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BIOMIMICRY: A SOURCE FOR ARCHITECTURAL INNOVATION IN EXISTING BUILDINGS

Thomas Button

ROCHESTER INSTITUTE OF TECHNOLOGY
Golisano Institute for Sustainability
Thesis for Master of Architecture
Department of Architecture
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Committee Approval:

Dennis A. Andrejko, FAIA Date

Associate Professor and Head, Department of Architecture

Julius Chiavaroli, AIA Date

Professor, Department of Architecture

Gregory Babbitt Date

Assistant Professor, College of Science

Abstract

Today designers, manufacturers and industries are seeking to find sustainable solutions to improve design processes and products that will reduce their environmental impacts. However, they often develop architecture in counterproductive ways by investing time and resources into unproven novel solutions. Yet, there are often better solutions, through biomimicry, that identify successful adaptations found in the natural environment and in biology that can serve to better inform design solutions. Through an in depth investigation of biomimicry, several design strategies are identified, and through a selective process, a few select examples are applied to a renovation of an existing headquarters for the New York State Department of Conservation, (NYSDEC), to create a more efficient, and sustainable building. This introduces a problem, commonly found in the existing building stock, that through re-using an existing building the methods to create a better building design are limited by what already exists. In addition to the proposed design continuing to serve as an environmental conservation office, it now also serves as an example of the applications of biomimicry to the re-design of existing buildings. The focus of this thesis suggests uses of biomimicry solutions derived from plants, bacteria, and other organisms through their natural cycles in order to weigh biomimicry as a possible solution to reaching the goals of the "2030 Challenge." Furthermore, biomimicry solutions for water, wind and solar collection, as well as response to light and waste management are presented throughout the possible solutions derived from cycles and functions found in nature. In addition, more common solutions derived from human intellectual thinking is used to find interior cosmetic, egress, plumbing and daylighting solutions.

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1.0 – Introduction

Sustainable design is a leading practice in today's society for services, consumer goods and more in response to the overwhelming evidence that suggests global climate change. The built environment is at the forefront of the discussion on how to reduce the environmental impact on the earth and its inhabitants. In an attempt to reduce the impact of the built environment there is a significant effort being made to change the way it is designed and constructed. This effort ranges from designing to maximize efficiency, using choice materials to changing construction practices in order to reduce the impact on the environment. There are several approaches being made in the design aspect, by designers, material manufacturers, building product suppliers and other members of the building industry, to help reduce this impact and be more sustainable. There are technology based solutions to maximize building efficiency and there are passive solutions to minimize the expense and impact of technologies by using more natural approaches of allowing nature to do the work. There is also the approach of using innovative natural methods that mimic the environment itself so as to minimize negative environmental impacts. We can find these approaches under a broad definition of ecological architecture, which is designing with the environment in mind by incorporating it into the design as well as preventing harm to the environment through alternative design and energy strategies. However; each of these approaches can be very different and could be a type of architecture of their own. Nature and the environment can provide the optimal solutions to the way the built environment is designed; it has had 3.8 billion years to evolve and learn what works as well as to optimize its performance.[1] The people involved in the built environment need to focus more on the past

[1] Benyus, Janine. 1997. *Biomimicry*. New York: William Morrow.

successes that can be found in nature and the environment to identify design solutions that will reduce the impacts upon it.

These design solutions are introduced through an approach known as biomimicry. The definition however is still often confused or unknown by people outside the science fields related to biology. There is a general consensus that biomimicry is the idea of using actual nature in design, and there is the argument, by others, particularly in the science fields, that biomimicry is merely the idea of using the natural design of nature and the environment to inspire our own design. From the accepted definition of biomimicry, by those who study and use it, it is the concept of mimicking biology, and is not necessarily using nature in design, but instead using it as a study model for design in an attempt to emulate it.[1,2] After identifying this definition of biomimicry, the conclusion could be drawn, by designers, manufacturers and more, that it has already been in practice for some time in the design of the built environment and is still developing. This conclusion can be made based on the use of sites and landscaping to create climate controlled zones for designs by mimicking nature's climate to create micro climates that are beneficial to a building's design and its users. Biomimicry can also be seen in examples of how we treat grey-water. There are more natural approaches that can clean water by creating systems that utilize stone, plants and bacteria to filter and clean it instead of using sewer systems and treatment plants. [3] These serve as great examples of the benefits that could come from designing through biomimicry.

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[2] Biomimicry 101. *Biomimicry.* http://biomimicry.org/what-is-biomimicry/#.VuDGOY-cGgk.
[3] Pawlyn, Michael. 2011. *Biomimicry in Architecture.* London: RIBA Publishing.

It is somewhat difficult to trace the origin of biomimicry due to the lack of its documentation. However, from the documentation and analysis that is available, evidence of biomimicry can be proven to have been in practice through Leonardo da Vinci, and may have been the inspiration for the first domes, which may have been designed based on eggs.[3] Leonardo da Vinci used nature and biology to inspire many of his designs and concepts during his time.[3] He used biomimicry in a unique way, by using it for ideas that had not been created before; he searched for understanding of anatomy and nature, which led to the design of concepts and machines that took inspiration from what he had been analyzing, such as his flying machines based on birds and flight.[4] However, the term biomimicry was not referenced in scientific literature until in 1962.[3] The practice, of using biomimicry for inspiration, first began to become popular in 1980 among material scientists who were seeking to redevelop materials based on mimicking nature to improve upon them and find new innovative approaches.[3] Today, the popularity of biomimicry is still growing and biologist Janine Benyus has been strongly emphasizing its use in architecture, engineering and other innovative fields through material alternatives and much more, along with its benefits and uses, through her publications, lectures, and teachings, leading to a growing interest.[1]

Biomimicry is applicable to many aspects of the architectural, engineering, and material development fields, such as building design, structure, materials and more. The uses for biomimicry have varied, however they all have had the same goal, which is to find answers and

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[4] Kapeleris, John. 2012. "Biomimicry – Design and Innovation Inspired by Nature." *John Kapeleris.* January 18th. http://johnkapeleris.com/blog/?p=1399

solutions through emulating nature. Scientific research has been conducted in the field to find solutions for material developments such as, adhesives.[5] For example, through studying natural adhesion found through a gecko, new adhesives have been developed.[5] In addition, the idea of suction cups also mimics similar ideas found in nature, like that of the suckers on an octopus.[6]

In architecture, biomimicry can be applied to improve the way the built environment is designed, through site work, construction, and daily operations, and to reduce the impact it has upon the natural environment through numerous strategies of reducing carbon emissions, waste and more. There are vast amounts of knowledge and ideas available to inform possible solutions to architectural design that will also allow designs to be more sustainable. In addition, there are several people involved in the field of biomimicry that have provided insight on the subject and the number is growing as it is becoming more popular among designers looking to a more sustainable future. In architectural design, there are several examples of biomimicry that can be found; although, many of these examples use it in different ways, and it is often considered not to be a total design solution but rather as a solution to a particular aspect of design.

Michael Pawlyn, an architect that uses biomimicry, has identified several ways in which biomimicry can be applied to architectural design; such as, in his book, "Biomimicry in Architecture," he identifies applications for water management, climate control, structural innovations, material developments, and energy production.[3] In addition, there are other forms of biomimicry; biomorphic, bio-utilization, and biophilia.[3] Biomorphic is the mimicking of natural

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[5] Hennighausen, Amelia, and Eric Roston. 2013. "14 Smart Inventions Inspired by Nature: Biomimicry." Bloomberg. Aug 19. http://www.bloomberg.com/slideshow/2013-08-18/14-smart-inventions-inspired-by-nature-biomimicry.html#slide12.
[6] "Suckers Allow Fine Attachment: Octopus." *Ask Nature.* http://www.asknature.org/strategy/a2a8d474a2a523727cad40d935dd3f79

forms such as designing a building to resemble the shape of a leaf.[3] Bio-utilization is the more direct use of nature for beneficial purposes such as using trees on a site to provide shading for windows.[3] Finally, biophilia is the idea that there is an instinctive bond between human beings and other living organisms which inspires the use of plants to create a comforting environment.[3] Thus, biomimicry, in the terms of architecture and use for this thesis, is the emulating of biological forms, processes and systems found in nature to produce architectural solutions that could be used for sustainable solutions.[3]

Examples of biomimicry in architecture exist in different forms, such as using biomorphic forms, which is the design of a building form that captures a form found in nature. An example of this is the TWA terminal, by Eero Saarinen, at the John F Kennedy Airport in New York, where the building form represents wings and flight.[3] The columns in the Johnson Wax building by Frank Lloyd Wright, which bear the appearance of water lilies, are another example of this.[3] Other, more purposeful, methods of using nature for inspiration exist. For example, the structure of the Palazzetto dello Sport, by Pier-Luigi Nervi, uses a ceiling structure that resembles a giant Amazon lily using ribbing to support itself which allows for a thinner and lighter roof.[3] Furthermore, there are uses of biomimicry in structures that actually use nature.[3] An example of this is the use of air to create structures, such as that in the Douglas River Bridge by Exploration, which uses hollow structures filled with pressurized air to create a stiffened structure.[3] These are but a few of the examples that exist that exemplify biomimicry, there are more that exist; however, as mentioned, not many of these designs use biomimicry as a total design solution, but rather as a component of a larger element or design.

The purpose of this thesis does not intend that biomimicry be a total design solution on its own; rather the design can involve improving portions of an existing building focusing on key

aspects to improve it. This presents the renovation and redesign of the existing building stock. Thus, this asserts that they are critical and essential in advancing sustainability in the built environment. The existing building stock consists of a large majority of structures that were built during a period that did not show concern for the environment and during a time that typically could not achieve the efficiencies of buildings built today. This poses a great concern to the built environment and future efficiency goals for developing carbon neutral buildings by 2030, which is the goal and purpose of the "2030 Challenge.[7]" The existing building stock needs to be brought up to this goal that is set by the challenge, which is to make all new buildings, developments, and major renovations carbon-neutral by 2030, however this can only be achieved in two ways.[7] The existing building stock can be demolished and rebuilt to be more efficient, or it can be renovated and improved to meet the standards. In an effort to be more sustainable and environmentally friendly, the optimal choice would be to focus on renovating and improving the existing building stock to avoid sending all the demolition debris to landfills. In doing so, waste streams can be minimized and the demand for new materials and their associated manufacturing processes can be reduced to minimize carbon footprints of buildings. In addition, project costs can be reduced by reusing materials. Keeping this in mind, following the optimal choice of renovation, these renovations are pursued through the use of biomimicry to emulate nature and create innovative solutions to be applied to existing buildings in order to improve upon their efficiency and impact on the environment.

[7] "The 2030 Challenge." *Architecture 2030*. http://architecture2030.org/2030_challenges/2030-challenge/

2.0 – Problem Statement

In today's design world, there are few designs with an ecological goal that have attempted to find solutions to design problems by mimicking nature. Those that have generally do not provide any educational benefit of teaching others about biomimicry or its applications. Furthermore, without being identified, most people, even designers, may not realize or make the correlation that the design attempts to mimic nature. Although architectural design does not commonly use the mimicking of nature as a design process, it has been used in the determination of alternative materials, such as adhesives and fibers. Biomimicry can offer several solutions to the way we design architecture, including: efficiency of structures, material manufacturing, zero-waste systems, water management, control of thermal environment, and energy production.[3]

With today's efforts to advance sustainably, in built environments, there needs to be a knowledge base of successful attempts of solving design issues, by mimicking nature, so that these design practices may be shared as to educate others. The knowledge bases that are available today are more conceptually based and in need of development and guidelines for practice. Typically, these conceptual ideas involve the identification of an element or process found in nature that could be used in design; however, they often do not describe a method or means to incorporate such ideas. Since the field of biomimicry is so seldom used in design, there are few technologies or practices to use or follow. Therefore, the next steps in the practice of biomimicry would be to take such concepts and develop them further into useable design practices and mock up models to test them as possible design solutions. Fortunately, not all of these concepts are unused, there have been some successful implementations of biomimicry in architecture. Some of these are quite obvious, while others require some thought to find the correlation between nature and the idea. However, in order for biomimicry to become a possible

solution to architectural problems, there needs to be more research on the subject and more testing and use of inspired ideas to develop the field. Information needs to be made available of the process of using biomimicry for design and how it can be beneficial to design so that others can be motivated and inspired with ideas for its applications to further expand its use.

Going beyond sustainability toward the next step, there is a greater issue that is becoming more apparent and time pressing every year; which is the "2030 Challenge." As time moves on, the ideal goal of having a carbon neutral future by 2030 is approaching.[7] As part of the "2030 Challenge," in an attempt to guide a progression of improvements, a series of benchmarks have been established, as shown in Figure 1.[7] As of the current benchmark period, designs are supposed to aim to reduce fossil fuel consumption by 70%, by 2020 the consumption is supposed to be reduced by 80%, 90% by 2025 and 100%, carbon neutral, by 2030.[7] The United States federal government has already adopted the challenge and governmental facilities are being upheld to this goal and are following the benchmark points of the "2030 Challenge.[7]"

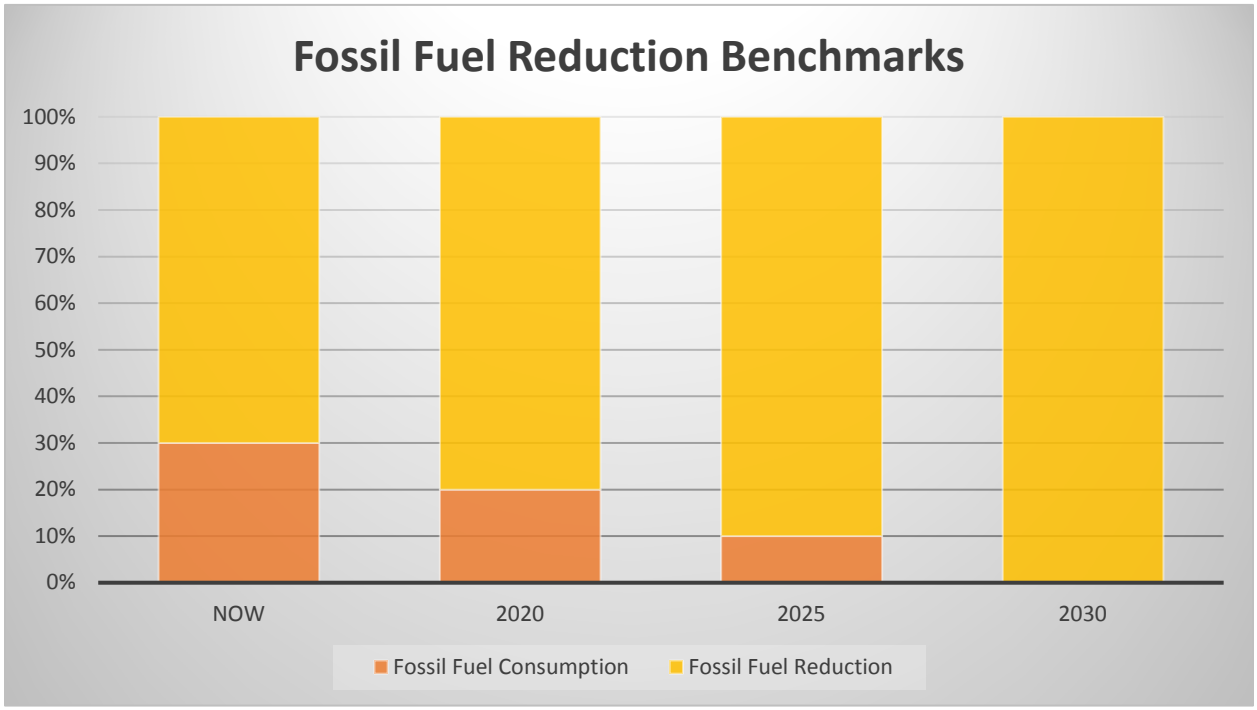

Figure 1 - 2030 Challenge Benchmarks.[7]

Even deeper into the issue of the approaching "2030 Challenge," there is an additional issue concerning the existing building stock. As part of the "2030 Challenge," it calls for new buildings and major renovations to meet the challenge and its challenges. Many new designs are being built every year in an attempt to create new designs that are better than their predecessors and showcase different approaches to create more efficient buildings. However, no matter how many new, efficient, zero energy and sustainable buildings we build in order to address future design goals and challenges, the existing building stock will still be there. Alongside continuing these advancements in new building designs, there needs to be improvements and advancements made to the existing building stock since that poses a greater challenge since applicable solutions are not as easily identified. In addition, many of the solutions found through exploring redesigns of existing buildings may aid in creating ideas and solutions for new buildings. As part of this thesis, biomimicry is used to meet these benchmarks; although, it is not the sole emphasis of the design solution as some aspects of designing would require more significant and in depth research to find solutions.

In the United States, the building stock has a 72 percent occupancy of existing buildings that are more than 20 years old, and 80 percent are 15 years or older.[8,9] According to Figure 2, as of 2012, only 12 percent of buildings were newer than 10 years old, leaving 88 percent of buildings greater than 10 years old.[10] Existing buildings in these age regions are more than likely to contain old outdated equipment, aging infrastructure, and inadequate operations resources.[8]

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[8] "Why Focus on Existing Buildings?" *Institute for Building Efficiency*. http://www.institutebe.com/Existing-Building-Retrofits/Why-Focus-On-Existing-Buildings.aspx
[9] "Existing Buildings." *Institute for Market Transformation.* http://www.imt.org/codes/existing-buildings
[10] "2012 CBECS Preliminary Results." *United States Energy Information Administration.* http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm

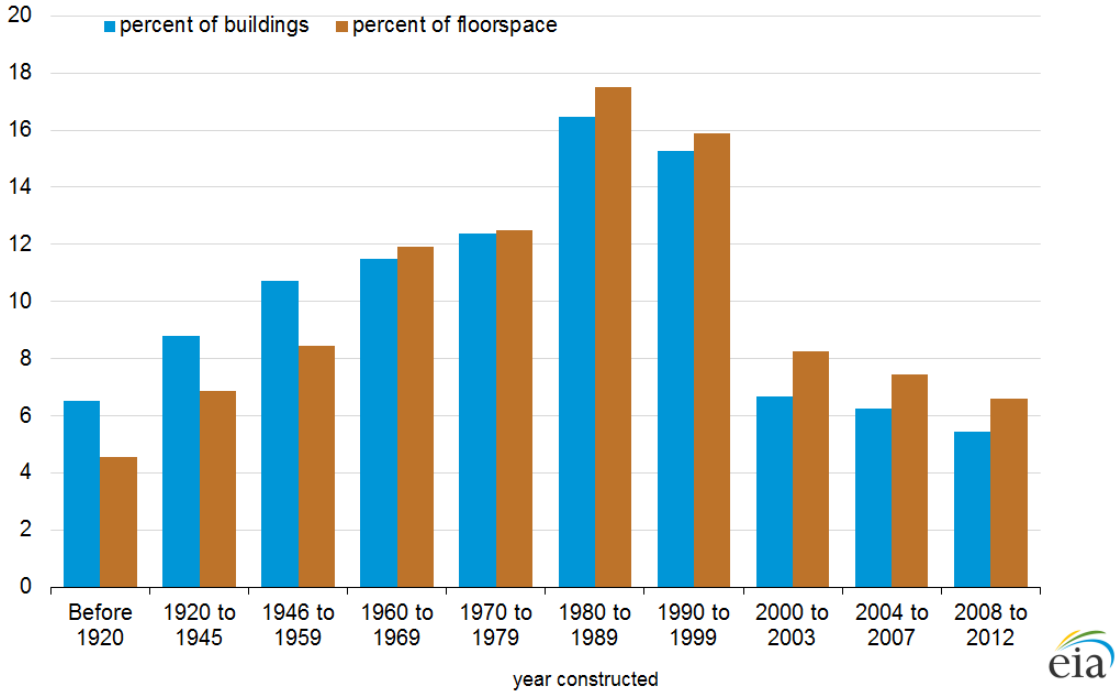

Figure 2 - Quantity of existing buildings by timeframe.[10]

Since the "2030 Challenge" bases the benchmark improvements off the average energy use in the country, existing buildings pose the fastest and most cost effective approach to achieving the benchmark goals.[7] It is more feasible to address existing buildings mainly due to the fact that the building is already constructed, therefore eliminating the costs of constructing a new building. Even if the building were in poor condition and needed to be rebuilt, the materials could be salvaged and save costs in new construction. With 80 percent of buildings being existing buildings that are 15 years old or older, new construction poses such a small percentage of buildings in the country.[9] Therefore, any new builds will have minimal effect upon the average energy consumed in the country due to them being only a small fraction. The fastest and greatest way to improve energy consumption in the country, with the most potential, would be to address the majority of the building stock, which is the existing building stock. Eliminating the highest energy consuming buildings in the country will result in a lower average energy consumption due to a narrowed spectrum between the highest and lowest consumers. Whereas constructing

new buildings that are more energy efficient than those before it only expands the gap between the energy consumption of existing and new buildings.

Furthermore, the most common existing building type that needs to be addressed is the office buildings, as shown in Figure 3, which is approximately 18% of the existing building stock.[10] Therefore, making the New York State Department of Environmental Conservation, (NYSDEC), Region 8 Headquarters the optimal choice to represent the application of biomimicry to existing buildings, which is seldom used for improving existing buildings, if ever. The facility also falls in the central portion of the age range of existing buildings, as shown earlier in Figure 2, having been designed in the early 1960's and built in 1970.[10] Also, with the NYSDEC being an organization for the environment it is even more influential and meaningful for the building to be updated with biomimicry to reduce its environmental impact.

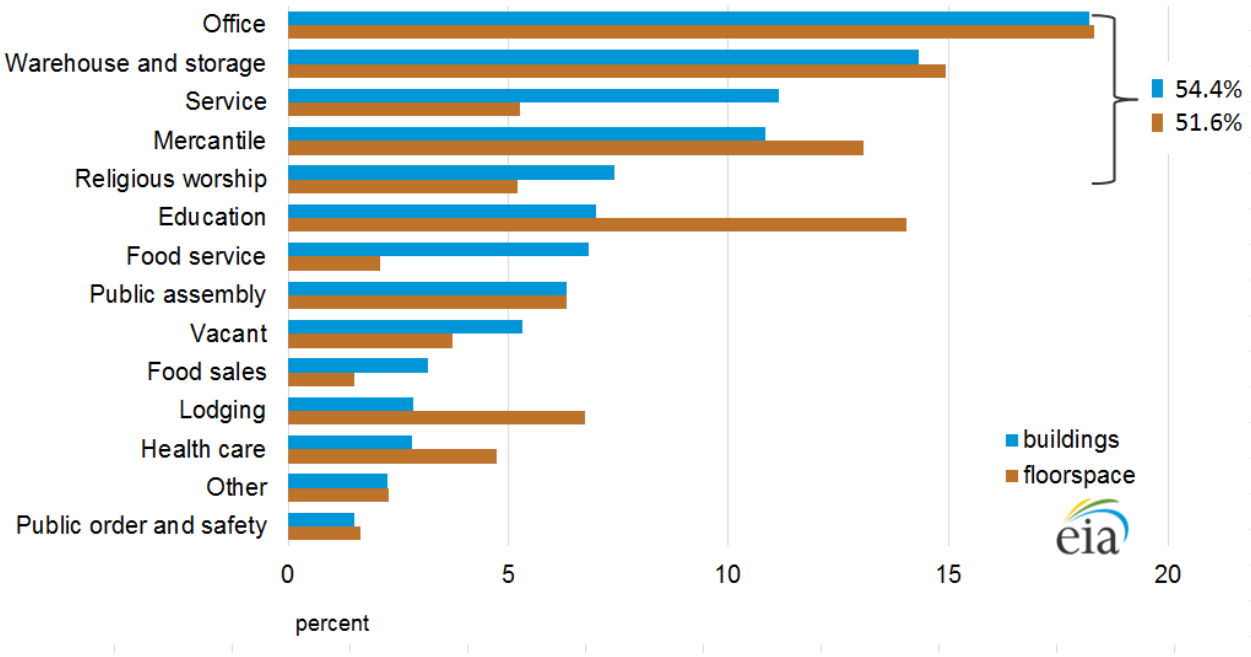

Figure 3 - Existing building stock percentages by type.[10]

Addressing biomimicry opportunities in existing buildings is challenging; there is no single solution since every building is different, especially when considering different regions

and climates. With biomimicry there are great opportunities as well as constraints with its application to existing buildings, as listed in Table 1 below. The condition, structure, orientation, size and more can greatly impact the choices for applications of biomimicry and the feasibility of those applications. When planning to address an existing building, the decision has to be made whether what currently stands is salvageable through an evaluation of its conditions and performance toward meeting code and enforcements upon the built environment. Consideration would also need to be given to whether or not what is salvageable can be brought up to standards or beyond, in order to reach future design goals. In some cases, salvageable elements of a building may have to be deconstructed so that something newer can replace it to meet future goals. With every existing building, before redesigning, the problem areas need to be identified to determine what needs to be improved or replaced.

