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Is Net-Zero Tall Possible?

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Are Net Zero tall buildings possible in dense city cores? Or are cities destined to lose ground on sustainable innovation to less-compact suburban areas? These are two questions asked at the onset of an ambitious research project undertaken by Chambers Design through the New York University (NYU)'s Green Grant Program.

Introduction

Net zero buildings, also known as Zero Energy Buildings (ZEBs), are an elusive but evergreen goal of architects and engineers. Many definitions exist for this building typology (Pless 2010) however the project covered in this paper defines ZEBs as buildings that produce as much energy as they consume on-site. They can be connected to the power grid. On-site renewable energy production and net-metering allows them to feed as much energy into the grid as they pull from it. ZEBs are not required to be off-the-grid edifices.

It has been widely suggested by design professionals that ZEBs are highly implausible for highly dense, urban infill projects. The National Renewable Energy Lab (NREL) reported that only 3% of buildings of four floors or more would be net zero by 2025 (Griffith 2007). However, with better technology for simulating energy performance for buildings on the market, and advances in on-site energy generation technology, a much higher percentage should be achievable than that predicted in the NREL report.

Other factors increase the likelihood of ZEBs in urban infill projects as well. A new focus on all aspects of energy efficiency, from plug-load reduction to thermally-active surface integration, is proving that all types of buildings are capable of achieving substantial energy savings. Lastly, the process of designing energy systems has become much more iterative and holistic, as sustainability has become the driving form-making force for buildings.

Because of these changes in the landscape of ZEB, the research team undertook an in-depth analysis of the Zipper Building (see Figure 1). The team included undergraduate and graduate students, administrators, and others from the university. The goal of this project was not to "achieve net zero," but to discover how close the building could get to it. The second goal for the project was to develop an approach that could be used for any type of capital project for the University at any location in the world.

Background – Above Ground

New York University's Master Plan for Greenwich Village was developed as preparation for the university's bicentennial in 2013 (NYU 2012). The strategic plan, completed by Grimshaw Architects, included up to 557,418 square meters of new space needed over the next 25 years (see Figure 2) with a split among four large buildings. The majority of the programming within the buildings is housing and academic spaces.

At the beginning of the research project, the Zipper Building, which encompasses just over 92,903 square meters, was first envisioned for

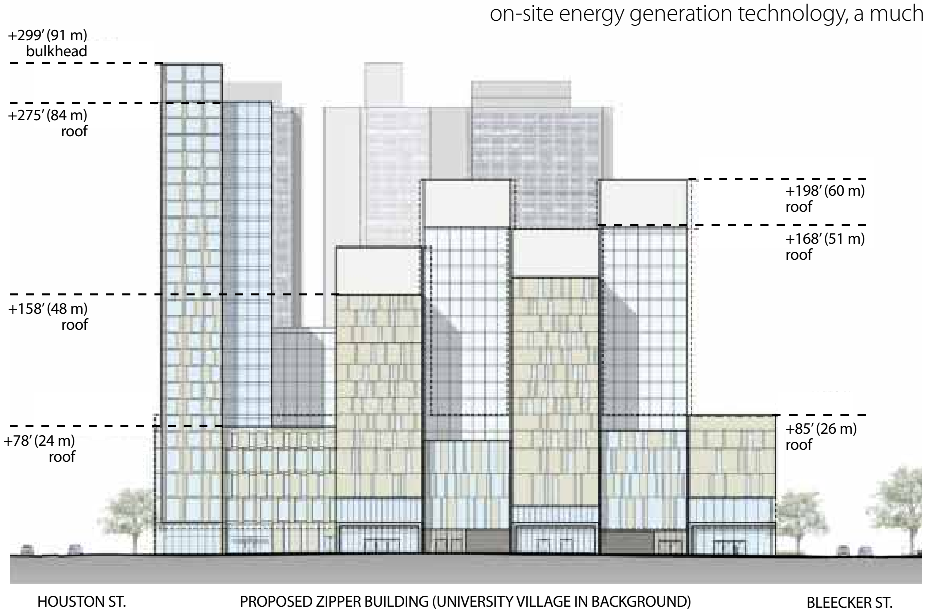


Figure 1. Zipper Building, New York. Source: New York University

an assortment of space requirements, including academic, hospitality, retail, recreational, and residential spaces. The complexity and potential intensity of the building made it a desirable research subject. The assumption was that if it could be net zero, then other, less-complex buildings could achieve net zero. The building was to rise at the corner of Houston and Mercer streets in Manhattan on a site currently occupied by Coles Sports and Recreation Center, a five-level building totaling 13,192 square meters. The Zipper Building, in contrast, would be nearly 91 meters tall at its highest point, with five other towers ranging from 51 to 69 meters. Since the study, some modifications have changed the height of the towers, based on New York City Council requests.

