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Imparting the Values of Energy Simulation towards Net-Zero Plus Status

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Imparting the Values of Energy Simulation towards Net-Zero Plus Status

Abstract

The vulnerability of our resources and the anthropogenic forces on the built environment has urged scientists, architects and engineers to rigorously consider energy consumption. The building sector is the top energy consumer, and with the increasing demand in all sectors, conventional energy sources may not be reliable to single-handedly support buildings. Moreover, buildings have an impact on climate change, as well as health and wellbeing. Therefore, the urgency to support buildings' reliance on the current conventional energy system and its sources is critical. This paper disseminates the Net-Zero framework executed by the authors in The Energy Simulation Academy "Energy Modeling Olympiad", in conjunction with IBPSA-USA, and was awarded first place in the following category "the model that best communicates the value of the energy simulation to the building owner". Proposing guidelines to achieve a Net-Zero status for energy demanding office buildings, in Manhattan, New York. The energy analysis first started with compliance to the ASHRAE 90.1 (2018) Standard, after which a series of specific energy efficiency measures proposed to optimize the performance. Alleviating the reliance on our infrastructure systems, this research conducted several steps: (1) illustrate the reduction in energy consumption and utility costs, reducing the Energy Use Intensity (EUI) by 51% from 89.5 Kbtu/ft2/year to 45.12 Kbtu/ft2/year; (2) achieve adequate daylighting and reduce electric lighting demand for 50% of the floor area, thus improving the occupants' experience and productivity; (3) demonstrate the application of active energy systems that lead beyond a Net-Zero status towards Net-Zero Plus by installing a PV System of 171 Kw using 540 Poly Crystalline Cells Panels arranged in 54 arrays with 10 cells in each array with a total system cost of $92,448 for two years payback period; (4) provide a higher level of self-sufficiency by organizing the water sources available on site, leading to the implementation of two permanent tanks:15,000 gallons Septic with a cost estimate of $23,500and Rainwater harvesting; and (5) calculating the active system optimal capacity by using a 33,500 gallons cistern that covers 40% of the water demand, proposing a greywater system to cover 70% of toilet-flushing demands and controlling building's water and sewage costs.

Learning Outcomes

This paper serves as an educational tool for emerging professionals including graduate and undergraduate students who are seeking a methodology to design Net-Zero energy buildings. The methodology proposed demonstrates the recommended steps of the Net-Zero procedure and illustrates how students can implement similar strategy sequences to and improve building's EUI in the classroom. Offering a vast majority of energy- saving opportunities to design sustainable buildings. Providing the ability to understand the major environmental systems that emphasize energy conservation and passive solar techniques, including explanation of human factors, climate/microclimate and building envelope. In addition, understanding principles in the selection of construction materials, products, components, and assemblies relative to performance, including their environmental impact and reuse is another aspect covered in this paper. More importantly is learning the purpose and use of building energy codes, including the difference between performance- vs. prescriptive-based codes and requirements for minimum building energy performance.

Motivation and Approach

In the last few decades, many countries worldwide changed their energy policies to deal with the energy crisis and climate change, while achieving low-carbon energy-saving objectives [1]. Over the last year, the U.S. electricity generation from renewable resources has doubled from 19% to 38% by 2050 [2]. Decreasing the overall energy consumption became a crucial goal for the building industry. Researchers, developers and practitioners, dedicated to improving the built environment [3]. This paper disseminates the lessons learned and best practices from a vertical course that focuses on Sustainable Design and the LEED initiative. Where the curriculum is aimed at advanced understanding of the theory and principles relating to design, energy conservation, and research methods applicable in different climatic regions throughout the world. The methodologies include climate responsive design, energy conservation, passive solar design, natural ventilation, and Net-Zero energy design [4], [5]. Research activities include exposing graduate students to real project-based problems and focus on practicing architecture through computer energy simulation techniques and 3d modeling software.

Through mastering sustainable green building and high-performance design, the authors were able to utilize their understanding of building energy codes, including the difference between performance-based vs. prescriptive codes and requirements for minimum building energy performance, in addition to the architect’s responsibility to work in the public interest, to respect historic resources, and to improve the quality of life. Having the ability to optimize, conserve, or reuse natural and built resources, provide healthful environments for occupants/users, and reduce the environmental impacts of building construction and operations through carbon-neutral, bioclimatic, and energy efficient design.

The research team utilized this knowledge to demonstrate the application and validation of suitable environmental techniques to achieve Net-Zero Energy at the Energy Modeling Olympiad competition [6], sponsored by the Energy Simulation Academy [7] in conjunction with International Building Performance Simulation Association (IBPSA) [8] and BuildSim [9]. The authors “Team: Living Wise” earned first place [10] in providing a clear and concise picture of the research and development executed on a medium size tech company investing in an energy efficient Manhattan Office Building (MOB) in Manhattan, New York. Presently a city that has lost its garden accolade as unplanned urbanization is wide spreading and creating challenges on its infrastructure [11]. But, sustainable building practices are one of the fastest growing building and design concepts, and their application should be feasible. [12] The client intends to retain the building operation rights and seeks to optimize both short-term investment and long-term savings. Creating this series of complexities, the research team aims to categorize and phase this process into four tangible approaches and sequential steps to pave the way for a successful approach to Net-Zero [13]. This approach is universal and can be applied to any building type within any climate zone. Investigating building energy performance, assessment, and energy conservation strategies, such as building form and orientation; passive solar design; building envelope materials and components; natural ventilation; and active solar design. The building will be investigated within the following four phases: 1) Basecase, 2) Passive Design, 3)

Active Design, and 4) Net-Zero Status. To quantify the research-based guideline, eQUEST software was used, which is an advanced accurate energy-analyzing tool that allows the integration of passive and active approaches. This research also discusses our successes and lessons learned concerning the strategies that fulfilled our expectations and the ones resulted in the opposite behavior and provided new understandings of the subject.