Table 1 - Opportunities and Constraints of Using Biomimicry

Opportunities:	**Constraints:**
• Create natural materials/products that are less harmful to the environment. • Use materials more efficiently to reduce use and waste. • Create a healthier environment. • Can create building elements and systems that are adaptable. • Can improve efficiency and performance in areas of application.	• The technological availability to mimic nature and ability to do so. • The applicability of the element or system to the existing building. • The financial cost. • The ability of the building to support the element or system, structurally or otherwise. • The ability of the system or element to reach its maximum effectiveness. • The effect of the building context and climate on the element or system.

As outlined in Table 2, which is derived from the key energy efficiency contributing components of a building, there are aspects of a building that need to be checked and analyzed when addressing an existing building in an attempt to make it more sustainable and energy efficient. Typical checks would be for the thermal performance of building components as well as contribution to energy consumption. Structural stability is also considered to evaluate whether what exists is capable of supporting future design goals. As listed the components of the building envelope are the most important factors to address first as they are the most significant in an efficient building. Without an efficient thermal envelope, the most efficient HVAC systems will be pumping air into a space that cannot maintain a consistent temperature forcing the system to run longer and more often to maintain comfortable thermal levels; therefore, compromising the efficiency of the system. The next most important category is the mechanical, HVAC, system since these systems are predominantly the highest consumers of energy in a building, which is then preceded by electrical and lighting loads. Following up at the bottom of the list is the plumbing which is low in consumption compared to others but offers a potential cost saver for a project if the predominant water source can be located on site rather than paying for outside water sources. Plus, the water from the site and building could be cleaned on site to reduce impacts on the environment and need for cleaning later. The items listed in Table 2 are from a very broad look at the building, further and more in depth analysis may be necessary to achieve greater results in a building redesign.

Table 2 - What to check when planning to redesign an existing building.

Category:	**What to check:**
Thermal Envelope	
Floor	• Sufficient insulation. (heat gain/loss) • Structural stability.
Walls	• Sufficient insulation. (heat gain/loss) • Structural stability. • Air and water sealed.
Windows/Openings	• Thermally efficient. • Air and water sealed. • Heat gain/loss.
Roof	• Sufficient insulation and ventilation. • Structural stability. • Air and water sealed. • Thermally efficient.
Mechanical/HVAC	
	• Efficiency/energy consumption. • Energy source.
Electrical/Lighting	
	• Efficiency/energy consumption. • Energy source. • Light quality.
Plumbing	
	• Fixture efficiency/ consumption. • Water sources. • Water uses.

In the scenario presented by this thesis, one existing building in particular, the NYSDEC Region 8 Headquarters, is addressed to serve as an example toward finding a solution to improving the existing building stock through use of biomimicry to solve the previously discussed problems. This is a governmental building; therefore, the redesign of this building is

aimed toward meeting the benchmarks of the “2030 Challenge.” The results of a self-conducted analysis and gathering of information, from building personnel, of this particular building are as listed in Table 3. As it stands, the existing building presents a poor thermal envelope that has a significant issue with air leakage that makes it difficult to maintain the interior thermal environment. Furthermore, the building has an outdated, in-efficient and failing heating, ventilating, and air conditioning (HVAC) system, it originally was designed with packaged terminal air conditioner (PTAC) systems which were later replaced with newer ones after the previous had begun to fail, but the connection to the exterior vents remained with poor sealant work, creating yet another source for the air leaking from the building and heat loss via conduction. As a result, the redesign needs to address the thermal envelope, ventilation, and its internal HVAC as well as the associated energy and costs. The building’s thermal envelope is as designed in 1963, which consisted of little to no insulation and elements that bear little thermal value. The original windows had been replaced in a later renovation but the windows do not perform as they should, which resulted in degraded rated insulation values.

Table 3 - Existing building analysis of the NYSDEC Region 8 Headquarters

Category:	**Results:**
Thermal Envelope	
Floor	• Sufficiently insulated and partially submerged. • No structural issues. • No significant thermal gain/loss.
Walls	• Insufficiently insulated. • No leaks. • Significant heat gains in summer, and loss in winter.
Windows/Openings	• Do not meet the desired thermal rating. • Significant air leak at windows and infilled exterior vent locations. • Significant heat loss in winter.
Roof	• Insufficient insulation in attic.

	• No specified issue with air or water leaks. • No specified issues with ventilation. • Significant thermal loss in summer and winter.
Mechanical/HVAC	
	• Outdated/failing systems – could benefit from a newer efficient system. • Gas powered heating – could be supplemented with an alternative source.
Electrical/Lighting	
	• Mostly original fixtures with more efficient bulb replacements – could add daylighting and lighting controls to minimize usage. • City power supply – could be supplemented with alternative sources.
Plumbing	
	• Old fixtures – could be replaced with modern efficient low-flow fixtures. • Town water supply – could be supplemented with filtered water from on site. • Water is used for drinking and plumbing – could be reused for irrigation of site.

Beyond the general self-conducted analysis done for this thesis, a previous energy audit was conducted between 2010 and 2011, the specifications of the building and results are summarized in Table 4.[11] The building is a 31,440 square feet office building built in 1970 consisting of a basement, first floor, and partial second floor.[11] The results, concluded in the audit report, reiterate and further explain the results determined earlier in which the wall and roof are poorly insulated and are sources of air leaks in the building and that the HVAC systems and lighting are in need of replacement. Thus confirming that the listed areas of the building are in need of improvements and that through the exploration of biomimicry a possible solution could be derived.

[11] Wendel. "Comprehensive Energy Audit ASHRAE Level 2 Report: New York Power Authority in cooperation with the Department of Environmental Conservation."

Table 4 - Summary of issues identified in energy audit

Category:	**Results:**
Envelope	
Floor	• No issue specified.
Walls	• Minimal insulation inside and outside of concrete block wall. • New exterior siding purchased, waiting installation over insulation and funding.
Windows/Openings	• Upgraded from single to double pane in 2003 but improperly installed causing operational problems. • Air leaking around frame to building and pane to frame.
Roof	• Interior space not properly sealed from unconditioned attic space. • Poor or missing vapor barrier seal. • Minimal roof insulation.
Mechanical/HVAC	
Systems	• Minor upgrade in 1988. • Singer PTAC units reached end of life and were replaced in 1988 with new Island Air PTAC cooling chassis units of approximately the same size. • Original cabinets and hydronic heating coils were not replaced. • 1988 PTAC units are beginning to fail and are reaching the end of their lives. • 22 of the 59 PTAC units are no longer operational. • Boiler was replaced. • Hot water is distributed by two Grundfos circulators. • Fin-tube radiator replacement. • Primary heat is from a propane boiler operating at 75% of its efficiency, supplying 180-degree hot water to PTAC units – issues with temperature reset and operational issues. • Cooling provided via AC units in PTAC's. • There are two air handler units serving offices on the ground floor. • Couple ductless mini-split systems installed to help in summer. • AHU with DX coil in basement open office area. • Trane model L-12 fan coil unit with 15T DX cooling and hot-water heating coils. • System originally for a lab space, may need to be replaced. • Domestic hot water- propane boiler in winter, electric elements in 40-gallon storage tank in summer.

Controls	• No set-back programming/control. • The primary method of temperature control is at PTAC units. • Pneumatic type night setback system in place is no longer operational.
Electrical/Lighting	
	• Lighting was upgraded from T-12 to T-8 lamps and ballasts. • No daylight harvesting control in-place.
Plumbing	
	• Fixtures could be upgraded to low-flow fixtures and aerators could be replaced.

In order to analyze possible biomimicry based solutions, this thesis focuses on renovating the existing building with biomimicry inspiring its re-design in order to narrow the results to addressing the issues found in the existing building stock. In relation to biomimicry, the most significant and effective solutions can be made to the thermal envelope, HVAC systems and energy production. While other solutions are available through biomimicry for other categories, these are the more important toward a buildings performance, efficiency and for reaching the goals of the "2030 Challenge" to reduce fossil fuel consumption. The building re-design serves as a conservation building as well as an educational facility with the goal of educating people on environmental conservation. As a result, not only is the building an educational piece so as to reduce environmental impacts, through the understanding of the biomimicry process, it teaches others how to help the environment. This design is not only a revival of the existing headquarters, it also serves as an example and educational piece for architecture through the exploration in applications of biomimicry to solve energy solutions in the built environment.

3.0 – Literature Review

Overview

While there is a large quantity of information available on the topic of biomimicry, that can be found in databases discussing different ideas and concepts for the application of it, there is a very limited amount of concepts that have been developed into an applicable element of a building. Among these sources of information on biomimicry there are three notable researchers in the field; Julian Vincent, Steven Vogel, and Janine Benyus.[3] The backgrounds of these researchers vary, Julian Vincent is a professor of Biomimetics, which is an early established idea of biomimicry in science referring to man-made processes, substances, devices or systems that imitate nature to solve issues, typically in a more mechanical application.[3] Steven Vogel is a professor of biology, and Janine Benyus is a published biological sciences writer.[3] Of these three researchers, Janine Benyus is the most notable in her efforts to promote biomimicry. Benyus has played a large role in the development of the Biomimicry Institute, Biomimicry 3.8, and the "ask nature" website. These all provide a vast amount of knowledge on biomimicry and its possible applications in various fields.

In an interview, conducted by others, with Janine Benyus, there is a discussion of the knowledge and ideas she has on the topic of biomimicry.[12] From the interview, insight and information on identifying and understanding the field of biomimicry is provided throughout the interview.[12] The interview provided a brief understanding to the topic of biomimicry and what it can be used for, which aids in the developing of the topic. Janine Benyus mentions how biomimicry is not what can be extracted from nature, but what we can learn from it.[12] From this,

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[12] "Conversation With Janine." *Biomimicry 3.8.* http://biomimicry.net/about/biomimicry/conversation-with-janine/.

two approaches to biomimicry are identified; biology to design, and design to biology.[12] Biology to design is when a biological phenomenon suggests a new way to solve a human design challenge.[12] On the other hand, design to biology starts with the human design challenge, identifies the functional problem, and then reviews how that problem has been addressed through organisms or ecosystems.[12] Further discussion describes multiple stages of biomimicry dependent upon how in depth the organism or ecosystem function is that is being mimicked.[12]

Janine Benyus's article "Saving for a rainy day," looks to solving runoff issues from the built environment by looking to forests and trees to be the solution.[13] The article continues to provide further information on how to apply metrics and values to the trees.[13] Applying value to trees is important for justifying their existence and preventing tree removal in the expansion of the built environment. The article places appreciation and value to trees and how using nature in a more literal sense can aid in improving the design of the built environment.[13] From this article, inspiration could be drawn for site related solutions that could be applied to designs that utilize nature as a way of managing runoff.

In an interview with Michael Pawlyn, in *Architecture Today*, Pawlyn discusses the idea of gathering resources through biomimicry.[14] The interview discusses Pawlyn's thoughts on the subject and his definition of it.[14] He mentions how it is different, from other "bio" inspired ideas; by stating that it is the incorporation of functions, from nature, into architecture, not simply its forms.[14] Pawlyn also discusses biomimicry's current place in architecture and its future.[14] He mentions how it currently consists of academic speculation; although he does believe it to be a

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[13] Benyus, Janine. 1998. "Saving for a rainy day." *American Forests*, 24-25.
[14] 2011. "Interview: Michael Pawlyn on natural resources." *Architecture Today*. July 12. http://www.architecturetoday.co.uk/?p=19857.

valuable source for improving architecture, he states how designers must work with what they have at hand to make it better.[14]

In another interview with Michael Pawlyn, by Karissa Rosenfield, for *ArchDaily*, there is a discussion of Pawlyn's interest and motivation toward biomimicry.[15] Additionally, the article discusses examples of buildings using biomimicry, closed loop systems, possible species that could offer design solutions, and how the construction industry needs to change.[15] He briefly mentions how the construction industry is limited by short term thinking, conventional economics and collaboration that achieves less than optimal results.[15] He also states that focus needs to be given toward achieving long term value at minimal costs.[15] The article further discusses the issues with attempting biomimicry, such as politics, where finding alternative energy solutions causes issues with short term thinking of an oil based society.[15] Other issues are identified with biomimetic design, which is distinctly different from biomimicry through the applications, where biomimetic design is more involved in the science field where it could be used for biological weapons and biomimicry is for achieving sustainable solutions.[15] The information from this interview inspires the need to change the way we approach designing the built environment and how we could do it.

Amelia Hennighausen and Eric Roston wrote the article, "14 Smart Inventions Inspired by Biomimicry."[5] The article addresses 14 design solutions that were inspired by nature. [5] These solutions provide effective examples of how biomimicry can be used as a solution to issues in the built environment for architecture. One of the examples given is the Watercube, the building

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[15] Rosenfield, Karissa. 2011. "Interview: Michael Pawlyn on Biomimicry." *ArchDaily*. Nov 17. http://www.archdaily.com/?p=185128.

known for hosting the 2008 Beijing Olympics, where the structure was built based on the structure of a conglomeration of soap bubbles, as seen in Figure 4.[5] This structural design provides a natural feel and a resistance to earthquakes.[5] The article also discusses examples as they apply outside the field of architecture.[5] Beyond these overviewing sources of biomimicry and its applications, the field can be made more approachable by breaking it down into different categories involved in construction, such as the site, alternative energy, structure, thermal envelope, heating, ventilating and cooling.

Figure 4 - Watercube design based on bubbles.[5]

Site

When looking into biomimicry as a source of concepts for site water management, whether it's for gathering or filtering water, there are few places to look other than plants and water itself for the way it carves a path for itself. In regard to both, an article, "Green Infrastructure Stormwater Control," discusses how, in site design, water can be managed and filtered of contaminants through the use of bio-swales, green roofs, rain gardens, tree trenches, and roadside plantings, similar to those in Figure 5.[16] These are basically man made ecosystems that mimic nature and its ability to purify water while also controlling its flow. The applications of these

Figure 5 - Bio-swale and roadside planting.[16]

[16] "Green infrastructure stormwater control." *Ask Nature*. http://www.asknature.org/product/bb4d6b1f04793153d0f62ac7a8156efb.

site elements are possible in less developed areas where open space in available, the more urban an area becomes the less applicable these elements are, except for green roofs which are applicable in urban environments.

In addition to these more site and envelope related uses of plants, there is an alternative method of using plants in a man-made attempt to mimic ecosystems in which, similar to swales, plants are used to filter contaminated water, as discussed in the article about the "Biolytix® water filter."[17] However this system utilizes the waste water that comes from a building and uses plants, stones and bacteria as a means to filter it, as shown in Figure 6, before releasing it to the environment or reusing it.[17] These systems use a more closed system by encapsulating these ecosystems in planting beds so that the water can be controlled in its use.[17]

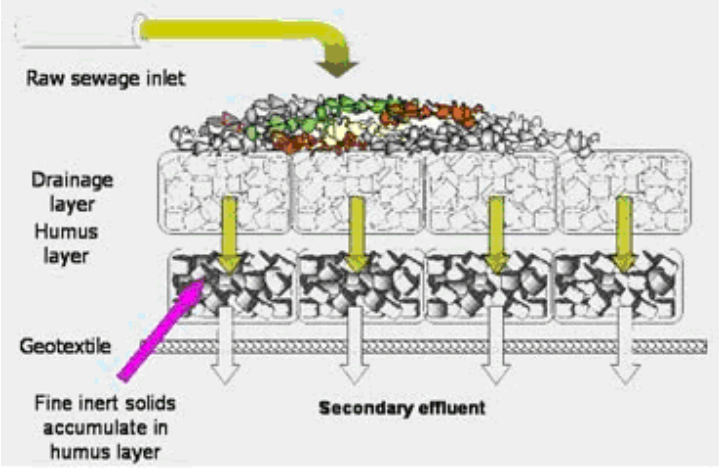

Figure 6 – Bio-filtration system process.[17]

[17] "Biolytix Water Filter." *Ask Nature*. http://www.asknature.org/product/f9d2ab73315de8d6e44bc15cac4549a3

Another means of using plants as an integrative site element for managing water is through the use of floating islands, as seen in Figure 7.[18] As discussed in the article "BioHaven® Floating Islands," these islands are essentially planting beds that are designed to float on top of water bodies; such as ponds, to aid in eliminating excess nutrients that can harm water ecosystems.[18] These floating islands can clean and prevent water from further exposure to excess nutrients so as to maintain a healthy ecosystem in the water.[18] This site element has limited applicability as it is very particular to sites with fairly large water bodies.

Figure 7 - Preparing floating island.[18]

Another article, "Algal turf scrubber," discusses a more natural method to cleaning water bodies for an improved ecosystem.[19] This article discusses introducing algal turf to water ecosystems to help remove excess nutrients through a method similar to that shown in Figure 8, where algae is grown on a rock.[19] The article also discusses the capability of harvesting the waste from the algal turf so that it may be used for creating biofuel.[19] Much like the previous

Figure 8 - Algal turf growing on a rock.[19]

[18] "BioHaven® floating islands." *Ask Nature*. http://www.asknature.org/product/adac1b16e98fd04e81172ef80f68aa9c.
[19] "Algal turf scrubber." *Ask Nature.* http://www.asknature.org/product/e37ad98658974d79f8b34b1da2574b49.

site design element, this one is also limited to applications where a water body is present that would support its use.

A leaf can also serve as an inspiration for water gathering and control, as mentioned in the article, "Elf Shelter Rainwater Collector."[20] A leaf structure is very lightweight and collects water for the leaf to use.[20] This structure can be mimicked as to create a roof top maximized in size for gathering water while not creating a heavy structure, as seen in Figure 9 where small wood members and sheathing are used to create a leaf like structure.[20] The applicability of this concept is dependent upon the existing building that is being addressed as it would have to be undergoing the design of a new roof or exterior shelter of some sort that could utilize it.

Figure 9 – Elf shelter based on leaf structure.[20]

Alternative Energy

Plants can also be used as inspiration for discovering a means of using alternative energy sources. This is especially true for leaves; they can be a source of ideas related to solar energy as well as wind. In the article "Vibro-Wind," from the "ask nature" database of concepts, there is a discussion of observing leaves in the wind and how they move and shake in the wind.[21] Therefore establishing how this could be an idea to use vibration as a source of energy

[20] "Elf Shelter Rainwater Collector." *Ask Nature*. http://www.asknature.org/product/8cb076fafce8b95b379adc020d7ed705
[21] "Vibro-Wind." *AskNature*. http://www.asknature.org/product/3345209b7cdb4ce09f12259d951eaf75.

production rather than the typical use of rotation.[21] This proposes the idea of using wind energy in more urban environments where there is insufficient space for turbines or windmills, but this idea would also be more affordable.[21] In addition, this method has no minimum wind load like a turbine, which has a required minimum to spin and a maximum to prevent damage, it can operate at variable wind speeds.[21] It would allow wind energy to be generated from wind and turbulent air against a building face.[21]

Another article, "SMIT SOLAR IVY," discusses Solar Ivy, and also focuses on the concept of leaves in the wind, as well as harvesting energy in the sun.[22] The article discusses having a mesh of leaf like solar panels, similar to leaf clusters or foliage, as shown in Figure 10, that can blow in the wind to harvest energy as well as harness energy from the sun through photovoltaics.[22] This proposes the idea of using this solar ivy as a mesh on the outside of a building, similar to a skin.[22] Similar to the last alternative energy producer, this can also be applied to a building façade of an existing building if sufficient sun exposure is available on a façade.

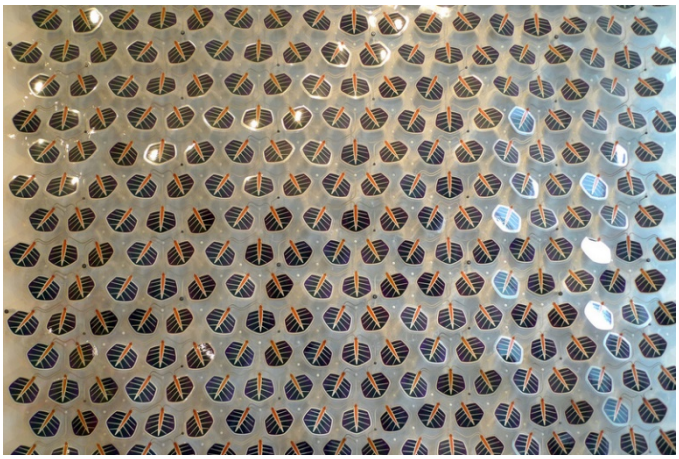

Figure 10 - Solar ivy wall mesh.[22]

[22] "SMIT SOLAR IVY." *Ask Nature.* http://www.asknature.org/product/256b9f497821497773d9f0c442ab367a.

In addition to this form of gathering solar energy, there is another concept more focused on the idea of replicating photosynthesis. From the article "Sunlight-Harnessing Artificial Leaf Could Soon Revolutionize the Energy Industry" a prototype, referred to as the "artificial leaf," mimics how a leaf creates energy through internal reactions caused by the sun.[23] The "artificial leaf" uses a chemical reaction caused by inducing an electrical reaction, from a solar panel, in water with nickel to cause a separation of oxygen and hydrogen.[23] The produced oxygen can be harnessed or released and the hydrogen can be harnessed as fuel for a fuel cell.[23] This concept in theory could be applied in any scenario for producing energy, but it is only in a prototype phase and isn't available for use as of yet.[23]

In contrast to mimicking energy production through leaves, plants themselves can be used for energy production through the use of green roofs.[24] A company called "Plant-e" creates green roofs that can create electricity from plants that are in water.[24] As organic compounds are broken down around the roots by micro-organisms, electrons are released, and these electrons are then harvested to create electricity.[24] This concept can be applied in the same situations of a green roof, which is anywhere, given that there is the structure to support its weight.

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[23] "Sunlight-Harvesting Artificial Leaf Could Soon Revolutionize the Energy Industry." *The Mind Unleashed*. http://themindunleashed.org/2015/09/sunlight-harnessing-artificial-leaf-could-soon-revolutionize-the-energy-industry.html.
[24] *Plant-e*. http://plant-e.com/index.html.

Structure

Beyond water management and alternative energy, biomimicry can be used in the built environment many ways, one of which is structure. In regard to structure, a chapter in the book "Biomimicry in Architecture" discusses the idea of mimicking the vein structure of a water lily to create a ceiling or roof.[3] The article discusses how this concept was used in the design of the roof to the Pallazetto dello Sport by Pier-Luigi Nerve, shown in Figure 11.[3] For structural applications of biomimicry there would need to be an area of an existing building that is undergoing reconstruction involving structure or having an addition.

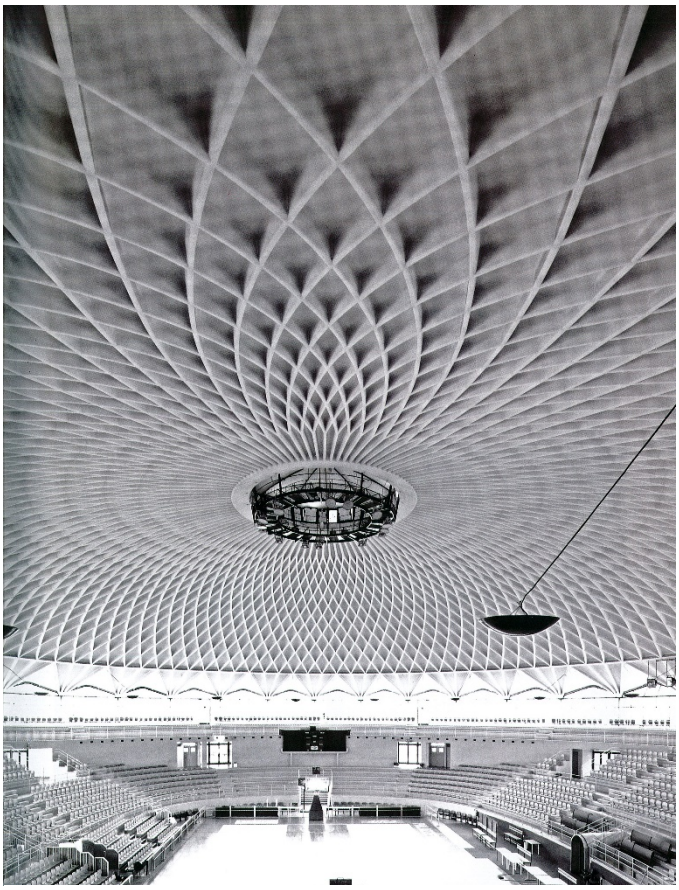

Figure 11 - Pallazetto dello Sport roof structure resembles amazon water lily.[3]

Thermal Envelope

Biomimicry can also be applied to the thermal envelope as discussed in the article "Feathers Trap Air to Provide Warmth: Emperor Penguin," where penguins are described as a significant source for creating an innovative envelope to a building.[25] The article discusses how penguins have a two part thermal layer of feathers.[25] The outer layer of feathers can be puffed up by attached muscles to allow air into the inner layer of feathers, also known as down, where the

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[25] "Feathers trap air to provide warmth: emperor penguin." *Ask Nature*. http://www.asknature.org/strategy/002043266864ae525a43a4a27f767999.

air is trapped in pockets formed by the feathers for an improved thermal barrier.[25] In addition, it discusses how the outer layer of feathers serves as a water and wind barrier when they are flattened to the body of the penguin.[25] This proposes a potentially more efficient thermal barrier system that can be mimicked in the thermal envelope of buildings given that a new envelope is necessary.