Along with the specifics of the case study of the Zipper Building, it was important that the analysis be able to not merely focus on projects within Manhattan, but also to create a process that was flexible enough to be used at the New York University (NYU)'s campus in neighboring Brooklyn, as well as buildings in China, the Middle East, and other potential locations for NYU satellite locations.

The Process – At the Beginning

At the beginning of the research, the Zipper Building was in late conceptual/early schematic design phase. There were no detailed designs for the mechanical, electrical or architectural systems of the building. The university was in the process of meeting with community and city groups and committees on modifications and other early stage approvals. An Environmental Impact Statement (EIS) was provided by the university that outlined the majority of the energy information for the project, such as energy consumption, grid-sourced energy, emissions, and the breakdown of energy types to be used for the building (natural gas and electricity).

The EIS stated that the project would pursue a LEED Silver certification as required by the NYU Sustainable Design Standards and Guidelines. The EIS indicated that energy performance would be 20% above the ASHRAE Standard 90.1-2004 and/or attain an energy performance score of 80 or higher under the USEPA Energy Star program.

NYU requested that no "morphological" changes be made to the Zipper Building. This meant that the volumes of the towers, the orientation of the building, the footprint, and other major architectural moves should be kept as-is. This added a level of difficulty to pursuing net zero for the building, and meant many of the options available to new construction were off the table. At times, it felt as if the team were redesigning an existing building within a significant set of constraints.

Fenestration, window-to-wall ratios, and other aspects of the skin could be altered, as long as the overall form of the building was maintained.

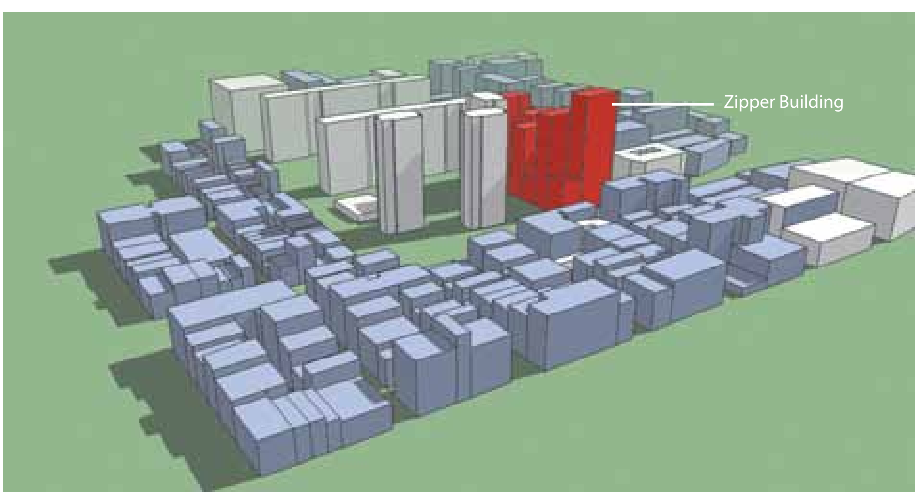


Figure 2. New York University (NYU) 2031 Core Plan.

The analysis undertaken in this study used two primary software packages for evaluating energy consumption, and tracking energy efficiency and generation. Extensive simulations were completed for the project, including: solar insolation analysis, solar thermal gain, bioclimatic integration, exterior and interior computational fluid dynamics (CFD), HVAC energy consumption, electric lighting analysis, daylighting analysis, photovoltaic (PV) electricity generation simulation, heating and cooling loads, and insulation optimization analysis. The team used IES-VE Pro and eQuest for all of the energy simulations. Both packages provide a visual virtual model for the process. eQuest was used to allow outside professionals to peer-review the simulations. A complete step-by-step outline of all modeling was provided to NYU within the final draft of the report.