Phase I - Step 1: Building description

Manhattan Office building is within the ASHRAE Climate Zone 4A (fig.1), which is a mixed-humid climate. Ultimately the building would be positioned at the northeast edge regarding the intersection of two streets with a primary entrance from the south (fig.2). Figure 3 provided by the competition committee illustrates the schematic ground floor plan, and fig. 4 illustrates basecase simulation 3dmodel, that will be used to verify that the office building complies with the minimum requirements for the ASHRAE 90.1 standards.

MOB is composed of 3 levels above ground, and 1 level below the grade, that is formed of an unconditioned basement parking, two typical floors, and a third level, which are respectively 17,890, 34,856, and 12,752 square feet. The conditioned areas in the two typical floors account for 79% of the floor area, while on the third level they are 70% of the floor area. Overall, the storages, mechanical rooms, restrooms, corridors, elevators, and staircases are unconditioned spaces.

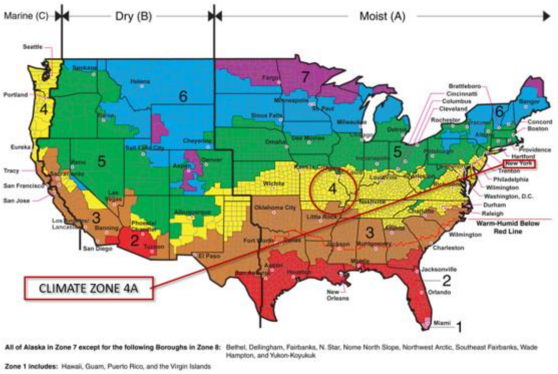


Figure 1: ASHRAE Climate Zones [17]

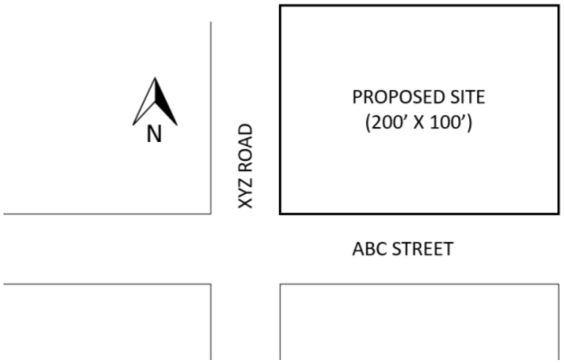


Figure 2: Proposed site location by IBPSA

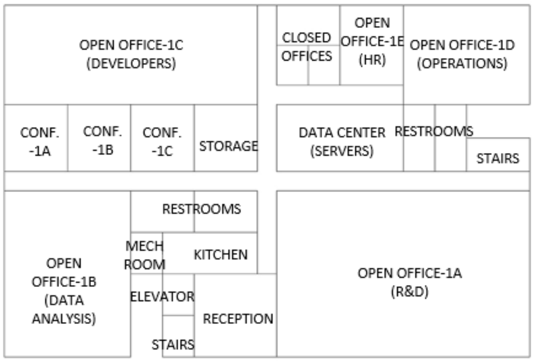


Figure 3: Schematic First Floor

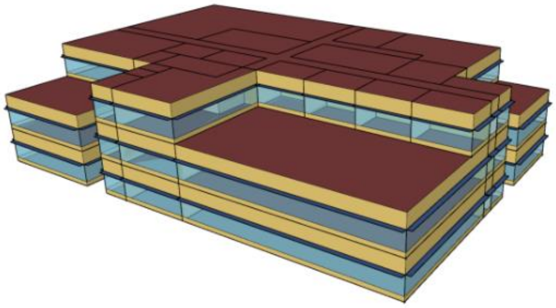


Figure 4: Basecase Simulation 3dModel

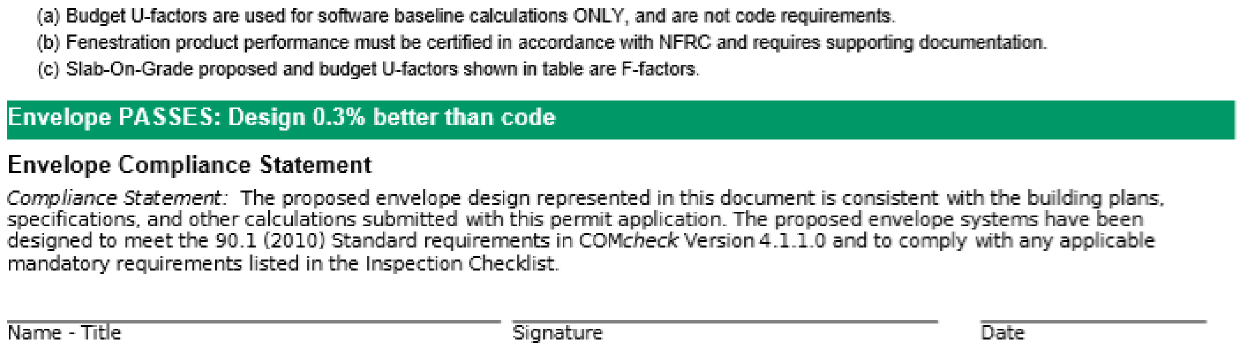
To simplify the building's energy model, the building is divided into two shells, shell no.1 that represents the first and second floors, and shell no.2 that represents the third floor. This table displays the zone summary and area by type to floor area for the mentioned shells.

Table 1: Area by Type to Floor Area

Zone	Shell 1 (First & Second Floor)	Shell 2 (Third Floor)
Open Offices	59.7%	42.1%
Conference and records	8.2%	16.7%
Storage and mechanical	1.9%	4.2%
Restrooms	5.3%	4.0%
Pantry/ kitchen and lobby	6.0%	8.2%
Corridors, elevators and stairs	12.3%	16.8%
Data center	2.4%	0.0%
Closed offices	4.2%	8.0%

By running the envelope compliance check using the DOE’s Building Energy Code Program, *COMcheck 4.1.1.0*, the building passed with 0.3% better than the ASHRAE 90.1 standards, in the building envelope category. In Fig. 5, the results are shown.

