	0.00	3776698.89	0.00	0.00	0.00
December	5146112.35	29-DEC-23:00	10075.89	0.00	5136036.46	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00	0.00	0.00
Minimum of Months	1037343.72		10075.89	0.00	1017191.94	0.00	0.00	0.00
Maximum of Months	6124857.36		20151.78	0.00	6104705.58	0.00	0.00	0.00

2. THE CORRIDOR DSF CALCULATION



Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2255	8360	2.776e+04	8.279e+04	1.403e+05	2.156e+05	2.719e+05	2.452e+05	1.855e+05	8.962e+04	4.743e+04	2658	1.315e+06
Interior Lighting	2.885e+05	2.603e+05	2.857e+05	2.834e+05	2.792e+05	2.854e+05	2.95e+05	2.792e+05	2.834e+05	2.885e+05	2.741e+05	2.95e+05	3.396e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.166e+05	1.957e+05	2.118e+05	2.118e+05	2.128e+05	2.116e+05	2.196e+05	2.128e+05	2.116e+05	2.166e+05	2.079e+05	2.196e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.69e+04	1.515e+04	1.659e+04	1.67e+04	1.768e+04	1.826e+04	2.022e+04	1.873e+04	1.721e+04	1.669e+04	1.607e+04	1.68e+04	2.07e+05
Pumps	6.801e+04	1.093e+05	1.196e+05	1.173e+05	1.227e+05	1.217e+05	1.288e+05	1.268e+05	1.203e+05	1.209e+05	1.169e+05	1.209e+05	1.393e+06
Heat Rejection	359.1	3868	1.336e+04	3.875e+04	6.175e+04	7.866e+04	9.326e+04	9.005e+04	8.009e+04	5.214e+04	2.353e+04	1038	5.373e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5.926e+05	5.928e+05	6.788e+05	7.506e+05	8.344e+05	9.293e+05	1.029e+06	9.727e+05	8.987e+05	7.805e+05	6.859e+05	6.56e+05	9.401e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4046	3069	1745	932.3	317.2	115.1	62.22	115	252.1	752.2	1973	3737	1.712e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4126	3140	1823	1008	395	190.4	140	192.8	327.4	830	2049	3815	1.803e+04

Program Version: **EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.29 20:09**

Tabular Output Report in Format: **HTML**

Building: **Large Office**

Environment: **RUN PERIOD 1 ** Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300**

Simulation Timestamp: **2013-05-29 20:26:10**

Table of Contents

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 Values gathered over 8760.00 hours**

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	52869.26	822.17	822.17
Net Site Energy	52869.26	822.17	822.17
Total Source Energy	127805.79	1987.50	1987.50
Net Source Energy	127805.79	1987.50	1987.50

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050

Building Area

	Area [m2]
Total Building Area	64304.69
Net Conditioned Building Area	64304.69
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	18059.50	0.00	0.00	0.00	0.00
Cooling	4735.37	0.00	0.00	0.00	0.00	0.00
Interior Lighting	12225.14	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	9187.64	966.50	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	745.09	0.00	0.00	0.00	0.00	0.00
Pumps	5015.57	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1934.45	0.00	0.00	0.00	0.00	32557.16
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	33843.26	19026.00	0.00	0.00	0.00	32557.16

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	18059.50	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	4735.37	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1512.38	0.00	0.00	0.00	0.00	0.00
	Lights	10712.76	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	919.37	966.50	0.00	0.00	0.00	0.00
	ElectricEquipment	8268.27	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	745.09	0.00	0.00	0.00	0.00	0.00
Pumps	General	5015.57	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	1934.45	0.00	0.00	0.00	0.00	32557.16
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.31	280.84	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.30	295.87	0.00	0.00	0.00	0.51

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.31	280.84	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.30	295.87	0.00	0.00	0.00	0.51

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	33843.26	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	33843.26	100.00
Total On-Site and Utility Electric Sources	33843.26	100.00
Total Electricity End Uses	33843.26	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	32557.16	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	32557.16	100.00
Total Water End Uses	32557.16	100.00

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Time Heating Setpoint Not Met	0.20
Tolerance for Time Cooling Setpoint Not Met	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	16.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	6946.00

Report: **Input Verification and Results Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.29 20:09
RunPeriod	RUN PERIOD 1
Weather File	Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300
Latitude [deg]	41.98
Longitude [deg]	-87.9
Elevation [m]	201.00
Time Zone	-6.0
North Axis Angle [deg]	30.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	1607.62
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 End Uses**

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	16-JUL-15:00	26-JAN-22:00	-	-	-	17-APR-17:00
Heating	0.00	5310959.75	0.00	0.00	0.00	0.00
Cooling	564353.98	0.00	0.00	0.00	0.00	0.00
Interior Lighting	870572.58	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	475299.57	20151.78	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	66207.59	0.00	0.00	0.00	0.00	0.00
Pumps	189351.17	0.00	0.00	0.00	0.00	0.00
Heat Rejection	152877.04	0.00	0.00	0.00	0.00	0.01
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2318661.93	5331111.54	0.00	0.00	0.00	0.01

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	5310959.75	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	564353.98	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	42769.69	0.00	0.00	0.00	0.00	0.00
	Lights	827802.89	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	39613.84	20151.78	0.00	0.00	0.00	0.00
	ElectricEquipment	435685.73	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	66207.59	0.00	0.00	0.00	0.00	0.00
Pumps	General	189351.17	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	152877.04	0.00	0.00	0.00	0.00	0.01
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Source Energy End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 Values gathered over 8760.00 hours**

Source Energy End Use Components Summary

	Source Electricity [GJ]	Source Natural Gas [GJ]	Source Other Fuel [GJ]	Source District Cooling [GJ]	Source District Heating [GJ]
Heating	0.00	19576.50	0.00	0.00	0.00
Cooling	14996.93	0.00	0.00	0.00	0.00
Interior Lighting	38717.03	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	29097.25	1047.69	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	2359.69	0.00	0.00	0.00	0.00
Pumps	15884.31	0.00	0.00	0.00	0.00
Heat Rejection	6126.41	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	107181.61	20624.18	0.00	0.00	0.00

Normalized Metrics

Source Energy End Use Components Per Conditioned Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.43	0.00	0.00	0.00
Cooling	233.22	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.70	0.00	0.00	0.00	0.00
Pumps	247.02	0.00	0.00	0.00	0.00
Heat Rejection	95.27	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1666.78	320.73	0.00	0.00	0.00

Source Energy End Use Components Per Total Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.43	0.00	0.00	0.00
Cooling	233.22	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.70	0.00	0.00	0.00	0.00
Pumps	247.02	0.00	0.00	0.00	0.00
Heat Rejection	95.27	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1666.78	320.73	0.00	0.00	0.00

Report: **Climatic Data Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DP=>MDB	28.90	10.50	23.80	Dewpoint [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG WIND 99.6% CONDNS WS=>MCDB	-3.50	0.00	-3.50	Wetbulb [C]	12.40	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS ENTH=>MDB	31.40	10.50	79200.00	Enthalpy [J/kg]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DB=>MWB	33.30	10.50	23.70	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG 99.6% CONDNS DB	-20.00	0.00	-20.00	Wetbulb [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS WB=>MDB	31.20	10.50	25.30	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HUM_N 99.6% CONDNS DP=>MCDB	-19.20	0.00	-25.70	Dewpoint [C]	4.90	270.00

Report: **Equipment Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 Central Plant**

	Type	Nominal Capacity [W]	Nominal Efficiency [W/W]	IPLV in SI Units [W/W]	IPLV in IP Units [Btu/W-h]
CHILLER ELECTRIC EIR 1	Chiller:Electric:EIR	12310761.30	5.50		
COOLING TOWER SINGLE SPEED 1	CoolingTower:SingleSpeed	11599664.10			
BOILER HOT WATER 1	Boiler:HotWater	8002751.46	0.80		

Cooling Coils

	Type	Nominal Total Capacity [W]	Nominal Sensible Capacity [W]	Nominal Latent Capacity [W]	Nominal Sensible Heat Ratio	Nominal Efficiency [W/W]	Nominal Coil UA Value [W/C]	Nominal Coil Surface Area [m2]
COIL COOLING WATER 1	Coil:Cooling:Water	9392524.20	6007256.95	3385267.25	0.64	-	969117.06	9829.32

Fans

	Type	Total Efficiency [W/W]	Delta Pressure [pa]	Max Air Flow Rate [m3/s]	Rated Electric Power [W]	Rated Power Per Max Air Flow Rate [W-s/m3]	Motor Heat In Air Fraction	End Use
FAN VARIABLE VOLUME 1	Fan:VariableVolume	0.60	500.00	300.88	248867.23	827.13	1.00	General

Pumps

	Type	Control	Head [pa]	Water Flow [m3/s]	Electric Power [W]	Power Per Water Flow Rate [W-s/m3]	Motor Efficiency [W/W]
PUMP VARIABLE SPEED 2	Pump:VariableSpeed	Intermittent	179352.00	0.4400	112422.87	255487.18	0.90
PUMP VARIABLE SPEED 3	Pump:VariableSpeed	Intermittent	179352.00	0.6221	158933.16	255487.18	0.90
PUMP VARIABLE SPEED 1	Pump:VariableSpeed	Intermittent	179352.00	0.1732	44247.30	255487.18	0.90

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
VAV WITH REHEAT	300.88	300.88	136.49	136.49

Report: **Object Count Summary**

For: **Entire Facility**

Timestamp: **2013-05-29 20:26:10 Surfaces by Class**

	Total	Outdoors
Wall	800	320
Floor	200	5
Roof	200	5
Internal Mass	0	0
Building Detached Shading	150	150
Fixed Detached Shading	0	0
Window	320	320
Door	0	0
Glass Door	0	0
Shading	650	650
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

HVAC

	Count
HVAC Air Loops	1
Conditioned Zones	200
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Input Fields

	Count
IDF Objects	5727
Defaulted Fields	5260
Fields with Defaults	14829
Autosized Fields	1040
Autosizable Fields	1267
Autocalculated Fields	4448
Autocalculatable Fields	4448

Annual and Peak Values - Gas

	Gas Annual Value [GJ]	Gas Minimum Value [W]	Timestamp of Minimum	Gas Maximum Value [W]	Timestamp of Maximum
Gas:Facility	19026.00	4030.36	10-MAR-24:00	5331111.54	26-JAN-23:00
Gas:Building	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
General:InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Plant	18059.50	0.00	23-FEB-23:00	5310959.75	26-JAN-23:00
Heating:Gas	18059.50	0.00	23-FEB-23:00	5310959.75	26-JAN-23:00
Boiler:Heating:Gas	18059.50	0.00	23-FEB-23:00	5310959.75	26-JAN-23:00