The Process – Toward Net Zero Architecture

Based on the EIS and other information gathered at the onset of the project, it was determined that the ASHRAE baseline energy consumption of the Zipper Building would be approximately 80,215 MMBTU. This level is exactly equal to the ASHRAE 90.1-2004 standard. It also represents standard systems within the building, such as forced-air heating and cooling, the appropriate air exchanges and light power densities (LPD) based on space type. Other criteria of the building, and therefore the energy systems, were derived from drawings and renderings received from NYU. For example, the window-to-wall ratio varies along different areas of the building. Some exterior walls bore a 90–95% glazing application, while other areas were more modest at 50 to 75% glazing. However, in all cases, based on the given information, all glazing was floor-to-ceiling glass.

To attain the 20% energy savings, basic energy-efficient measures were applied to the building, such as high-efficiency forced-air HVAC systems, high-albedo roofing materials, occupancy sensors for lighting and climate control, improved light power density through basic energy-efficient light fixtures and Energy Star appliances. In today's green-building industry, these moves are seen as conventional, if not standard. Through their application, the building's energy consumption was simulated at 64,111 MMBTU, a 20% savings over ASHRAE 90.1-2004.

Forcing Air

Forced-air heating and cooling systems are much less effective from an energy consumption perspective than thermally active surfaces (TAS), e.g., radiant heating and cooling (Moe 2010). Radiant systems can reduce peak cooling loads by 21 to 25% and electricity demand by 27% during peak times (Raftery et al. 2010). The façade of the building, along with other architectural features, must be adjusted in order for radiant systems to perform effectively. The building needs monitoring systems for humidity levels that set off alarms, so that issues with condensation do not arise. The application of TAS brings additional benefits such as indoor comfort, increased boiler life, quiet operation, and flexible room layout.

All of these benefits point to a positive trend for TAS. During the study for the Zipper Building, TAS was used in lieu of forced-air systems for the majority of spaces. Some spaces, such as computer labs and large auditoriums, do not fit into the cooling profile for hydronic systems (Bauman et al. 2013). These areas represented a minor percentage of the overall building. When TAS was applied to the energy model, it resulted in a 44% improvement over the baseline (see Figure 3).

In the EIS, it was indicated that the mechanical systems would need 13,935 square meters of dedicated space, roughly 15% of the total area of the Zipper Building. A TAS system would reduce needed dedicated space (Moe 2010) to 7,246 square meters, a 48% reduction – the equivalent of one of the dormitory towers in the project. Three important points to this reduction:

1. Eliminating that square footage would save millions of dollars in construction costs
2. The massing and programming of the building would more easily fit into building (and thereby onto site)
3. The reduced massing could help with city approvals, community support, and speed of project completion. All three of these points have significant financial benefits. Overall, a 44% energy cost savings over the baseline would translate into nearly US$2 million of energy cost savings annually.

Enhancing Optimized Systems

Once the TAS was integrated into the building, geothermal heat exchangers and solar thermal collectors were applied. Geothermal heat exchangers are considered one of the best ways to eliminate unnecessary energy consumption. Initial discussions around these technologies looked at how the two systems may be directly linked with the TAS as a fully closed-loop system. With some investigation, it was found that a more conventional approach was required for the project. The geothermal system would need between 250 and 300 wells to be effective for the size of the Zipper Building, but it would improve the heating and cooling of the building by an additional 8%.