Within this phase there are no attempts to apply energy strategies to the building design, the information extracted from the building schedule and schematic design was used to generate the following envelope compliance statement. An informative education tool where students can assess the minimum code requirements of their buildings that are new commercial or high-rise residential buildings, to the International Energy Conservation Code used in their city and the ASHRAE 90.1 Standard. There are three basic building systems that have to illustrate compliance for a commercial building. The building envelope, lighting systems, and the mechanical system.



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

Envelope PASSES: Design 0.3% 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 90.1 (2010) Standard requirements in COM*check* Version 4.1.1.0 and to comply with any applicable mandatory requirements listed in the Inspection Checklist.

Name - Title

Signature

Date

Figure 5: COMcheck Envelope Compliance Statement

The intent is demonstrating an improvement of up to 5% for new construction, 3% for major renovations, or 2% for core and shell projects in the proposed building performance rating [18]. For this specific example, the building falls under the major renovations category, where the simulation model for the basecase compliance should not exceed 3%.

Phase 01 - Step 2: Basecase simulation

Using the requirements provided by the IBPSA as parametric data, this phase starts from creating an accurate energy model of the building using eQUEST 3.65 software. The project site, building shell components, HVAC system, hours of operation, internal loads, and utility rates are all inputs to the model. Fig. 6 shows views of the energy model created in eQUEST, and the blue platforms describe the levels above grade, and the yellow one represents the basement floor.

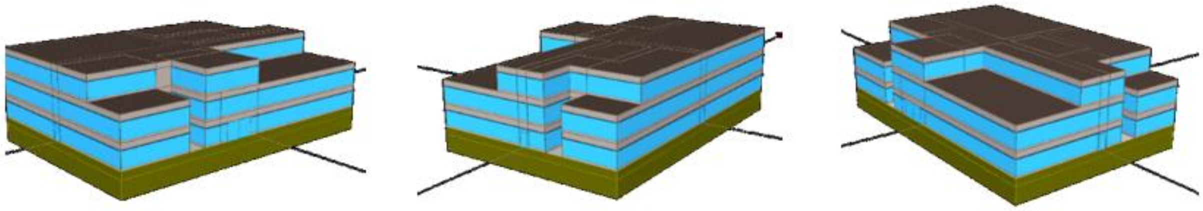


Figure 6: Energy Basecase Model Perspective Views, view from the southeast (left), view from the northeast(middle), view from the southwest (right), by the authors

Phase I - Step 3: Basecase simulation results and discussion

After running the simulation using eQUEST, highly detailed reports are generated providing information about building energy performance, building utility performance, life cycle analysis, energy end-use, general project parameters, and etc. The following two sections (2.3.1 and 2.3.3) are summarizing the most important data for architects, researchers, and clients, used to evaluate and benchmark building performance; which are the electric and gas consumption monthly use and their equivalent costs in U.S. Dollars.

Phase I - Step 4: Building description Electric and gas consumption by month

After performing the base case simulation run, the results show the monthly energy consumption by sector in thousands of Kwh. with an average monthly energy consumption of (44.69X1000) Kwh. The monthly gas consumption is also shown by sector in million Btu and it shows that the space heating is a huge consumer in the underheated season. The average monthly gas consumption is 175.85 X 1,000,000 Btu. All results are shown in fig. 7.

By using the information on this step, researchers can extract the peak demand, predict energy use patterns and accordingly list all the potential strategies that can address the challenges related to the peak months. In addition, the data can be compared with any utility bills obtained from similar buildings in the area.

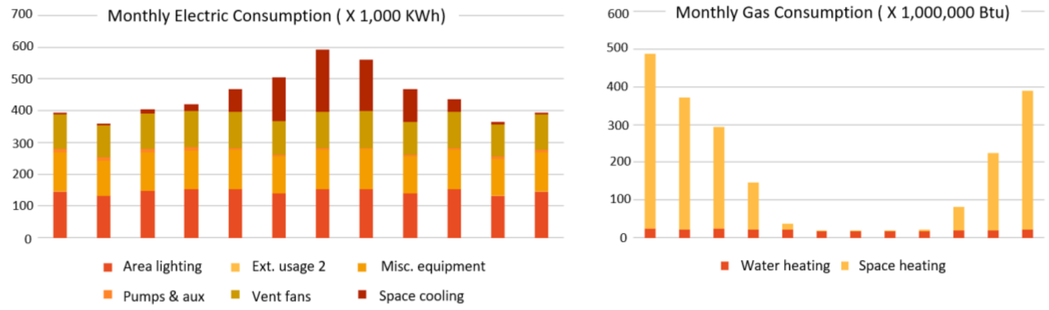
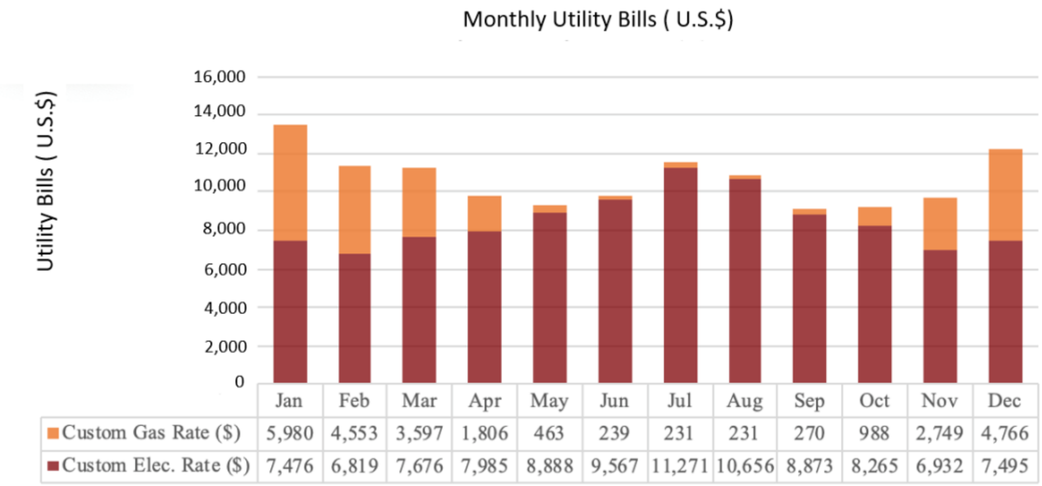


Figure 7: Electric and Gas Consumption by Month (X1000 Kwh, X 1,000,000 Btu respectively)

Phase I - Step 5: Utility bills by month – costs

In this section, all costs are calculated according to the utility rates for commercial buildings in Manhattan. The electric rate is 20 cents per kwh and the natural gas price is 1.226 per therms as obtained from the U.S. Bureau of Labor Statics website. The simulation reports show that the average monthly electric bill is 8,492 USD and the average monthly gas bill is 2,156 USD. The total annual electricity bill is 101,895 USD, and the year-long gas bill is 25,871 USD. Overall, the yearly bill across all rates is 127,766 USD. In Fig. 8, the monthly utility bills across all rates are shown.