Annual and Peak Values - Cooling

	Cooling Annual Value [GJ]	Cooling Minimum Value [W]	Timestamp of Minimum	Cooling Maximum Value [W]	Timestamp of Maximum
PlantLoopCoolingDemand:Facility	21773.79	-3.07	07-JAN-06:00	4166742.67	17-JUL-15:00
PlantLoopCoolingDemand:HVAC	21773.79	-3.07	07-JAN-06:00	4166742.67	17-JUL-15:00
CoolingCoils:PlantLoopCoolingDemand	21773.79	-3.07	07-JAN-06:00	4166742.67	17-JUL-15:00

Annual and Peak Values - Water

	Annual Value [m3]	Minimum Value [m3/s]	Timestamp of Minimum	Maximum Value [m3/s]	Timestamp of Maximum
Water:Facility	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00
Water:Plant	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:Water	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Facility	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Plant	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:MainsWater	32557.16	0.00	01-JAN-01:00	0.01	17-APR-18:00

Annual and Peak Values - Other by Weight/Mass

	Annual Value [kg]	Minimum Value [kg/s]	Timestamp of Minimum	Maximum Value [kg/s]	Timestamp of Maximum
Carbon Equivalent:Facility	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00
CarbonEquivalentEmissions:Carbon Equivalent	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00

Branch

	Maximum Flow Rate [m3/s]
BRANCH {97268710-89E1-42E3-9133-F3E567298227}	300.88

AirLoopHVAC

	Design Supply Air Flow Rate [m3/s]
VAV WITH REHEAT	300.88

Controller:OutdoorAir

	Maximum Outdoor Air Flow Rate [m3/s]	Minimum Outdoor Air Flow Rate [m3/s]
CONTROLLER OUTDOOR AIR 1	300.88	40.31

Coil:Cooling:Water

	Design Water Flow Rate [m3/s]	Design Air Flow Rate [m3/s]	Design Inlet Air Temperature [C]	Design Outlet Air Temperature [C]	Design Inlet Water Temperature [C]	Design Inlet Air Humidity Ratio	Design Outlet Air Humidity Ratio
COIL COOLING WATER 1	0.440033	300.88	30.71	12.80	7.22	0.014966	0.008500

Fan:VariableVolume

	Maximum Flow Rate [m3/s]
FAN VARIABLE VOLUME 1	300.88

Controller:WaterCoil

	Maximum Actuated Flow [m3/s]	Controller Convergence Tolerance
CONTROLLER WATER COIL 2	0.440033	0.000001
CONTROLLER WATER COIL 1	0.078000	0.000008

Chiller:Electric:EIR

	Reference Chilled Water Flow Rate [m3/s]	Reference Capacity [W]	Reference Condenser Water Flow Rate [m3/s]
CHILLER ELECTRIC EIR 1	0.440033	12319761.30	0.622079

PlantLoop

	Maximum Loop Flow Rate [m3/s]	Plant Loop Volume [m3]
CHILLED WATER LOOP	0.440033	1980.15
CONDENSER WATER LOOP	0.622079	2799.35
HOT WATER LOOP	0.173188	779.35

CoolingTower:SingleSpeed

	Design Water Flow Rate [m3/s]	Fan Power at Design Air Flow Rate [W]	Design Air Flow Rate [m3/s]	U-Factor Times Area Value at Design Air Flow Rate [W/C]	Air Flow Rate in Free Convection Regime [m3/s]	U-Factor Times Area Value at Free Convection Air Flow Rate [W/C]
COOLING TOWER SINGLE SPEED 1	0.622079	152877.34	412.03	876718.24	41.20	87671.82

Boiler:HotWater

	Nominal Capacity [W]	Design Water Flow Rate [m3/s]
BOILER HOT WATER 1	8002753.46	0.173189

Pump:VariableSpeed

	Rated Flow Rate [m3/s]	Rated Power Consumption [W]
PUMP VARIABLE SPEED 2	0.440033	112422.87
PUMP VARIABLE SPEED 3	0.622079	158933.16
PUMP VARIABLE SPEED 1	0.173188	44247.30

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY**

For: **Meter**

Timestamp: **2013-05-29 20:26:10**

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY [J]	PUMPS:ELECTRICITY [J]
January	0.103863E+13	0.00	0.779619E+12	0.00	0.608379E+11	0.294837E+12
February	0.937199E+12	0.00	0.704538E+12	0.00	0.545524E+11	0.359629E+12
March	0.102849E+13	0.00	0.778924E+12	0.00	0.597177E+11	0.439558E+12
April	0.102042E+13	0.00	0.761883E+12	0.00	0.601383E+11	0.422152E+12
May	0.100504E+13	0.00	0.760017E+12	0.00	0.636438E+11	0.441727E+12
June	0.102042E+13	0.00	0.761883E+12	0.00	0.657261E+11	0.438089E+12
July	0.106203E+13	0.00	0.790527E+12	0.00	0.727838E+11	0.463753E+12
August	0.100504E+13	0.00	0.760013E+12	0.00	0.673773E+11	0.456318E+12
September	0.102042E+13	0.00	0.761863E+12	0.00	0.619438E+11	0.432979E+12
October	0.103863E+13	0.00	0.779619E+12	0.00	0.606691E+11	0.435379E+12
November	0.986813E+12	0.00	0.748261E+12	0.00	0.578513E+11	0.420744E+12
December	0.106203E+13	0.00	0.790527E+12	0.00	0.604658E+11	0.435389E+12
Annual Sum or Average	0.122251E+14	0.00	0.918764E+13	0.00	0.745087E+12	0.501557E+13
Minimum of Months	0.937199E+12	0.00	0.704538E+12	0.00	0.545524E+11	0.294837E+12
Maximum of Months	0.106203E+13	0.00	0.790527E+12	0.00	0.727838E+11	0.463753E+12

	HEATING:ELECTRICITY [J]	COOLING:ELECTRICITY [J]	HEATREJECTION:ELECTRICITY [J]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	0.00	0.811623E+10	0.129363E+10	0.00	0.00	0.00	0.00
February	0.00	0.308935E+11	0.139252E+11	0.00	0.00	0.00	0.00
March	0.00	0.999308E+11	0.481812E+11	0.00	0.00	0.00	0.00
April	0.00	0.298058E+12	0.139485E+12	0.00	0.00	0.00	0.00
May	0.00	0.805224E+12	0.222385E+12	0.00	0.00	0.00	0.00
June	0.00	0.776023E+12	0.283194E+12	0.00	0.00	0.00	0.00
July	0.00	0.978898E+12	0.335727E+12	0.00	0.00	0.00	0.00
August	0.00	0.882008E+12	0.324192E+12	0.00	0.00	0.00	0.00
September	0.00	0.667853E+12	0.280137E+12	0.00	0.00	0.00	0.00
October	0.00	0.308249E+12	0.187719E+12	0.00	0.00	0.00	0.00
November	0.00	0.175748E+12	0.846427E+11	0.00	0.00	0.00	0.00
December	0.00	0.953794E+10	0.370143E+10	0.00	0.00	0.00	0.00
Annual Sum or Average	0.00	0.473557E+13	0.193449E+13	0.00	0.00	0.00	0.00
Minimum of Months	0.00	0.811623E+10	0.129363E+10	0.00	0.00	0.00	0.00
Maximum of Months	0.00	0.978898E+12	0.335727E+12	0.00	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS**

For: **Meter**

Timestamp: **2013-05-29 20:26:10**

	INTERIOREQUIPMENT:GAS [J]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS [J]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	0.820863E+11	0.00	0.427085E+13	0.00	0.00	0.00
February	0.741424E+11	0.00	0.323831E+13	0.00	0.00	0.00
March	0.820863E+11	0.00	0.183877E+13	0.00	0.00	0.00
April	0.794383E+11	0.00	0.983850E+12	0.00	0.00	0.00
May	0.820863E+11	0.00	0.334671E+12	0.00	0.00	0.00
June	0.794383E+11	0.00	0.121416E+12	0.00	0.00	0.00
July	0.820863E+11	0.00	0.656478E+11	0.00	0.00	0.00
August	0.820863E+11	0.00	0.121361E+12	0.00	0.00	0.00
September	0.794383E+11	0.00	0.265957E+12	0.00	0.00	0.00
October	0.820863E+11	0.00	0.793640E+12	0.00	0.00	0.00
November	0.794383E+11	0.00	0.208187E+13	0.00	0.00	0.00
December	0.820863E+11	0.00	0.394317E+13	0.00	0.00	0.00
Annual Sum or Average	0.966500E+12	0.00	0.180595E+14	0.00	0.00	0.00
Minimum of Months	0.741424E+11	0.00	0.656478E+11	0.00	0.00	0.00
Maximum of Months	0.820863E+11	0.00	0.427085E+13	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-29 20:26:10**

	ELECTRICITY:FACILITY (Maximum) [W]	ELECTRICITY:FACILITY (TIMESTAMP)	INTERIORLIGHTS:ELECTRICITY (AT MAX/MIN) [W]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY (AT MAX/MIN) [W]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY (AT MAX/MIN) [W]	PUMPS:ELECTRICITY (AT MAX/MIN) [W]	HEATING:ELECTRICITY (AT MAX/MIN) [W]	COOLING:ELECTRICITY (AT MAX/MIN) [W]	HEATREJECTION:ELECTRICITY (AT MAX/MIN) [W]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	1678294.10	21-JAN-16:00	870572.58	0.00	475299.57	0.00	22572.82	163986.96	0.00	145862.16	0.00	0.00	0.00	0.00	0.00
February	1809307.66	11-FEB-16:00	870571.58	0.00	475299.57	0.00	22827.70	162383.11	0.00	123347.67	152877.04	0.00	0.00	0.00	0.00
March	2018993.51	27-MAR-15:00	870572.58	0.00	475299.57	0.00	27383.86	168255.44	0.00	324605.02	152877.04	0.00	0.00	0.00	0.00
April	2114006.36	16-APR-13:00	870572.58	0.00	475299.57	0.00	37641.49	176282.66	0.00	378383.02	152877.04	0.00	0.00	0.00	0.00
May	2103958.14	05-MAY-13:00	870572.58	0.00	464638.90	0.00	47126.96	184124.71	0.00	384618.36	152877.04	0.00	0.00	0.00	0.00
June	2181747.93	08-JUN-12:00	870572.58	0.00	464638.90	0.00	43047.25	185136.88	0.00	509707.60	108644.71	0.00	0.00	0.00	0.00
July	2318661.93	16-JUL-15:00	870572.58	0.00	475299.57	0.00	66207.59	189351.17	0.00	564353.98	152877.04	0.00	0.00	0.00	0.00
August	2303888.71	04-AUG-15:00	870572.58	0.00	475299.57	0.00	53269.67	188840.42	0.00	575049.16	149837.31	0.00	0.00	0.00	0.00
September	2086652.33	11-SEP-15:00	870571.58	0.00	475299.57	0.00	45217.64	175999.36	0.00	366686.14	152877.04	0.00	0.00	0.00	0.00
October	2068660.16	01-OCT-15:00	870572.58	0.00	475299.57	0.00	31865.03	171359.77	0.00	366686.14	152877.04	0.00	0.00	0.00	0.00
November	2060347.45	03-NOV-16:00	870572.58	0.00	475299.57	0.00	25258.27	169653.83	0.00	366686.14	152877.04	0.00	0.00	0.00	0.00
December	1706251.18	07-DEC-16:00	870572.58	0.00	475299.57	0.00	22811.23	161717.77	0.00	91898.37	94151.68	0.00	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00						0.00	0.00	0.00	0.00
Minimum of Months	1678294.10		870571.58	0.00	464638.90	0.00	22572.82	161717.77	0.00	91898.37	0.00	0.00	0.00	0.00	0.00
Maximum of Months	2318661.93		870571.58	0.00	475299.57	0.00	66207.59	189351.17	0.00	575049.16	152877.04	0.00	0.00	0.00	0.00