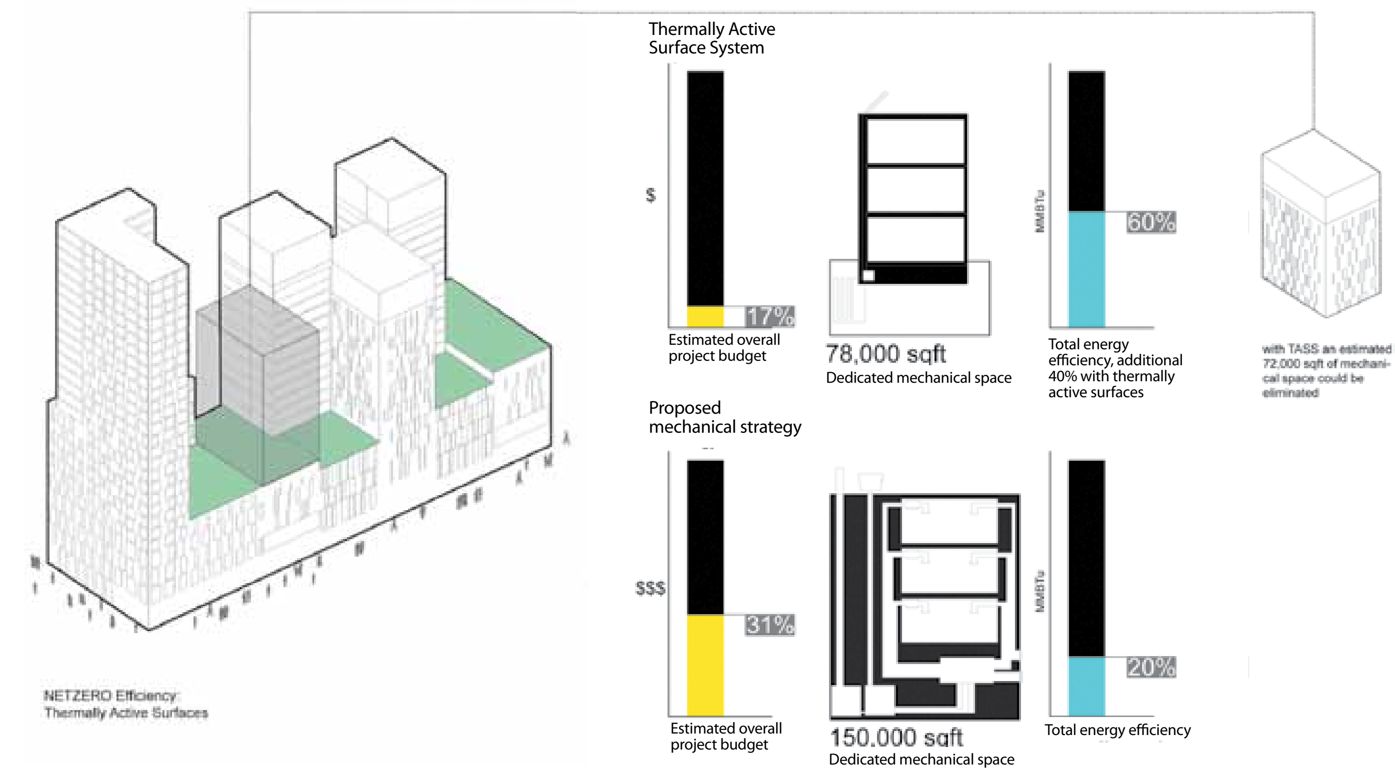


Figure 3. Heating and cooling systems comparison between forced air and Thermally Active Surface System (TASS).

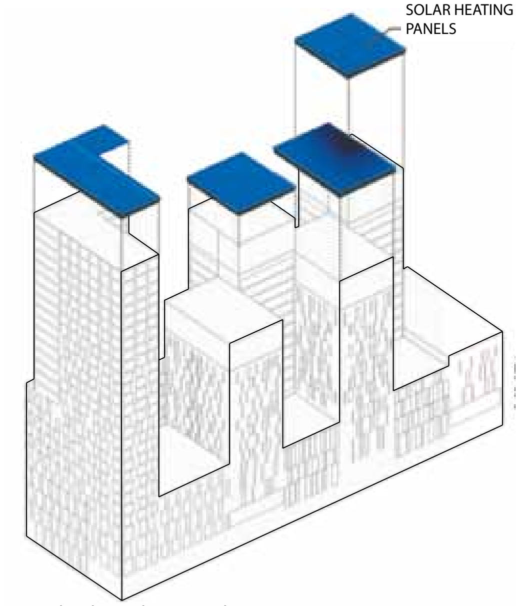


Figure 4. Solar Thermal (ST) panels.

> "It was important that the analysis be able to not merely focus on projects within Manhattan, but also to create a process that was flexible enough to be used at the NYU's campus in neighboring Brooklyn, as well as buildings in China, the Middle East, and other potential locations for NYU satellite locations."

The solar thermal collectors were minimized on the project, to only be applied on the flat roofs on four of the towers. This decision was made based on a solar-radiation analysis for PV panels. It was understood that though solar thermal (ST) panels had a strong chance of reducing energy consumption, the trade off for PV panels would be too high for the goal of possibly reaching net zero. The applied ST did improve the efficiency of the building by an additional 2% (see Figure 4).