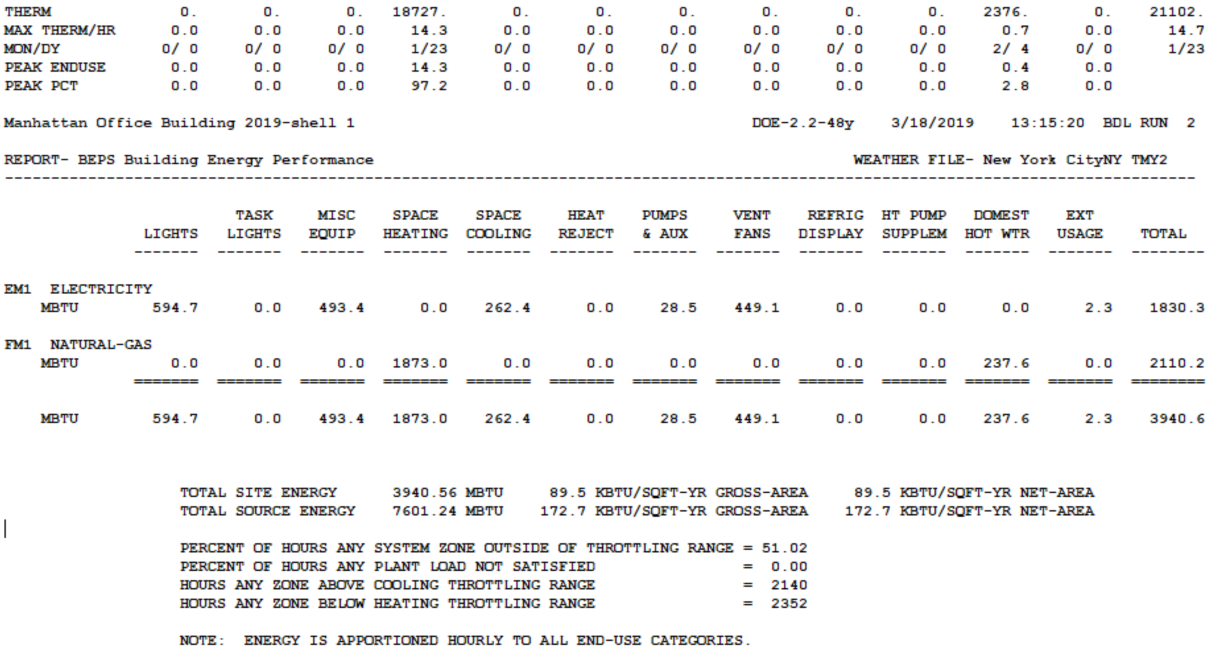
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟧 Custom Gas Rate ($)	5,980	4,553	3,597	1,806	463	239	231	231	270	988	2,749	4,766
🟥 Custom Elec. Rate ($)	7,476	6,819	7,676	7,985	8,888	9,567	11,271	10,656	8,873	8,265	6,932	7,495

Figure 8: Monthly utility bills by rate - basecase

Phase I - Step 6: Performance based evaluation of the project with comparison to similar projects

By using the Department of Energy Building Performance Database (BPD), MOB is compared with conventional office buildings that have the same floor area in Manhattan; in order to educated architects on the effective of the benchmarking tool to compare proposed projects with similar projects in their area.

By using the commercial buildings dataset in the database, the site Energy Use Intensity (EUI) of MOB is 89.5 Kbtu/ft$_2$-year, which is 13% higher than the benchmark in the area. The source EUI of MOB is 172 Kbtu/ft$_2$-year, which is 8.5% lower than the benchmark in the area. In Fig. 9, the basecase's site and source EUI and neighbor buildings' site and source EUI are shown. By conclusion, office buildings in high demanding areas are excessively consuming energy; therefore, implementing passive design strategies is very crucial to reduce energy consumption and promote relying on renewable energy sources.



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THERM              0.       0.       0.   18727.       0.       0.       0.       0.       0.       0.    2376.       0.   21102.
MAX THERM/HR      0.0      0.0      0.0     14.3      0.0      0.0      0.0      0.0      0.0      0.0      0.7      0.0     14.7
MON/DY           0/ 0     0/ 0     0/ 0     1/23     0/ 0     0/ 0     0/ 0     0/ 0     0/ 0     0/ 0     2/ 4     0/ 0     1/23
PEAK ENDUSE       0.0      0.0      0.0     14.3      0.0      0.0      0.0      0.0      0.0      0.0      0.4      0.0
PEAK PCT          0.0      0.0      0.0     97.2      0.0      0.0      0.0      0.0      0.0      0.0      2.8      0.0

Manhattan Office Building 2019-shell 1                                         DOE-2.2-48y    3/18/2019    13:15:20  BDL RUN  2

REPORT- BEPS Building Energy Performance                                                WEATHER FILE- New York CityNY TMY2
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                           TASK     MISC    SPACE    SPACE     HEAT    PUMPS     VENT   REFRIG  HT PUMP   DOMEST      EXT
                 LIGHTS   LIGHTS    EQUIP  HEATING  COOLING   REJECT    & AUX     FANS  DISPLAY  SUPPLEM  HOT WTR    USAGE     TOTAL
                -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  --------