However, in thermal envelopes, there is the vulnerability of windows. In the article, "Pigment Filters Excessive Light: Balloonfish," it discusses how light can be controlled through pigmentation.[26] As demonstrated by the balloon fish, it can disperse a pigment or dye in its eye to control the amount of light it perceives as a way to minimize light when it is too excessive.[26] Similar to the concept of controlling light, pigmentation can also control the heat that comes from light, as described in the article "RavenBrick."[27] This concept is also discussed in the article "Sage Glass, Quantum Glass (Europe)."[28] These articles describe a window product that changes the glass pigmentation based on light intensity to reduce the light intensity and the associated heat that comes with it, as demonstrated in Figure 12.[27,28] This design idea could be implemented in multiple scenarios where new glazing is needed for existing window assemblies or in the scenario of using an entirely new window assembly.

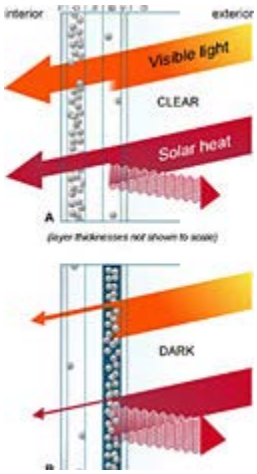

Figure 12 - Pigmented glass functionality.[28]

[26] "Pigment filters excessive light: balloonfish." *Ask Nature*. http://www.asknature.org/strategy/490a33371ad553ae7d223a83542cbeef.
[27] "RavenBrick." *Ask Nature*. http://www.asknature.org/product/4c61cb49bbcffa2302633dc8d3c135b0.
[28] "Sage Glass, Quantum Glass (Europe)." *Ask Nature.* http://www.asknature.org/product/02f1efba126122650d1691e800739a78.

Looking further into the concept of the thermal envelope vulnerabilities, the article "Leaves Protect From Frost: Cabbage Groundsel" discusses how the cabbage groundsel protects its vulnerabilities.[29] The article states that the cabbage groundsel protects its buds, from the cold, by having its freeze resistant leaves, fold over and cover its buds.[29] From this, the idea of creating a movable covering, or form of insulation, for vulnerabilities, such as windows and vents, on the exterior shell of a building could help protect from external temperatures. More related to temperature management, the article "Bodies Stay Warm In Cold Water: Skipjack Tuna," discusses skipjack tuna and how they use their venous structure at their gills to warm water, through heat exchange, before breathing in the cold water.[30] This proposes the idea of heating external elements of a building, such as windows, to control the heat transfer to the inside.[30] As before, this application would be limited to existing buildings that are having windows replaced.

Heating, Ventilating, and Air Conditioning

Another source for biomimicry is bird feet, which are discussed in the article "Why Birds' Feet Don't Freeze" as a concept that can be seen as a benefit to HVAC, as well as to the thermal envelope, similar to the skipjack tuna.[31] The article discusses the idea of why bird feet do not freeze in cold temperatures.[31] It discusses how they do not freeze due to the veins in their feet.[31] Birds pump warm blood through their feet in order to prevent them from getting cold; they also use heat exchange to reheat the blood flow returning to the body as to prevent a drop in

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[29] "Leaves protect from frost: cabbage groundsel." *Ask Nature*. http://www.asknature.org/strategy/60d36e8d0f6e66329937aa3bf14d0baf.
[30] "Bodies stay warm in cold water: skipjack tuna." *Ask Nature*. http://www.asknature.org/strategy/56f8681be2ff5c27211f80910cc83ef6.
[31] Hamilton, Mike. 2013, "Why Birds' Feet Don't Freeze." *Bird Note*. http://birdnote.org/show/why-birds-feet-dont-freeze.

internal temperature.[31] This establishes the idea of running HVAC systems near the vulnerabilities, such as windows, of a building to control the transfer of external temperatures to the interior. Depending upon the existing HVAC layout this may require either rerouting ducts or using stand alone units at windows.

In a more focused discussion of penguin feet, the article "How Penguins are Adapted to their Environment and Survive Cold Conditions- Science of the Cold," discusses their feet as a concept that can be seen as a benefit to HVAC as well.[32] However unlike other bird species, this article about penguin feet describes how penguins utilize the ground and its temperature to their advantage.[32] The article discusses how penguins in Antarctica use blood flow to their feet as a way to release heat, when in excess, through heat exchange with the colder ground temperatures.[32] Conversely, the penguins protect themselves from the freezing temperatures through heat exchange, of the cold blood flow returning from their feet, further up in their warm bodies.[32] This natural process inspires use of the ground for controlling indoor temperatures, which is used today as geo-exchange.

Penguins also provide a great example for HVAC design through their wings, as discussed in the article "Wings Reduce Heat Loss: Penguin."[33] The article discusses how penguins can experience a difference in 30°C, or 86°F, from their wing tip to their body through an elaborate thermal exchange system from veins branching from main arteries in their wings.[33] This serves as inspiration to HVAC designs and layouts in buildings to provide temperature

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[32] "How Penguins Are Adapted to their Environment and Survive Cold Conditions- Science of the Cold." *Cool Antarctica.* http://www.coolantarctica.com/Antarctica%20fact%20file/science/cold_penguins.php.
[33] "Wings reduce heat loss: penguin." *Ask Nature.* http://www.asknature.org/strategy.org/strategy/740c420618b1b9abb92630cdaff6e0dd.

control. The idea of running ductwork to disperse heat to prevent temperature change, which is already commonly done, can be derived from this. However, it is done in a more efficient manner in penguin wings by having a complex branching system of veins, or ducts, that reach throughout an area rather than using zones.

The article, "Vascular Lining Helps Maintain Body Temperature: Leatherback Sea Turtle," discusses the potential of the leatherback sea turtle as another source of inspiration for designing HVAC systems.[34] The turtle uses heat exchange through blood flow at its trachea in order to maintain its warmth.[34] Although already available in the built environment and HVAC systems, heat exchange systems could be used to mimic this concept by designing for heat exchange at the air intake for a building.

The article, "Ventilated Nests Remove Heat and Gas: Termites," discusses how termites dig and bury holes in their mounds as a means of ventilating the mounds to maintain the internal temperature.[35] This practice is commonly used today with the use of operable windows that people can open and close as necessary to maintain a desired internal temperature. This idea could also be incorporated with the application of an automated system that has a building monitoring system. This application would require window replacement and installation of a new system, but could be incorporated anywhere.

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[34] "Vascular lining helps maintain body temperature: leatherback sea turtle." *Ask Nature*. http://www.asknature.org/strategy/6a439c1556fd2b0b46f83a0c55fd6df2.
[35] "Ventilated nests remove heat and gas: termites." *Ask Nature*. http://www.asknature.org/strategy/04518d273f2a32dad9d43e7f458943b9.

When monitoring and managing indoor temperatures, thermostats are commonly used alongside HVAC systems. The article "Internal Thermostat Regulates Temperature: Skunk Cabbage" discusses how nature provides an example of this through skunk cabbage.[36] The article describes how skunk cabbage has its own internal thermostat that dictates when to induce a chemical reaction within the cabbage to produce heat when it is cold.[36] In fact the cabbage is capable of melting surrounding snow with the heat it produces.[36] This process serves as nature's example for the thermostats we use today to control the on and off time of HVAC systems. It inspires further exploration through the application of monitoring systems that could control multiple components of a building that could react and adapt to changing scenarios such as weather and temperature.

Beyond this previously discussed research related to biomimicry there are existing constructed examples of biomimicry applications in the built environment. However, not many practicing architects dedicate themselves to biomimicry based architectural solutions. Even though architects have applied it to their design process, they often do not cite their inspiration. One architect that has dedicated his designs to use solutions derived from biomimicry is Michael Pawlyn, a practicing architect in the United Kingdom.

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[36] "Internal thermostat regulates temperature: skunk cabbage." *Ask Nature*. http://www.asknature.org/strategy/7e985ec13e9adf0cbca843df1225fa98.

Michael Pawlyn has used biomimicry to find design solutions for efficient structures, material manufacturing, zero-waste systems, water management, controlling thermal environment, and energy production.[3] One of Pawlyn's more notable designs is the Sahara Forest Project.[3] In addition to using biomimicry to find design solutions, it has commonly been used for aesthetic purposes. For example, the TWA terminal, by Eero Saarinen, at the John F Kennedy Airport in New York.[3] For this example there is no purpose or solution provided by the design of the buildings form that looks like wings, as shown in Figure 13, rather it is just a representation of flight.[3] Another example of this is the columns in the Johnson Wax building by Frank Lloyd Wright, which bear the appearance of water lilies, as seen in Figure 14, yet have no purpose but to provide a different approach to the design of the space and its appearance.[3]

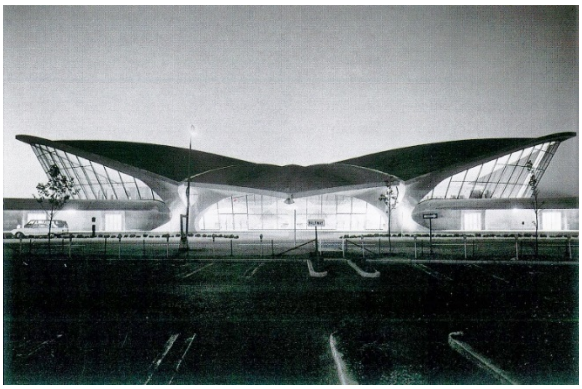

Figure 13 – TWA terminal designed to mimic wings in flight.[3]

Figure 14 - Johnson Wax building has columns that appear similar to that of a water lily.[3]

From this previously discussed research it can be seen that there is a greater amount knowledge available, beyond typical technological solutions, for making improvements to building envelopes, heating and cooling and site development that can be developed into designs. Based on this information, these categories can be prioritized as the main focus areas of addressing future sustainability issues within existing buildings and their redesigns. Meanwhile

the other information discussed can be implemented as well, and it may become easier as it is developed more and more opportunities are discovered through the study of nature.

4.0 – Case Studies

The biomimicry field consists of an extensive database of concepts and strategies; however, there are few products or designs that exist that were developed with biomimicry in mind. Despite this lack of biomimicry inspired products and designs, there are examples of biomimicry available; although that may not have been the intention of the design. The Pallazetto dello Sport, Douglas River Bridge, Eastgate Center and Upper Riccarton Community and School Library are just a few examples of biomimicry in buildings. Although, biomimicry has been used in many ways: the following case studies will demonstrate a few such uses.

Products

Case Study 1 - Burdock

Biomimicry has been used for material developments such as Velcro, which was developed from the burdock, to create an alternative way of fastening as opposed to zippers.[3] Velcro was developed in 1948 by George de Mestral, who had observed how burdock burrs clung to his dog's fur.[3] From this discovery he developed the idea of Velcro by observing the burrs under a magnifying glass.[3] This idea created a new, easier, efficient alternative to fastening versus zippers, string and lace; there is no stuck or broken zippers, or worn or broken strings or lace. Velcro applications have expanded dramatically over the years, predominantly in apparel, but even in other applications such as exercise equipment. This is just one of many great examples of biomimicry applications in products and materials.

Water Management and Treatment

Case Study 1 – Micro-organisms

Biomimicry has also been used for water treatment where plants and micro-organisms are used to treat waste water.[3] Such a water treatment process has been created by Living Machine®,

which uses an ecosystem of wetland beds to treat sewage to an extent where it is safe for reuse.[3] However, the water from this treatment is not drinkable, but it can be used for flushing toilets or for irrigation purposes. The water treatment process starts by pumping water into the system where microorganism begin to breakdown the waste and feed it as nutrients to the plants leaving cleaner water.[3]

Case Study 2 – Plants

Biomimicry has also been used in water management, such as water harvesting like that of a cactus which uses its ribs to quickly absorb, expand and store water as a reaction to the lack of access to water.[3] In general, other plants have developed similar strategies by swelling up their roots by absorbing water.[3] These methods serve as inspiration for creating membrane like storage vessels that expand when filled with water. Furthermore, these expandable elements could be incorporated into the building and structure rather than the traditional means of having storage tanks above or below ground.[3]

Alternative Energy

Case Study 1 - Whale Tubercles

Furthermore, biomimicry has been used in energy production, such as developing wind and water turbines that mimic whale tubercles, lumps on their flippers, as shown in application in Figure 15, to operate more efficiently at slower speeds.[3] The tubercles create vortices that provide lift to allow for movement at slow speeds.[3] This concept

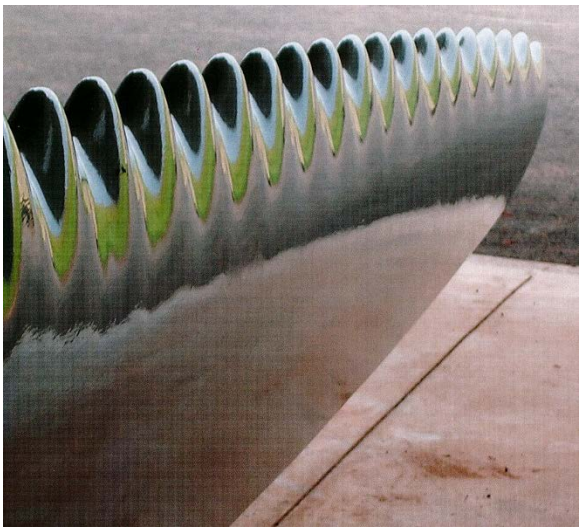

Figure 15 - Blade created to mimic tubercles of a whale for ease of movement.[3]

will help to reduce the required wind or water speed that is necessary to turn a turbine therefore allowing for greater energy production.

Case Study 2 - Leaves

In addition, leaves also provide insight into wind turbines. Wind turbines typically are turned off at high wind speeds and have brake systems to prevent damage.[3] However, leaves can change by rolling over and becoming more aerodynamic as to allow wind to blow with less strain on the leaves and tree.[3] Introducing this concept into turbines or allowing for flexibility would allow for extended operation times without the downside of damaging them from high winds.[3]

Structures

Case Study 1 - Palazetto dello Sport

Biomimicry has been used in new innovative approaches to structures.[3] For example, the structure of the Palazzetto dello Sport, by Pier-Luigi Nervi, uses a ceiling structure that resembles a giant Amazon water lily, which has ribbing for structural support allowing for a large spanning space.[3] The use of the ribbing allows for a thinner roof or ceiling that has the ability to create an effective dome construction.[3] The ribbing structure reduces spanning loads while the outer shell layer connects and stiffens all the ribbing.[3] However, the issue that was presented in this use of biomimicry was the construction material, which ended up being reinforced concrete.[3] Furthermore, the structure was developed in a cost effective manner through new concrete developments of using steel mesh sprayed with mortar to create a lighter-weight structure with less material for a reduced cost without sacrificing strength.[3]

Case Study 2 - Douglas River Bridge

Another example uses air to create structure; the Douglas River Bridge, by Exploration, uses hollow structures filled with pressurized air to create a stiffened structure that is also lightweight.[3] The bridge was inspired by a leaf; leaves maintain their stiffness based upon pressurized cell membranes that form in-flow of water.[3] Due to the lack of ability to recreate this method on a large scale such as a building, alternative methods were explored; as a result, pressurized air was discovered to create the same affects as the pressure in a leaf.[3] Since the development of forms and strength were created by pressurized air, pneumatics, there have been significant developments in the field; such as, tires, military uses, instant inflatable buildings, blow-up playhouses, inflatable mattresses, and much more.[3] Even more developments have been made in building materials, although they are not commonly used.[3] Swiss-Italian engineering firm, Airlight Structures, had created large spanning beams that are stiffened by air to create a structure that has significantly less material with the same strength and it is lightweight; however, the air structure spans are limited.[3] These developments inspired the design of the Douglas River Bridge by Exploration, shown in Figure 16.[3]

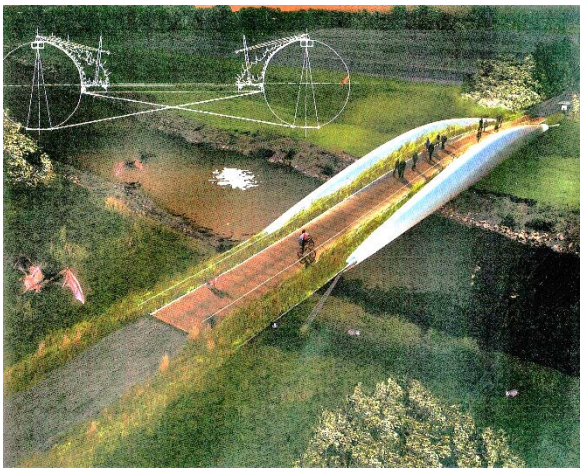

Figure 16 - Douglas River Bridge uses a pneumatic structure.[3]

HVAC

Case Study 1 - Upper Riccarton Community and School Library

Figure 17 – Operable wall of the Upper Riccarton Community and School Library.[37]

The Upper Riccarton Community and School Library, by Warren and Mahoney Architects Limited, is a new joint use facility in Christchurch, New Zealand, Figure 17.[37] The facility combines a new community library with a local high school.[37] The building was designed to be able to adapt to changing conditions, based on the inspiring strategy of ventilation that is used by termites in termite mounds.[37] The building enclosure uses passive ventilation as a method for reducing the need for air conditioning; as well as the associated energy use.[37] The building was designed to have the ability, through mechanisms, to reconfigure itself based upon changing climate conditions.[37] The incorporated elements that aid in this are as follows: motorized operable windows at high and low locations for cross ventilation, roof mounted extraction fans for high temperatures, motorized sun tracking louvers, a raised floor slab with radiant heating, solar water heating, low energy lighting, low flow toilets, double glazing, higher than code insulation, strategic placement of thermal mass, and storm water capture and reuse from the roof and paved areas.[37] The inspiration from termite mounds is mostly seen through the motorized

[37] "Upper Riccarton Community and School Library. *Ask Nature*. http://www.asknature.org/product/522c0afe35244302db654f838bde07d0.

operable windows that respond to the climate to create ventilation when needed to maintain the interior temperature as termites dig and bury in holes and shafts as needed for ventilation.[37]

Case Study 2 - Eastgate Center

The Eastgate Center in Harare, Zimbabwe, by architect Mick Pearce in collaboration with Arup engineers, consists of offices and a shopping center.[38] The building is designed around the ventilation and cooling system of local termite mounds.[38] The building does not consist of any conventional air conditioning or heating due to mimicking strategies of the self-cooling termite mounds in Africa.[38] Termite mounds in Africa are kept at a consistent 87 degrees Fahrenheit in a climate that varies from 35 to 104 degrees Fahrenheit.[38] This temperature control comes from digging and plugging shafts in the termite mound for allowing ventilation through convection air flow.[38] The air is drawn into the mound and flows down in the mound as it cools where it then flows back up and out through chimneys, or stacks, as the air warms and becomes stale.[38] The Eastgate Center mimics this process by drawing air flow, through constant fans on the first floor, into the masonry voids of the building, where the air is conditioned by the masonry and then released into the building.[38] After being released into the building, as the air warms and becomes stale it rises, and is also pushed up by the new air, and flows out chimneys, as shown in Figure 18.[38] In addition, the building utilizes natural air flow by having the design made of two buildings with a central space, atrium, between them that can be opened to allow in breezes.[38]

[38] "Biomimetic Architecture: Green Building in Zimbabwe Modeled After Termite Mounds." *Inhabitat.* http://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/.

This innovative approach allows the building to eliminate the air conditioning unit saving it on energy costs as well as the 3.5 million dollar air conditioner it would have required.[38] The design uses less than 10 percent of the energy that buildings of its typical size use in its region.[38]

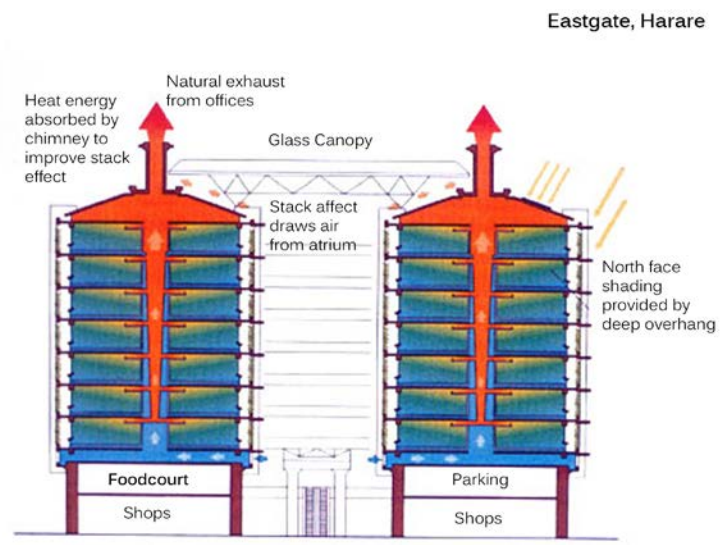

Figure 18 - Natural convection design of Eastgate Center.[38]

As seen through these case studies, biomimicry can be very effective in providing an alternative means to creating new materials, improvements and alternatives to energy production structural designs as well as a more efficient and effective means of air conditioning and ventilation. Of the listed case studies, case study two for HVAC is by far the most influential in the biomimicry field as well as to the development of this thesis due to the ability to completely eliminate the need for a mechanical based HVAC system and improving energy consumption. In addition, it is the most capable to implement in the existing conditions of the existing building in this thesis design. Furthermore, the case studies presented suggest that having maneuverable or adaptable elements, as found in nature, incorporated into a design are the most significant and impactful approaches to improving designs. Thus informing the approach of the redesign of existing buildings, such as the one of this thesis, as well as new building designs to incorporate adaptable components. Moving forward, the information provided gives the basis for the redesign of this thesis to use a similar approach to the HVAC as in case study two, except for the approach involves incorporating it into an existing building. Other redesign approaches involve

the use of adaptable and operable elements, as commonly seen in the discussed case studies, for use in an existing building.

5.0 – Theory and Methods

For the architecture design exploration in this thesis, biomimicry is being used for resource and energy solutions related to the site, building envelope, HVAC and thus building performance. The end goal of this thesis is to use biomimicry to achieve an 80% reduction in energy consumption, as outlined in the "2030 Challenge" benchmarks, as well as to have a design that meets code efficiency requirements and determine whether biomimicry is a viable solution to architectural design challenges of the built environment.[7] Biomimicry is being used assessed for the management of water resources and finding solutions to reduce energy use. In the case of this thesis, a large portion is dedicated to research as biomimicry essentially requires heavy research of biological systems in order to identify possible solutions. In a developing field of design such as biomimicry, it can be said that design does in fact equal research.

Unlike other designs that have used biomimicry, which tend to focus on a specific aspect of the design in which to incorporate it, this thesis identifies multiple aspects of building designs for incorporating biomimicry. A particular focus is given to plants for providing the methods necessary to achieve a more energy efficient building design through energy production since they are able to simply take the weather and its reoccurring elements to create energy and growth rather than through consumption of other species and nature as animals do. The study of plants is used to find methods for solar and wind use in providing alternative energy, and for water collection throughout designs. Plants are also used to identify design methods for water filtration. However, these practices and methods are not very applicable to the design of the building for this thesis, but some of them, particularly the solutions for water, will be incorporated into the site design. Due to the existing buildings conditions, the building is not in the ideal orientation for solar collection as the façades are dominant to the east and west rather than to the south. The

design utilizes the site location with the available pond on the site as well as nearby streams in an effort to branch out from providing solutions to the building design but also to the surrounding environment. Beyond seeking inspiration from plants, this thesis also looks towards other organisms as a way to improve the thermal envelope, heating, ventilating, and cooling of the building.