More than Half Way

All of the technology mentioned so far in this report is available on the market today and has been used in numerous real-world cases throughout the New York City metropolitan area and around the world. The team surveyed several construction, engineering, and design firms about the barriers to application of technologies. Two major issues emerged;

One is first cost, either assumed or real. When compared to their conventional alternatives, TAS, geothermal, and solar thermal do have a higher first cost. However, as the research for the Zipper Building shows, financial benefits for TAS greatly outweigh first-cost concerns. Strangely, though these technologies have been used on countless projects, a lack of first-hand experience within design and construction firms alike make their usage incredibly tricky. When professionals feel uneasy about a technology, concerns of liability and performance trump other benefits.

At this point in the analysis, with the usage of the EIS efficiencies, TAS, geothermal, and ST systems, the overall energy savings was shown to be 54%, more than half way to net zero.

The Architect's Energy System

The team intentionally did not improve the façade or insulation of the building over the ASHRAE 90.1-2004 requirements until the mechanical systems were redefined. As mentioned, the window-to-wall ratio varied from area to area of the building. Façade design should be one of the biggest energy-saving strategies within any project. Too often that is not the case. Good façade design is overpowered by the sense of what provides a better view (floor-to-ceiling) versus what is better for glare control, interior comfort, and daylight harvesting (to name a few). To evaluate the building's exterior skin, the façade was divided into two types: Type One – curtain-wall systems with floor-to-ceiling glazing and Type Two – wall systems with patterned glazing (see Figure 5).

Type One represented approximately 3,646 square meters of façade area. These areas underwent solar radiation analysis to determine the total kBTU/sqf annually. Daylight analysis was simulated to determine the Daylight Factor in the spaces. The daylight factor ranged from 38 to 52 within the building as far as 3 to 4.6 meters from the glazing. A daylight factor of 2 is a typical level desired for an office space, 14 for discussion group rooms, and 2 for school classrooms. Based on these simulations, it was assumed glazing would need shading, darkening or other strategies to compensate for over saturation of daylight. Type Two incorporated data from the same two simulations. The daylight factor was much more appropriate for the interior spaces with the patterned windows.

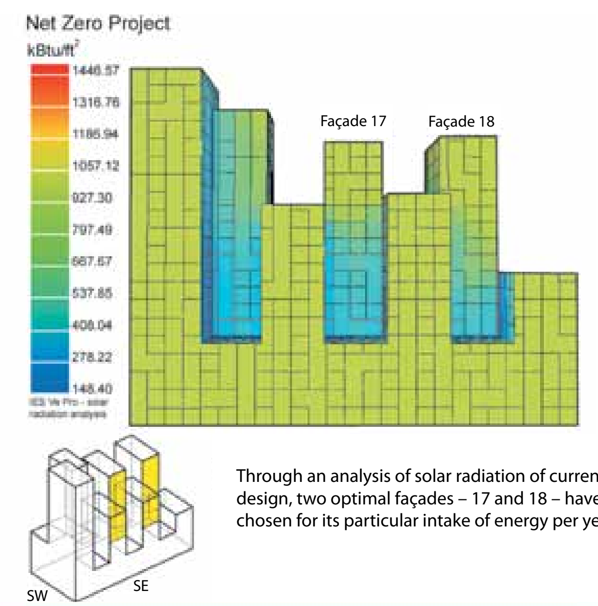
The team recommended that the percentage of the curtain wall's opacity be increased. From the floor, the increase should be 610 to 762 millimeters, and from the ceiling by as much as 305 to 457 millimeters. The opaque area would become the location for building-integrated PV panels. The PV panels would act as a rain screen, providing additional protection from the elements while allowing airflow to go behind the PV panels. When simulating rain screens on the façade, the thermal performance greatly increased. Other exterior adjustments included optimized insulation, placement of glazing, and improved *u*-factor glazing. When the changes were made to the skin, the energy performance of the building improved by 77% over the baseline, and by 47% over a simple adjustment of mechanical systems.