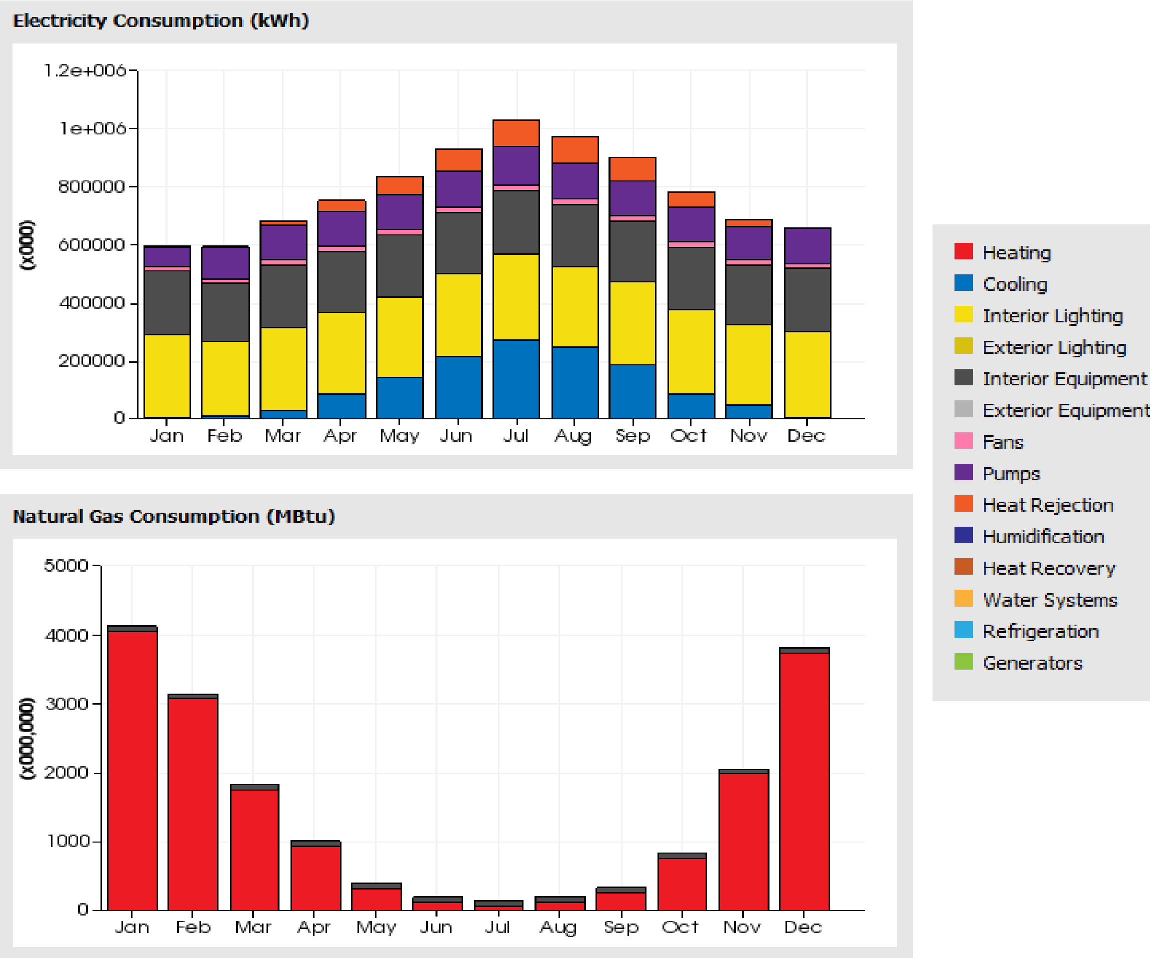
Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-29 20:26:10**

	GAS:FACILITY (Maximum) [W]	GAS:FACILITY (TIMESTAMP)	INTERIOREQUIPMENT:GAS (AT MAX/MIN) [W]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS (AT MAX/MIN) [W]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	5331111.54	26-JAN-22:00	20151.78	0.00	5310959.75	0.00	0.00	0.00
February	4850082.24	06-FEB-22:00	20151.78	0.00	4829930.46	0.00	0.00	0.00
March	3625375.72	02-MAR-06:00	20151.78	0.00	3605223.94	0.00	0.00	0.00
April	3211021.63	06-APR-05:00	20151.78	0.00	3190869.85	0.00	0.00	0.00
May	2048058.04	11-MAY-05:00	20151.78	0.00	2027906.26	0.00	0.00	0.00
June	1385499.61	24-JUN-05:00	20151.78	0.00	1365347.83	0.00	0.00	0.00
July	1001155.93	03-JUL-05:00	20151.78	0.00	981004.14	0.00	0.00	0.00
August	1757364.91	17-AUG-05:00	20151.78	0.00	1737213.13	0.00	0.00	0.00
September	2525084.01	14-SEP-05:00	20151.78	0.00	2504932.22	0.00	0.00	0.00
October	2753390.28	18-OCT-05:00	20151.78	0.00	2733238.49	0.00	0.00	0.00
November	3926961.20	25-NOV-23:00	10075.89	0.00	3916885.31	0.00	0.00	0.00
December	4811735.96	29-DEC-23:00	10075.89	0.00	4801660.07	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00	0.00	0.00
Minimum of Months	1001155.93		10075.89	0.00	981004.14	0.00	0.00	0.00
Maximum of Months	5331111.54		20151.78	0.00	5310959.75	0.00	0.00	0.00

3. MULTI-STOREY DSF CALCULATION



Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2208	8431	2.791e+04	8.304e+04	1.406e+05	2.139e+05	2.723e+05	2.456e+05	1.858e+05	8.384e+04	4.757e+04	2696	1.318e+06
Interior Lighting	2.865e+05	2.603e+05	2.857e+05	2.824e+05	2.792e+05	2.824e+05	2.95e+05	2.792e+05	2.824e+05	2.865e+05	2.745e+05	2.95e+05	3.366e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.166e+05	1.957e+05	2.158e+05	2.116e+05	2.128e+05	2.116e+05	2.196e+05	2.128e+05	2.116e+05	2.166e+05	2.079e+05	2.196e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.693e+04	1.518e+04	1.662e+04	1.473e+04	1.773e+04	1.828e+04	2.124e+04	1.879e+04	1.725e+04	1.671e+04	1.61e+04	1.682e+04	2.073e+05
Pumps	6.825e+04	1.095e+05	1.198e+05	1.175e+05	1.229e+05	1.219e+05	1.29e+05	1.27e+05	1.205e+05	1.211e+05	1.171e+05	1.213e+05	1.396e+06
Heat Rejection	384.1	3874	1.341e+04	3.889e+04	6.183e+04	7.88e+04	9.34e+04	9.12e+04	8.073e+04	5.227e+04	2.788e+04	1030	5.384e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5.829e+05	5.93e+05	6.792e+05	7.512e+05	8.351e+05	9.3e+05	1.03e+06	9.735e+05	8.993e+05	7.81e+05	6.863e+05	6.583e+05	9.407e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4047	3069	1742	932.4	317.1	115.2	62.33	115.2	252.4	752.8	1974	3737	1.712e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4125	3139	1820	1008	394.9	190.4	140.1	193	327.7	830.6	2049	3815	1.803e+04

Program Version:**EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.30 17:32**

Tabular Output Report in Format: **HTML**

Building: **Large Office**

Environment: **RUN PERIOD 1 ** Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300**

Simulation Timestamp: **2013-05-30 17:49:40**

Table of Contents

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 Values gathered over 8760.00 hours**

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	52891.86	822.52	822.52
Net Site Energy	52891.86	822.52	822.52
Total Source Energy	127879.03	1988.64	1988.64
Net Source Energy	127879.03	1988.64	1988.64

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050

Building Area

	Area [m2]
Total Building Area	64304.69
Net Conditioned Building Area	64304.69
Unconditioned Building Area	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	18058.70	0.00	0.00	0.00	0.00
Cooling	4745.08	0.00	0.00	0.00	0.00	0.00
Interior Lighting	12225.14	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	9187.64	966.50	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	746.18	0.00	0.00	0.00	0.00	0.00
Pumps	5024.43	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1938.19	0.00	0.00	0.00	0.00	32614.89
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	33866.66	19025.20	0.00	0.00	0.00	32614.89

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	18058.70	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	4745.08	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1512.38	0.00	0.00	0.00	0.00	0.00
	Lights	10712.76	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	919.37	966.50	0.00	0.00	0.00	0.00
	ElectricEquipment	8268.27	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	746.18	0.00	0.00	0.00	0.00	0.00
Pumps	General	5024.43	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	1938.19	0.00	0.00	0.00	0.00	32614.89
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.67	280.83	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.66	295.86	0.00	0.00	0.00	0.51

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.67	280.83	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.66	295.86	0.00	0.00	0.00	0.51

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	33866.66	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	33866.66	100.00
Total On-Site and Utility Electric Sources	33866.66	100.00
Total Electricity End Uses	33866.66	100.00

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	32614.89	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	32614.89	100.00
Total Water End Uses	32614.89	100.00

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Time Heating Setpoint Not Met	0.20
Tolerance for Time Cooling Setpoint Not Met	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	16.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	6946.00

Report: **Input Verification and Results Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.30 17:32
RunPeriod	RUN PERIOD 1
Weather File	Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300
Latitude [deg]	41.98
Longitude [deg]	-87.9
Elevation [m]	201.00
Time Zone	-6.0
North Axis Angle [deg]	30.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	1607.62
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 End Uses**

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	16-JUL-15:00	26-JAN-22:00	-	-	-	17-APR-17:00
Heating	0.00	5336166.87	0.00	0.00	0.00	0.00
Cooling	565231.43	0.00	0.00	0.00	0.00	0.00
Interior Lighting	870572.58	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	475299.57	20151.78	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	66385.57	0.00	0.00	0.00	0.00	0.00
Pumps	189666.57	0.00	0.00	0.00	0.00	0.00
Heat Rejection	153138.72	0.00	0.00	0.00	0.00	0.01
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2320294.44	5356318.65	0.00	0.00	0.00	0.01