There are many design solutions to choose from when looking for inspiration from plants and organisms. However, deciding upon what solution will best fit the development of this thesis depends greatly upon the applicability of these solutions based on the environment and climate that they are best suited for, as well as to what benefit they will provide to the existing building and whether or not they are achievable or feasible for use in the existing building. Prior to determining what solutions can be applied to the existing DEC building, the building needs to be analyzed, as shown earlier in Table 2 and Table 3, to determine its faults and what can be altered. In an approach aiming to be sustainable, it would be best to maintain as much of the existing building as possible in order to reduce the waste produced from deconstruction and from the new construction that would replace it. The following Table 5 lists just some examples of biomimicry that could apply to existing buildings and labels those that will be used in this thesis.

Table 5 - Identified applications of Biomimicry and usage in design

Category:	**Solution:**	**Application used for:**
Site:		
Green Infrastructure	Controlling water flow, and run-off water filtration.	√ - Parking and roads
Biolytix®	Water filtration.	
Floating Islands	Cleaning water bodies.	√ - Pond
Algal Turf	Cleaning water bodies.	

Elf Shelter	Collecting rainwater with lightweight structures.	
Alternative Energy:		
Vibro-wind	Wind energy alternative to wind turbines.	
Solar Ivy	Wind and solar energy producing building skin.	
Artificial Leaf	Photosynthesis inspired energy production using water.	
Plant-e	Energy production from plants in water, with rooftop applications.	
Structure:		
Amazon Water Lily	Thinner lightweight large spanning structure.	
Thermal Envelope:		
Penguin Feathers	Thermal envelope improvements using air pockets and a ventilating façade.	√ - New Façade
Balloon Fish	Using pigmentation to control light intensity.	√ - New Windows
Cabbage Groundsel	Protecting thermal envelope vulnerabilities with maneuverable elements.	√ - Window coverings
Skipjack Tuna	Controlling interior temperatures through heat exchange at exterior.	
HVAC:		
Bird Feet	Resisting temperature exchange through heat transfer at vulnerabilities.	
Penguin Feet	Controlling temperature through contact with the ground and its temperature.	√ - New geo-exchange system
Penguin Wings	Preventing temperature loss through pumping heat.	√ - New ductwork
Sea Turtle	Heat exchange at intakes to reduce temperature from external air.	
Termite Mounds	Natural heating and cooling of air without mechanical systems.	√ - New ventilation system
Skunk Cabbage	Monitoring internal temperatures and inducing reactions as necessary.	√ - New monitoring system

Site

For water collection, solutions are more about maximizing the surface of collection without using an abundance of material to create the surface. A solution to this is the study of a leaf, by mimicking the structure of a leaf, a collecting surface area can be increased while using minimal material to construct it; furthermore, a good example of this is the Elf Shelter.[20] This idea is good for when a new roof structure is being created, but may not be justified if an existing roof does not need replacement. When looking to find solutions to light response, plants are the best examples, as many plants track light throughout the day to maximize their solar gain, which could be used in building design to maximize solar gain as well as create responsive shading elements. In addition, plants provide a great example and solution to water filtration. There are bio-filtration methods that emulate nature and its filtration methods by constructing filtration beds from plants and aggregates, making drainage layers, with bacteria to naturally breakdown and filter contaminants in water, an example of this is the Biolytix® water filter.[17] Furthermore, there are direct uses of plants; such as, algae turf and floating planting beds in water bodies to aid in removing excess nutrients to create a better environment for fish and wildlife.[18,19] In addition, the waste produced from algae can be used to create bio-fuels.[19] Additionally, there are ways to mimic nature and the filtration of water for improved quality, in site design, such as creating bio-swales.[16] These concepts can be applied to existing buildings to create applications for water gathering and collection for filtration of runoff water and waste water for reuse in greywater applications to aid in reducing potable water use.

Energy

Despite the need for further analysis, some solutions, as shown in Table 5, that could be considered, are for capturing wind energy through vibrations as studied from looking at the

leaves of a tree as they shake and move in the wind.[21] This could be used in a way of harvesting wind energy through the vibrations developed against the side of a building. Prototypes are currently under development for this solution that will allow for wind energy to be harvested as it collides with the building envelope.[21] Another possible solution is solar ivy, which emulates the function of ivy by creating a series of leaf shaped solar panels that attach to a façade that also generate wind energy as they blow in the wind, providing a hybrid energy production system.[22] These concepts allow for the application of energy producing components that can simply be attached to an existing building wall. For this thesis, these applications are not considered, in part to their aesthetic appearance and the existing building orientation and shape are not ideal. Plant processes serve as a source of information, particularly photosynthesis, where prototypes are under development that mimic photosynthesis by using water and a chemical reaction to cause a separation of hydrogen and oxygen so that the system gives off oxygen and produces hydrogen that can then be used for fuel.[23] This proposes a new take on capturing solar energy that could be a component that is attached or detached from the building. But, this concept is still under development and is not ready for implementation. Furthermore, plants themselves can be used for green roofs that, through new developments, are capable of producing electricity; this idea comes from the company "plant-e."[24] This solution proposes green roof application that could be applied to an existing building roof to create electricity. Although this application is dependent upon the building structures ability to support the weight of the system as well as the slope of the roof. For this thesis the sloped roof would not permit this design component.

Structure

There are several other innovations that can come from nature. As mentioned before, plants can provide inspiration to structural designs; furthermore, bone structure of organisms can

also provide inspiration to structural design. Since existing buildings typically do not need structural work, structural innovations through biomimicry are not the optimal choice. Where structural may be needed in existing buildings, typical construction methods may suffice. Unless a building needs a significant structural redesign, which it may not even be feasible to pursue biomimicry as a solution. If it is feasible, it would greatly help in creating a strong yet light structure that efficiently uses materials. As per this thesis, the existing building is structurally sound and not in need of improvements, as a result the structure is not addressed.

Thermal Envelope

In addition, nature has many sources for inspiration to a building's thermal envelope. For example, a penguin is able to survive extreme temperatures, this is due to their feathers.[25] A penguin has two layers of feathers, the outer layer is attached to muscle so that it can be puffed out or laid flat.[25] When puffed out, air can freely ventilate to the penguins body; however, when the feathers are flat they act like an air and water barrier.[25] As for the underlying layer of feathers, more commonly known as "down," they trap air, in air pockets, to provide an additional thermal layer.[25] This thermal layer equals to approximately 80% of a penguins thermal insulation which allows them to survive extreme cold temperatures.[32] In addition to penguins, this same concept can be seen with other animals, except for these animals there are layers of fur instead of feathers. However, feathers provide a better thermal barrier due to their construction.[25] Therefore, mimicking a penguin's feathers could improve a buildings thermal envelope, especially during colder weather. Having a maneuverable façade could also be useful for shading windows and other solar solutions and possibly integrating these into one idea. This concept would be implemented when a new façade is needed or could be added to an existing one by

creating maneuverable façade components and air pockets of insulation. Which, for this thesis, is applicable as its envelope is in need of significant improvement.

Other than penguins, the balloon fish also provides an innovative concept toward improving a building's envelope.[26] The balloon fish has the ability to release a pigment in its eyes to reduce light intensity, this concept can be seen in what is considered smart glass, which can change its pigment to reduce light intensity as well as solar heat gain.[26] Therefore, having pigmented glass will aid in controlling excess heat coming in from windows to reduce the load on the HVAC system.[27,28] This could be applied to existing buildings where new windows are placed, if there is excessive sun exposure. For this thesis, the new windows could use this to reduce morning and evening sun light and heat transmittance from the east and west façades.

In addition to birds, plants, which are not only good for innovations in energy production, are also good sources for envelope improvements. For example, the cabbage groundsel uses its outer leaves, which are resistant to freezing, to cover and protect its buds, at its center, in the cold.[29] This could inspire covering windows and other vulnerable aspects of a building in cold temperatures. In warmer climates this covering could be implemented as part of the façade that is simply a maneuverable panel or covering. Where in colder climates where freezing temperatures occur, it would be an internal element to avoid components becoming frozen. For this thesis an interior insulated window covering would be ideal.

HVAC

In addition to providing inspiration to thermal envelope solutions, penguins can also aid in heating and cooling designs.[32] Penguin feet play a key role in maintaining body temperature.[32] Penguins use their feet as a means for releasing excess heat by pumping warm blood through them so that the cold ground can cool it off before it returns to the body.[32] This concept inspires

the idea of using the ground to control the temperature of the building, which is already commonly done through using geo-exchange, by exchanging temperatures with the ground. This is applicable to existing buildings assuming there is sufficient space for wells to be dug for running water or coolant through pipes in the ground to exchange temperatures for application to the HVAC system. For this thesis there is ample space as well as the unique opportunity to utilize the onsite pond for the geo-exchange of temperatures. Penguins also inspire the use of ducts to carry tempered air throughout a building based on their wings and how they pump blood through them to maintain interior temperatures.[33]

Other birds can provide solutions as well. Similar to penguins, other birds have unique properties to their feet so that they don't freeze in cold weather.[31] The vein structure in a bird's feet allows for the warm blood to flow through their feet to prevent them from freezing while there is a heat exchange of the cold blood, coming from the feet, with the warm blood so that the bird stays warm.[31] This inspires the idea of creating a heat exchange at the vulnerabilities of a building, such as the windows. In this case, the glass could be heated or heat could be distributed through the HVAC system at the window location where it can be returned to the system and be reheated through heat exchange. However, this is not the only form of heat exchange found in nature that could be applied to buildings. The leatherback sea turtle and the skipjack tuna use heat exchange as they breathe in order to maintain their body temperature when in cold environments.[34] Unlike birds, termites provide inspiration for regulating temperature inside termite mounds, where termites have developed a system of digging and burying holes in the mound to provide the necessary ventilation to maintain interior temperatures.[35] In addition, these holes are strategically dug to be angled down and outward from the mound to maximize on bringing in cooler temperatures, as seen in Figure 19.[35] This inspires the idea of incorporating

operable windows and vents in a building in order to control the indoor temperature. Since this thesis already has the vents and openings, this implementation would be ideal.

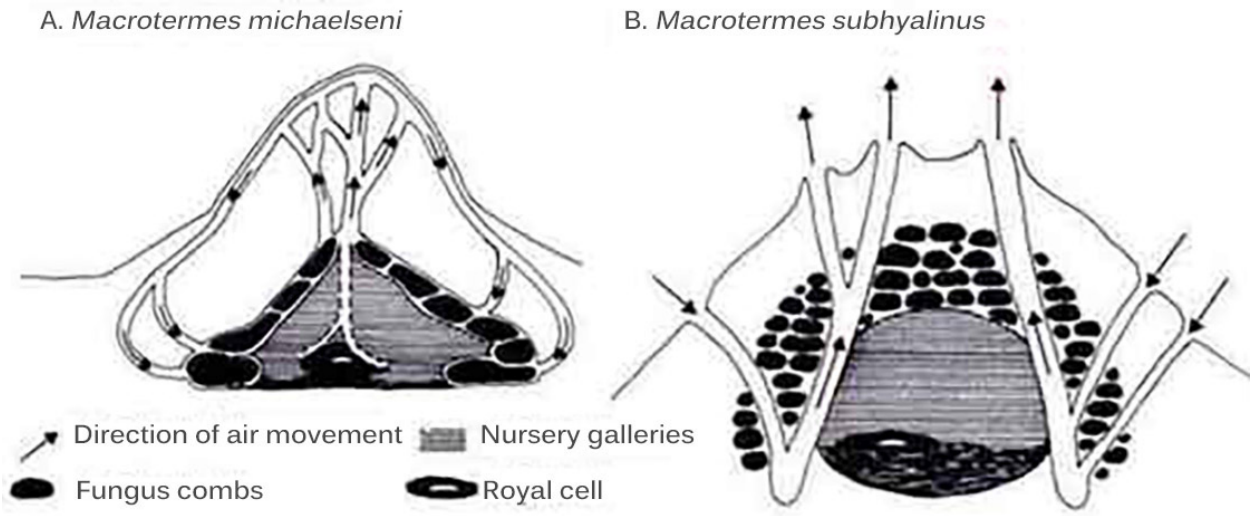

Figure 19 - Ventilation shafts of termite mounds shown in section (Not to scale).[35]

Furthermore, plants also provide good examples for HVAC, a skunk cabbage can adapt to cold temperatures by use of an internal thermostat that induces a chemical reaction that produces enough heat to melt snow around the cabbage.[36] From the skunk cabbage the commonly used idea of thermostats can be derived as a method for controlling the internal temperature of a building through the HVAC system. Implementing new thermostats that are connected to a network of building components, that regulate the interior temperature, would be a great improvement to an existing building. With the possible temperature controlling aspects of this thesis, this would be very helpful to regulate the interior temperature.

Upon completing a building analysis as outlined previously in Tables 2 and 3 it can be determined that considering the thermal load of the building, the building's thermal envelope of the building needs to be addressed. Since the envelope does not consist of any significant thermal rating it would only be appropriate to improve it; however, the entire envelope is structural, consisting of a concrete masonry wall, but the outer siding can be removed to place an external

layer of insulation as well as new maneuverable siding elements that will improve the buildings thermal rating. In addition, new furring and insulation can be applied on the inner side of the concrete masonry wall for further insulation. The old vents can be reused in a new ventilation systems or sealed off and windows can be replaced for more efficient ones to provide a better barrier. For addressing the thermal envelope, heating, ventilating, and air conditioning (HVAC) can be upgraded and incorporate alternative heating and cooling to improve efficiency. Looking beyond the building itself there are other issues that need addressing with the DEC building and its site. Water filtration methods for the building and paved areas run off water can also be added to aid in reducing contaminated water. However, under the proposal of this thesis, these solutions will be explored through nature inspired methods to identify if biomimicry is a possible method for achieving a better future and achieving the “2030 Challenge” goals.

6.0 – Design

Overview

After having done prior research and exploration of the biomimicry field, to determine its possible exploration as a thesis topic for applications to architecture, further exploration was given toward how and where to apply it. Upon coming to the conclusion of using an environmental building serving the New York State Department of Environmental Conservation (NYSDEC), in which an ecological and environmentally conscious design would be complimentary to their goals, it became apparent that addressing existing buildings would be an impactful goal as well. Especially since they would be a major part in the future of designs as the existing building stock would need to be addressed as much as, if not more than, new designs.

During the conceptual approach of this thesis, the existing conditions of the NYSDEC building were analyzed and addressed to determine the goals and outcomes for the design. This raised questions of the building code compliance and how far it was from meeting the “2030 Challenge” goals. In addition, research was done to explore the field of biomimicry and its applications for the built environment, with a focus on possible applications to existing buildings. Upon researching these possibilities, they were explored and developed to address the NYSDEC building, and the areas for improvement that were addressable for bringing the building up to code and the “2030 Challenge.”

Existing Conditions

Figure 20 - NYSDEC Region 8 Headquarters - Before re-design.

In order to begin the design process for the redesign of the NYSDEC Region 8 Headquarters, shown in Figure 20, existing documentation was gathered regarding the building's architectural, structural, mechanical, electrical and plumbing drawings from its original construction and modifications over following years. After, documenting and modeling the existing conditions of the building, and having spoken with the operations supervisor regarding the building's existing conditions, as well as what future plans were undergoing consideration, the redesign process began. In an attempt to improve the building's efficiency and environmental impact, the building envelope and mechanical systems were determined to be inefficient and failing to perform, resulting in a need for improvement. Furthermore, from a code compliance analysis, the building was determined to be 38% below code for the envelope thermal efficiency, not accounting for air leaks, as shown in the COMcheck analysis in Appendix A. This poor efficiency is due to the existing wall construction having little to no thermal value with it consisting of a concrete masonry wall with wood furring and siding equaling out to an insulation

value of R-2.1 with approximately half being just the concrete masonry wall. Without there being a good thermal envelope, all other existing and future systems pertaining to the heating and cooling of the building would not be able to perform to their potential since there would be significant temperature loss from the envelope causing systems to run more than usual. So, in order to improve the thermal envelope, the wood furring and siding was removed from the exterior, as well as the interior furring, as highlighted in Figure 21. In addition to envelope deficiencies, the air conditioning systems of the building were failing and those that had quit working were temporarily replaced with window units and other temporary systems for air conditioning. Although the failing systems had been replaced, the replacement systems were not ideal for efficiency, but were affordable. In order to improve the efficiency, of systems, they would need to be replaced with more efficient ones.

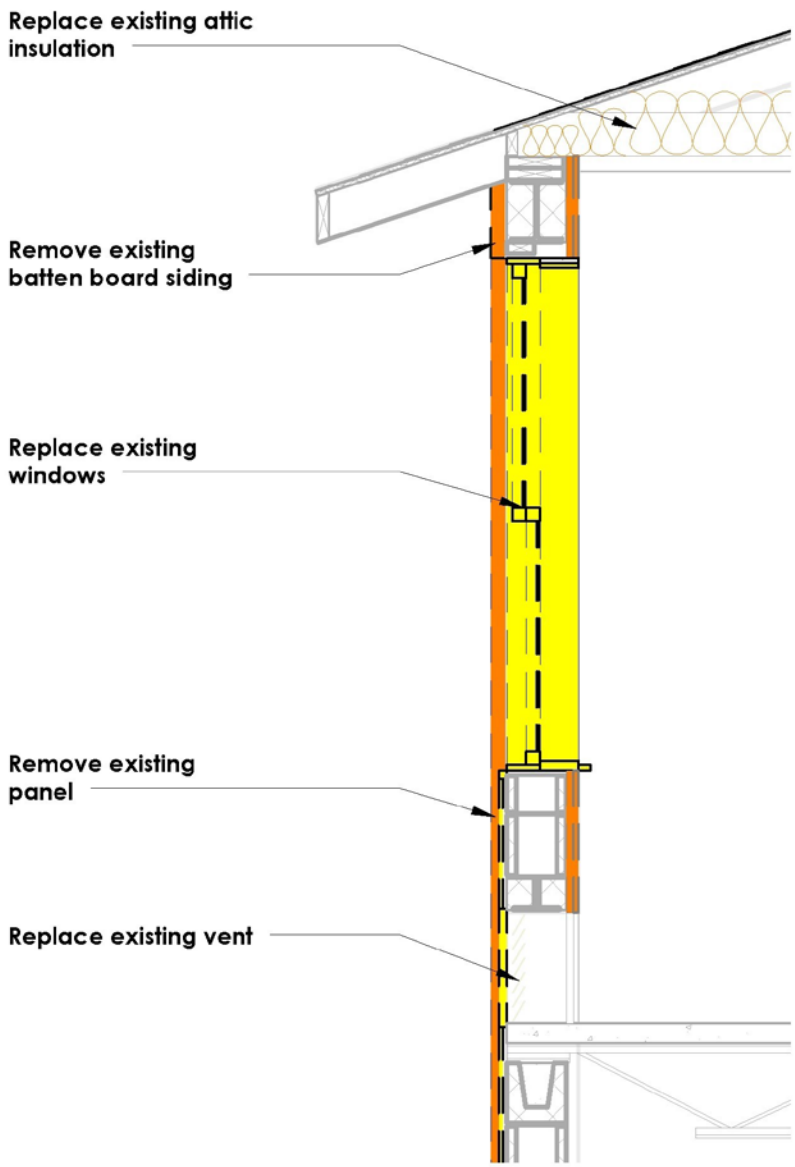

Figure 21 -Target areas for demolition or replacement in existing envelope (Not to scale).

Internally, the existing building was determined to be 10% below code for lighting efficiency, as shown in the COMcheck analysis in Appendix A, which is primarily due to the abundance of less efficient lighting fixtures compared to LED fixtures. The existing plumbing systems were based on old standards and don't meet efficiency goals of new designs. Newer modern efficient plumbing fixtures would offer water savings for the building. As for the site for the building, it was generic in that there were not any outstanding elements that provide benefit to the environment, or the building, other than the pond which contains algae. The site simply serves its purpose as a location for the facility and parking, as shown in Figure 22.[39] So, new site features should be added to help the environment and pond by reducing pollutants coming from the building and parking lots.

Figure 22 - Existing site.[39]

[39] *Google Maps.* https://www.google.com/maps/search/NYSDEC+Region+8+Headquarters/@42.9007605,-77.6660494,1660m/data=!3m1!1e3

Goals and Benchmarks

The goal of this renovation is to use biomimicry for innovative solutions, to existing buildings, that can improve efficiency and energy use of the building and systems as to meet code standards. In order to achieve such goals, consideration was given to possibly proposing phases of the building redesign as to maintain the budgets for renovations and, as for this thesis, to maintain the government budget for addressing the "2030 Challenge." Based upon information in a previous energy audit, conducted on the NYSDEC building, the building was determined to have a 38.5% margin for improvement in energy consumption in order to meet the "2030 Challenge" benchmark of an 80% reduction in energy use by 2020. Per the "2030 Challenge," this reduction is to be deducted from the average for the building type rather than for the specific building undergoing the redesign.[7] The 38.5% reduction was determined from the energy use index (EUI) for the office building type average, compared to the EUI determined for the existing NYSDEC building.[11] The existing buildings EUI was determined to be 43.88, by the previous energy audit, placing it above the 25th percentile for its building type, but it was below the 50th percentile, meaning that there were buildings that were less efficient throughout the country.[11] However the mean EUI was 75, meaning that the DEC facility used 41.5% less energy than the average for its building type leaving only the 38.5% difference for this thesis design to make up for. The previous energy audit broke down the typical office building energy consumption by: 43% heating, 4% cooling, 6% ventilation, 2% water heating, 25% lighting, 1%

cooking, 3% refrigeration, 4% office equipment, 4% computers and 8% miscellaneous, as shown in Figure 23.[11]

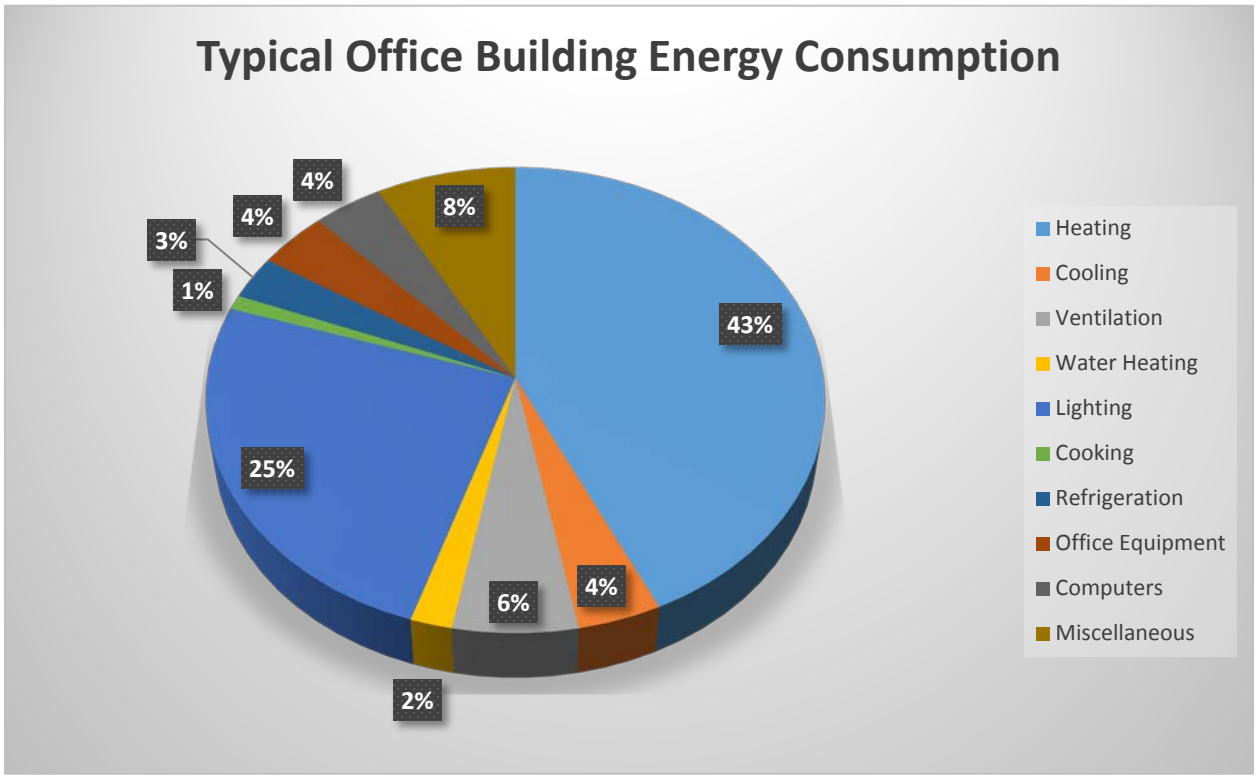

Figure 23 - Typical Office Building Energy Consumption.[11]

Based upon this breakdown of energy use, the 38.5% reduction is addressed through focusing improvements toward the thermal envelope, mechanical systems and lighting, using biomimicry. This is done in order to reduce energy consumption in relation to heating, cooling and lighting, which together occupy the majority of an office building's energy consumption.[11] Additional improvements are addressed through the plumbing to improve efficiency in water use. These improvements aid in reducing both energy consumption and improving efficiency to meet code standards in the building. These improvements are addressed throughout the building as outlined in Table 6, followed by general site improvements. Consideration was also given to alternative energy to reduce the energy costs for the building despite it not being incorporated.