Standardizing Façade Design

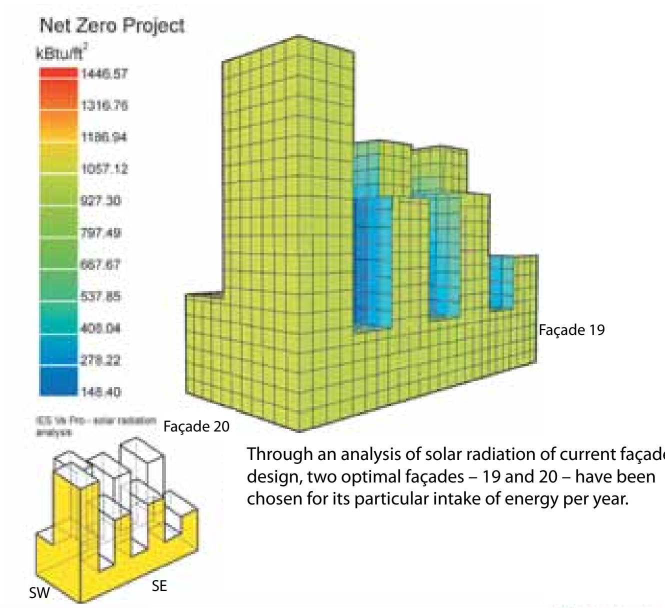
Because the net zero analysis was undertaken at such an early stage in the design process, many of the interior layouts were not determined. To maximize the assessment, the team developed a matrix of design options for how the exterior skin could interrelate to the interior spaces (see Figure 7). The matrix was organized into a Climate Impact Analysis (CIA) for easy reference. The building was designed to house multiple space types, from retail to classrooms, so the first aspect of the CIA was five room sizes: 3 x 3 meters, 3 x 6 meters, 6 x 6 meters, 9 x 12 meters, and 12 x 12 meters. These represented the majority of potential room sizes. Each sized space was then fit with four different glazing percentages from 40 to 90%, sun shading at the top of the glazing and 910 millimeters down from the top, extending the shade at both positions by 305, 607, and 914 millimeters. The last option explored was an opaque rain screen with no shading. All of these options were than rotated to face the four cardinal directions (N, S, E, and W) and the four intercardinal directions (NE, NW, SE, and SW). In total, the CIA included 3,840 results, proving solar gain heat load and cooling load for all options. This could be used as a tool to calculate the most effective glazing and shading options for the space sizes based on orientation throughout New York City. Once the model was constructed, the climatic variables could be changed to anywhere on the planet, and then easily output the same detailed information for specific site in the Middle East, Asia, and elsewhere in the United States.

Plug Loads for Net Zeros

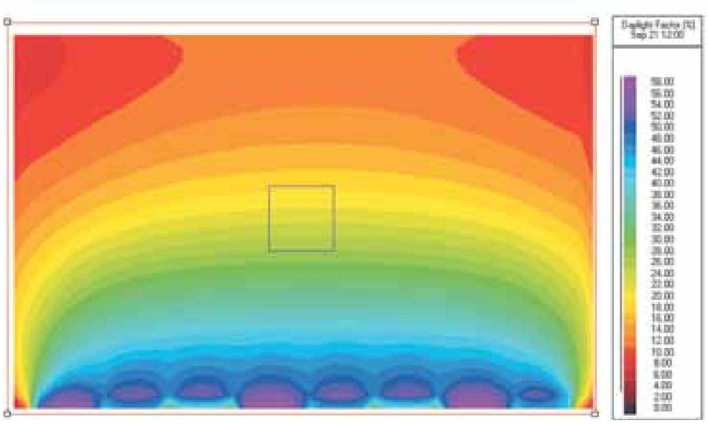
The analysis only briefly evaluated the plug loads for the Zipper Building. Minor changes showed a slight increase to energy performance of 1.6% over the previous changes, and brought the overall energy efficiency to 77% above the baseline. This is the one area that needs additional evaluation (Lebot et al. 2000) of its effectiveness in achieving net zero. With all the energy savings applied, the plug load represents 25% of the



Through an analysis of solar radiation of current façade design, two optimal façades – 17 and 18 – have been chosen for its particular intake of energy per year.



Through an analysis of solar radiation of current façade design, two optimal façades – 19 and 20 – have been chosen for its particular intake of energy per year.


Analysis of façade Type One.