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	5336166.87	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	565231.43	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	42769.69	0.00	0.00	0.00	0.00	0.00
	Lights	827802.89	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	39613.84	20151.78	0.00	0.00	0.00	0.00
	ElectricEquipment	435685.73	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	66385.57	0.00	0.00	0.00	0.00	0.00
Pumps	General	189666.57	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	153138.72	0.00	0.00	0.00	0.00	0.01
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Source Energy End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 Values gathered over 8760.00 hours**

Source Energy End Use Components Summary

	Source Electricity [GJ]	Source Natural Gas [GJ]	Source Other Fuel [GJ]	Source District Cooling [GJ]	Source District Heating [GJ]
Heating	0.00	19575.63	0.00	0.00	0.00
Cooling	15027.66	0.00	0.00	0.00	0.00
Interior Lighting	38717.03	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	29097.25	1047.69	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	2363.15	0.00	0.00	0.00	0.00
Pumps	15912.37	0.00	0.00	0.00	0.00
Heat Rejection	6138.26	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	107255.72	20623.31	0.00	0.00	0.00

Normalized Metrics

Source Energy End Use Components Per Conditioned Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.42	0.00	0.00	0.00
Cooling	233.69	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.75	0.00	0.00	0.00	0.00
Pumps	247.45	0.00	0.00	0.00	0.00
Heat Rejection	95.46	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1667.93	320.71	0.00	0.00	0.00

Source Energy End Use Components Per Total Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.42	0.00	0.00	0.00
Cooling	233.69	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.75	0.00	0.00	0.00	0.00
Pumps	247.45	0.00	0.00	0.00	0.00
Heat Rejection	95.46	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1667.93	320.71	0.00	0.00	0.00

Report: **Climatic Data Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
CHICAGO OHARE INTL AP ANN HUM_N 99.6% CONDNS DP=>MCDB	-19.20	0.00	-25.70	Dewpoint [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DB=>MWB	33.30	10.50	23.70	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS WB=>MDB	31.20	10.50	25.50	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG 99.6% CONDNS DB	-20.00	0.00	-20.00	Wetbulb [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DP=>MDB	28.90	10.50	23.80	Dewpoint [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS ENTH=>MDB	31.40	10.50	79200.00	Enthalpy [J/kg]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG WIND 99.6% CONDNS WS=>MCDB	-3.50	0.00	-3.50	Wetbulb [C]	12.40	270.00

Report: **Equipment Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 Central Plant**

	Type	Nominal Capacity [W]	Nominal Efficiency [W/W]	IPLV in SI Units [W/W]	IPLV in IP Units [Btu/W-h]
CHILLER ELECTRIC EIR 1	Chiller:Electric:EIR	12340846.99	5.50		
COOLING TOWER SINGLE SPEED 1	CoolingTower:SingleSpeed	11619519.21			
BOILER HOT WATER 1	Boiler:HotWater	8009136.49	0.80		

Fans

	Type	Total Efficiency [W/W]	Delta Pressure [pa]	Max Air Flow Rate [m3/s]	Rated Electric Power [W]	Rated Power Per Max Air Flow Rate [W-s/m3]	Motor Heat In Air Fraction	End Use
FAN VARIABLE VOLUME 1	Fan:VariableVolume	0.60	500.00	301.41	249306.23	827.13	1.00	General

Pumps

	Type	Control	Head [pa]	Water Flow [m3/s]	Electric Power [W]	Power Per Water Flow Rate [W-s/m3]	Motor Efficiency [W/W]
PUMP VARIABLE SPEED 2	Pump:VariableSpeed	Intermittent	179352.00	0.4408	112615.31	255487.18	0.90
PUMP VARIABLE SPEED 3	Pump:VariableSpeed	Intermittent	179352.00	0.6231	159205.21	255487.18	0.90
PUMP VARIABLE SPEED 1	Pump:VariableSpeed	Intermittent	179352.00	0.1733	44282.60	255487.18	0.90

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
VAV WITH REHEAT	301.41	301.41	136.50	136.50

Report: **Object Count Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 17:49:40 Surfaces by Class**

	Total	Outdoors
Wall	800	320
Floor	200	5
Roof	200	5
Internal Mass	0	0
Building Detached Shading	150	150
Fixed Detached Shading	0	0
Window	320	320
Door	0	0
Glass Door	0	0
Shading	644	644
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

HVAC

	Count
HVAC Air Loops	1
Conditioned Zones	200
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Input Fields

	Count
IDF Objects	5724
Defaulted Fields	5057
Fields with Defaults	14826
Autosized Fields	1040
Autosizable Fields	1267
Autocalculated Fields	4445
Autocalculatable Fields	4445

Annual and Peak Values - Gas

	Gas Annual Value [GJ]	Gas Minimum Value [W]	Timestamp of Minimum	Gas Maximum Value [W]	Timestamp of Maximum
Gas:Facility	19025.20	4030.36	10-MAR-24:00	5356318.65	26-JAN-23:00
Gas:Building	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
General:InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Plant	18058.70	0.00	23-FEB-23:00	5336166.87	26-JAN-23:00
Heating:Gas	18058.70	0.00	23-FEB-23:00	5336166.87	26-JAN-23:00
Boiler:Heating:Gas	18058.70	0.00	23-FEB-23:00	5336166.87	26-JAN-23:00

Annual and Peak Values - Cooling

	Cooling Annual Value [GJ]	Cooling Minimum Value [W]	Timestamp of Minimum	Cooling Maximum Value [W]	Timestamp of Maximum
PlantLoopCoolingDemand:Facility	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00
PlantLoopCoolingDemand:HVAC	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00
CoolingCoils:PlantLoopCoolingDemand	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00

Annual and Peak Values - Cooling

	Cooling Annual Value [GJ]	Cooling Minimum Value [W]	Timestamp of Minimum	Cooling Maximum Value [W]	Timestamp of Maximum
PlantLoopCoolingDemand:Facility	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00
PlantLoopCoolingDemand:HVAC	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00
CoolingCoils:PlantLoopCoolingDemand	21807.10	-3.06	07-JAN-06:00	4171479.24	17-JUL-15:00

Annual and Peak Values - Water

	Annual Value [m3]	Minimum Value [m3/s]	Timestamp of Minimum	Maximum Value [m3/s]	Timestamp of Maximum
Water:Facility	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00
Water:Plant	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:Water	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Facility	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Plant	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:MainsWater	32614.89	0.00	01-JAN-01:00	0.01	17-APR-18:00

Annual and Peak Values - Other by Weight/Mass

	Annual Value [kg]	Minimum Value [kg/s]	Timestamp of Minimum	Maximum Value [kg/s]	Timestamp of Maximum
Carbon Equivalent:Facility	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00
CarbonEquivalentEmissions:Carbon Equivalent	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00

Branch

	Maximum Flow Rate [m3/s]
BRANCH (05D5B14A-250A-41F1-B07D-EB5D05BF8AFE)	301.41

AirLoopHVAC

	Design Supply Air Flow Rate [m3/s]
VAV WITH REHEAT	301.41

Controller:OutdoorAir

	Maximum Outdoor Air Flow Rate [m3/s]	Minimum Outdoor Air Flow Rate [m3/s]
CONTROLLER OUTDOOR AIR 1	301.41	40.31

CoilCooling:Water

	Design Water Flow Rate [m3/s]	Design Air Flow Rate [m3/s]	Design Inlet Air Temperature [C]	Design Outlet Air Temperature [C]	Design Inlet Water Temperature [C]	Design Inlet Air Humidity Ratio	Design Outlet Air Humidity Ratio
COIL COOLING WATER 1	0.440787	301.41	30.70	12.80	7.22	0.014969	0.008500

Fan:VariableVolume

	Maximum Flow Rate [m3/s]
FAN VARIABLE VOLUME 1	301.41

Controller:WaterCoil

	Maximum Actuated Flow [m3/s]	Controller Convergence Tolerance
CONTROLLER WATER COIL 2	0.440787	0.000001
CONTROLLER WATER COIL 1	0.076134	0.000006

Chiller:Electric:EIR

	Reference Chilled Water Flow Rate [m3/s]	Reference Capacity [W]	Reference Condenser Water Flow Rate [m3/s]
CHILLER ELECTRIC EIR 1	0.440787	12340848.99	0.623144

PlantLoop

	Maximum Loop Flow Rate [m3/s]	Plant Loop Volume [m3]
CHILLED WATER LOOP	0.440787	1983.54
CONDENSER WATER LOOP	0.623144	2804.15
HOT WATER LOOP	0.173326	779.97

CoolingTower:SingleSpeed

	Design Water Flow Rate [m3/s]	Fan Power at Design Air Flow Rate [W]	Design Air Flow Rate [m3/s]	U-Factor Times Area Value at Design Air Flow Rate [W/C]	Air Flow Rate in Free Convection Regime [m3/s]	U-Factor Times Area Value at Free Convection Air Flow Rate [W/C]
COOLING TOWER SINGLE SPEED 1	0.623144	153138.72	412.74	881225.06	41.27	88122.51

Boiler:HotWater

	Nominal Capacity [W]	Design Water Flow Rate [m3/s]
BOILER HOT WATER 1	8009138.49	0.173326

Pump:VariableSpeed

	Rated Flow Rate [m3/s]	Rated Power Consumption [W]
PUMP VARIABLE SPEED 2	0.440787	112615.31
PUMP VARIABLE SPEED 3	0.623144	159205.21
PUMP VARIABLE SPEED 1	0.173326	44282.60