EM1  ELECTRICITY
    MBTU          594.7      0.0    493.4      0.0    262.4      0.0     28.5    449.1      0.0      0.0      0.0      2.3    1830.3

FM1  NATURAL-GAS
    MBTU            0.0      0.0      0.0   1873.0      0.0      0.0      0.0      0.0      0.0      0.0    237.6      0.0    2110.2
                =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  ========

    MBTU          594.7      0.0    493.4   1873.0    262.4      0.0     28.5    449.1      0.0      0.0    237.6      2.3    3940.6


                     TOTAL SITE ENERGY       3940.56 MBTU       89.5 KBTU/SQFT-YR GROSS-AREA     89.5 KBTU/SQFT-YR NET-AREA
                     TOTAL SOURCE ENERGY     7601.24 MBTU      172.7 KBTU/SQFT-YR GROSS-AREA    172.7 KBTU/SQFT-YR NET-AREA

                     PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE = 51.02
                     PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED                =  0.00
                     HOURS ANY ZONE ABOVE COOLING THROTTLING RANGE                =  2140
                     HOURS ANY ZONE BELOW HEATING THROTTLING RANGE                =  2352

                     NOTE:  ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.
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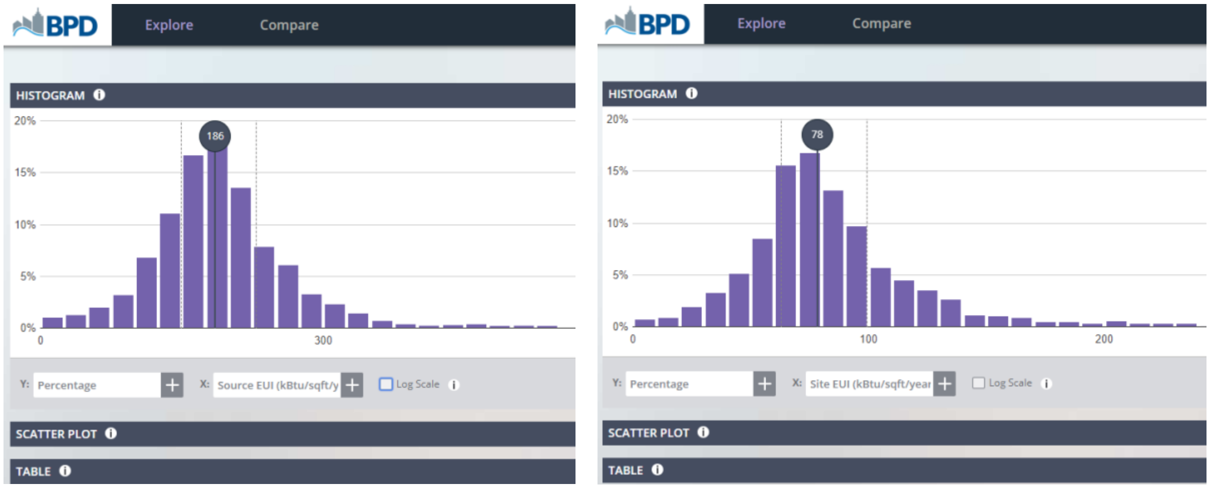

Figure 9: Total Site and Source Energy Use Intensity Simulation Report by eQUEST – basecase (top) Benchmark site energy use intensity (bottom-left), benchmark source energy use intensity (bottom-right) Source: BPD Website https://bpd.lbl.gov/

After simulating the basecase, the results explain the high consuming sectors, and listing the challenges associated with the basecase, the passive design phase is ready for execution. The proposed design alterations are classified into envelope, shading, and interior space qualities, while the active design includes HVAC equipment and similarly energy consuming parameters.

Each challenge is addressed and simulated separately, assessing its individual impact on the building, and playing a major role in its applicability and selection. Once the strategies have been decided on, a combined run is required to group the qualified strategies together and witness the large energy savings on the project. The simulated combined case has achieved 51% savings in contrast with the base case, which equals to 45.6 K-Btu/ft2/year. For the effort of reducing the reliance on active strategies and renewable resources, this step is crucial in the success of the Net-Zero process.

Phase II: Challenges, problem identification and strategies - Passive design

With a 51% reduction in energy consumption, the building has shifted scales, displaying the importance and effectiveness of passive design and its appropriateness in professional practice. In the following three sections, the discussion brings the attention to the envelope components, shading structures and interior finishes.

Phase II - Step 1: Envelope challenges

In a cold dominated weather, building envelopes become a primary concern for architecture engineers, in regard to their heat loss during the underheated seasons. Therefore, architects should pay special attention to ensure the performance of the envelope. The envelope's effectiveness can be increased by reducing its infiltration, proposing walls, and roofs with greater R-values, and installing windows and doors that have higher performance than conventional ones.

Infiltration occurs when there is a pressure difference between indoor and outdoor air (stack effect), particularly when air moves into a conditioned space through cracks, leaks or, other building envelope openings. To address this issue, infiltration can be eliminated by using an air barrier layer or an appropriate sealant, by decreasing its rates from 1 ACH (Air Changes per Hour) to 0.35 ACH and achieving 8% energy savings, which is equivalent to 7.16 K-Btu/ft$_2$/year. Also, it is essential to mention that applying a vapor retarder can eliminate moisture penetrating the wall assembly and damaging the insulation layer.

Another approach is designing wall and roof assemblies with higher R-values than what is required by the code. This approach would increase the R-value of these sections from R-4 to R-21, which will increase the wall's overall insulation efficiency. By doing so, walls and roofs become better insulators and decrease heat loss. Regarding this issue, using 3 inches of polyisocyanurate as an insulating material instead of the code's requirement of 1 inch of polystyrene would achieve 1% energy savings, which is equivalent to 0.89 K-Btu/ft$_2$/year.

