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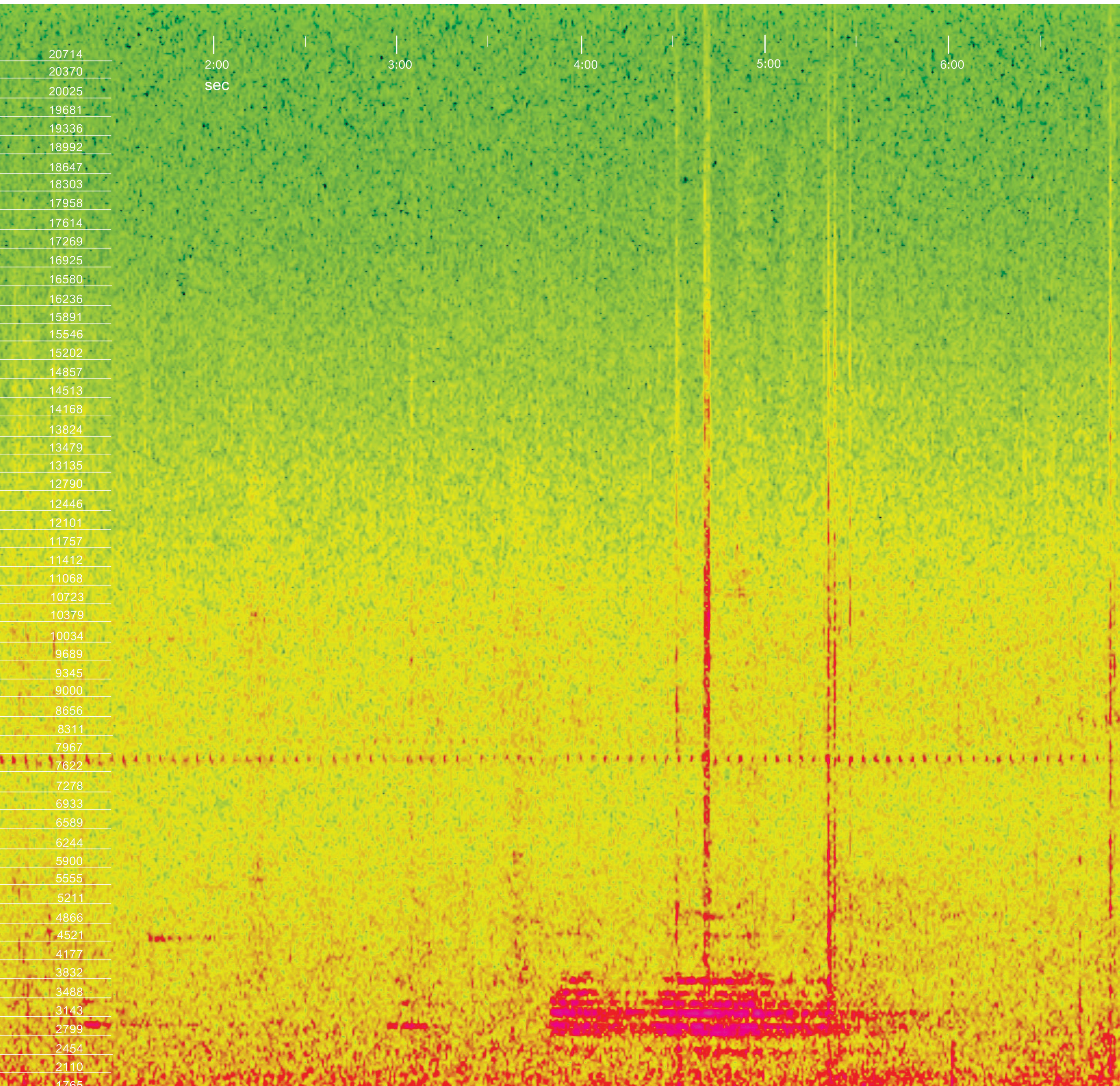

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01

Revolutionizing the Office Paradigm: The Future Net-Zero Energy Office Building

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Abstract

What is the future of the net-zero building? It is not a super-tall tower predicated on technology that does not exist, but instead a more thoughtful integration into the existing urban fabric that considers people, communities, and density. This new building typology will be prevalent where governments are encouraging resilient zoning overlays, developers are creating new neighborhoods focused on sustainable development, and progressive clients understand the significance of communicating their value with other like-minded innovators. These conditions might not exist where height is the solution to the economics of population growth, but these ingredients to net-zero do exist in cities like Washington, DC, where regulations are encouraging density over height and innovation from early adopters. It is upon this stage that we envision the workplace of the future.

This article explores the opportunities and considerations to achieve a next generation net-zero office building, and uses a project developed for a global environmental group in Washington, DC as a case-study. The article provides actionable results and recommendations that should be considered for other similar projects.