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY**

For: **Meter**

Timestamp: **2013-05-30 17:49:40**

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY [J]	PUMPS:ELECTRICITY [J]	HEATING:ELECTRICITY [J]	COOLING:ELECTRICITY [J]	HEATREJECTION:ELECTRICITY [J]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	0.103863E+13	0.00	0.779619E+12	0.00	0.609347E+11	0.245683E+12	0.00	0.823638E+10	0.138274E+10	0.00	0.00	0.00	0.00
February	0.937195E+12	0.00	0.704538E+12	0.00	0.546408E+11	0.394285E+12	0.00	0.303462E+11	0.139478E+11	0.00	0.00	0.00	0.00
March	0.102849E+13	0.00	0.776924E+12	0.00	0.398171E+11	0.401294E+12	0.00	0.100491E+12	0.462783E+11	0.00	0.00	0.00	0.00
April	0.102042E+13	0.00	0.761863E+12	0.00	0.602128E+11	0.422877E+12	0.00	0.298953E+12	0.138873E+12	0.00	0.00	0.00	0.00
May	0.100504E+13	0.00	0.766017E+12	0.00	0.637415E+11	0.442502E+12	0.00	0.506293E+12	0.222648E+12	0.00	0.00	0.00	0.00
June	0.102042E+13	0.00	0.761863E+12	0.00	0.658148E+11	0.438828E+12	0.00	0.777377E+12	0.283888E+12	0.00	0.00	0.00	0.00
July	0.106203E+13	0.00	0.790127E+12	0.00	0.728694E+11	0.464516E+12	0.00	0.980203E+12	0.336257E+12	0.00	0.00	0.00	0.00
August	0.100504E+13	0.00	0.766017E+12	0.00	0.674868E+11	0.457574E+12	0.00	0.884207E+12	0.324728E+12	0.00	0.00	0.00	0.00
September	0.102042E+13	0.00	0.761863E+12	0.00	0.620198E+11	0.433709E+12	0.00	0.668994E+12	0.290639E+12	0.00	0.00	0.00	0.00
October	0.103863E+13	0.00	0.779619E+12	0.00	0.601624E+11	0.438124E+12	0.00	0.309838E+12	0.188158E+12	0.00	0.00	0.00	0.00
November	0.986653E+12	0.00	0.748261E+12	0.00	0.579453E+11	0.421472E+12	0.00	0.171268E+12	0.848982E+11	0.00	0.00	0.00	0.00
December	0.106203E+13	0.00	0.790127E+12	0.00	0.607649E+11	0.438090E+12	0.00	0.870448E+10	0.370846E+10	0.00	0.00	0.00	0.00
Annual Sum or Average	0.122251E+14	0.00	0.918764E+13	0.00	0.746179E+12	0.502440E+13	0.00	0.474508E+13	0.193819E+13	0.00	0.00	0.00	0.00
Minimum of Months	0.937195E+12	0.00	0.704538E+12	0.00	0.546408E+11	0.245683E+12	0.00	0.823638E+10	0.138274E+10	0.00	0.00	0.00	0.00
Maximum of Months	0.106203E+13	0.00	0.790127E+12	0.00	0.728694E+11	0.464516E+12	0.00	0.980203E+12	0.336257E+12	0.00	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS**

For: **Meter**

Timestamp: **2013-05-30 17:49:40**

	INTERIOREQUIPMENT:GAS [J]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS [J]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	0.820863E+11	0.00	0.427022E+13	0.00	0.00	0.00
February	0.741424E+11	0.00	0.323757E+13	0.00	0.00	0.00
March	0.820863E+11	0.00	0.183818E+13	0.00	0.00	0.00
April	0.794383E+11	0.00	0.983710E+12	0.00	0.00	0.00
May	0.820863E+11	0.00	0.334599E+12	0.00	0.00	0.00
June	0.794383E+11	0.00	0.121493E+12	0.00	0.00	0.00
July	0.820863E+11	0.00	0.657608E+11	0.00	0.00	0.00
August	0.820863E+11	0.00	0.121564E+12	0.00	0.00	0.00
September	0.794383E+11	0.00	0.266341E+12	0.00	0.00	0.00
October	0.820863E+11	0.00	0.794264E+12	0.00	0.00	0.00
November	0.794383E+11	0.00	0.208235E+13	0.00	0.00	0.00
December	0.820863E+11	0.00	0.394265E+13	0.00	0.00	0.00
Annual Sum or Average	0.966500E+12	0.00	0.180587E+14	0.00	0.00	0.00
Minimum of Months	0.741424E+11	0.00	0.657608E+11	0.00	0.00	0.00
Maximum of Months	0.820863E+11	0.00	0.427022E+13	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-30 17:49:40**

	ELECTRICITY:FACILITY [Maximum] [W]	ELECTRICITY:FACILITY {TIMESTAMP}	INTERIORLIGHTS:ELECTRICITY {AT MAX/MIN} [W]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY {AT MAX/MIN} [W]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY {AT MAX/MIN} [W]	PUMPS:ELECTRICITY {AT MAX/MIN} [W]	HEATING:ELECTRICITY {AT MAX/MIN} [W]	COOLING:ELECTRICITY {AT MAX/MIN} [W]	HEATREJECTION:ELECTRICITY {AT MAX/MIN} [W]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	1679432.27	21-JAN-16:00	870572.58	0.00	475299.57	0.00	22610.54	164271.26	0.00	146678.32	0.00	0.00	0.00	0.00	0.00
February	1810426.13	11-FEB-16:00	870572.58	0.00	475299.57	0.00	22864.74	162664.70	0.00	123885.82	153138.72	0.00	0.00	0.00	0.00
March	2019983.95	27-MAR-15:00	870572.58	0.00	475299.57	0.00	27406.97	168537.68	0.00	329308.44	153138.72	0.00	0.00	0.00	0.00
April	2115352.50	16-APR-15:00	870572.58	0.00	475299.57	0.00	57747.42	179585.39	0.00	379008.82	153138.72	0.00	0.00	0.00	0.00
May	2105012.80	05-MAY-15:00	870572.58	0.00	475299.57	0.00	48724.30	185257.47	0.00	371026.16	153138.72	0.00	0.00	0.00	0.00
June	2182214.56	08-JUN-12:00	870572.58	0.00	464638.90	0.00	43025.46	185408.84	0.00	309919.36	108658.22	0.00	0.00	0.00	0.00
July	2320294.44	16-JUL-15:00	870572.58	0.00	475299.57	0.00	66385.57	189666.57	0.00	365231.43	153138.72	0.00	0.00	0.00	0.00
August	2305153.88	04-AUG-15:00	870572.58	0.00	475299.57	0.00	53413.15	189151.98	0.00	575871.39	140845.23	0.00	0.00	0.00	0.00
September	2087914.68	11-SEP-15:00	870572.58	0.00	475299.57	0.00	45292.67	176297.15	0.00	367313.80	153138.72	0.00	0.00	0.00	0.00
October	2069847.27	01-OCT-15:00	870572.58	0.00	475299.57	0.00	31876.85	171642.75	0.00	367313.80	153138.72	0.00	0.00	0.00	0.00
November	2041496.38	03-NOV-16:00	870572.58	0.00	475299.57	0.00	25248.34	169925.38	0.00	367313.80	153138.72	0.00	0.00	0.00	0.00
December	1707838.83	07-DEC-16:00	870572.58	0.00	475299.57	0.00	22648.94	161988.74	0.00	92272.81	85046.19	0.00	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00						0.00	0.00	0.00	0.00
Minimum of Months	1679432.27		870572.58	0.00	464638.90	0.00	22610.54	161988.74	0.00	92272.81	0.00	0.00	0.00	0.00	0.00
Maximum of Months	2320294.44		870572.58	0.00	475299.57	0.00	66385.57	189666.57	0.00	575871.39	153138.72	0.00	0.00	0.00	0.00

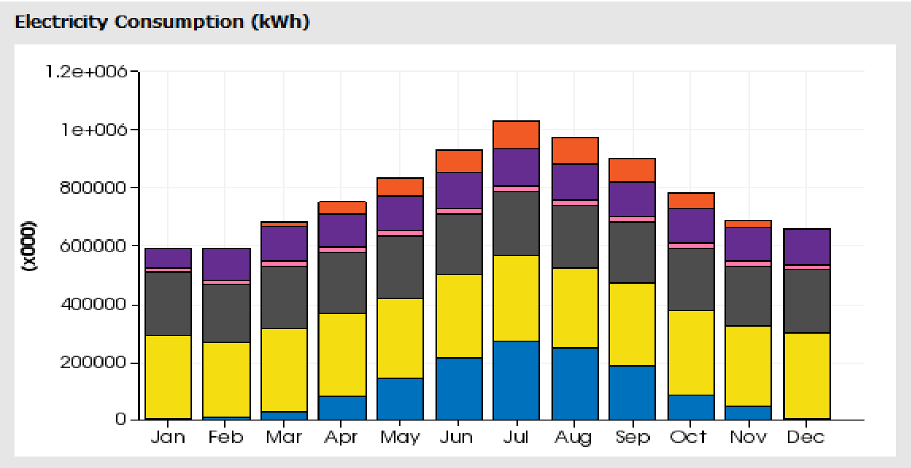
Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND**

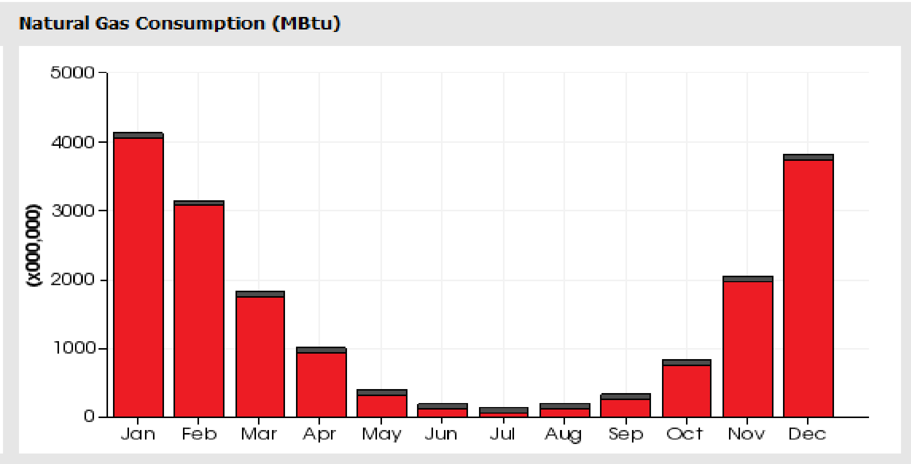
For: **Meter**

Timestamp: **2013-05-30 17:49:40**

	GAS:FACILITY [Maximum] [W]	GAS:FACILITY {TIMESTAMP}	INTERIOREQUIPMENT:GAS {AT MAX/MIN} [W]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS {AT MAX/MIN} [W]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	5356318.65	26-JAN-22:00	20151.78	0.00	5336166.87	0.00	0.00	0.00
February	4873780.30	06-FEB-22:00	20151.78	0.00	4853628.52	0.00	0.00	0.00
March	3625530.77	02-MAR-06:00	20151.78	0.00	3605378.98	0.00	0.00	0.00
April	3211978.54	06-APR-05:00	20151.78	0.00	3191826.76	0.00	0.00	0.00
May	2047144.16	11-MAY-05:00	20151.78	0.00	2026992.38	0.00	0.00	0.00
June	1385443.40	24-JUN-05:00	20151.78	0.00	1365291.62	0.00	0.00	0.00
July	1001557.55	03-JUL-05:00	20151.78	0.00	981405.77	0.00	0.00	0.00
August	1757682.37	17-AUG-05:00	20151.78	0.00	1737530.59	0.00	0.00	0.00
September	2526076.45	14-SEP-05:00	20151.78	0.00	2505924.67	0.00	0.00	0.00
October	2754968.48	19-OCT-05:00	20151.78	0.00	2734816.70	0.00	0.00	0.00
November	3922556.15	25-NOV-23:00	10075.89	0.00	3912480.26	0.00	0.00	0.00
December	4841539.64	29-DEC-23:00	10075.89	0.00	4831463.75	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00	0.00	0.00
Minimum of Months	1001557.55		10075.89	0.00	981405.77	0.00	0.00	0.00
Maximum of Months	5356318.65		20151.78	0.00	5336166.87	0.00	0.00	0.00