Table 6 - Outline of categories addressed and modifications made in redesign

Category:	**Results:**
Envelope	
Floor	• No changes needed.
Walls	• New interior furring and gypsum wall board filled with spray foam insulation. • New rigid insulation, inflatable air pocket layer and adjustable louvered siding on the exterior.
Windows/Openings	• New properly installed operable windows with pigmented glass. • Replaced vents for ventilation.
Roof	• New spray foam insulation sprayed on the underside of decking. • New secondary metal roof with air gap.
Mechanical/HVAC	
Systems	• New geo-exchange system. • New supplemental HVAC system.
Controls	• New building management system.
Artificial/ Natural lighting	
	• New upgraded efficient LED lighting with daylight and occupancy sensors.
Plumbing	
	• New efficient and low-flow fixtures and aerators.
Site	
Water management	• New bio-swales and roadside plantings.

Renovation

In an attempt to reduce these energy consumption categories, the thermal envelope is addressed with it being the most needed improvement to the building, since it was well below code, by 38%, for its thermal efficiency, it was addressed as part of the first phase of the building redesign. New insulation and siding panels were added to the exterior of the concrete masonry wall with new furring and insulation on the interior as well, as highlighted in Figure 24. The

ventilation and mechanical systems are addressed next as part of the envelope and first phase. The existing vents are replaced with automated vents for use as part of the new ventilation and mechanical system. The windows are also replaced as part of the envelope and first phase, as highlighted in Figure 24. The next category for improvement is the lighting for the building, which was determined to be 10% below code efficiency, and it is addressed as part of the second phase. Improvements include fixture replacement, replacing internal walls with curtain walls, changing finishes in renovation areas and improving egress. This is followed by general site improvements to help the environment and pond, in addition to the aesthetics of the site and building as part of the third phase.

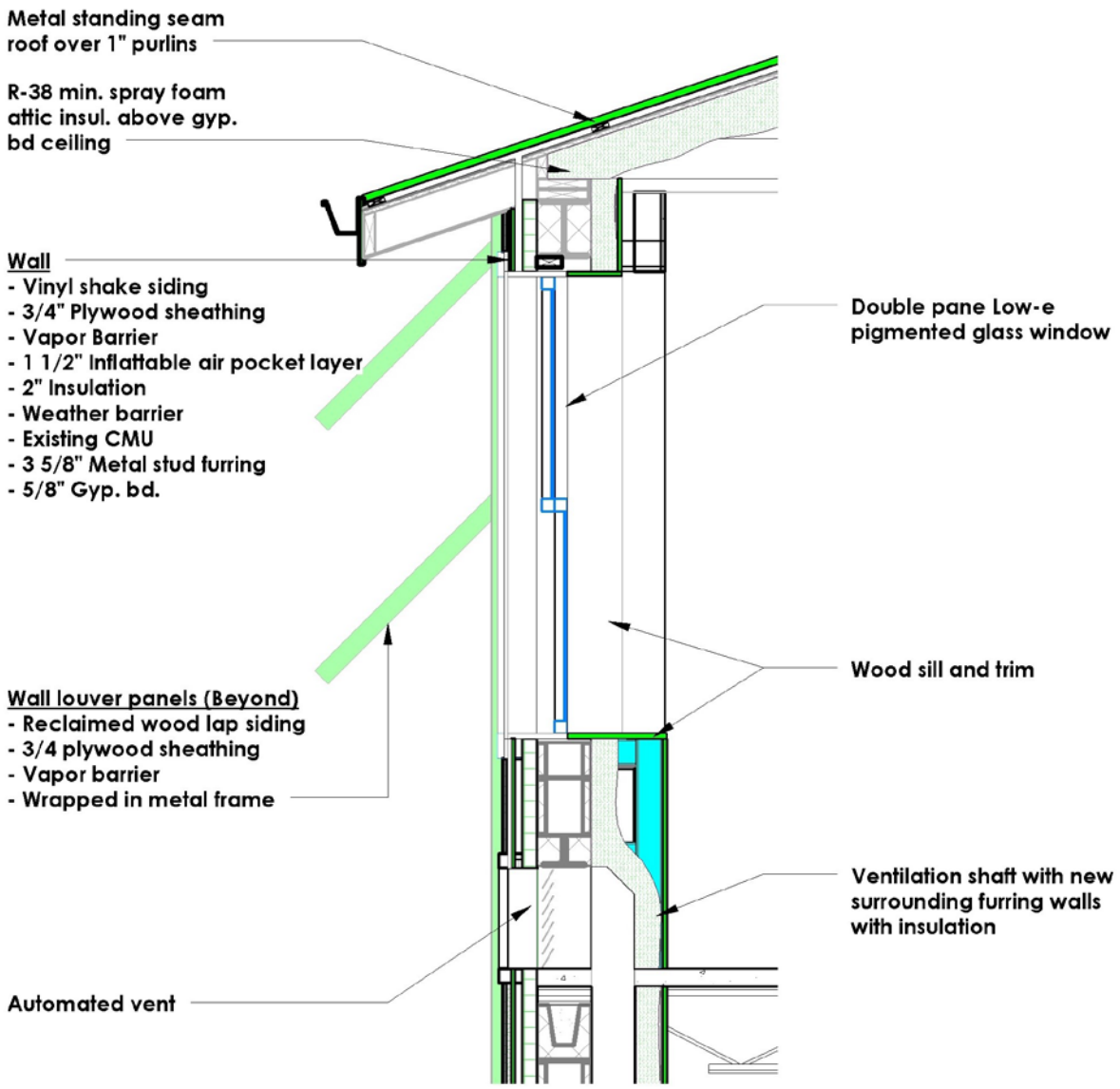

Figure 24 - Envelope improvements in redesign (Not to scale).

Phase I

Since the purpose of this thesis is to use biomimicry, the envelope redesign takes inspiration from penguins and their feathers. Consideration was given to people and how we add and remove layers to maintain our temperature, in addition to dogs who can grow and shed winter coats, which could of lead to a temporary, or removable, design solution. Consideration was also given toward other animals, specifically local animals, such as deer who puff up their

fur to trap air and stay warm. These solutions were left out to find a better solution through penguins, who are able to survive temperature extremes by living in the coldest places on earth. In doing so, the façade was designed to be maneuverable and adaptable as a penguin's feathers are, to allow the building envelope to be adaptable to the exterior conditions. Beyond the insulation provided by a penguin's feathers, there is the penguin's fat, or blubber, that insulates as well.[32]

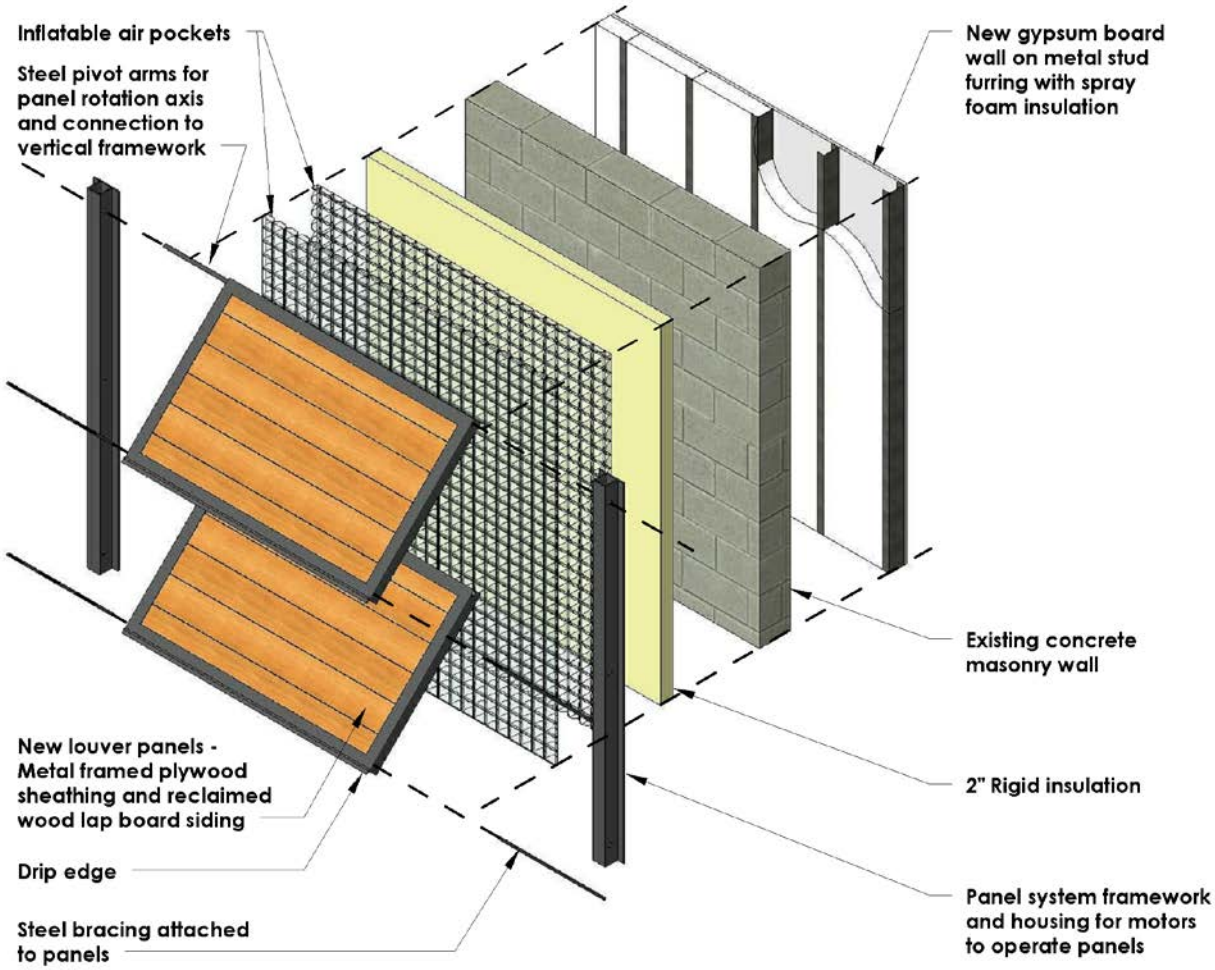

Figure 25 - Exploded axonometric of new redesigned wall assembly (Not to scale).

The penguin's blubber is another part of the penguin that serves to insulate it.[32] This is mimicked through the added rigid insulation on the exterior of the concrete masonry wall, adding a continuous R-13 insulation layer compared to the code R-11.4 requirement, as shown in Figure

25. It is also mimicked through the addition of new furring and gypsum wallboard filled with spray foam insulation, which adds on another layer of insulation, equal up to an approximate R-25 value, to wall cavities which is not required by code for the mass wall type. With these additional insulating elements, the wall is improved from its previous R-value of 2.1 to a 39.1.

The underlying layer of a penguin's feathers, or down, is replicated in the sense of the air pockets that the feathers create. The goal is to achieve a similar function of the feathers insulating properties, which essentially is the air pocket layer that they form.[25] The design approach incorporates pressure controlled arrays of inflatable air pockets, or bubbles, similar to that of bubble wrap, within the façade, as shown in Figure 25. The air is delivered through pressure controlled valves at the bottom of the air pocket wall system at the first floor. But, rather than simply mimicking the penguin's ability to create a thermal layer of air pockets by inflating its feathers with the surrounding air, the design improves upon this by incorporating the ability to inflate the air pockets with the pre-conditioned stale air from the interior of the building. In doing so, the thermal capabilities can be improved, to help to prevent temperature loss at the exterior, while also giving a purpose to the stale exhaust air from the building. This system creates an area of similar temperature on both sides of the wall, therefore improving the skins thermal efficiency from the previous R-value of 39.1 to 40.9, thus reducing temperature loss through the envelope during winter by reducing conduction. As shown in Figure 26, the air pocket layer of the façade consists of two interlocking layers to create a consistent thermal insulating layer.

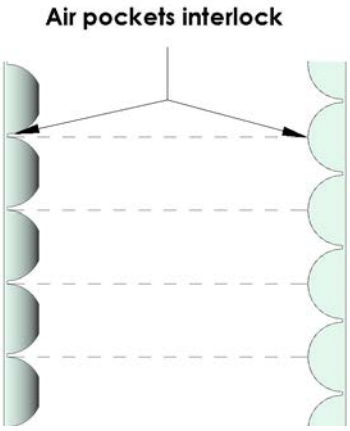

Figure 26 - Interlocking air pocket layers based on penguin down feathers (Not to scale).

In addition to the inner underlying air pockets of the façade that act similar to that of the penguin's down feathers, creating a continuous thermal layer comprised of air surrounding the building, an additional element was incorporated to expand this design to the envelope as a whole, which is a double roof. The double roof consists of a secondary metal roof system on purlins, above the existing roof, that creates an air gap between the roof system to improve the ventilation of the envelope and create a better thermal barrier. This is done by connecting the wall air pockets to the air gap between the roofs for a continuous air barrier with ventilation at the peak of the roof, as shown in Figure 27. At the top of the inflatable air pocket in the wall is a series of pressure release valves in which air that was pumped into the inflatable air pocket, from the lower inflating valves, is released from the upper release valves as pressure builds.

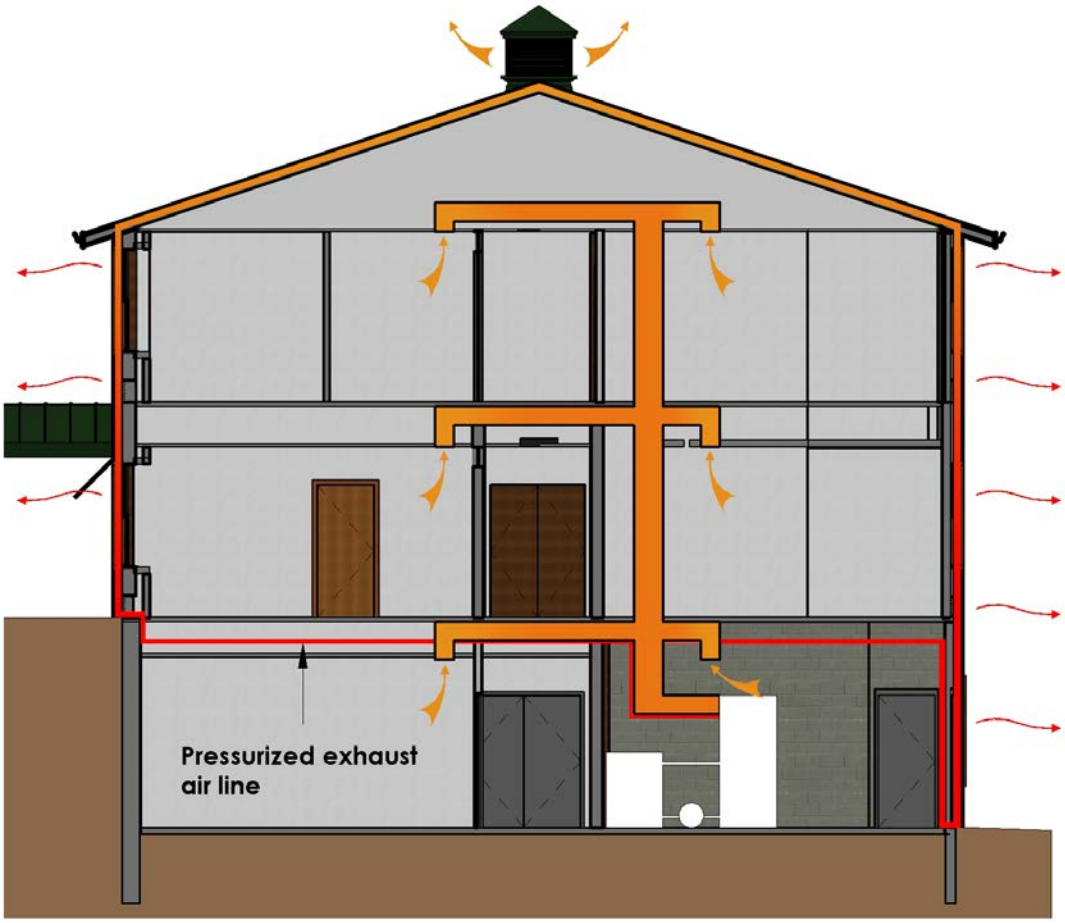

Figure 27 - Pressurized continuous air barrier filled with pre-conditioned air (Not to scale).

In regard to the outer layer of feathers, penguins have the ability to puff them out to allow them to ventilate and release air from the inner layer of feathers, which helps them to stay cooler. This function was mimicked by creating a louvered façade, to essentially emulate feathers, which can open or close as a penguin puffs and flattens its feathers. The louvered façade consists of columns of panels between the windows of the all the façades except for the existing stone walls facing the north and south to allow use of the thermal mass they provide. There is also a new non-operable shake siding wall assembly vertically in line with the windows, as seen in Figure 28, which also contains the inflatable air gap and other insulation improvements behind it. The

Figure 28 - Louver panels located in columns between windows.

panels can open and close to allow ventilation into the building envelope, which occurs when the weather and interior of the building are warm, in order to help cool the interior temperature of the building. The panels are constructed as a typical wall that is then inserted into the metal framework that was shown earlier in Figure 25. The panels consist of exterior grade plywood sheathing, with a moisture barrier applied to cover it, in which the wood lap siding is then attached to. These components are constructed to fit the metal frame systems dimensions so that they can be inserted and screwed into the frames. The panels are then inserted into the vertical metal framing members that attach through the air pocket and rigid insulation to the masonry wall behind them. The mounting penetration locations are then sealed to prevent water penetration into the wall assembly. In regard to the panels themselves, they provide little thermal

improvement to the rest of the envelope by only increasing it from an R-value of 40.9 to a value 42.6, but they do offer thermal improvement through their adaptability. During warmer months, when the panels are open, the inner air pocket layer deflates to allow a more natural ventilation process, similar to that of a penguin's. With the inner air pockets deflated, and the panels open, the air and wind can pass under the panels and through the air gap that is left behind by the deflated air pocket. The air then passes through the air gap in the roof, allowing the building envelope to ventilate and remain cool, as shown in Figure 29, diminishing heat gained through the wall.

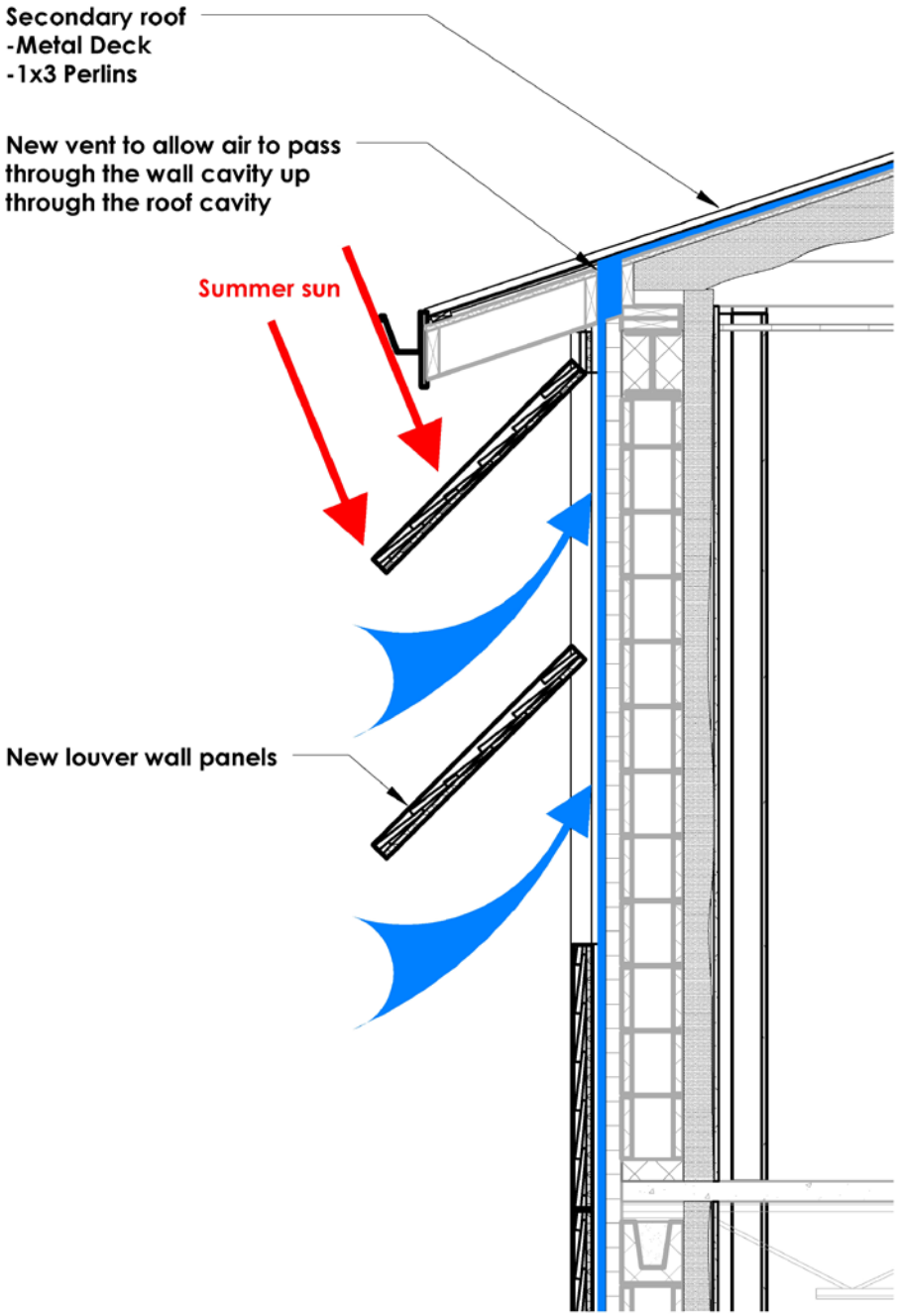

Figure 29 - Open façade louver ventilation diagram (Not to scale).

Another benefit to the panel design is that the heat transfer through solar radiation is also diminished due to the shadow casted by the open panels. While the panels are open they are separated from the building, therefore absorbing the solar transmitted heat and blocking it from contacting the remainder of the wall, as shown in Figure 29, while casting a shadow on the wall behind it. This creates a cooler shaded building surface that will help prevent the wall mass from heating up in the warmer months through solar heat gain while also encouraging airflow along the building skin. During colder months the panels remain closed to prevent air penetration and the inflatable air gap is filled with warm stale interior exhaust air. Beyond the thermal properties and benefits this façade provides, another function that is key to a penguin's feathers is the weather sealing function they provide by sealing out water and air when closed, or flattened. The panels are designed to have an overlapping edge, which acts as a drip edge, which laps the panel below it to allow water to run down the outside of the façade. Additional weather sealing is provided by the under layer of air pockets. When the panels are closed, the air pockets inflate and press up against the panels to create a weather seal. This function of opening, or puffing, the outer panels would work well for cooling the building in warmer temperatures, but for when it is colder the previously discussed function of trapping air in pockets would work better.

In addition to the automated louver panels of the façade, there are also operable insulating blinds at the windows. As inspiration, the groundsel cabbage covers its vulnerable buds with its leaves to protect from frost and freezing.[29] This function essentially acts as a means of protecting the buds from harmful weather and temperatures. This function is mimicked in the design by protecting the interior from harmful external temperatures. The new façade provides protection everywhere except the windows, so this function is used to provide protection at the windows which bare less thermal protection. One option for this idea was to have seasonal

window coverings; this was determined to be less than ideal as having year round coverings could offer more protection from not only cold weather, but also for warm weather. So, with year-round coverings, the windows are covered overnight to help maintain a warmer interior temperature by providing an extra thermal layer over the windows protecting from exterior temperatures. This served as inspiration to extend the idea of automated façade panels to also have them cover the windows, as shown in Figure 30.