Keywords: *net-zero energy, future workplace, zoning influence on sustainability, density and height*

1.0 Introduction

The world has a crisis of urban population growth, centered around cities both large and small[1]. The current 2019 world population of 7.7 billion has roughly 51 percent of people living in cities. By 2050, population is predicted to increase to 9.0 billion, with about 70 percent living in cities[2]. To satisfy these demands for urban living and workspace, we need to build a city the size of Chicago (6.5 million urban dwellers) each month to accommodate the influx of people. The demands required to build a city this size each month cannot solely be resolved with expensive, tall, mixed-use buildings, but perhaps a more thoughtful solution could be found within a more common mid-rise urban habitat. The five to fourteen story tower provides a case study in the economics of solving our habitat challenges layered with some unique benefits that improve the overall urban environment. Is it in this context of the "short buildings" that we can find the economic, efficiency, and constructability drivers we need to satisfy population growth while also achieving net-zero energy buildings? Washington, DC provides an interesting case study to explore these needs and their resulting environmental challenges because of its fixed height limits, height uniformity characteristics, and desired densities. By focusing on the correlation of urban habitat and net-zero energy buildings, we imagine a people-centric design solution focused on resolving our future workplace needs. Figure 1 shows the case study building that was used in this study.

Figure 1: *Revolution: changing the office paradigm.*

2.0 The Paradigm to Net-Zero

Changing the paradigm to achieve net-zero energy consumption in buildings requires a multi-step approach that starts with energy conservation and reduction. Success is identifying ways to reduce energy consumption prior to starting design. Assessing the current best-in-practices in sustainable design includes exploring LEED v.4 guidelines, WELL building certification, *Passive House* strategies, resilient urban development strategies, and existing case studies. Evaluating these assessment tools helps to focus on what shared opportunities will have a larger impact on achieving both the net-zero paradigm and a high-performance building. For example, a synergy might include using *Passive House* enclosure guidelines to reduce heating and cooling loads, shrinking the size of the mechanical system while decreasing the overall energy consumption and ultimately using less energy from renewable and non-renewable sources. Having a clear understanding of these assessment tools enhances opportunities. In addition, it is also essential in this pre-assessment phase to understand the geographic limitations of the site, both at a macro and micro level, that will limit the environmental impacts including local climate considerations, neighborhood opportunities, energy sources, and access to resources.

3.0 Background to This Study

When this study began, the goal was to achieve a new paradigm for the office building that revolutionized sustainability. Achieving these goals would allow this client to reflect a culture and values within the building and set an example for current partners and future constituents. The client, who is an environmental stewardship association headquartered in Washington, DC, recognized that their future business model would depend on revolutionizing the typical office building to achieve greater environmental goals. The project was also championed by a commercial development partner who wanted to differentiate the typical office product in the competitive Washington, DC metropolitan market. It was further bolstered by a series of local governmental regulations and regulators which, with the changing climate landscape, understand the buildings in their community will need to be more resilient and future flexible.

To achieve this new urban commercial habitat, the building needed to promote the health and wellbeing of its occupants while also benefitting the local people and community. The client's core goals centered around providing an adaptable work environment that enhanced accessibility but could also "flex" with the ever-evolving workplace to respond to new technologies and the needs of its occupants throughout its predicted fifty-year lifetime. This new office type must provide an environment to facilitate its intended use as a workspace for collaboration but also enhance entrepreneurship, innovation, and discovery. Further requirements must include comfort to all occupants, provisions for heating, ventilation, dehumidification, and cooling while minimizing the baseline 2019 office building energy consumption. Beyond this one project and its occupants, the process recognizes that significant consideration should be given to leveraging synergies between multiple buildings to support the creation of sustainable neighborhood overlays, which requires working with a development partner who knows this is essential to their future commercial strategy.

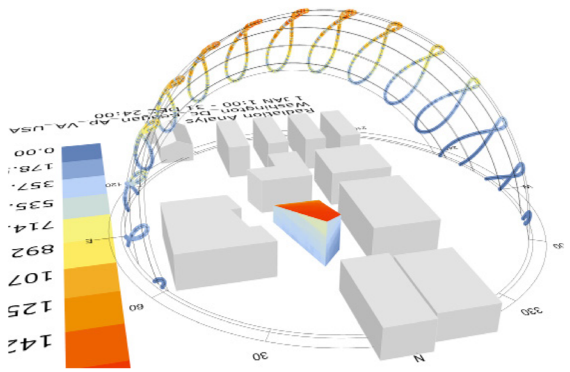
4.0 A Convergence of Factors

Washington, DC values and promotes opportunity and innovation through governmental, NGO's, and educational frameworks. The region is home to several universities with graduates who join the local organizations and associations with the general optimism to transform the world[3]. These forward-looking associations are willing to take on complex projects because they are supported by federal governmental incentives and can operate semi-independently from market forces. In addition, the Washington, DC metropolitan region also benefits from the 4th highest level of GDP per person in the United States[4] contributing to its overall economic stability and ability to "take risks."