Windows and doors are vulnerable areas, in which heat losses may occur, notably when using single-pane windows. Thus, the issue is tackled by using high-performance glazing for windows and doors, that achieved 11% energy savings, which is equivalent to 9.84 K-Btu/ft$_2$/year. We define the high-performance windows and doors as those windows or doors which have double or triple-pane glazing with quality framing materials and thermal break and that have low-emittance coatings on both sides of the glass to reduce solar heat loss in winter and reduce solar heat gain in summer.

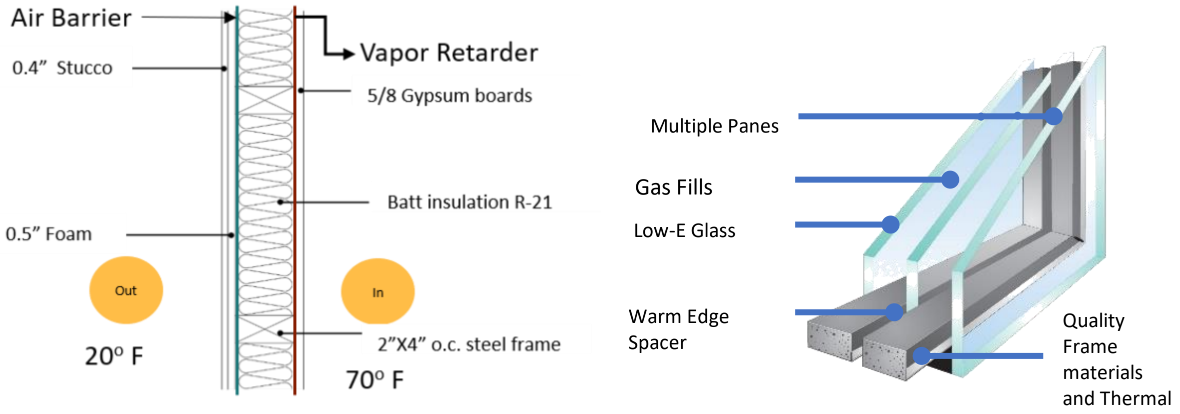

Figure 10: All the envelope improvements used in MOB passive design phase. Wall assembly section to reduce infiltration and increase R-value (left), high performance window section to reduce heat loss in different seasons (right)

Phase II - Step 2: Shading challenges

Although MOB is in a cold dominated weather region, shading is crucially vital in the overheated seasons, and further critically reducing the overall glare, correlated to the fact that the office envelope is 80% clear glazing. Shading the windows will mitigate the solar heat gain [19], and provide visual comfort for the occupant during the day. In Fig. 11. The diagrams describe the difference between a shaded and unshaded window.

Therefore, to tackle these issues, shading devices that are specified, with the orientation of the façade should be designed. The principal step that should be taken is to propose horizontal overhangs on the south façade determining their length according to the sun angles (azimuth and altitude).For this latitude the intense. For this latitude, the intense period of the year is (June – August), that requires fully shaded windows to reduce the heat gain and the cooling load on the building's mechanical system. The overhangs can be extended into the interior of the spaces for them to play role as light shelves, and diffuse daylight inside. Besides, adding vertical fins that can block the low altitude sun angles on the east and west are necessities to reduce the glare. Also, window blinds can be used by the user's preferences to address more flexibility in the interior spaces. This strategy saved 5% of the annual energy consumption which is equivalent to 4.48 K-Btu/ft$_2$/year. In Fig. 12. The composition of the shading devices are demonstrated.