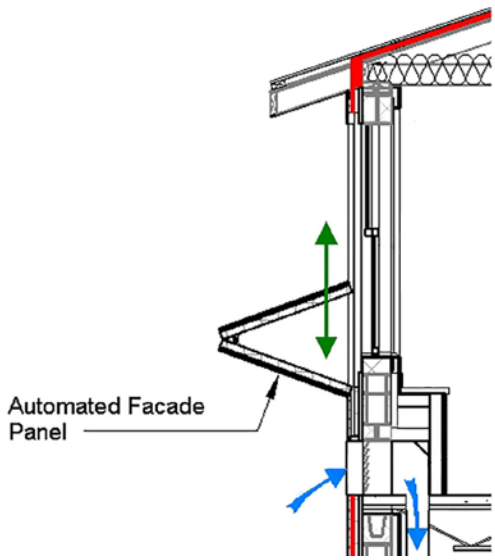

Figure 30 - Automated panel window coverings (Not to scale).

However, due to the mechanized design of this concept the external temperature and climatic weather would prove to make its use more difficult as the mechanics have the potential to freeze. Therefore, the design was altered to incorporate the ability to cover the windows from the interior through the means of thermal blinds, as shown in Figure 31. Thermal blinds will aid in preventing heat transfer at the windows, due to their thermal values, rather than just blocking direct solar gains as shades would. The blinds are designed to have individual collapsible cells that open as the blind is pulled down allowing air to

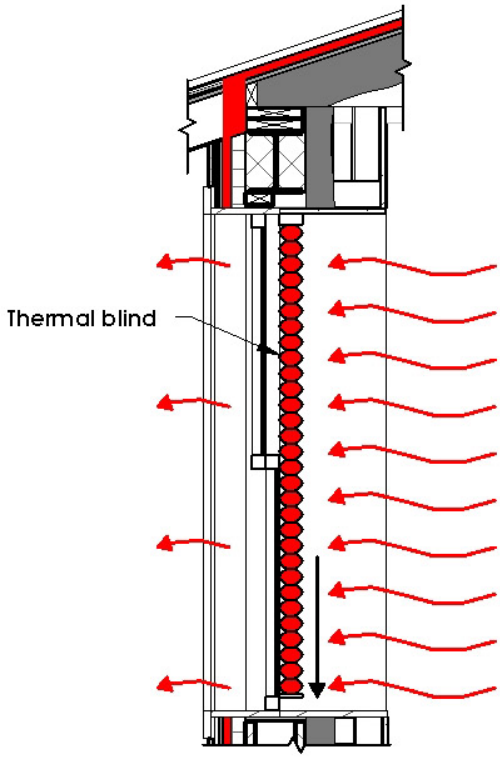

Figure 31 - Thermal blind – Block heat transmission when down (Not to scale).

fill them and create an air barrier, as seen in Figure 31. When retracted the cells collapse and close, thus removing the air barrier to allow heat and light transmittance at the windows, as seen in Figure 32. The use of the thermal blinds will help with temperature loses during colder temperatures and after typical operational hours when they are pulled down. During after-hours the thermal properties of the blinds can help to prevent not only heat loss, but heat gains as well. As a result of maintaining a warmer interior, during morning operations there is less of a load on the HVAC system. This is due to the interior temperature being closer to the desired temperature as it is better maintained by resonating temperatures from the day before. This same concept works for maintaining cooler indoor temperatures as well. This will allow the building to maintain interior temperatures for longer periods; therefore, reducing the need for run time of the HVAC.

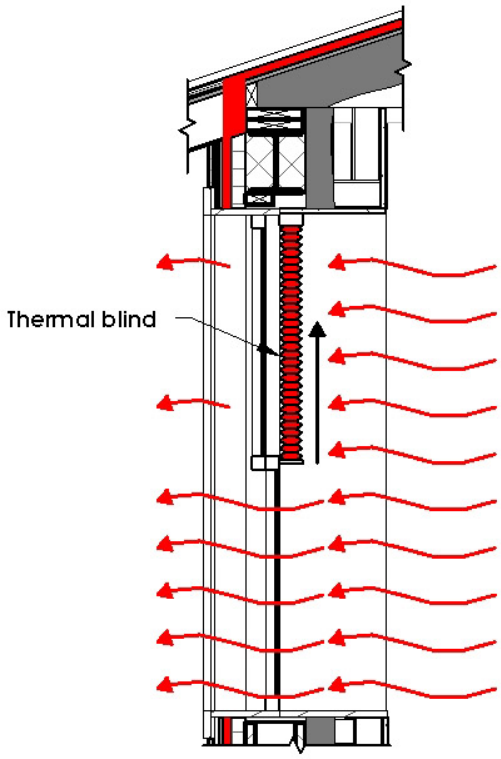

Figure 32- Thermal blind – Allow heat transmission when up (Not to scale).

Further window improvements are made by replacing the existing windows with more efficient ones that also incorporate pigmented glass that allows the windows to change their pigmentation in response to light. This will aid in cooling costs during the summer and unwanted glare making for a more comfortable work environment. This function comes from the balloon fish that has a unique ability to how it perceives light. It has the ability to release a pigmentation into its eyes as a means of diffusing light, to reduce the intensity of it, to improve its vision in

bright light. This function of releasing pigmentation to control light, as done by the balloon fish, is emulated through the means of how a building perceives light, which is through its windows. The windows change pigmentation, and become tinted, to reduce intensity and glare while also having the benefit of reduced solar heat transmittance through the windows.

These new exterior façade and envelope improvements will improve the insulation values of the building and its adaptability to the temperature conditions. With the new design the building envelope thermal efficiency, as determined by a COMcheck analysis, is 42% above the previously existing design and 4% above code. However, this result from the building code analysis, as found in Appendix A and B, is not entirely accurate as it is not capable of measuring the adaptable components of the façade. The façade design allows for an adaption in performance depending on exterior and interior conditions. Therefore, it could be said that, in theory, it would be more energy efficient than measured. Unfortunately, the code compliance analysis does not reflect the improvements of energy consumption, by the systems in place, as it only shows the building's thermal efficiency. However, the thermal envelope improvements result in a reduced demand for heating and cooling in the building, which will, in turn, result in a reduced energy and fossil fuel consumption.

The next step in the design process, for the first phase, is the ventilation, which is addressed as part of the skin ventilation. Fortunately, the existing external wall construction consists of vents below the window assemblies from previous air conditioning units. These existing openings were repurposed in the new design to serve as the intakes for ventilation shafts that aid in the incorporation of a geo-exchange system inspired by a collaboration of termite mounds and penguin feet. Although, original thoughts were to seal off the vents and incorporate a central air system, this was passed over so that the vents could be repurposed for a solution using biomimicry. As a result, the repurposed vent openings draw upon the outside air so that it may be brought into the building walls where it is heated through heat exchange with the building. As shown in Figure 33, the air enters the vents and passes through the new ventilation shafts enclosed in the new furring walls where it is the drawn into the basement. As the air

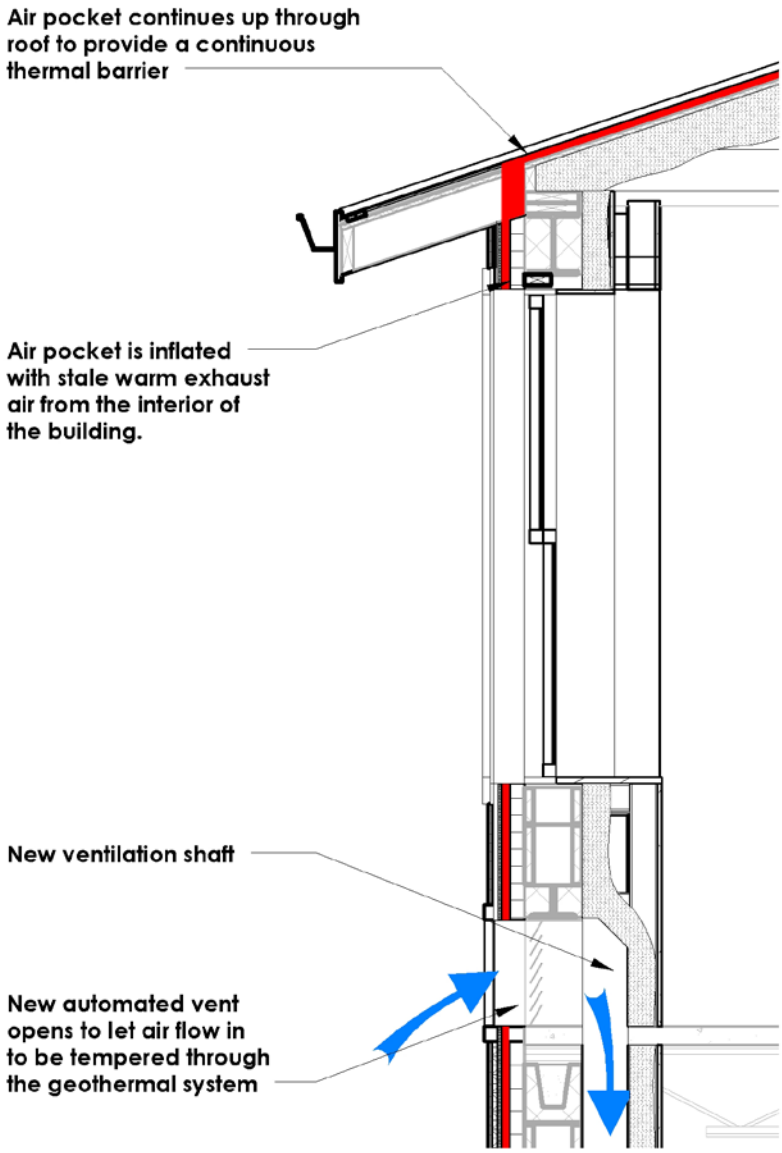

Figure 33 - Wall redesign and ventilation diagram (Not to scale).

travels through the vents it is undergoing a heat exchange with the wall temperature. This is done prior to the air entering the geo-exchange system for tempering where it is also dehumidified before being dispersed into the building's interior, as shown in Figure 34. The air flow of the intake system relies mostly on natural air flow with the addition of a running fan system for when additional air flow is needed. The fan aids in drawing air into the ventilation shaft intakes. In order to further improve the efficiency of this system, the automated vents open and close as necessary and depending upon the season the vents draw air either from the cool shaded side of the building or from the warm sun bathed side. As for the geo-exchange system, the piping for the water in the system was originally considered for heat exchange with the onsite pond, but after concern was expressed for altering the water temperature and ecosystem for the fish, the pipe lines were located to the ground below the parking lot adjacent to the building.

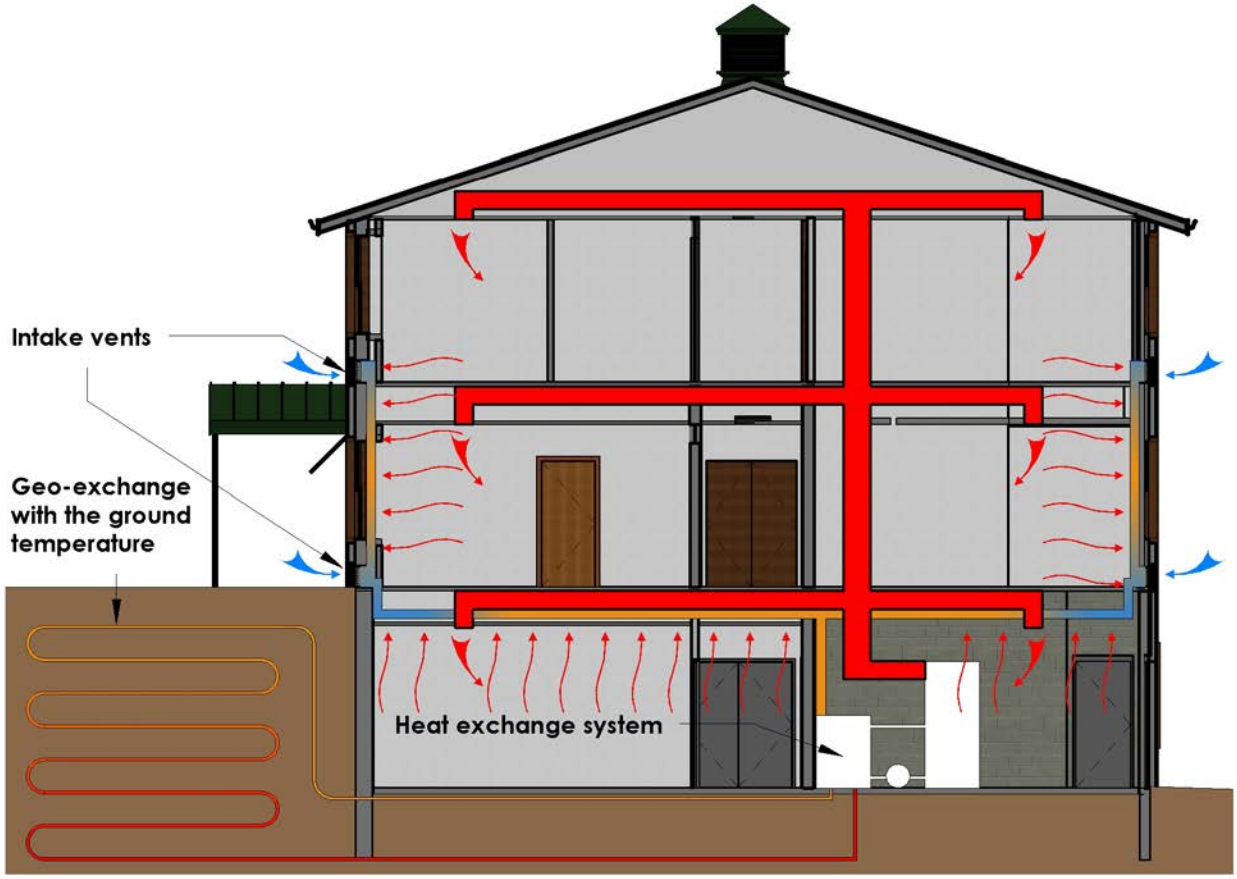

Figure 34 - Geo-exchange system diagram (Not to scale).

The inspiration for the ventilation system comes from the termite mound and the way that termites draw air from shafts that they can open and close where cooler air naturally flows down through the shafts into the mound. From this point, in the design, the geo-exchange system takes place with inspiration from penguin feet. Penguins have the ability to exchange heat, through blood flow in their feet, with the colder ground beneath them. This function is mimicked in the new building design by using a geo-exchange system that runs water through piping, similar to blood through veins, in the ground to exchange heat. Upon transferring heat with the ground, the water returns to a heat exchange system so that the water temperature can then be transferred to the air that was drawn in through the ventilation shafts in order to temper the air.

Using this new ventilation system, with geo-exchange, there is the potential to eliminate the need for mechanical cooling systems. However, there is still a need for a heating system. The use of the geo-exchange eliminates the need for other cooling systems since the temperature of the ground averages 50 degrees Fahrenheit, at a steady state, which is cooler than the typical indoor air used in buildings. This temperature difference allows for the geothermal system to cool the air from the warmer outdoor temperatures, of warmer months, to the indoor temperature desired. Another benefit of this system is its ability to provide partial heating for when the building temperature is cooler than the ground. In this scenario, rather than expelling heat to the ground, the water absorbs heat from the ground, which is typically 50 degrees Fahrenheit, to be transferred to the air in the heat exchange system where it is then heated by a HVAC system to heat the remainder of the temperature difference to reach desired indoor temperatures during the colder months. As a result, implementing these systems dramatically reduces heating and cooling loads on the building as well as decrease the gas and electrical consumption from the heating and cooling systems. Finally, a building management system is incorporated to monitor and control

the HVAC, geo-exchange system, and automated panels and louvers of the façade so that the building systems operate more efficiently and effectively in one collective effort. In addition, with the newly available data from the building management system, studies of the building could be performed to determine how the biomimicry inspired changes were able to improve the building. With this knowledge classes or events could be held as a means to educate others of the possibilities of biomimicry and its value to design, and particularly this design method.

As for determining energy consumption, related to cooling, it can be dramatically decreased by the geo-exchange system to almost nothing as there is still a need to pump air and water through the system. Without the geo-exchange system, the envelope alone, provides a 50.25% reduction in cooling. In combination with the geo-exchange system, and based upon the simplified heating and cooling load calculations outlined in Appendix C, that account for the building size and surface area, and include the envelope improvements, the cooling can be reduced by 100%. In terms of total building energy reduction, the cooling load typically accounts for only 4% and with a 100% reduction the total is reduced by that 4%. In regard to heating, the geo exchange system is able to reduce the need for heating by a mechanical system by raising air temperatures to match that of the ground. With this reduction and inclusion of the envelope improvements, the calculations outlined in Appendix C suggest an 87% reduction in energy consumed for heating. As for the envelope by itself, it would attribute to a 66% reduction in heating. Since heating typically uses 43% of an office buildings energy consumption, as mentioned in the energy audit, the reduction from the combination of the two translates to only a 37.41% reduction in total building energy use.[11] In total the heating and cooling can be determined to have a 41.41% reduction in total building energy use.

Phase II

Beyond the first phase, which consists mostly of envelope improvements, the second phase pertains more to the interior and improving efficiency through more practical means commonly used in design that do not utilize biomimicry. The most significant need of energy improvement, in the interior, is the lighting load. The current facility lighting is not fully utilized, only part of the lights are used in order to cut costs. Therefore, new LED energy efficient lighting was used to replace the existing lights with the addition of daylight and occupancy sensor controls to reduce electricity output to lighting fixtures. Based upon the calculations in the previous energy audit, a LED lighting upgrade with occupancy sensors would attribute for a savings of 55.66% for lighting.[11] With the typical office building having lighting consume 25% of total energy as outlined in the energy audit, this upgrade could attribute to a 13.9% reduction in the total building energy use.[11]

In addition, to reduce the need for artificial lighting, consideration was given toward opening the interior of the building to create an open office plan to allow for more daylighting. On the other hand, with this option, the office spaces would be less private and concern was expressed by the staff regarding this matter. As a result, another idea to mitigate this was to replace the existing interior office walls that are facing the interior with curtain walls consisting of clear glazing and frosted glazing to allow for daylight, as shown in Figure 35 through Figure 37 during the fall season, to spread throughout the building while still allowing for privacy where needed.

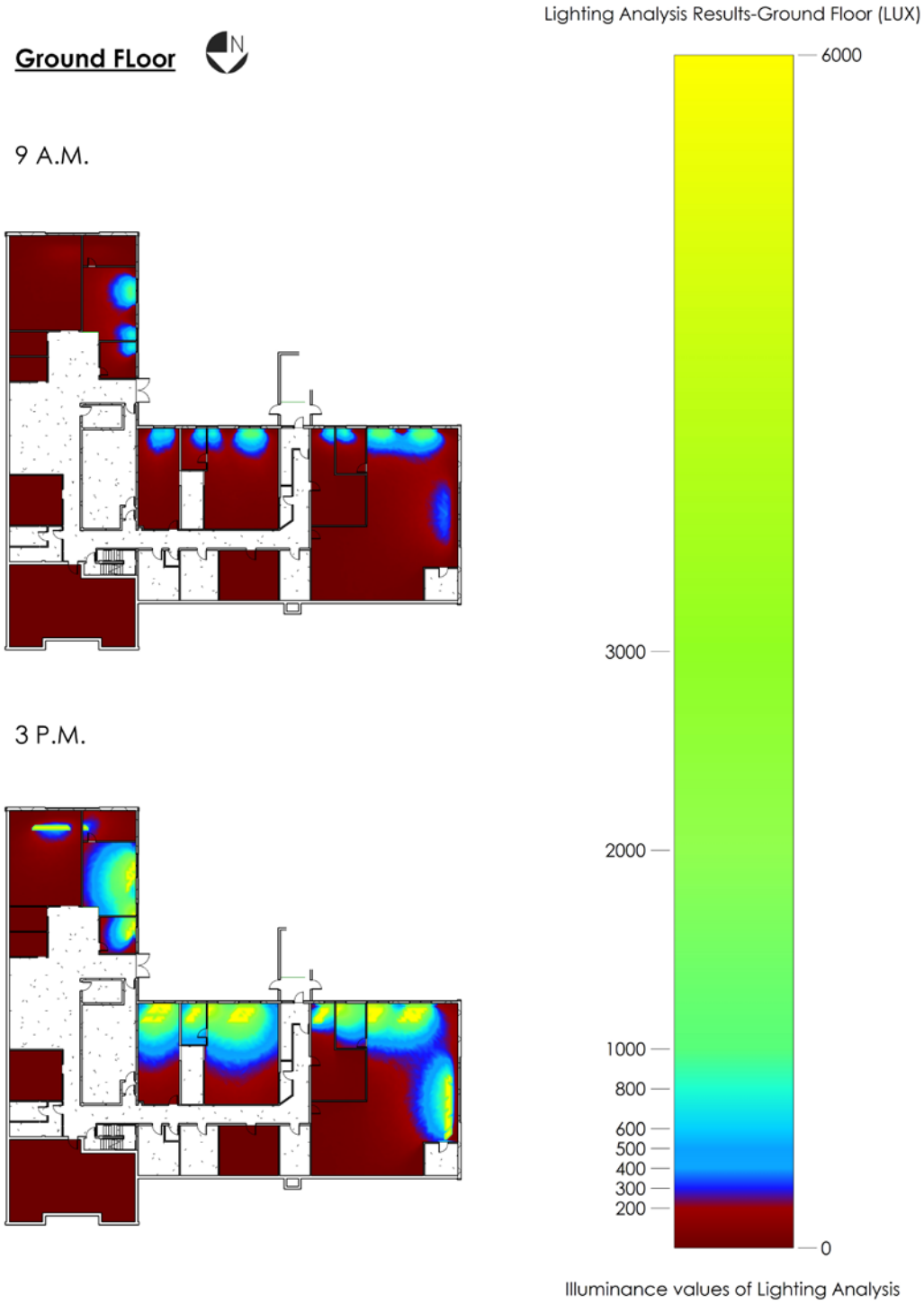

Figure 35 - Daylight study of existing facility ground floor conditions.

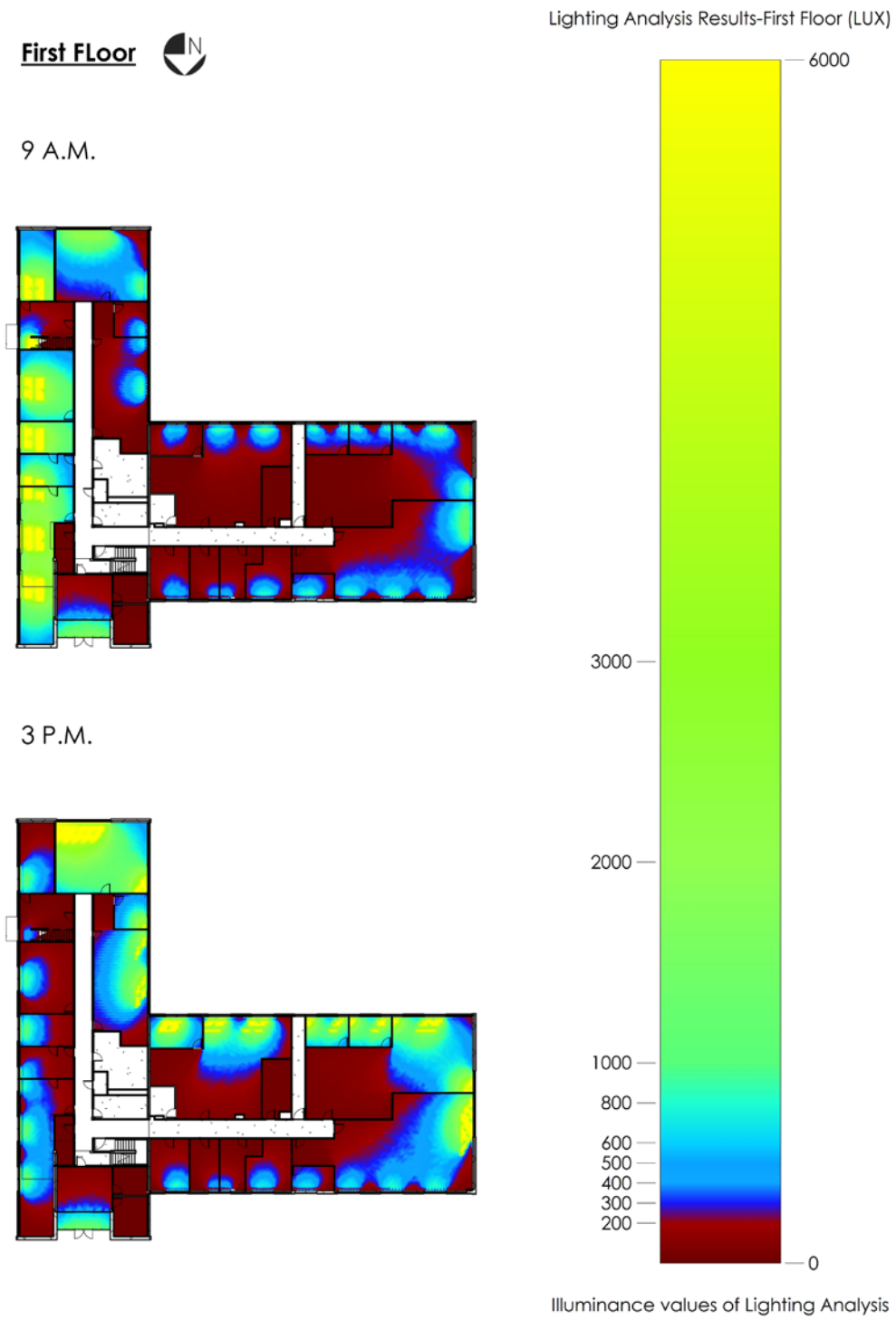

Figure 36 - Daylight study of existing facility first floor conditions.