Prior to the selection of the building location, the client engaged a commercial brokerage team to assess potential opportunities in the entire Washington, DC metro area with both an economic and environmental lens. This process led the client to find the appropriate commercial developer for these net-zero specific goals. The development had to be urban and well connected, and had to be desirable in its neighborhood amenities, have residential and mixed-use overlays, and general walkability. The selected developer, Forest City/Brookfield, had master planned and redeveloped "The Yards" over the last two decades in the Southeast quadrant of Washington, DC through a series of incremental steps that began by building community infrastructure first and then adding residential and office buildings over time as market forces allowed[5]. Through this deliberate development approach, Forest City recognized that flexibility in the master plan timeline was beneficial to the project to allow it to adapt over time. They also understood that holistic neighborhood strategies were important to the project's sustainable success.

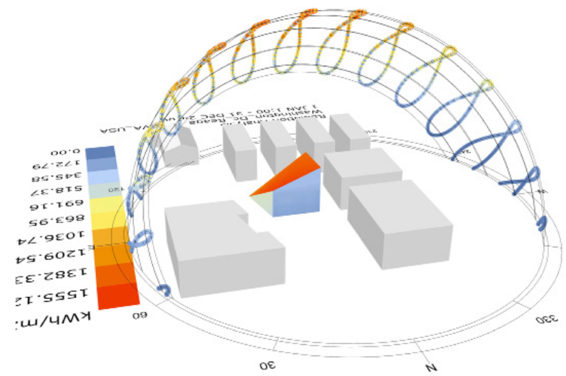
After an initial assessment on the neighborhood advantages, the developer offered two sites for consideration. Each site was analyzed and assessed regarding its size, efficiency, and energy potential. While choosing the most appropriate site is an opportunity not usually afforded to a project team, the building location and site geometry does factor as an important part in achieving net-zero goals. Larger building sites, lower zoning densities, and flexible urban master plans do allow the design team to more carefully consider the orientation and building form, and the impact on energy generation and shaping the design strategy. For this opportunity, the development team was offered two adjacent sites. Both sites were studied for building area, building shape, solar energy, connectivity to infrastructure, and neighbor solar shading potential. Ultimately, site "G" was selected due to its increased solar potential, square-shaping, and reduced neighborhood shading, shown in Figure 2.

The site selected for the project design is part of a planned urban development (PUD) that provides specific



Site A2 Analysis

Building Volume	2,924,000 ft3
Building Area	250,000 ft2
Solar Exposure - no context	92.6e5 kWh/m2
Solar Exposure - Full Year context	70.2e5 kWh/m2
Solar Exposure - December	2.9e5 kWh/m2



Site G Analysis

Building Volume	3,200,000 ft3
Building Area	250,000 ft2
Solar Exposure - no context	89.3e5 kWh/m2
Solar Exposure - Full Year context	76.1e5 kWh/m2
Solar Exposure - December	3.6e5 kWh/m2

Figure 2: *Neighborhood site analysis.*

zoning constraints in height and urban density that ultimately were essential to achieving our project goals. The development zoning allows the project to maximize height (130' for Washington, DC) while providing a lower floor area ratio (FAR) that reduces the site density. The zoning also specifies that the first and second level must be fixed to 80 percent of the property line to encourage urban street wall edges while also mandating setbacks at the upper levels to provide relief from the urban solar "canyon" effect. This allowed the massing to take advantage of the solar orientation and avoid shading from adjacent neighbor buildings. *The Yards* master plan also specifically recognized the ratio of site dimensions to commercial floor plate efficiency to allow for floor plate sizes of 20,000 to 30,000 SF, shown in Figure 3. Creating an efficient and functional floorplate is significant to the economic success of the project.

In addition to the advantageous zoning, the Department of Energy and Environment for the city (DDOE) and DCWater also put regulations and incentives for developers and owners to promote sustainable goals including responding to the DC climate adaptation plan[6]. The resilience guidelines in the DC Climate Adaptation Plan recognize the need to reduce the potential of climate change impact on people, buildings, and infrastructure. These guidelines helped formulate our community sustainable strategies.