4. SHAFT BOX DSF CALCULATION





Electricity Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	2254	8360	2.776e+04	8.279e+04	1.403e+05	2.156e+05	2.719e+05	2.452e+05	1.859e+05	6.562e+04	4.743e+04	2658	1.315e+06
Interior Lighting	2.883e+05	2.603e+05	2.857e+05	2.834e+05	2.792e+05	2.834e+05	2.93e+05	2.762e+05	2.834e+05	2.883e+05	2.742e+05	2.93e+05	3.396e+06
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	2.366e+05	1.957e+05	2.158e+05	2.116e+05	2.128e+05	2.116e+05	2.156e+05	2.128e+05	2.116e+05	2.166e+05	2.076e+05	2.156e+05	2.552e+06
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	1.69e+04	1.512e+04	1.659e+04	1.67e+04	1.788e+04	1.826e+04	2.022e+04	1.872e+04	1.721e+04	1.669e+04	1.607e+04	1.68e+04	2.07e+05
Pumps	6.801e+04	1.093e+05	1.196e+05	1.173e+05	1.227e+05	1.217e+05	1.288e+05	1.268e+05	1.203e+05	1.209e+05	1.189e+05	1.209e+05	1.393e+06
Heat Rejection	109	3853	1.336e+04	3.875e+04	6.175e+04	7.866e+04	9.326e+04	8.303e+04	8.059e+04	5.216e+04	2.353e+04	1026	5.379e+05
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	5.926e+05	5.927e+05	6.788e+05	7.506e+05	8.344e+05	9.293e+05	1.029e+06	9.727e+05	8.987e+05	7.805e+05	6.859e+05	6.56e+05	9.401e+06

Natural Gas Consumption (MBtu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	4048	3069	1743	932.5	317.2	115.1	62.22	115	252.1	752.2	1973	3737	1.712e+04
Cooling	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Exterior Lighting	—	—	—	—	—	—	—	—	—	—	—	—	—
Interior Equipment	77.8	70.27	77.8	75.29	77.8	75.29	77.8	77.8	75.29	77.8	75.29	77.8	916.1
Exterior Equipment	—	—	—	—	—	—	—	—	—	—	—	—	—
Fans	—	—	—	—	—	—	—	—	—	—	—	—	—
Pumps	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Rejection	—	—	—	—	—	—	—	—	—	—	—	—	—
Humidification	—	—	—	—	—	—	—	—	—	—	—	—	—
Heat Recovery	—	—	—	—	—	—	—	—	—	—	—	—	—
Water Systems	—	—	—	—	—	—	—	—	—	—	—	—	—
Refrigeration	—	—	—	—	—	—	—	—	—	—	—	—	—
Generators	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	4126	3140	1821	1008	395	190.4	140	192.8	327.4	830	2049	3815	1.803e+04

Program Version: **EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.30 21:58**

Tabular Output Report in Format: **HTML**

Building: **Large Office**

Environment: **RUN PERIOD 1 ** Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300**

Simulation Timestamp: **2013-05-30 22:17:36**

Table of Contents

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 Values gathered over 8760.00 hours**

Site and Source Energy

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	52869.16	822.17	822.17
Net Site Energy	52869.16	822.17	822.17
Total Source Energy	127805.49	1987.50	1987.50
Net Source Energy	127805.49	1987.50	1987.50

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050
Diesel	1.050
Coal	1.050
Fuel Oil #1	1.050
Fuel Oil #2	1.050
Propane	1.050

Building Area

	Area [m2]
Total Building Area	64304.69
Net Conditioned Building Area	64304.69
Unconditioned Building Area	0.00

Normalized Metrics

Utility Use Per Conditioned Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.30	280.84	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.29	295.87	0.00	0.00	0.00	0.51

Utility Use Per Total Floor Area

	Electricity Intensity [MJ/m2]	Natural Gas Intensity [MJ/m2]	Other Fuel Intensity [MJ/m2]	District Cooling Intensity [MJ/m2]	District Heating Intensity [MJ/m2]	Water Intensity [m3/m2]
Lighting	190.11	0.00	0.00	0.00	0.00	0.00
HVAC	193.30	280.84	0.00	0.00	0.00	0.51
Other	142.88	15.03	0.00	0.00	0.00	0.00
Total	526.29	295.87	0.00	0.00	0.00	0.51

Electric Loads Satisfied

	Electricity [GJ]	Percent Electricity [%]
Fuel-Fired Power Generation	0.00	0.00
High Temperature Geothermal*	0.00	0.00
Photovoltaic Power	0.00	0.00
Wind Power	0.00	0.00
Net Decrease in On-Site Storage	0.00	0.00
Total On-Site Electric Sources	0.00	0.00
Electricity Coming From Utility	33843.17	100.00
Surplus Electricity Going To Utility	0.00	0.00
Net Electricity From Utility	33843.17	100.00
Total On-Site and Utility Electric Sources	33843.17	100.00
Total Electricity End Uses	33843.17	100.00

On-Site Thermal Sources

	Heat [GJ]	Percent Heat [%]
Water-Side Heat Recovery	0.00	
Air to Air Heat Recovery for Cooling	0.00	
Air to Air Heat Recovery for Heating	0.00	
High-Temperature Geothermal*	0.00	
Solar Water Thermal	0.00	
Solar Air Thermal	0.00	
Total On-Site Thermal Sources	0.00	

Water Source Summary

	Water [m3]	Percent Water [%]
Rainwater Collection	0.00	0.00
Condensate Collection	0.00	0.00
Groundwater Well	0.00	0.00
Total On Site Water Sources	0.00	0.00
-	-	-
Initial Storage	0.00	0.00
Final Storage	0.00	0.00
Change in Storage	0.00	0.00
-	-	-
Water Supplied by Utility	32557.47	100.00
-	-	-
Total On Site, Change in Storage, and Utility Water Sources	32557.47	100.00
Total Water End Uses	32557.47	100.00

Comfort and Setpoint Not Met Summary

	Degrees [deltaC]
Tolerance for Time Heating Setpoint Not Met	0.20
Tolerance for Time Cooling Setpoint Not Met	0.20

	Facility [Hours]
Time Setpoint Not Met During Occupied Heating	16.00
Time Setpoint Not Met During Occupied Cooling	0.00
Time Not Comfortable Based on Simple ASHRAE 55-2004	6946.00

Report: **Input Verification and Results Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 General**

	Value
Program Version and Build	EnergyPlus-Windows-OMP-32 7.2.0.006, YMD=2013.05.30 21:58
RunPeriod	RUN PERIOD 1
Weather File	Chicago Ohare Intl Ap IL USA TMY3 WMO#=725300
Latitude [deg]	41.98
Longitude [deg]	-87.9
Elevation [m]	201.00
Time Zone	-6.0
North Axis Angle [deg]	30.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

ENVELOPE

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Conditioned Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	20596.69	4543.96	5754.39	4543.96	5754.39
Window Opening Area [m2]	15447.52	3407.97	4315.79	3407.97	4315.79
Window-Wall Ratio [%]	75.00	75.00	75.00	75.00	75.00

Skylight-Roof Ratio

	Total
Gross Roof Area [m2]	1607.62
Skylight Area [m2]	0.00
Skylight-Roof Ratio [%]	0.00

Report: **Demand End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 End Uses**

	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Time of Peak	16-JUL-15:00	26-JAN-22:00	-	-	-	17-APR-17:00
Heating	0.00	5310906.18	0.00	0.00	0.00	0.00
Cooling	564353.35	0.00	0.00	0.00	0.00	0.00
Interior Lighting	870572.58	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	475299.57	20151.78	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	66207.58	0.00	0.00	0.00	0.00	0.00
Pumps	189350.72	0.00	0.00	0.00	0.00	0.00
Heat Rejection	152876.63	0.00	0.00	0.00	0.00	0.01
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	2318660.42	5331057.97	0.00	0.00	0.00	0.01

End Uses By Subcategory

	Subcategory	Electricity [W]	Natural Gas [W]	Propane [W]	District Cooling [W]	Steam [W]	Water [m3/s]
Heating	Boiler	0.00	5310906.18	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	564353.35	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	42769.69	0.00	0.00	0.00	0.00	0.00
	Lights	827802.89	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	39613.84	20151.78	0.00	0.00	0.00	0.00
	ElectricEquipment	435685.73	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	66207.58	0.00	0.00	0.00	0.00	0.00
Pumps	General	189350.72	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	152876.63	0.00	0.00	0.00	0.00	0.01
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

End Uses

	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	0.00	18059.49	0.00	0.00	0.00	0.00
Cooling	4735.36	0.00	0.00	0.00	0.00	0.00
Interior Lighting	12225.14	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	9187.64	966.50	0.00	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Fans	745.09	0.00	0.00	0.00	0.00	0.00
Pumps	5015.56	0.00	0.00	0.00	0.00	0.00
Heat Rejection	1934.39	0.00	0.00	0.00	0.00	32557.47
Humidification	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00	0.00
Total End Uses	33843.17	19025.99	0.00	0.00	0.00	32557.47

Note: Natural gas appears to be the principal heating source based on energy usage.