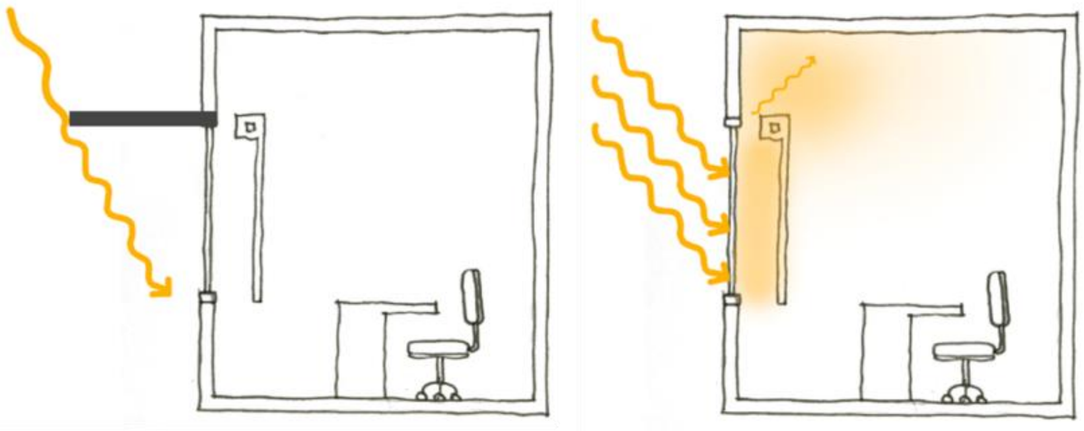

Figure 11: Shaded vs. unshaded office space – Prepared by the authors

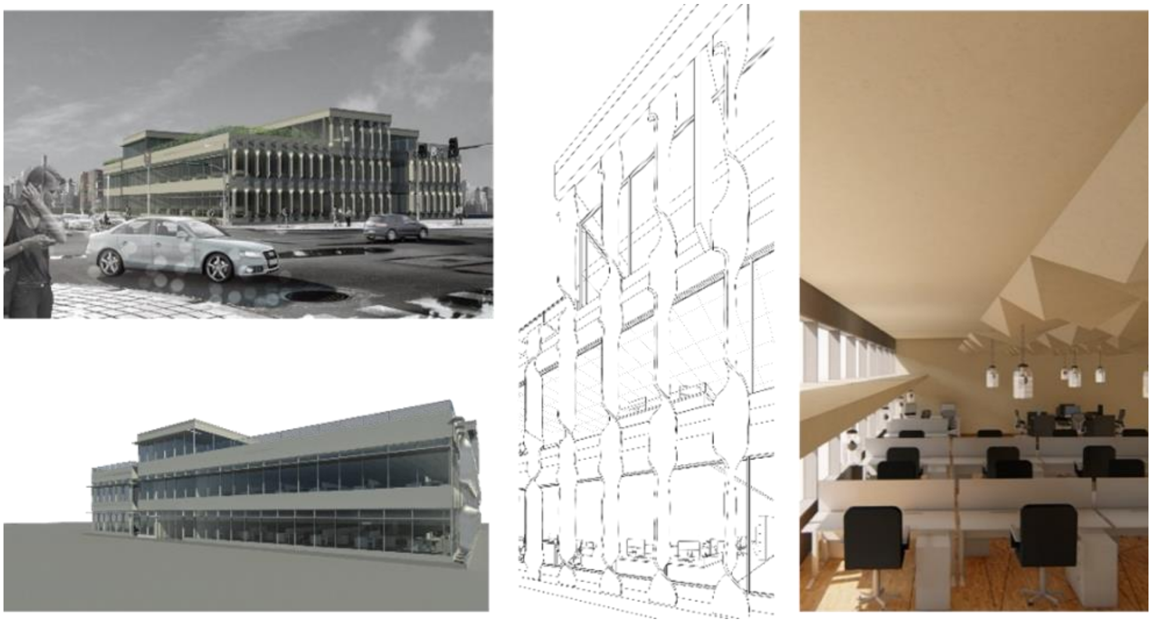

Figure 12:Shading devices design, vertical fins on the east (top left), horizontal overhangs on the south (bottom left), vertical fins technical drawing (middle), overhangs extend to a light shelf inside the space (right)

Phase II – Step 3: Interior space challenges

It is very crucial to design office environments with adequate daylighting to improve occupants' health and productivity and save energy. adequate daylighting is defined as any daylighting that provide the space with illumination levels equivalent to (300-500) lux on the desk level, which is 30" above the finish floor level as recommended by the IESNA.

The daylighting performance of the base case can be analyzed using VELUX Daylight Visualizer 2 or equivalent software. After simulating the base case provided by the IBPSA, only 20% of the floor area achieved adequate daylighting criteria. Hence, supplementing light shelves on the south façade is an appropriate method to enhance daylight diffusion, the shelf can be an extension of the horizontal overhangs to prevent the direct sunlight, shade the windows, and support diffusing the daylight inside the space. Another supporting action ca be using a designed ceiling geometry configuration that can help to diffuse daylight instead of the conventional flat ceilings.

The mixed overhang/light shelf became as one horizontal surface, as shown in Fig.11. One achievable method to tackle this issue is to take advantage of a white reflective coating on the top layer of the light shelf finish material. By implementing this strategy, 50% of the floor area achieved adequate daylighting, which means an additional 30% of the spaces have sufficient daylighting. In addition, high efficiency LED lights, are added for the rest of the spaces to evenly distribute light throughout the space. This strategy saved 18% of the baseline annual energy consumption, which is equivalent to 16.11 K-Btu/ft2/ year. To conclude this is one of the most significant approaches for saving energy and providing office occupants with a more desirable environment. In Fig.13, The simulation results of the design case after implementing this strategy are shown.

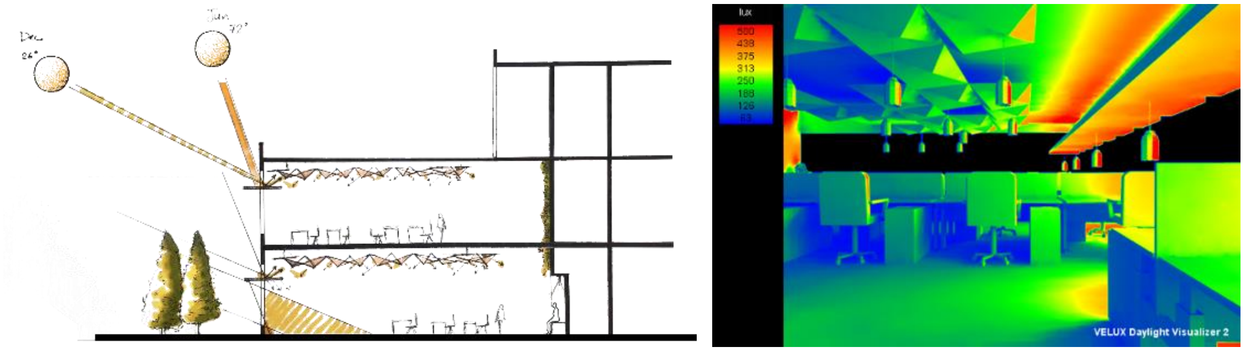

Fig. 13: Sketch showing the light shelf strategy used in two times of the year Dec.20 and Jun19 at 12:00 p.m. clock time (left), simulation results of the design case showing illumination levels at 12:00 p.m. clock time on Mar. 21st

Phase III: Mechanical equipment and challenges- Active design

After rigorous applications of energy efficient strategies, the required HVAC load on the building has now been significantly decreased. In the base case scenario, the recommended HVAC system is System#5 Packaged rooftop VAV with Reheat according to the code (ASHRAE 90.1 2010 – Appendix G, Table G3.11.1A). All units are <65 K-Btu constant volume with standard SEER = 13 for cooling efficiency and AFUE = 0.75 for heating efficiency. The proposed system does not have an economizer, and the thermostat setpoints, if occupied, is 75°F for cooling and 70°F for heating, and the unoccupied is 80°F for cooling, and 65°F for heating.

The proposed HVAC system uses an economizer, is a higher SEER = 23, and is supplied through an underfloor air distribution system where the air is directly supplied to the base of the occupied zone. By implementing this strategy, the proposed design saved 9% from the base case annual energy consumption, which translates to an amount of 8.06 K-Btu/ft2/year. In Fig. 14 illustrations of the strategy are shown, which also increase occupant thermal satisfaction.