Figure 3: *Plan diagram options.*

In 1910, the United States Congress passed the Height of Buildings Act that mandated buildings could not be taller than the US Capitol[7]. Indirectly, this act also created an interesting 21st century catalyst for net-zero building design. The maximum building height of 130' on major avenues and 110' on secondary streets provided every building parcel greater solar energy potential by reducing the energy demand of each site because of the reduced building density. The height limit also eliminated the shading of roof solar photovoltaic panels from neighboring buildings because no building could be significantly taller than the adjacent. In addition, the uniform building heights and street widths code mandated gracious separations between buildings[8], which allows today's modern buildings to use solar PV panels in a vertical façade orientation due to the reduced solar "canyon" effect. These early century maximum and uniform building height codes effectively opened the opportunity for solar photovoltaic energy generation on both the roof and exterior wall surfaces while also improving the overall street-level daylight pedestrian experience, thus establishing a framework to utilize 21st century technology to achieve net-zero energy in Washington, DC office buildings.

The client's program requirements and building economics—including the size of the plot, floor area ratio (FAR), and the building height—required a commercial office building of 250,000 gross square feet (GSF), which was of an achievable scale that would work for both practical leasing and pragmatic net-zero energy economics. Achieving a net-zero building requires lower site FAR and density allowing the building to be shaped and formed. Based on commercial office building economics, the preliminary design accommodated ten floors at 24,000 GSF, with building core efficiencies of 90 percent, as shown in Figure 4.