End Uses By Subcategory

	Subcategory	Electricity [GJ]	Natural Gas [GJ]	Other Fuel [GJ]	District Cooling [GJ]	District Heating [GJ]	Water [m3]
Heating	Boiler	0.00	18059.49	0.00	0.00	0.00	0.00
	Boiler Parasitic	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	General	4735.36	0.00	0.00	0.00	0.00	0.00
Interior Lighting	General	1512.38	0.00	0.00	0.00	0.00	0.00
	Lights	10712.76	0.00	0.00	0.00	0.00	0.00
Exterior Lighting	General	0.00	0.00	0.00	0.00	0.00	0.00
Interior Equipment	General	919.37	966.50	0.00	0.00	0.00	0.00
	ElectricEquipment	8268.27	0.00	0.00	0.00	0.00	0.00
Exterior Equipment	General	0.00	0.00	0.00	0.00	0.00	0.00
Fans	General	745.09	0.00	0.00	0.00	0.00	0.00
Pumps	General	5015.56	0.00	0.00	0.00	0.00	0.00
Heat Rejection	General	1934.39	0.00	0.00	0.00	0.00	32557.47
Humidification	General	0.00	0.00	0.00	0.00	0.00	0.00
Heat Recovery	General	0.00	0.00	0.00	0.00	0.00	0.00
Water Systems	General	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration	General	0.00	0.00	0.00	0.00	0.00	0.00
Generators	General	0.00	0.00	0.00	0.00	0.00	0.00

Report: **Source Energy End Use Components Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 Values gathered over 8760.00 hours**

Source Energy End Use Components Summary

	Source Electricity [GJ]	Source Natural Gas [GJ]	Source Other Fuel [GJ]	Source District Cooling [GJ]	Source District Heating [GJ]
Heating	0.00	19576.49	0.00	0.00	0.00
Cooling	14996.88	0.00	0.00	0.00	0.00
Interior Lighting	38717.03	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	29097.25	1047.69	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	2359.69	0.00	0.00	0.00	0.00
Pumps	15884.27	0.00	0.00	0.00	0.00
Heat Rejection	6126.20	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	107181.31	20624.18	0.00	0.00	0.00

Normalized Metrics

Source Energy End Use Components Per Conditioned Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.43	0.00	0.00	0.00
Cooling	233.22	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.70	0.00	0.00	0.00	0.00
Pumps	247.02	0.00	0.00	0.00	0.00
Heat Rejection	95.27	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1666.77	320.73	0.00	0.00	0.00

Report: **Climatic Data Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 SizingPeriod:DesignDay**

	Maximum Dry Bulb [C]	Daily Temperature Range [deltaC]	Humidity Value	Humidity Type	Wind Speed [m/s]	Wind Direction
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DB=>MWB	33.30	10.50	23.70	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS DP=>MDB	28.90	10.50	23.80	Dewpoint [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS WB=>MDB	31.20	10.50	25.50	Wetbulb [C]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG WIND 99.6% CONDNS WS=>MCDB	-3.50	0.00	-3.50	Wetbulb [C]	12.40	270.00
CHICAGO OHARE INTL AP ANN HUM_N 99.6% CONDNS DP=>MCDB	-19.20	0.00	-25.70	Dewpoint [C]	4.90	270.00
CHICAGO OHARE INTL AP ANN CLG .4% CONDNS ENTH=>MDB	31.40	10.50	79200.00	Enthalpy [J/kg]	5.20	230.00
CHICAGO OHARE INTL AP ANN HTG 99.6% CONDNS DB	-20.00	0.00	-20.00	Wetbulb [C]	4.90	270.00

Source Energy End Use Components Per Total Floor Area

	Source Electricity [MJ/m2]	Source Natural Gas [MJ/m2]	Source Other Fuel [MJ/m2]	Source District Cooling [MJ/m2]	Source District Heating [MJ/m2]
Heating	0.00	304.43	0.00	0.00	0.00
Cooling	233.22	0.00	0.00	0.00	0.00
Interior Lighting	602.09	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00
Interior Equipment	452.49	16.29	0.00	0.00	0.00
Exterior Equipment	0.00	0.00	0.00	0.00	0.00
Fans	36.70	0.00	0.00	0.00	0.00
Pumps	247.02	0.00	0.00	0.00	0.00
Heat Rejection	95.27	0.00	0.00	0.00	0.00
Humidification	0.00	0.00	0.00	0.00	0.00
Heat Recovery	0.00	0.00	0.00	0.00	0.00
Water Systems	0.00	0.00	0.00	0.00	0.00
Refrigeration	0.00	0.00	0.00	0.00	0.00
Generators	0.00	0.00	0.00	0.00	0.00
Total Source Energy End Use Components	1666.77	320.73	0.00	0.00	0.00

Report: **Equipment Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 Central Plant**

	Type	Nominal Capacity [W]	Nominal Efficiency [W/W]	IPLV in SI Units [W/W]	IPLV in IP Units [Btu/W-h]
BOILER HOT WATER 1	Boiler:HotWater	8002742.73	0.80		
CHILLER ELECTRIC EIR 1	Chiller:Electric:EIR	12319728.24	5.50		
COOLING TOWER SINGLE SPEED 1	CoolingTower:SingleSpeed	11598632.87			

Cooling Coils

	Type	Nominal Total Capacity [W]	Nominal Sensible Capacity [W]	Nominal Latent Capacity [W]	Nominal Sensible Heat Ratio	Nominal Efficiency [W/W]	Nominal Coil UA Value [W/C]	Nominal Coil Surface Area [m2]
COIL COOLING WATER 1	Coil:Cooling:Water	9392500.18	6007241.59	3385258.51	0.64	-	969114.57	9829.30

Fans

	Type	Total Efficiency [W/W]	Delta Pressure [pa]	Max Air Flow Rate [m3/s]	Rated Electric Power [W]	Rated Power Per Max Air Flow Rate [W-s/m3]	Motor Heat In Air Fraction	End Use
FAN VARIABLE VOLUME 1	Fan:VariableVolume	0.60	500.00	300.88	248866.60	827.13	1.00	General

Pumps

	Type	Control	Head [pa]	Water Flow [m3/s]	Electric Power [W]	Power Per Water Flow Rate [W-s/m3]	Motor Efficiency [W/W]
PUMP VARIABLE SPEED 2	Pump:VariableSpeed	Intermittent	179352.00	0.4400	112422.57	255487.18	0.90
PUMP VARIABLE SPEED 1	Pump:VariableSpeed	Intermittent	179352.00	0.1732	44247.24	255487.18	0.90
PUMP VARIABLE SPEED 3	Pump:VariableSpeed	Intermittent	179352.00	0.6221	158932.74	255487.18	0.90

System Design Air Flow Rates

	Calculated cooling [m3/s]	User cooling [m3/s]	Calculated heating [m3/s]	User heating [m3/s]
VAV WITH REHEAT	300.88	300.88	136.49	136.49

Report: **Object Count Summary**

For: **Entire Facility**

Timestamp: **2013-05-30 22:17:36 Surfaces by Class**

	Total	Outdoors
Wall	800	320
Floor	200	5
Roof	200	5
Internal Mass	0	0
Building Detached Shading	150	150
Fixed Detached Shading	0	0
Window	320	320
Door	0	0
Glass Door	0	0
Shading	650	650
Overhang	0	0
Fin	0	0
Tubular Daylighting Device Dome	0	0
Tubular Daylighting Device Diffuser	0	0

HVAC

	Count
HVAC Air Loops	1
Conditioned Zones	200
Unconditioned Zones	0
Supply Plenums	0
Return Plenums	0

Input Fields

	Count
IDF Objects	5727
Defaulted Fields	5060
Fields with Defaults	14829
Autosized Fields	1040
Autosizable Fields	1267
Autocalculated Fields	4448
Autocalculatable Fields	4448

Annual and Peak Values - Gas

	Gas Annual Value [GJ]	Gas Minimum Value [W]	Timestamp of Minimum	Gas Maximum Value [W]	Timestamp of Maximum
Gas:Facility	19025.99	4030.36	10-MAR-24:00	5331057.97	26-JAN-23:00
Gas:Building	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
InteriorEquipment:Gas:Zone:THERMAL ZONE 16	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
General:InteriorEquipment:Gas	966.50	4030.36	01-JAN-01:00	60455.35	01-JAN-17:00
Gas:Plant	18059.49	0.00	23-FEB-23:00	5310906.18	26-JAN-23:00
Heating:Gas	18059.49	0.00	23-FEB-23:00	5310906.18	26-JAN-23:00
Boiler:Heating:Gas	18059.49	0.00	23-FEB-23:00	5310906.18	26-JAN-23:00

Annual and Peak Values - Cooling

	Cooling Annual Value [GJ]	Cooling Minimum Value [W]	Timestamp of Minimum	Cooling Maximum Value [W]	Timestamp of Maximum
PlantLoopCoolingDemand:Facility	21773.75	-3.07	07-JAN-06:00	4166739.11	17-JUL-15:00
PlantLoopCoolingDemand:HVAC	21773.75	-3.07	07-JAN-06:00	4166739.11	17-JUL-15:00
CoolingCoils:PlantLoopCoolingDemand	21773.75	-3.07	07-JAN-06:00	4166739.11	17-JUL-15:00

Annual and Peak Values - Water

	Annual Value [m3]	Minimum Value [m3/s]	Timestamp of Minimum	Maximum Value [m3/s]	Timestamp of Maximum
Water:Facility	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00
Water:Plant	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:Water	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Facility	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00
MainsWater:Plant	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00
HeatRejection:MainsWater	32557.47	0.00	01-JAN-01:00	0.01	17-APR-18:00

Annual and Peak Values - Other by Weight/Mass

	Annual Value [kg]	Minimum Value [kg/s]	Timestamp of Minimum	Maximum Value [kg/s]	Timestamp of Maximum
Carbon Equivalent:Facility	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00
CarbonEquivalentEmissions:Carbon Equivalent	0.00	0.000	01-JAN-01:00	0.000	01-JAN-01:00

Branch

	Maximum Flow Rate [m3/s]
BRANCH {E7520E46-0D00-4114-8F2D-27F168F4F24C}	300.88

AirLoopHVAC

	Design Supply Air Flow Rate [m3/s]
VAV WITH REHEAT	300.88

Controller:OutdoorAir

	Maximum Outdoor Air Flow Rate [m3/s]	Minimum Outdoor Air Flow Rate [m3/s]
CONTROLLER OUTDOOR AIR 1	300.88	40.31

Coil:Cooling:Water

	Design Water Flow Rate [m3/s]	Design Air Flow Rate [m3/s]	Design Inlet Air Temperature [C]	Design Outlet Air Temperature [C]	Design Inlet Water Temperature [C]	Design Inlet Air Humidity Ratio	Design Outlet Air Humidity Ratio
COIL COOLING WATER 1	0.440032	300.88	30.71	12.80	7.22	0.014966	0.008500

Fan:VariableVolume

	Maximum Flow Rate [m3/s]
FAN VARIABLE VOLUME 1	300.88

Controller:WaterCoil

	Maximum Actuated Flow [m3/s]	Controller Convergence Tolerance
CONTROLLER WATER COIL 2	0.440032	0.000001
CONTROLLER WATER COIL 1	0.076000	0.000006

Boiler:HotWater

	Nominal Capacity [W]	Design Water Flow Rate [m3/s]
BOILER HOT WATER 1	8002742.73	0.173188

PlantLoop

	Maximum Loop Flow Rate [m3/s]	Plant Loop Volume [m3]
HOT WATER LOOP	0.173188	779.34
CHILLED WATER LOOP	0.440032	1980.14
CONDENSER WATER LOOP	0.622077	2799.35

Chiller:Electric:EIR

	Reference Chilled Water Flow Rate [m3/s]	Reference Capacity [W]	Reference Condenser Water Flow Rate [m3/s]
CHILLER ELECTRIC EIR 1	0.440032	12316728.24	0.622077

CoolingTower:SingleSpeed

	Design Water Flow Rate [m3/s]	Fan Power at Design Air Flow Rate [W]	Design Air Flow Rate [m3/s]	U-Factor Times Area Value at Design Air Flow Rate [W/C]	Air Flow Rate in Free Convection Regime [m3/s]	U-Factor Times Area Value at Free Convection Air Flow Rate [W/C]
COOLING TOWER SINGLE SPEED 1	0.622077	152876.63	412.03	879716.88	41.20	87971.69