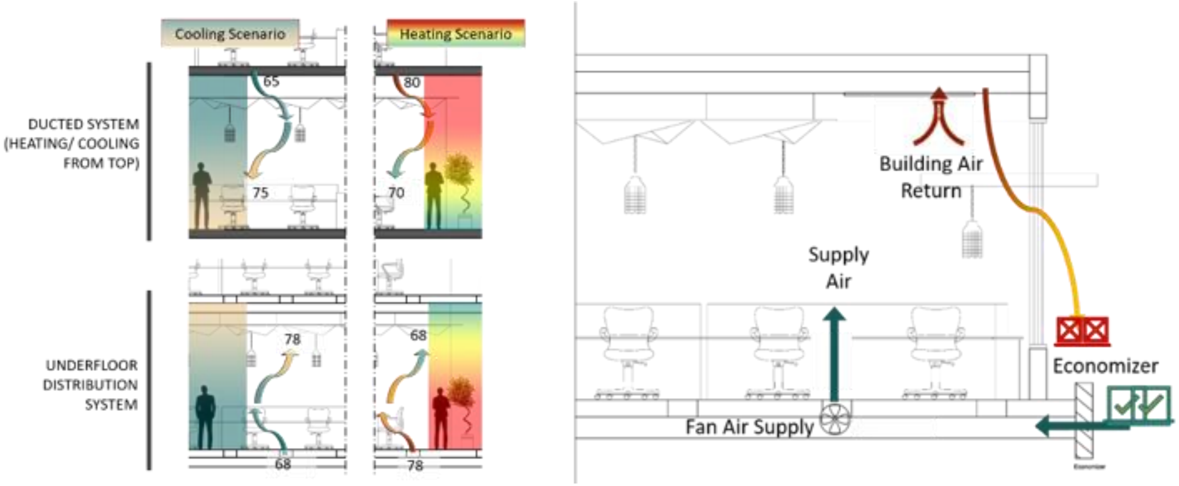

Figure 14: HVAC equipment using underfloor air distribution system vs. conventional system (left), building section using economizer (right)

Phase IIII: Net-Zero Plus Scenario – Achieving Net-Zero Plus Status

Phases 2&3 disseminate this simulation process to the design case scenario in this paper. Eventually, the design investigated the best options for installing Photovoltaic Panels on MOB’s roof to achieve a Net-Zero plus status and provide the building's energy from renewable energy sources with a payback period of 2 years. The short-term payback period allows the methodology to be reliable and adequately reasonable for owners and clients. This summary refers to the Net-Zero Plus scenario in this paper. Similar office buildings can adopt this methodology and slightly adjust the strategies to suitably fit their projects’ locations and climates. By examining various alternatives to assess the most beneficial price, accomplish a short payback period, and reach the net-zero status Trina Solar Photovoltaic panels were proposed, that have a system capacity of 170.8 kW. The average sunshine hours of New York City were considered, 4.6 hours per day, and the panels shall be tilted 41 degrees due south.

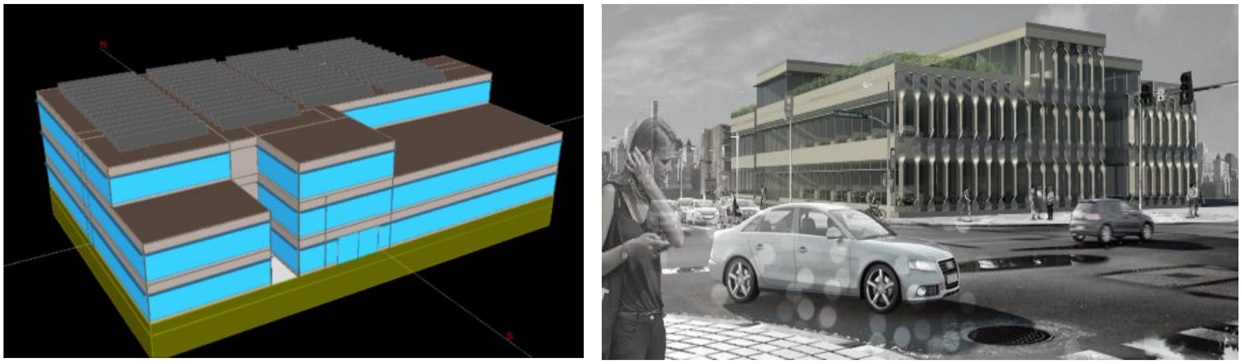

Figure 15: Perspective view of the Net-Zero Model (Left), Final Rendered building Design by the authors (Right)

Therefore, by applying 540 panels arranged in 54 arrays, 10 each, and using 330 polycrystalline cells, the system produces 299,198 kWh annually. Which compared to the annual demand of 282,870 kWh with a supply of 299,198 kWh, the proposed design can achieve 105% energy coverage from renewable sources. The system cost is $54,540 for the panels, $22,500 for inverters, and $15,408 for other system components. The total cost is $92,448. with two years payback period. In Fig. 15, a 3D view of the building model with the solar panels are shown.

Conclusion

The concept of a Net-Zero Energy Building (NZEB), one which produces as much energy as it uses over the course of a year, which lately has been advancing from research to professional practice, due to the effects of rising cost and adverse impacts on the environment. However, Net-Zero milestones is not merely a status, it is celebrated in this paper as a symbol of education, empowering a green building revolution. Where buildings are reducing their reliance on non-renewable energy sources, the city’s infrastructure, and at the same time sequestering greenhouse gases as a result. The authors believe that educating our future generations of architects and engineering with knowledge about Net-zero is vital. Our pedagogies should integrate Net-Zero processes and steps into architectural studios and lectures to well prepare and equip our future leaders and designers. This paper has utilized a complex commercial building to outline and document the relationships between the general building performance criteria, and the application of a series of passive design solutions. The proposed milestones of Net-Zero were the accomplished to save 51% of the annual energy consumption of the original building design (*basecase*), which is equivalent to 45.12 K-Btu/ft2/year as well as securing/generating over 100% of renewable energy at 299,198 kWh. The proposed design has earned the building a Net-Zero Plus status, with surplus energy returned to the grid. The paper fills in a critical educational gap by providing a sequentially executed tool kit that trains students, professionals, building officials as well as emerging rating systems to effectively adapt Net-Zero.

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