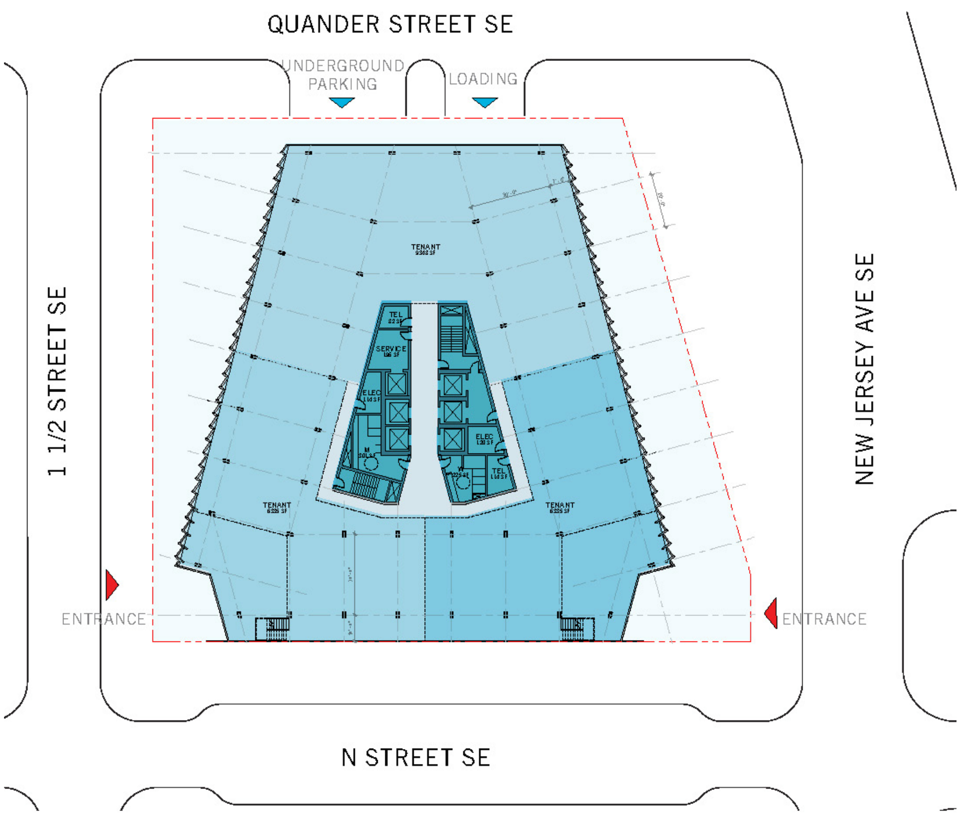


Figure 4: *Typical 24,000 GSF office plan.*

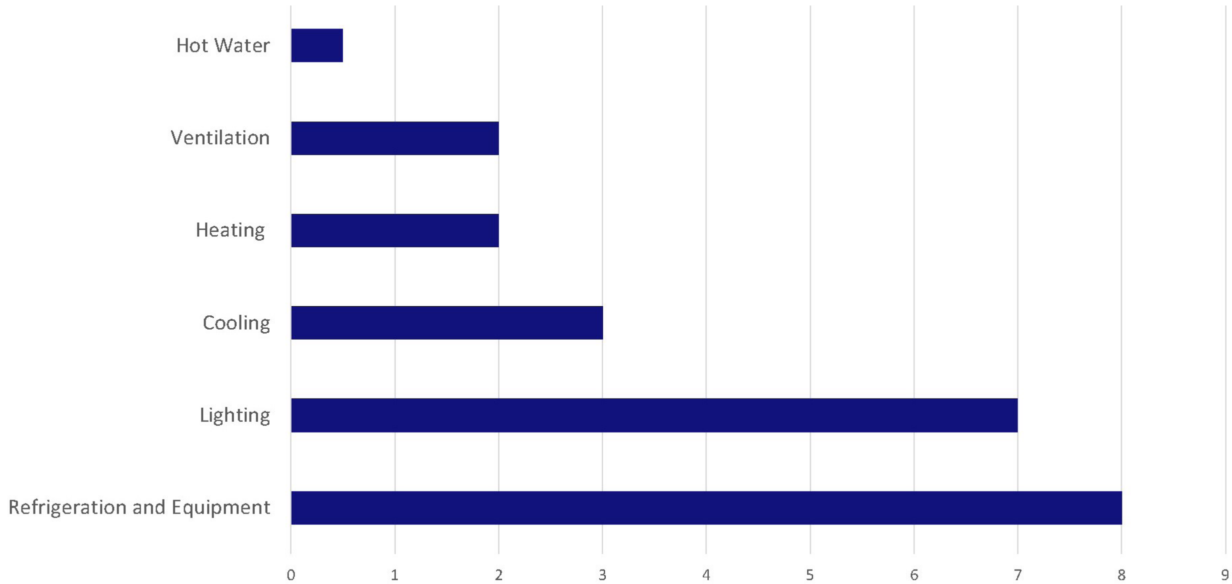


Figure 5: *Average commercial office building consumption in 2019 (kWh/SF).*

A calculation of preliminary energy consumption of this 250,000 GSF office building indicated that the typical energy consumption of 22 kWh/sf for average (2019) commercial office space would need to be reduced to 6 kWh/sf in hopes of achieving net-zero energy consumption. For reference, typical energy usage in new office buildings has reduced significantly in recent years due to newer energy code requirements[9], but the average rate of new and old office buildings in the United States is still close to 22 kWh/sf based on the most recent US energy Information administration survey[10]. Figure 5 shows the average energy consumption for office buildings.

With the implementation of *Passive House* and efficient distribution strategies, energy consumption on this building would need to be 40 percent of a typical commercial building with a target EUI (Energy Use Intensity) of 19-21 kBtu per square foot, which will get a total building energy consumption of approximate 5,261,522 kBtu/year or 1,542,000 kWh/year, as seen in Figure 6. Based on a massing design strategy that includes integrated PV panels, the building could generate the total energy required to run per year using horizontal and vertical solar arrays. Additionally, if the building implements other energy production and/or savings strategies, such as eliminating inverters by using direct current (DC) to power lighting and equipment, the new office building comes close to net-positive energy.