Pump:VariableSpeed

	Rated Flow Rate [m3/s]	Rated Power Consumption [W]
PUMP VARIABLE SPEED 2	0.440032	112422.57
PUMP VARIABLE SPEED 1	0.173188	44247.24
PUMP VARIABLE SPEED 3	0.622077	158931.74

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY**

For: **Meter**

Timestamp: **2013-05-30 22:17:36**

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY [J]	PUMPS:ELECTRICITY [J]	HEATING:ELECTRICITY [J]	COOLING:ELECTRICITY [J]	HEATREJECTION:ELECTRICITY [J]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	0.103863E+13	0.00	0.779619E+12	0.00	0.608374E+11	0.244836E+12	0.00	0.811604E+10	0.129294E+10	0.00	0.00	0.00	0.00
February	0.937190E+12	0.00	0.704536E+12	0.00	0.549523E+11	0.383628E+12	0.00	0.300953E+11	0.138720E+11	0.00	0.00	0.00	0.00
March	0.102849E+13	0.00	0.779324E+12	0.00	0.597179E+11	0.438557E+12	0.00	0.899300E+11	0.481010E+11	0.00	0.00	0.00	0.00
April	0.102043E+13	0.00	0.761963E+12	0.00	0.601182E+11	0.422151E+12	0.00	0.298657E+12	0.139499E+12	0.00	0.00	0.00	0.00
May	0.100304E+13	0.00	0.768817E+12	0.00	0.636437E+11	0.441728E+12	0.00	0.303223E+12	0.222284E+12	0.00	0.00	0.00	0.00
June	0.102042E+13	0.00	0.761863E+12	0.00	0.657263E+11	0.438088E+12	0.00	0.776022E+12	0.283183E+12	0.00	0.00	0.00	0.00
July	0.106203E+13	0.00	0.780527E+12	0.00	0.727837E+11	0.463754E+12	0.00	0.978696E+12	0.335726E+12	0.00	0.00	0.00	0.00
August	0.100304E+13	0.00	0.768817E+12	0.00	0.673772E+11	0.456317E+12	0.00	0.882806E+12	0.324191E+12	0.00	0.00	0.00	0.00
September	0.102042E+13	0.00	0.761863E+12	0.00	0.610437E+11	0.432874E+12	0.00	0.697851E+12	0.290138E+12	0.00	0.00	0.00	0.00
October	0.103863E+13	0.00	0.779619E+12	0.00	0.600690E+11	0.433374E+12	0.00	0.308248E+12	0.187719E+12	0.00	0.00	0.00	0.00
November	0.986813E+12	0.00	0.748261E+12	0.00	0.578510E+11	0.420763E+12	0.00	0.170745E+12	0.846805E+11	0.00	0.00	0.00	0.00
December	0.106203E+13	0.00	0.780527E+12	0.00	0.604857E+11	0.435388E+12	0.00	0.957028E+10	0.369222E+10	0.00	0.00	0.00	0.00
Annual Sum or Average	0.122251E+14	0.00	0.918764E+13	0.00	0.745066E+12	0.501558E+13	0.00	0.473536E+13	0.183439E+13	0.00	0.00	0.00	0.00
Minimum of Months	0.937190E+12	0.00	0.704536E+12	0.00	0.549523E+11	0.244836E+12	0.00	0.811604E+10	0.129294E+10	0.00	0.00	0.00	0.00
Maximum of Months	0.106203E+13	0.00	0.780527E+12	0.00	0.727837E+11	0.463754E+12	0.00	0.978696E+12	0.335726E+12	0.00	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS**

For: **Meter**

Timestamp: **2013-05-30 22:17:36**

	INTERIOREQUIPMENT:GAS [J]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS [J]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	0.820863E+11	0.00	0.427085E+13	0.00	0.00	0.00
February	0.741424E+11	0.00	0.323831E+13	0.00	0.00	0.00
March	0.820863E+11	0.00	0.183877E+13	0.00	0.00	0.00
April	0.794383E+11	0.00	0.983851E+12	0.00	0.00	0.00
May	0.820863E+11	0.00	0.334667E+12	0.00	0.00	0.00
June	0.794383E+11	0.00	0.121415E+12	0.00	0.00	0.00
July	0.820863E+11	0.00	0.656477E+11	0.00	0.00	0.00
August	0.820863E+11	0.00	0.121360E+12	0.00	0.00	0.00
September	0.794383E+11	0.00	0.265955E+12	0.00	0.00	0.00
October	0.820863E+11	0.00	0.793638E+12	0.00	0.00	0.00
November	0.794383E+11	0.00	0.208187E+13	0.00	0.00	0.00
December	0.820863E+11	0.00	0.394317E+13	0.00	0.00	0.00
Annual Sum or Average	0.966500E+12	0.00	0.180599E+14	0.00	0.00	0.00
Minimum of Months	0.741424E+11	0.00	0.656477E+11	0.00	0.00	0.00
Maximum of Months	0.820863E+11	0.00	0.427085E+13	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-30 22:17:36**

	ELECTRICITY:FACILITY {Maximum}[W]	ELECTRICITY:FACILITY {TIMESTAMP}	INTERIORLIGHTS:ELECTRICITY {AT MAX/MIN} [W]	EXTERIORLIGHTS:ELECTRICITY [Invalid/Undefined]	INTERIOREQUIPMENT:ELECTRICITY {AT MAX/MIN} [W]	EXTERIOREQUIPMENT:ELECTRICITY [Invalid/Undefined]	FANS:ELECTRICITY {AT MAX/MIN} [W]	PUMPS:ELECTRICITY {AT MAX/MIN} [W]	HEATING:ELECTRICITY {AT MAX/MIN} [W]	COOLING:ELECTRICITY {AT MAX/MIN} [W]	HEATREJECTION:ELECTRICITY {AT MAX/MIN} [W]	HUMIDIFIER:ELECTRICITY [Invalid/Undefined]	HEATRECOVERY:ELECTRICITY [Invalid/Undefined]	WATERSYSTEMS:ELECTRICITY [Invalid/Undefined]	COGENERATION:ELECTRICITY [Invalid/Undefined]
January	1678292.45	21-JAN-16:00	870572.58	0.00	475299.57	0.00	22572.78	163986.53	0.00	145861.00	0.00	0.00	0.00	0.00	0.00
February	1809306.65	11-FEB-16:00	870572.58	0.00	475299.57	0.00	22827.70	162382.68	0.00	125347.49	152876.63	0.00	0.00	0.00	0.00
March	2018993.03	27-MAR-15:00	870572.58	0.00	475299.57	0.00	27383.90	168255.03	0.00	324605.32	152876.63	0.00	0.00	0.00	0.00
April	2114054.72	16-APR-15:00	870572.58	0.00	475299.57	0.00	57641.44	179282.20	0.00	378382.31	152876.63	0.00	0.00	0.00	0.00
May	2103956.55	05-MAY-13:00	870572.58	0.00	464638.90	0.00	47126.92	184123.86	0.00	384617.67	152876.63	0.00	0.00	0.00	0.00
June	2181747.18	08-JUN-12:00	870572.58	0.00	464638.90	0.00	43047.29	185136.46	0.00	509707.25	108644.71	0.00	0.00	0.00	0.00
July	2218660.42	16-JUL-15:00	870572.58	0.00	475299.57	0.00	66207.58	189350.72	0.00	564353.35	152876.63	0.00	0.00	0.00	0.00
August	2203667.36	04-AUG-15:00	870572.58	0.00	475299.57	0.00	53269.64	188839.97	0.00	575048.52	140637.07	0.00	0.00	0.00	0.00
September	2086650.45	11-SEP-15:00	870572.58	0.00	475299.57	0.00	45217.61	175998.81	0.00	366685.16	152876.63	0.00	0.00	0.00	0.00
October	2068658.35	01-OCT-15:00	870572.58	0.00	475299.57	0.00	31865.08	171359.33	0.00	366685.16	152876.63	0.00	0.00	0.00	0.00
November	2060345.62	03-NOV-16:00	870572.58	0.00	475299.57	0.00	25258.27	169653.41	0.00	366685.16	152876.63	0.00	0.00	0.00	0.00
December	1706225.25	07-DEC-16:00	870572.58	0.00	475299.57	0.00	22611.18	161717.32	0.00	91897.58	84127.03	0.00	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00						0.00	0.00	0.00	0.00
Minimum of Months	1678292.45		870572.58	0.00	464638.90	0.00	22572.78	161717.32	0.00	91897.58	0.00	0.00	0.00	0.00	0.00
Maximum of Months	2218660.42		870572.58	0.00	475299.57	0.00	66207.58	189350.72	0.00	575048.52	152876.63	0.00	0.00	0.00	0.00

Report: **BUILDING ENERGY PERFORMANCE - NATURAL GAS PEAK DEMAND**

For: **Meter**

Timestamp: **2013-05-30 22:17:36**

	GAS:FACILITY [Maximum] [W]	GAS:FACILITY {TIMESTAMP}	INTERIOREQUIPMENT:GAS {AT MAX/MIN} [W]	EXTERIOREQUIPMENT:GAS [Invalid/Undefined]	HEATING:GAS {AT MAX/MIN} [W]	COOLING:GAS [Invalid/Undefined]	WATERSYSTEMS:GAS [Invalid/Undefined]	COGENERATION:GAS [Invalid/Undefined]
January	5331057.97	28-JAN-22:00	20151.78	0.00	5310906.18	0.00	0.00	0.00
February	4850018.57	06-FEB-22:00	20151.78	0.00	4829886.79	0.00	0.00	0.00
March	3625469.33	02-MAR-06:00	20151.78	0.00	3605317.55	0.00	0.00	0.00
April	3211034.78	06-APR-05:00	20151.78	0.00	3190882.99	0.00	0.00	0.00
May	2049993.12	11-MAY-05:00	20151.78	0.00	2025841.34	0.00	0.00	0.00
June	1383493.74	24-JUN-05:00	20151.78	0.00	1365341.96	0.00	0.00	0.00
July	1001102.81	03-JUL-05:00	20151.78	0.00	980951.03	0.00	0.00	0.00
August	1757345.09	17-AUG-05:00	20151.78	0.00	1737193.31	0.00	0.00	0.00
September	2529094.92	14-SEP-05:00	20151.78	0.00	2504845.14	0.00	0.00	0.00
October	2753490.32	19-OCT-05:00	20151.78	0.00	2733338.54	0.00	0.00	0.00
November	3928941.08	25-NOV-23:00	10075.89	0.00	3916865.19	0.00	0.00	0.00
December	4813898.87	29-DEC-23:00	10075.89	0.00	4801822.98	0.00	0.00	0.00
Annual Sum or Average				0.00		0.00	0.00	0.00
Minimum of Months	1001102.81		10075.89	0.00	980951.03	0.00	0.00	0.00
Maximum of Months	5331057.97		20151.78	0.00	5310906.18	0.00	0.00	0.00