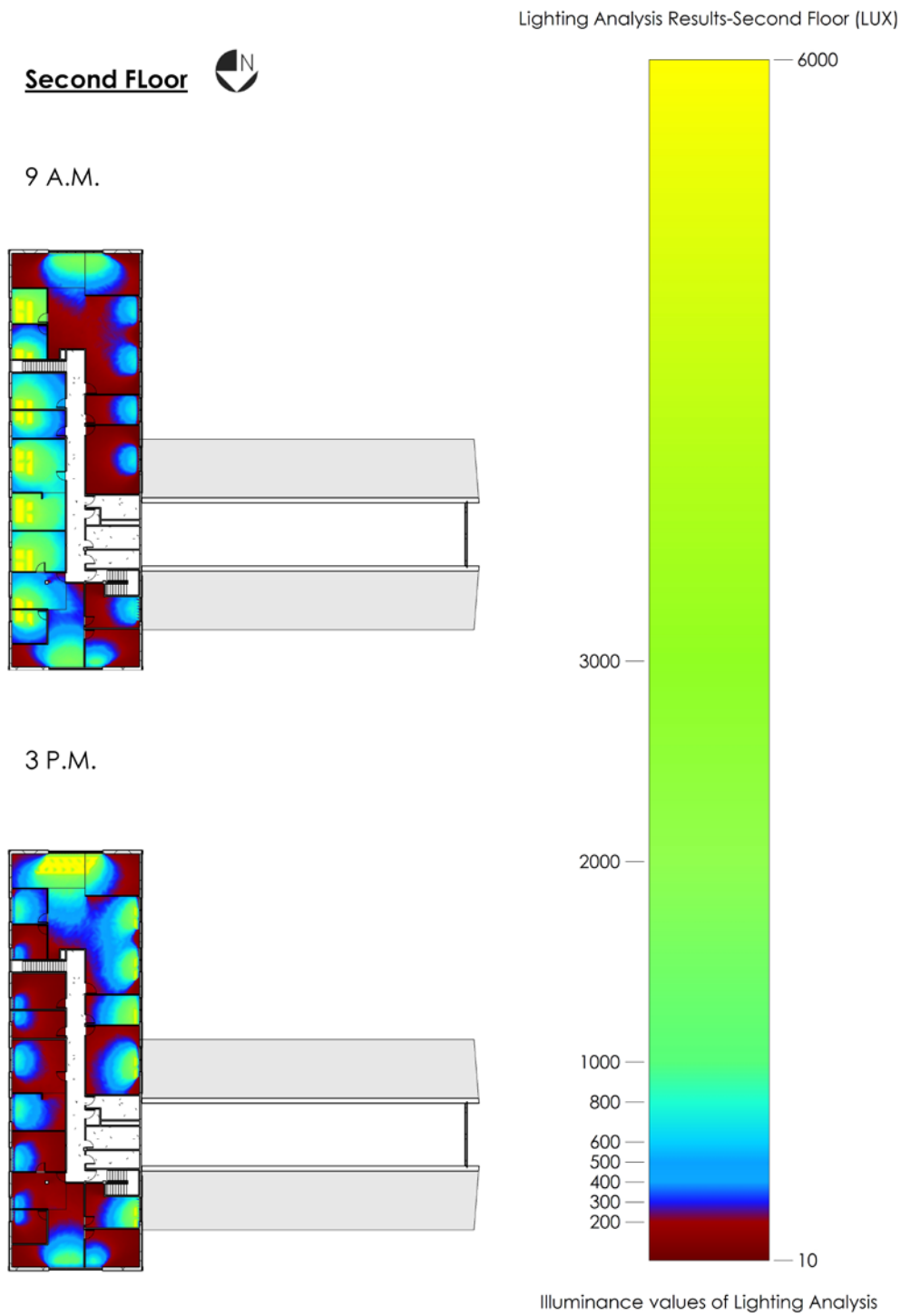

Figure 37 – Daylight study of existing facility second floor conditions.

It can be seen in these images, showing daylight penetration into the building, that during the early times of the day, there is substantial light entering the building that is essentially blocked

off from the corridor and the offices on the other side of the building. By exchanging the walls out, for curtain walls, daylight and artificial light is allowed to spread more throughout the spaces. In doing so, the need for artificial light is reduced and a more open feeling is provided to the space in comparison to the closed off spaces and corridors that were running through the building, as shown in the existing conditions of Figure 38 and renovation in Figure 39.

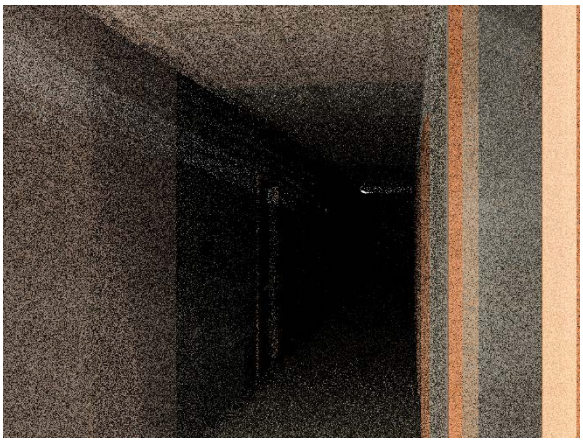

Figure 38 - Existing corridor and lacking daylight.

Figure 39 –Re-designed corridor and daylight.

Alongside these interior improvements, the existing facility is lacking the egress requirements of buildings today. The previous existing facility consisted of three floors but currently only two of them were accessible to the handicapped due to there not being an elevator; fortunately, the site allows access to the two lower floors, with entrances at grade since the building is partially sub-merged in the ground. Therefore, as part of the second phase of development, but outside the applications of biomimicry, an elevator was added to the facility to provide access to all floors. This was achieved while minimizing any disruption to the existing facility program and circulation, as shown in the floor plan diagrams in Figure 40 through Figure 42 showing the location off the entry lobby and respective floors. Further second phase improvements were made for replacing the existing plumbing fixtures for higher efficiency and low flow toilets as well as new aerators for sinks to help reduce water consumption. Finally,

during the second phase, more general improvements were made by applying new finishes to areas undergoing renovations.

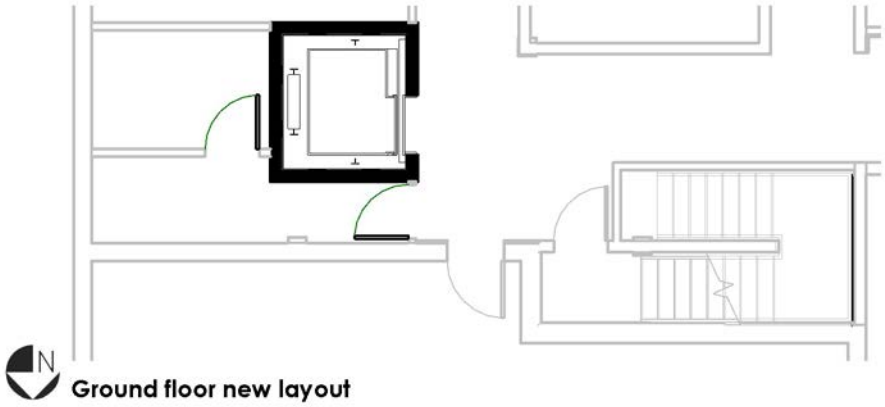

Figure 40 - Ground floor egress (Not to scale).

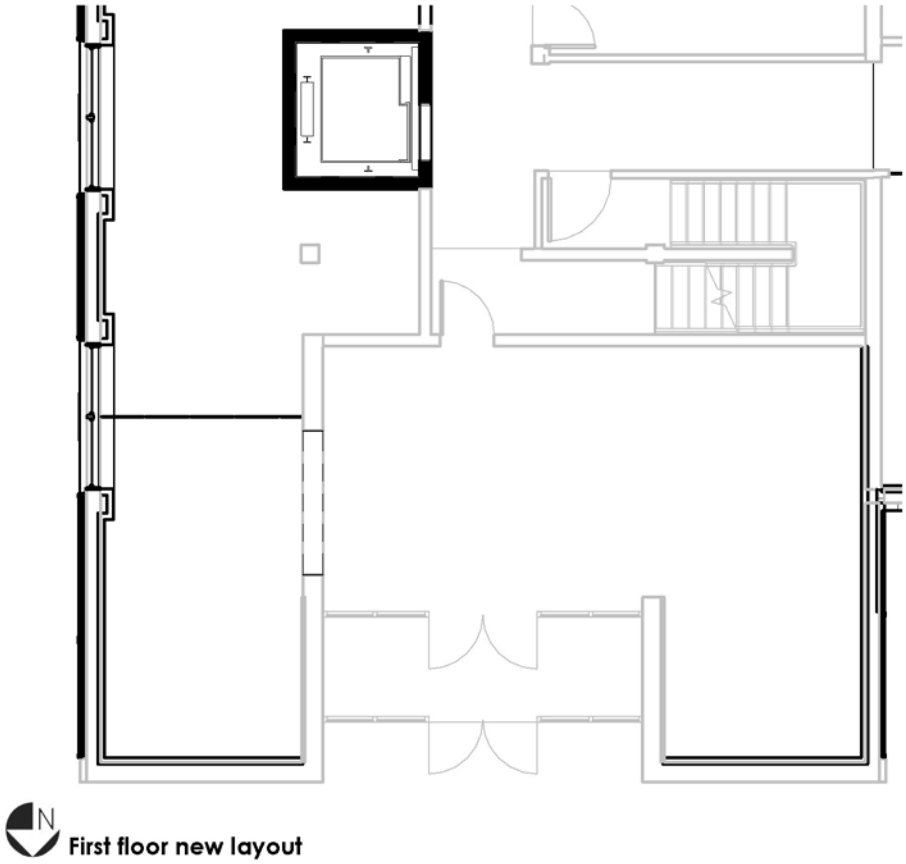

Figure 41 - First floor egress improvements (Not to scale).

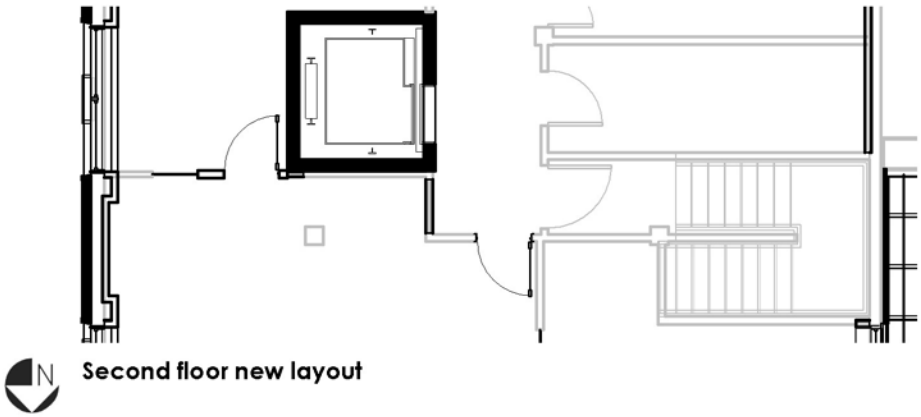

Figure 42 - Second floor egress improvements (Not to scale).

Phase III

The first two phases result in an improved facility that is closer to reaching its "2030 Challenge" progress. Another phase was implemented to aid in improving the site water management and treatment. The main site improvements involve the incorporation of bio-swales along the road side to improve upon the existing drainage and water filtration. In addition, to aid in cleaning and maintaining the water of the pond on site, bio-swales are placed along the perimeter of the driveways and parking lots, as shown in Figure 43 to catch and filter run off water before it can reach the pond. Further water cleaning improvements are made through incorporating floating planting beds on the pond to aid in cleansing excess nutrients. Beyond these site water management changes, additional exterior improvements were made to the building and site by incorporating a new entry canopy at the main entrance and a planting bed along the side of the building for roof water runoff, as seen in Figure 44.

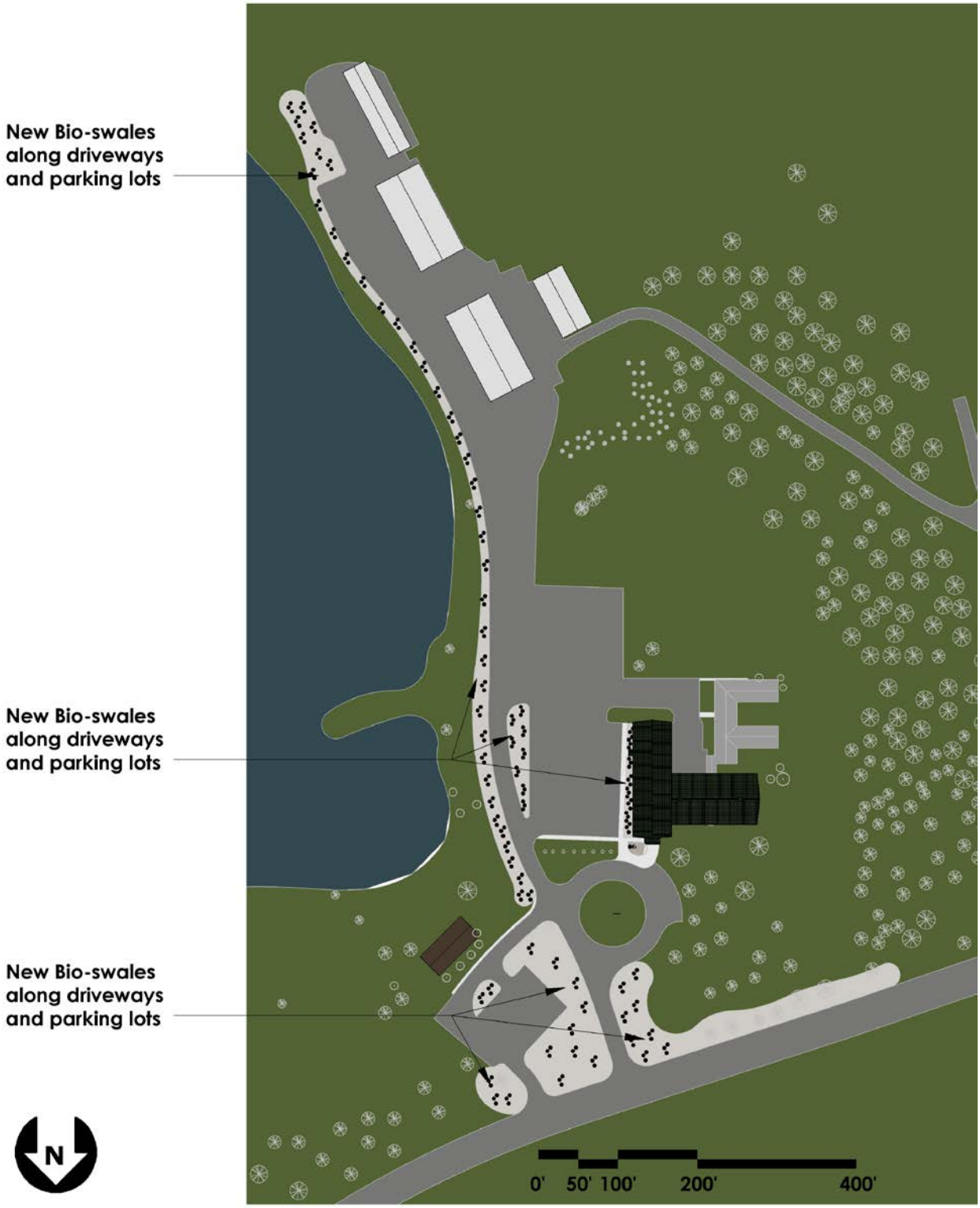

Figure 43 - Bio-swale improvements to existing site (Not to scale).

Figure 44 - NYSDEC Region 8 Headquarters - After re-design.

The calculated energy reduction results, which came from the re-design of the existing NYSDEC Region 8 Headquarters, were determined from a combination of calculations and data for a typical office building in the same region. The calculations, as seen in Appendix C, were made for energy consumption of the existing building based upon its envelope construction and thermal values and for the re-designed envelope construction and thermal values. From the two calculated energy consumption values, the percentage reduction total was calculated to be 41.41%. As a result, in combination with the building having already been 41.5 % below the average for its building type, the re-designed facility resulted in a total of an 82.91% reduction in energy consumption. This was achieved simply through the modifications to the envelope, including the pigmented windows, and the incorporation of a geo-exchange system, which were the primary biomimicry inspired elements. With this reduction alone the building was able to meet and exceed the "2030 Challenge" benchmark goal of an 80% reduction by 2020.[7] Altogether, with the additional reduction from lighting improvements, the reduction amounts, shown in Figure 45, total to an energy savings of 55.31% for the DEC facility. This total, in respect to the average for the building type, surpasses the "2030 Challenge" goal of 80%

reduction by 2020 with a total of 96% reduction; therefore, allowing it to meet the next benchmark goal of a 90% reduction by 2025.[7]

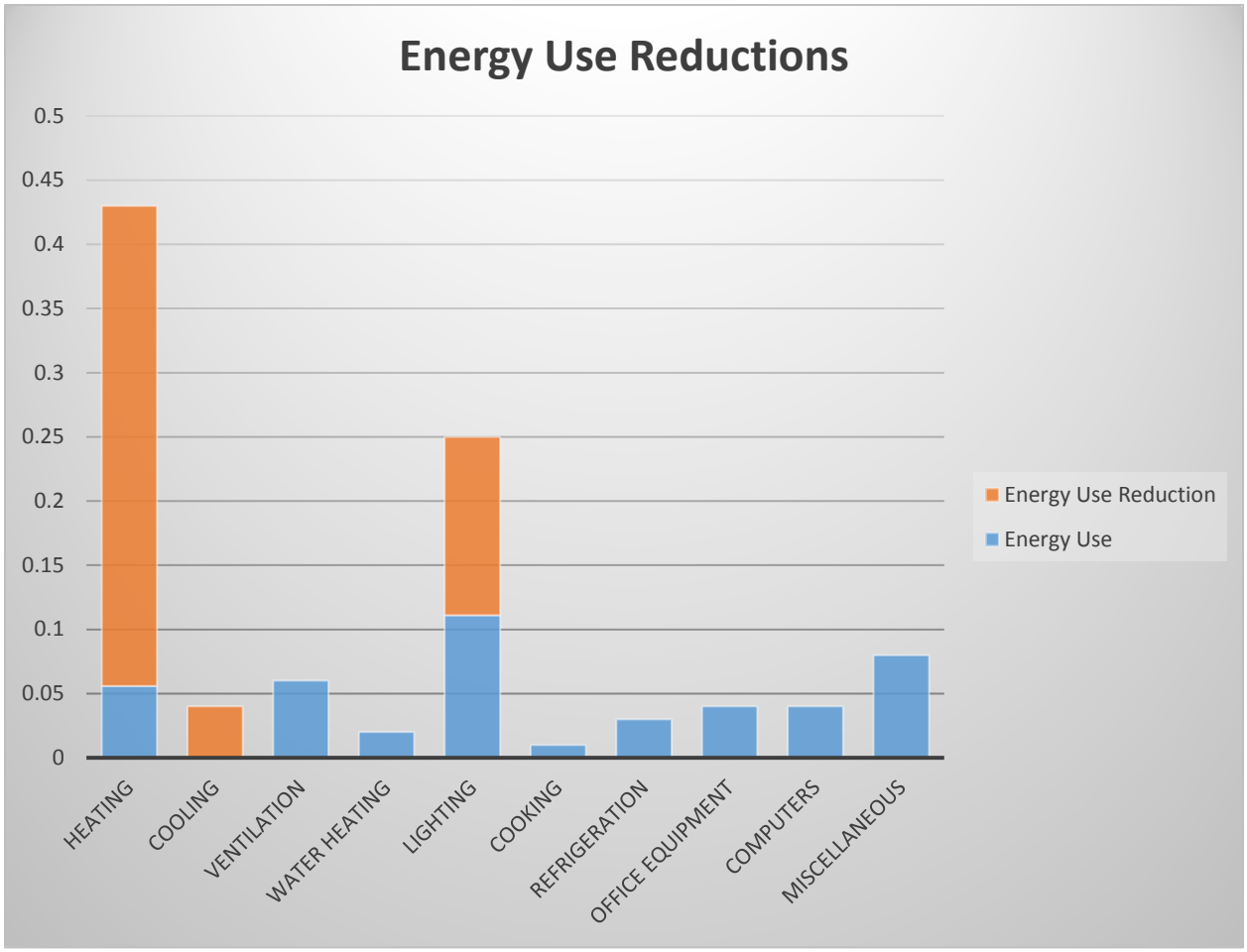

Figure 45 –NYSDEC building energy use reductions based on a typical office building.

However, the building performance results that were determined are at a minimum since the results were derived from a typical static system that cannot adapt. Thus leaving potential for even greater results in energy use reduction with the incorporation of an adaptable façade. Based upon research, the solution outlined in this thesis for the new façade has not been done before, therefore the assessment of its abilities and feasibility, for improving the thermal envelope, is difficult to achieve. A working model would need to be constructed and tested to discover the true potential of the system to identify how much greater of a reduction could be achieved. Furthermore, the typical breakdown of an office building energy consumption, that was outlined,

does not account for the fact that the pre-existing NYSDEC facility had air leaks that could amount to a greater percentage of energy being consumed by the heating and cooling. Which, in turn, could also result in a potential increase in energy reduction through the improvements made in the re-design.

7.0 – Summary and Conclusion

With the future of the design of the built environment being directed toward improving efficiency, and reducing impacts upon the natural environment, a change needs to be made in how this is achieved. As per the "2030 Challenge," the existing building stock needs to be improved as well as new buildings. The greatest results for improving efficiency and reducing impacts of the building stock as a whole, upon the natural environment, comes from addressing the existing building stock. One such way of achieving these results is through the usage of biomimicry as demonstrated by this thesis. Through emulating multiple aspects of nature, such as: penguin feathers, the cabbage groundsel, the balloon fish, the skunk cabbage, termite mounds and penguin feet, the building envelope, windows, ventilation and mechanical systems were improved to reduce energy consumption in the building. The NYSDEC Region 8 Headquarters was able to achieve a 55.31% reduction in energy usage and a 96% reduction from the average of its building type. On top of these energy use reductions, further improvements were made to reduce impacts upon the environment also using biomimicry by imitating nature's way of managing and filtering water throughout the site to reduce pollutions from spreading into the environment.

Although the re-designed DEC facility is not net-zero like the end goal of the "2030 Challenge," it was able to reach the 2020 benchmark goal, in addition to the 2025 benchmark goal, and pass code efficiency standards for the envelope. Furthermore, it was able to reach this goal through the means of using biomimicry as a source for architectural innovation in application to an existing building. In the end the building reached the beginning goals of being a place for not only educating on improving the environment but for also being a showcase for how to achieve such a goal through reducing impacts on the environment through more efficient

buildings but also through improving the environment through site water management. All of this can be taught through educational courses provided by the NYSDEC and through teachings of the building and its systems.

The potential to improve upon the impact that is made upon the natural environment is by far greater through addressing existing buildings than through building new ones. With every existing building that is improved to reduce its energy the margin between energy consumption of old and new buildings is decreased, significantly reducing the impact made upon the natural environment. Upon determining the results outlined in this thesis, it can be said that biomimicry is a potential and promising solution to the “2030 Challenge,” existing buildings, and future energy and environmental goals at this time in its development. Even more so, over time as the field of biomimicry develops the designs that evolve from it will aid in teaching others about the field. As a result, the field will become even more evolved and will pose an even greater opportunity and potential to improve not only existing buildings but to also improve the way we construct new buildings as well.