The neighborhood and community resilience of the project is also important. Using guidelines from the DC Climate Adaptation Plan and specific opportunities targeted for this location factored into the overall resilience strategy. As the resilience of cities, neighborhoods, and buildings becomes more important, institutions including the Council on Tall Buildings and Urban Habitat are recognizing that designing resilient buildings will be essential to the growth of the urban environment[11]. We will need systems that allow us to respond to these environmental pressures and allow cities to continue to function. Cities that are not resilient will not be able to adapt to climate change and must establish infrastructure that can reassure community continuity during shocks and stressors. For this project, resilience strategies included providing this Southeast community a building in The Yards that could operate "off-grid" including a system of redundant and sacrificial spaces that allowed for continuity of use. Using the Climate Ready DC resiliency plan, which included strategies specific to Ward 6, the project integrated design solutions for flooding, heat, green infrastructure, and stormwater[6]. Within the building, the design included ground-level community spaces that could rely

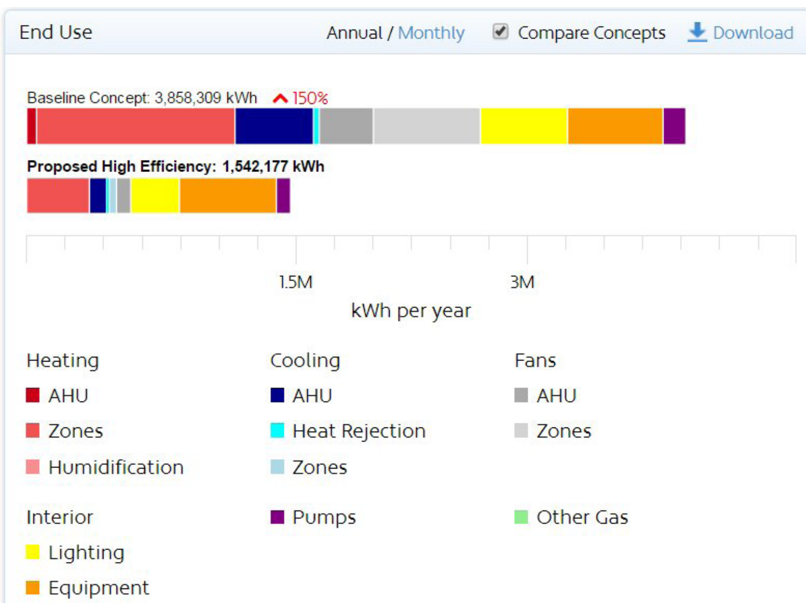


Figure 6: *Energy comparison (Baseline 250,000 GSF building versus High Efficiency Building).*

on on-site renewable power, placement of mechanical and life-safety systems that would not be subject to flooding, daylighting, and natural ventilation that could allow the building to operate off-grid.

Achieving net-zero energy means making the building operation net neutral to the electrical grid or even a net positive contributor. Getting to net-zero energy begins with conservation. Conservation includes setting enclosure goals that exceed ASHRAE 90.1 standards and, thus, require a much more environmentally airtight façade.

Using *Passive House*[12] enclosure strategies that are highly efficient but that can also breathe with minimal input from mechanical systems, is a simple first step that reduces loads. This includes mandating higher R-value (thermal resistance) facades and enclosures with a maximum of 40 percent glass, which has a lower thermal resistance than solid insulation products, shown in Figure 7. Minimizing elevations oriented east-west because of gain and glare and the use of self-shading facades reduces solar heat gain and, thus, overall heating and cooling energy consumption.

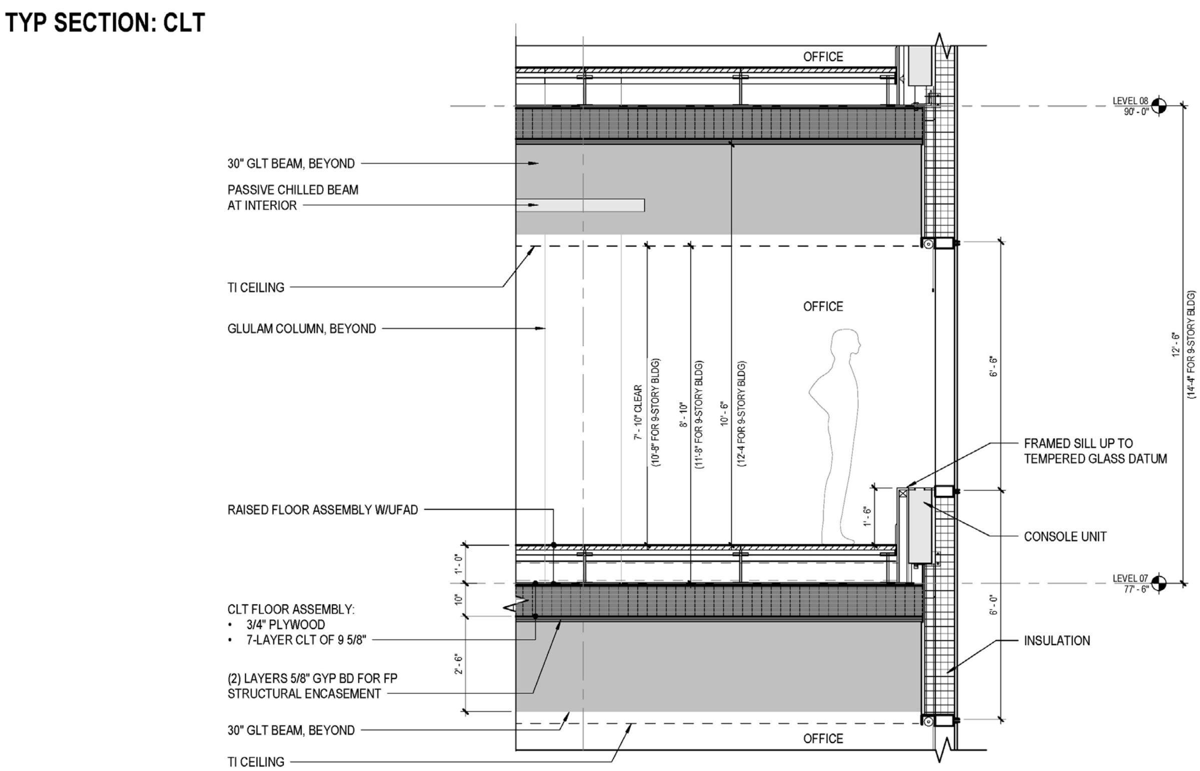


Figure 7: *Passive House building section.*

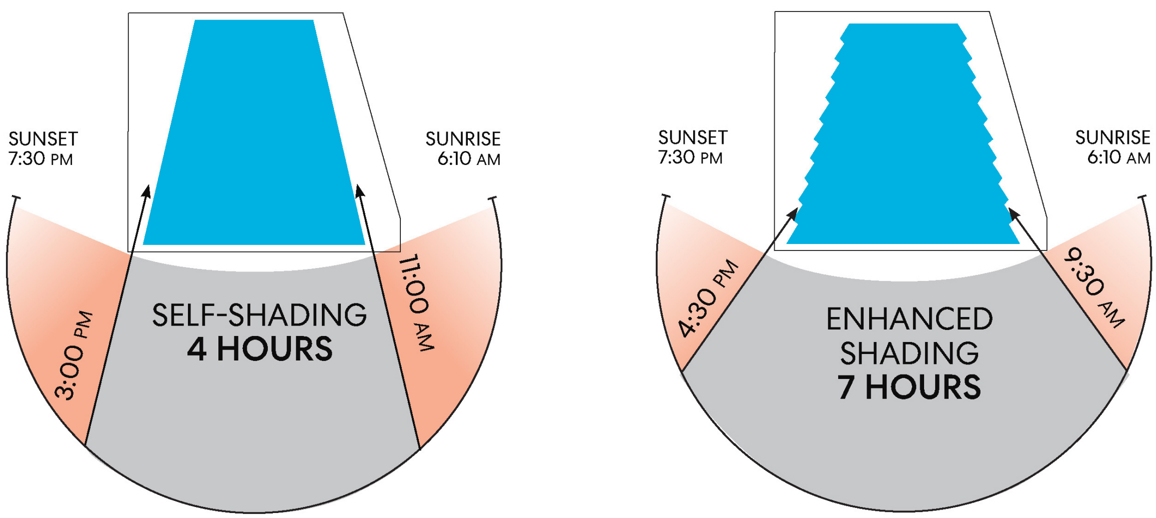


Figure 8: *Self-shading design strategies.*

Additional energy conservation strategies include optimizing the building leasing depths, integrating daylighting and LED lighting into occupied spaces and reducing zonal heating demands. Using liquid instead of air volume to distribute heating and cooling with outdoor air for ventilation and exhaust can reduce zonal energy-use demands. In addition, flexibility on the end-user controls allows for individual adjustability but can also easily evolve as new technologies become available.

For a 250,000 SF office building, achieving net-zero energy does require the introduction of renewable power that is integrated on the building or by expanding neighborhood or district generation strategies. Initial options explored for onsite power generation included solar PV power, solar hot water, and wind power. Solar PV power was deemed a viable solution based on the location, whereas, due to low hot water demand, solar hot water was minimized onsite. Through various studies, wind power generation was proven ineffective at this building scale and is also less effective in this geographic location.

For solar PV renewable power, the design included a rooftop solar canopy that benefited from being unobstructed by adjacent buildings, along with a full south-facing solar façade that included both 60 percent high-performance PV panels and 40 percent integrated photovoltaics in vision glass. The building height and street width were beneficial in optimizing the energy potential of the south façade. On the east and west façades, with the optimized building shape to maximize self-shading potential (as shown in Figure 8), the façade included diagonal integrated PV solar shades that enhanced the energy potential and reduced solar glare (as shown in Figure 9). The rooftop photovoltaics provided potential of 854,813 kWh/year, the south façade 282,595 kWh/year and the innovative east and west façade 236,666 kWh/year. This combination of photovoltaic strategies allowed the building to be close to energy independent.

A fuel cell system was also considered but eliminated as an energy solution based on the sustainability of its power source, which would be either bio-mass pellets or