Appendix A – Existing Building Code Compliance

COMcheck Software Version 4.0.2.6

Envelope Compliance Certificate

Project Information

Energy Code:	2014 New York Energy Conservation Construction Code
Project Title:	
Location:	Livingston County, New York
Climate Zone:	5a
Project Type:	New Construction
Vertical Glazing / Wall Area:	20%

Construction Site:
Avon-Lima Rd.
Avon, NY 14414

Owner/Agent:

Designer/Contractor:

Building Area	Floor Area
1-Office : Nonresidential	31392

Additional Efficiency Package

On-site Renewable Energy

Envelope Assemblies

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Floor 1: Slab-On-Grade:Unheated, Horizontal with vertical 2 ft., [Bldg. Use 1 - Office] (d)	527	---	9.0	0.441	0.441
Roof 2: Attic Roof with Wood Joists, [Bldg. Use 1 - Office]	6456	30.0	0.0	0.034	0.027
Roof 1: Attic Roof with Wood Joists, [Bldg. Use 1 - Office]	6160	30.0	0.0	0.034	0.027
NORTH					
Basement Wall 1 copy 1: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	1139	0.0	0.6	0.334	0.108
Basement Wall 1 copy 3: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	138	0.0	0.6	0.334	0.108
Basement Wall 1 copy 5: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	186	0.0	0.6	0.334	0.108
Basement Wall 1 copy 7: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	138	0.0	0.6	0.334	0.108
Exterior Wall 14 copy 4: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1184	---	---	0.476	0.064
Window 4 copy 13: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 14: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 15: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 16: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Window 4 copy 17: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 18: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 19: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Exterior Wall 14 copy 6: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	143	---	---	0.513	0.064
Exterior Wall 14 copy 8: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	194	---	---	0.476	0.064
Window 41: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	194	---	---	0.800	0.380
Exterior Wall 14 copy 10: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	143	---	---	0.513	0.064
Exterior Wall 14 copy 3: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.513	0.064
Exterior Wall 14 copy 4: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	161	---	---	0.476	0.064
Window 39 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 14 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.513	0.064
EAST					
Basement Wall 1: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	1470	0.0	0.6	0.334	0.108
Basement Wall 1 copy 4: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	32	0.0	0.6	0.334	0.108
Exterior Wall 13: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1528	---	---	0.476	0.064
Window 1 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 3: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 5: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 6: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 7: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 20: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	31	---	---	0.800	0.380
Window 21: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	12	---	---	0.800	0.380
Door 3: Glass (> 50% glazing):Metal Frame, Entrance Door, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	25	---	---	0.800	0.770
Exterior Wall 14 copy 7: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	36	---	---	0.513	0.064
Exterior Wall 13 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1248	---	---	0.476	0.064
Window 1 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 11: Vinyl/Fiberglass Frame:Operable, Perf. Specs.:	43	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)					
Window 1 copy 12: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 13: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 14: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 15: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
SOUTH					
Exterior Wall 1 copy 2: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	137	---	---	0.350	0.064
Exterior Wall 1 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	189	---	---	0.413	0.064
Window 3: Metal Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	26	---	---	0.350	0.450
Exterior Wall 1 copy 3: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	137	---	---	0.513	0.064
Exterior Wall 1 copy 3: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1139	---	---	0.476	0.064
Window 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 3: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 5: Vinyl/Fiberglass Frame:Fixed, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.380
Window 10: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	28	---	---	0.800	0.380
Window 11: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	11	---	---	0.800	0.380
Door 2: Glass (> 50% glazing):Metal Frame, Entrance Door, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	23	---	---	0.800	0.770
Exterior Wall 1 copy 3: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	142	---	---	0.513	0.064
Exterior Wall 14: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.476	0.064
Window 39: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 1 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	142	---	---	0.513	0.064
Exterior Wall 14 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1184	---	---	0.476	0.064
Window 4 copy 6: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 7: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 8: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Window 4 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 11: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 12: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Exterior Wall 1 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.513	0.064
Exterior Wall 14 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	161	---	---	0.476	0.064
Window 39 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 1 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.513	0.064
WEST					
Exterior Wall 1 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	683	---	---	0.476	0.064
Window 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Door 1: Insulated Metal, Swinging, [Bldg. Use 1 - Office]	64	---	---	0.650	0.370
Exterior Wall 1 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.513	0.064
Exterior Wall 1 copy 4: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	231	---	---	0.413	0.064
Window 12: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	61	---	---	0.800	0.380
Exterior Wall 1 copy 6: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.350	0.064
Basement Wall 1 copy 2: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	163	0.0	0.6	0.334	0.108
Basement Wall 1 copy 6: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	32	0.0	0.6	0.334	0.108
Exterior Wall 14 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	710	---	---	0.476	0.064
Window 1 copy 8: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Exterior Wall 14 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	205	---	---	0.513	0.064
Exterior Wall 14 copy 3: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	240	---	---	0.476	0.064
Window 38: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	121	---	---	0.350	0.450
Exterior Wall 14 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	205	---	---	0.513	0.064
Exterior Wall 14 copy 5: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	169	---	---	0.476	0.064
Exterior Wall 14 copy 9: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	36	---	---	0.513	0.064
Exterior Wall 14 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1248	---	---	0.476	0.064

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Window 1 copy 16: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 17: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 18: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 19: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 20: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, PF 0.34, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450

(a) Budget U-factors are used for software baseline calculations ONLY, and are not code requirements.
(b) 'Other' components require supporting documentation for proposed U-factors.
(c) Fenestration product performance must be certified in accordance with NFRC and requires supporting documentation.
(d) Slab-On-Grade proposed and budget U-factors shown in table are F-factors.

Envelope FAILS: Design 38% worse than code

COM*check* Software Version 4.0.2.6

Interior Lighting Compliance Certificate

Project Information

Energy Code: 2014 New York Energy Conservation Construction Code
Project Title:
Project Type: New Construction

Construction Site:
Avon-Lima Rd.
Avon, NY 14414

Owner/Agent:

Designer/Contractor:

Additional Efficiency Package

On-site Renewable Energy

Allowed Interior Lighting Power

A Area Category	B Floor Area (ft2)	C Allowed Watts / ft2	D Allowed Watts (B X C)
1-Common Space Types:Office - Enclosed	12616	1 .10	13878
2-Common Space Types:Office - Enclosed	12616	1 .10	13878
3-Common Space Types:Office - Enclosed	6456	1 .10	7102
		Total Allowed Watts =	34857

Proposed Interior Lighting Power

A Fixture ID : Description / Lamp / Wattage Per Lamp / Ballast	B Lamps/ Fixture	C # of Fixtures	D Fixture Watt.	E (C X D)
1-Common Space Types:Office - Enclosed				
Type H: Incandescent 150W:	1	29	150	4350
Type B: Incandescent 75W:	2	22	150	3300
Type J: Incandescent 300W:	1	5	300	1500
Type D: Incandescent 100W:	2	1	200	200
Type H-1: Incandescent 100W:	1	2	100	200
8 Foot Linear Fluorescent: Other: Electronic:	4	70	58	4060
4 Foot Linear Fluorescent: Other: Electronic:	2	16	29	464
2-Common Space Types:Office - Enclosed				
Type C: Incandescent 150W:	1	7	150	1050
Type C-1: Incandescent 100W:	1	2	100	200
Type H-1: Incandescent 100W:	1	1	100	100
Type B: Incandescent 75W:	2	25	150	3750
Type E: Incandescent 150W:	1	23	150	3450
8 Foot Linear Fluorescent: Other: Electronic:	4	127	58	7366
4 Foot Linear Fluorescent: Other: Electronic:	2	35	29	1015
3-Common Space Types:Office - Enclosed				
Type B: Incandescent 75W:	2	14	150	2100
Type H: Incandescent 150W:	1	2	150	300
Type H-1: Incandescent 100W:	1	2	100	200
8 Foot Linear Fluorescent: Other: Electronic:	4	75	58	4350

A Fixture ID : Description / Lamp / Wattage Per Lamp / Ballast	B Lamps/ Fixture	C # of Fixtures	D Fixture Watt.	E (C X D)
4 Foot Linear Fluorescent: Other: Electronic:	2	8	29	232
		Total Proposed Watts =		38187

Interior Lighting FAILS: Design 10% worse than code

COM*check* Software Version 4.0.2.6

Exterior Lighting Compliance Certificate

Project Information

Energy Code:	2014 New York Energy Conservation Construction Code
Project Title:	
Project Type:	New Construction
Exterior Lighting Zone	2 (Residential mixed use area)

Construction Site:
Avon-Lima Rd.
Avon, NY 14414

Owner/Agent:

Designer/Contractor:

Allowed Exterior Lighting Power

A Area/Surface Category	B Quantity	C Allowed Watts / Unit	D Tradable Wattage	E Allowed Watts (B X C)
Main entry	6 ft of door	20	Yes	120
Other door (not main entry)	3 ft of door	20	Yes	60
Illuminated length of facade wall or surface	108 ft	2.5	No	270
Illuminated length of facade wall or surface	108 ft	2.5	No	270
Illuminated length of facade wall or surface	60 ft	2.5	No	150
Illuminated length of facade wall or surface	68 ft	2.5	No	170
Illuminated length of facade wall or surface	140 ft	2.5	No	350
			Total Tradable Watts (a) =	180
			Total Allowed Watts =	1390
			Total Allowed Supplemental Watts (b) =	600

(a) Wattage tradeoffs are only allowed between tradable areas/surfaces.
(b) A supplemental allowance equal to 600 watts may be applied toward compliance of both non-tradable and tradable areas/surfaces.

Proposed Exterior Lighting Power

A Fixture ID : Description / Lamp / Wattage Per Lamp / Ballast	B Lamps/ Fixture	C # of Fixtures	D Fixture Watt.	E (C X D)
Main entry (6 ft of door width): Tradable Wattage				
LED 1: LED Other Fixture Unit 60W:	1	2	78	156
Other door (not main entry) (3 ft of door width): Tradable Wattage				
LED 2: LED Other Fixture Unit 60W:	1	1	150	150
Illuminated length of facade wall or surface (108 ft): Non-tradable Wattage				
LED 3: LED Other Fixture Unit 125W:	1	1	175	175
LED 3 copy 1: LED Other Fixture Unit 125W:	1	1	175	175
LED 5: LED Other Fixture Unit 90W:	1	1	150	150
LED 5 copy 1: LED Other Fixture Unit 90W:	1	1	150	150
LED 5 copy 2: LED Other Fixture Unit 90W:	1	1	150	150
Illuminated length of facade wall or surface (60 ft): Non-tradable Wattage				
LED 8: LED Other Fixture Unit 60W:	1	1	175	175
Illuminated length of facade wall or surface (68 ft): Non-tradable Wattage				
LED 9: LED Other Fixture Unit 60W:	1	1	175	175
Illuminated length of facade wall or surface (140 ft): Non-tradable Wattage				

A Fixture ID : Description / Lamp / Wattage Per Lamp / Ballast	B Lamps/ Fixture	C # of Fixtures	D Fixture Watt.	E (C X D)
LED 10: LED Other Fixture Unit 80W:	1	1	150	150
LED 10 copy 1: LED Other Fixture Unit 80W:	1	1	150	150
LED 10 copy 2: LED Other Fixture Unit 80W:	1	1	150	150
LED 10 copy 3: LED Other Fixture Unit 80W:	1	1	150	150
	Total Tradable Proposed Watts =			306

Exterior Lighting FAILS: Design 27% worse than code

Appendix B – Building Renovation Code Compliance

COMcheck Software Version 4.0.2.6

Envelope Compliance Certificate

Project Information

Energy Code:	2014 New York Energy Conservation Construction Code
Project Title:	
Location:	Livingston County, New York
Climate Zone:	5a
Project Type:	New Construction
Vertical Glazing / Wall Area:	21%

Construction Site:
Avon-Lima Rd.
Avon, NY 14414

Owner/Agent:

Designer/Contractor:

Building Area	Floor Area
1-Office : Nonresidential	31392

Additional Efficiency Package

On-site Renewable Energy

Envelope Assemblies

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Floor 1: Slab-On-Grade:Unheated, Horizontal with vertical 2 ft., [Bldg. Use 1 - Office] (d)	527	---	9.0	0.441	0.441
Roof 2: Attic Roof with Wood Joists, [Bldg. Use 1 - Office]	6456	40.0	1.6	0.025	0.027
Roof 1: Attic Roof with Wood Joists, [Bldg. Use 1 - Office]	6160	40.0	1.6	0.025	0.027
NORTH					
Basement Wall 1 copy 1: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	1139	24.5	0.6	0.116	0.108
Basement Wall 1 copy 3: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	138	24.5	0.6	0.116	0.108
Basement Wall 1 copy 5: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	186	24.5	0.6	0.116	0.108
Basement Wall 1 copy 7: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	138	24.5	0.6	0.116	0.108
Exterior Wall 14 copy 4: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1184	---	---	0.023	0.064
Window 4 copy 13: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 14: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 15: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 16: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Window 4 copy 17: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 18: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 19: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Exterior Wall 14 copy 6: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	143	---	---	0.038	0.064
Exterior Wall 14 copy 8: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	194	---	---	0.023	0.064
Window 41: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	194	---	---	0.800	0.380
Exterior Wall 14 copy 10: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	143	---	---	0.038	0.064
Exterior Wall 14 copy 3: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.038	0.064
Exterior Wall 14 copy 4: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	161	---	---	0.023	0.064
Window 39 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 14 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.038	0.064
EAST					
Basement Wall 1: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	1470	24.5	0.6	0.116	0.108
Basement Wall 1 copy 4: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	32	24.5	0.6	0.116	0.108
Exterior Wall 13: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1528	---	---	0.023	0.064
Window 1 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 3: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 5: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 6: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 7: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 20: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	31	---	---	0.800	0.380
Window 21: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	12	---	---	0.800	0.380
Door 3: Glass (> 50% glazing):Metal Frame, Entrance Door, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	25	---	---	0.800	0.770
Exterior Wall 14 copy 7: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	36	---	---	0.038	0.064
Exterior Wall 13 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1248	---	---	0.023	0.064
Window 1 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 11: Vinyl/Fiberglass Frame:Operable, Perf. Specs.:	43	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)					
Window 1 copy 12: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 13: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 14: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 15: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
SOUTH					
Basement Wall 9: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 9.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	137	---	---	0.037	0.108
Basement Wall 10: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 5.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	189	---	---	0.037	0.108
Window 3: Metal Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	26	---	---	0.350	0.450
Basement Wall 11: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 2.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	137	---	---	0.038	0.108
Exterior Wall 1 copy 3: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1139	---	---	0.023	0.064
Window 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 2: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 3: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 4: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 5: Vinyl/Fiberglass Frame:Fixed, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.380
Window 10: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	28	---	---	0.800	0.380
Window 11: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	11	---	---	0.800	0.380
Door 2: Glass (> 50% glazing):Metal Frame, Entrance Door, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	23	---	---	0.800	0.770
Exterior Wall 1 copy 3: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	142	---	---	0.038	0.064
Exterior Wall 14: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.023	0.064
Window 39: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 1 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	142	---	---	0.038	0.064
Exterior Wall 14 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1184	---	---	0.023	0.064
Window 4 copy 6: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 7: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 8: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Window 4 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 11: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Window 4 copy 12: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	40	---	---	0.350	0.450
Exterior Wall 1 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.038	0.064
Exterior Wall 14 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	161	---	---	0.023	0.064
Window 39 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	99	---	---	0.350	0.450
Exterior Wall 1 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	116	---	---	0.038	0.064
WEST					
Exterior Wall 1 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	683	---	---	0.023	0.064
Window 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 1: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Door 1: Insulated Metal, Swinging, [Bldg. Use 1 - Office]	64	---	---	0.650	0.370
Basement Wall 12: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 2.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.038	0.108
Basement Wall 13: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 5.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	231	---	---	0.037	0.108
Window 12: Metal Frame:Fixed, Perf. Type: Energy code default, Double Pane, Clear , SHGC 0.70, VT 0.60, [Bldg. Use 1 - Office]	61	---	---	0.800	0.380
Basement Wall 14: Other Basement Wall, Light Density, Furring: Metal, Wall Ht 10.5, Depth B.G. 9.0, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	197	---	---	0.037	0.108
Basement Wall 1 copy 2: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	163	24.5	0.6	0.116	0.108
Basement Wall 1 copy 6: Solid Concrete:12" Thickness, Normal Density, Furring: Metal, Wall Ht 10.7, Depth B.G. 10.0, [Bldg. Use 1 - Office]	32	24.5	0.6	0.116	0.108
Exterior Wall 14 copy 1: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	710	---	---	0.023	0.064
Window 1 copy 8: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 9: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 10: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Exterior Wall 14 copy 4: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	205	---	---	0.038	0.064
Exterior Wall 14 copy 3: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	240	---	---	0.023	0.064
Window 38: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	121	---	---	0.350	0.450
Exterior Wall 14 copy 5: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	205	---	---	0.038	0.064
Exterior Wall 14 copy 5: Other Exterior Wall, Heat capacity 1.0, [Bldg.	169	---	---	0.023	0.064

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	Proposed U-Factor	Budget U-Factor(a)
Use 1 - Office] (b)					
Exterior Wall 14 copy 9: Other Mass Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	36	---	---	0.038	0.064
Exterior Wall 14 copy 2: Other Exterior Wall, Heat capacity 1.0, [Bldg. Use 1 - Office] (b)	1248	---	---	0.023	0.064
Window 1 copy 16: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 17: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 18: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 19: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450
Window 1 copy 20: Vinyl/Fiberglass Frame:Operable, Perf. Specs.: Product ID NA, SHGC 0.54, VT 0.56, [Bldg. Use 1 - Office] (c)	43	---	---	0.350	0.450

(a) Budget U-factors are used for software baseline calculations ONLY, and are not code requirements.
(b) 'Other' components require supporting documentation for proposed U-factors.
(c) Fenestration product performance must be certified in accordance with NFRC and requires supporting documentation.
(d) Slab-On-Grade proposed and budget U-factors shown in table are F-factors.

Envelope PASSES: Design 4% better than code

Envelope Compliance Statement

Compliance Statement: The proposed envelope design represented in this document is consistent with the building plans, specifications, and other calculations submitted with this permit application. The proposed envelope systems have been designed to meet the 2014 New York Energy Conservation Construction Code requirements in COM*check* Version 4.0.2.6 and to comply with the mandatory requirements listed in the Inspection Checklist.

Name - Title _____ Signature _____ Date _____

Appendix C – Energy Consumption Calculations

Existing Building Values

	North Wall	South Wall	East Wall	West Wall	Total
Glazing Area	573	806	627	676	2682
Wood Siding	966	2064	2149	2605	7784
Stone Wall Area	518	790	36	840	2184
Conc. Wall Area	1601	0	1502	195	3298
				Roof Area	12616
				Total Wall Area	15948

		R-Value	U-Value
Wall Construction 1		2.10075	0.476020469
	Wood Siding	0.5	
	Weather Barrier	0.00075	
	CMU	1.04	
	Gypsum	0.56	
Wall Construction 2		1.95	0.512820513
	Stone	0.35	
	CMU	1.04	
	Gypsum	0.56	
Wall Construction 3		2.84	0.352112676
	Concrete	2.28	
	Gypsum	0.56	
Roof Construction		31.63	0.031615555
	Insulation	30	
	Asphalt Shingle Ro	1.63	
Glazing			
	Glazing		0.35

	Square Footage
Ground Floor	12616
First Floor	12616
Second Floor	6160
Total	31392

Winter Outdoor Temp.	16
Winter Indoor Temp.	72
Change in Temp.	56
Summer Outdoor Temp.	85
Summer Indoor Temp.	72
Change in Temp.	13

Existing Building Heat Load Calculations

Item	Quantity	U-Value	Change in Temp.	BTUH	Total
Glass	2682	0.35	67	62892.9	
Net Siding Wall	7784	0.47602	67	248258	
Net Stone Wall	2184	0.512821	67	75040	
Net Conc. Wall	3298	0.352113	67	77804.93	
Roof	12616	0.031616	67	26723.74	
Outside Air	2000	1.08	67	144720	
					635439.6 BTUH

Existing Building Cooling Load Calculations

Solar:

	Exposure	Area	SHGF	SC	TLF	BTUH	Subtotal
	N	573	38	0.51	0.76	8439.602	
	S	806	109	0.51	0.53	23746.94	
	E	627	41	0.51	0.29	3802.065	
	W	676	41	0.51	0.4	5654.064	
							41642.67 BTUH

Transmission:

	Exposure	Area	U-Value	TLF	Change in Temp.	BTUH	Subtotal
Glass	N	573	0.35	0.55	13	1433.933	
	S	806	0.35	0.38	13	1393.574	
	E	627	0.35	0.35	13	998.4975	
	W	676	0.35	0.35	13	1076.53	
Net siding wall	N	966	0.47602	0.55	13	3287.826	
	S	2064	0.47602	0.38	13	4853.581	
	E	2149	0.47602	0.35	13	4654.504	
	W	2605	0.47602	0.35	13	5642.152	
Net stone wall	N	518	0.512821	0.55	13	1899.333	
	S	790	0.512821	0.38	13	2001.333	
	E	36	0.512821	0.35	13	84	
	W	840	0.512821	0.35	13	1960	
Net conc. wall	N	1601	0.352113	0.55	13	4030.687	
	S	0	0.352113	0.38	13	1.739437	
	E	1502	0.352113	0.35	13	2406.373	
	W	195	0.352113	0.35	13	312.412	
Roof		12616	0.031616	0.36	13	1866.673	
							37903.15 BTUH

Cooling Total:	79545.82 BTUH

Re-Design Values

	North Wall	South Wall	East Wall	West Wall	Total
Glazing Area	573	806	627	676	2682
Wood Siding	966	2064	2149	2605	7784
Stone Wall Area	518	790	36	840	2184
Conc. Wall Area	1601	0	1502	195	3298
				Roof Area	12616
				Total Wall Area	15948

		R-Value	U-Value
Wall Construction 1		42.6615	0.0234403
	Wood Siding	0.81	
	3/4" Plywood	0.94	
	Weather Barrier	0.00075	
	1 1/2" Air Pockets	1.84	
	Rigid Insulation	13	
	Weather Barrier	0.00075	
	CMU	1.04	
	Spray Foam	24.47	
	Gypsum	0.56	
Wall Construction 2		26.42	0.0378501
	Stone	0.35	
	CMU	1.04	
	Spray Foam	24.47	
	Gypsum	0.56	
Wall Construction 3		27.31	0.0366166
	Concrete	2.28	
	Spray Foam	24.47	
	Gypsum	0.56	
Roof Construction		43.19	0.0231535
	Air Gap	1.56	
	Asphalt Shingle Roo	1.63	
	Insulation	40	
Glazing			
	Glazing		0.347

	Square Footage
Ground Floor	12616
First Floor	12616
Second Floor	6160
Total	31392

Geo-exchange

Winter Ground Temp.	50	
Winter Indoor Temp.	72	
Change in Temp.	22	
Summer Ground Temp.	50	
Summer Indoor Temp.	72	
Change in Temp.	-22	less than zero, assume 0 energy for cooling calculations

Re-design Heat Load Calculations

Item	Quantity	U-Value	Change in Temp.	BTUH	Total
Glass	2682	0.347	22	20474.39	
Net Siding Wall	7784	0.02344	22	4014.111	
Net Stone Wall	2184	0.03785	22	1818.622	
Net Conc. Wall	3298	0.036617	22	2656.756	
Roof	12616	0.023154	22	6426.302	
Outside Air	2000	1.08	22	47520	
					82910.18 BTUH

Re-design Cooling Load Calculations

Solar:

Exposure	Area	SHGF	SC	TLF	BTUH	Subtotal
N	573	38	0.382	0.76	6321.428	
S	806	109	0.382	0.53	17786.92	
E	627	41	0.382	0.29	2847.821	
W	676	41	0.382	0.4	4235.005	
						31191.17 BTUH Eliminated by geo-exchange

Transmission:

	Exposure	Area	U-Value	TLF	Change in Temp.	BTUH	Subtotal
Glass	N	573	0.35	0.55	0	0	
	S	806	0.35	0.38	0	0	
	E	627	0.35	0.35	0	0	
	W	676	0.35	0.35	0	0	
Net siding wall	N	966	0.02344	0.55	0	0	
	S	2064	0.02344	0.38	0	0	
	E	2149	0.02344	0.35	0	0	
	W	2605	0.02344	0.35	0	0	
Net stone wall	N	518	0.03785	0.55	0	0	
	S	790	0.03785	0.38	0	0	
	E	36	0.03785	0.35	0	0	
	W	840	0.03785	0.35	0	0	
Net conc. wall	N	1601	0.036617	0.55	0	0	
	S	0	0.036617	0.38	0	0	
	E	1502	0.036617	0.35	0	0	
	W	195	0.036617	0.35	0	0	
Roof		12616	0.023154	0.36	0	0	
							0 BTUH

Cooling Total:	0 BTUH

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