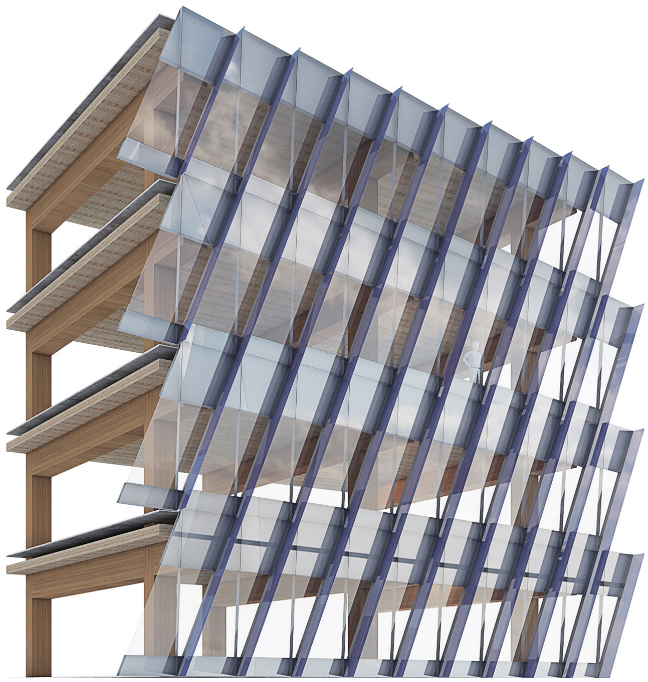


Figure 9: *East-west exterior with integrated diagonal PV solar shades.*

natural gas. Although not specifically generating power, a geothermal system was also considered and rejected due to the small urban footprint, but wastewater heat recovery was accepted as a viable solution. Wastewater heat recovery utilizes the existing sanitary sewer system beneath the streets as a means to reject heat in the summer and a source from which to pull heat in the winter. The sewer effluent is brought through a heat exchanger as a means to add or extract heat from a separate closed loop system[13]. While the sewer water temperatures are not as ideal as a traditional geothermal well system, they provide a more efficient system operation compared to cooling towers with the added benefit of not requiring water treatment or make up water. Fan energy associated with cooling towers is also eliminated. Studying adjacent street utilities determined that the 12' diameter large sewer water discharge provided an abundant source for heat exchange. DCWater, in recognizing the need to innovate, has allowed new developments to take advantage of this technology to reduce energy use[14].

Part of achieving net-zero energy consumption involved reducing the amount of carbon consumption of the building during its operation but also during its construction. This included assessing the embodied energy (EE) of the materials and energy sources used within the building during its lifetime. The manufacturing and construction phase of a building causes the most intense carbon emissions in the building's life cycle. The selection of the appropriate lower EE materials for the major construction systems, including a mass timber structure, reduced the total embodied energy of the building and embedded carbon within its structure. A hybrid mass timber wood structure is an appropriate choice for buildings of this scale because of fire and life safety codes, repetitive structural modules, and speed of construction, as seen in Figure 10.

80 percent of all commercial buildings in the United States are 5-14 stories[15], which directly benefits from the economics of mass timber construction. The use of mass timber in this project included a volumetric efficiency study that compared the perimeter-to-floor area and the core factor to achieve reasonable leasing rates for market rate commercial space. Recognizing that using

Figure 10: *Hybrid structure building section.*

mass timber requires different column spacing, beam depths, and exterior wall conditions were properly considered as a part of each option. Working with mass timber structural engineers in the design provided strategies for prefabrication, optimal floor-to-floor heights, and potential construction efficiencies. The use of a hybrid structural system recognized current code limitations for building heights but also included preliminary discussions with District life safety code officials who indicated a willingness to consider revisions to IBC type IV construction for 2021[16].

5.0 Revolutionizing the Paradigm

To successfully deliver on this net-zero energy goal, the design study identified four complementary characteristics that all needed to work in tandem to revolutionize the office paradigm. These four characteristics are:

- *Efficiency:* Revolutionizing the office building requires that it be efficient in design, structure, and building systems. It needs to be simple, functional, and durable, which requires examination of existing technologies and methodologies already adopted by the construction community.
- *Sustainability:* The new paradigm must combine strategies to reduce energy loads and maximize efficiency, while also promoting health and wellbeing. The building's performance will be measured and designed for flexibility to new technologies.
- *Resiliency:* With a changing environment, the building must be adaptable, providing safety to its occupants during shocks and stressors and providing shelter, social connections, and respite to the surrounding community.
- *Desirability:* Creating the office of the future requires that the building be desirable so that occupants and visitors are drawn to and respond positively to the aesthetics of the urban experience, the public space, the workplace, and ultimately user comfort. The building will not be considered a success unless it is desired by its occupants.

Figure 11: *West elevation of the case study building.*

6.0 Future Thinking

In considering the future office typology, our movement towards urban environments must rely on a broad systems approach that reduces consumption by integrating clients, neighborhoods, developers, and governmental institutions into a larger urban ecosystem. Key takeaways for consideration in exploring the future of this building typology include:

1. There must be a focus on how the synergy between neighborhood and the building are interdependent to achieving net-zero. This broad interrelated view can help target a more holistic design approach to projects that are future flexible. These abundant commercial projects must leverage existing adjacent infrastructure, operational and construction embodied energy.

2. The urban population explosion needs to involve like-minded clients who can work with jurisdictional constraints to improve the neighborhood's sustainable development strategy. Zoning constraints need to evolve to put a value on the energy potential of each individual building site, its zoning density, adjacencies, and height uniformity. This includes adjusting zoning constraints to leverage the energy potential of each site while creating renewable energy code overlays in existing and future planned urban districts.

3. Establishing partnerships with innovative local partners who are advocates for new technologies can assist in early adaptors of innovative solutions, such as wastewater heat recovery systems. Jurisdictions also need to promote systems that benefit carbon reduction, such as the next generation of mass timber life safety codes.

4. Creating synergistic relationships between governments and commercial development partners can also create integrated neighborhoods that view net-zero design holistically at a broader scale and share infrastructure and energy resources. This will ultimately create a framework of buildings, neighborhoods, and cities that promote health and wellbeing with a focus on improving the human condition and our relationship with the planet.

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