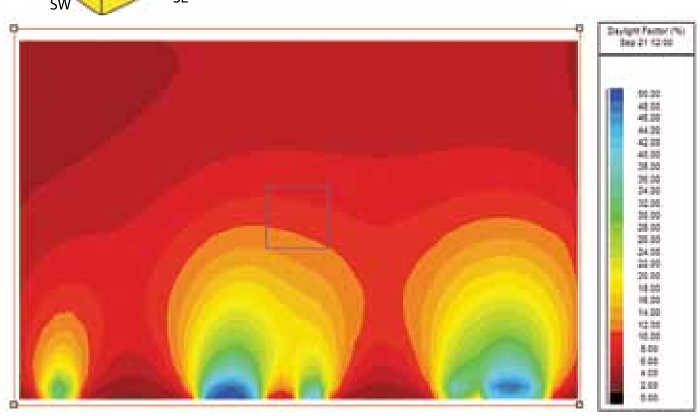

Analysis of façade Type Two.

Figure 5. Determining the curtain wall system

remaining energy load. Studies (Kaneda et al. 2010) have shown that with accurate surveying of space occupancy and usage, along with advanced plug load reduction strategies, processing power could be cut to as little as 13%.

Benefits of In-Depth Energy Efficiencies

At 77% energy efficiency, the Zipper Building would reduce its annual load from 80,215 to 18,136. Many additional methods of energy reduction were not evaluated for this project. For example, set points remained the same throughout the analysis. With the official temperature and humidity range prescribed as minimums by ASHRAE 170, any change would have to be consistent with the baseline and design case energy model. Though changing the set points would not show energy savings as a factor of the baseline, it would produce an energy reduction. Neither LED lighting nor daylight sensors were included in the energy modeling. These could have also improved the energy performance. The timeline of the analysis did not allow for these technologies to be included.

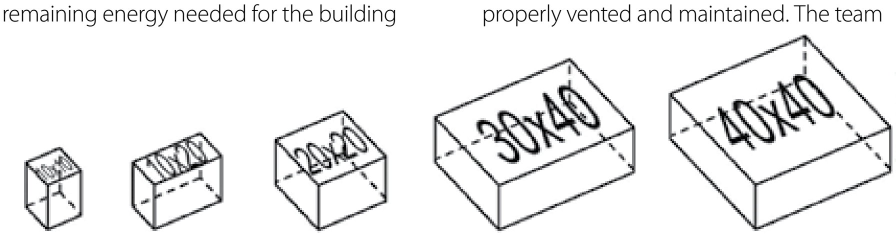
With the 77% energy savings, the building could save as much as US$2.7 million per year. New York City energy costs are expected to increase by 4.5 to 5.5% annually, which means a correlated increase in energy savings over the next 10 to 30 years. These are significant savings and should be taken as serious options for implementing the strategies explored in this paper. It is important to note that for the cost benefit, electricity was assumed to be delivered at a cost of US$0.16 per kWh. New York's rates are often as much as US$0.25 per kWh.

Energy Generation

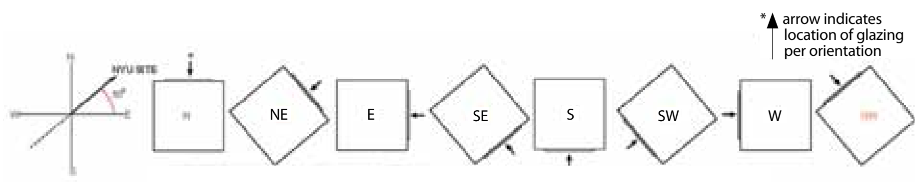
The changes to the façade of the Zipper Building set up the opportunity for a large-scale application of PV panels. The research team performed an exhaustive analysis of solar radiation for all surfaces of the building, evaluating potential shading from neighboring buildings and flora. The application of PV panels should only be used where most effective. Without a deep evaluation of all surfaces, a project can place expensive PV panels in areas that will not provide a strong return on investment. Moreover, depending on how the array is wired, a small amount of shading on a few panels could cause large portions of the array to shut off completely. Once the optimum locations were identified, the PVs could be used for the greatest benefit.

As an alternative, the team identified a semi-transparent solar panel by Sharp as a way to increase the energy production of the exterior walls while still allowing ample solar radiation through to the interior. The panels would also assist in reducing glare and thermal solar gain for the building. The combination of standard PV and semi-transparent PV would generate 28% of the remaining energy needed for the building with all the other improvements included. In comparison, the same amount of electricity generation only represents 6.2% of the energy needed for the baseline.

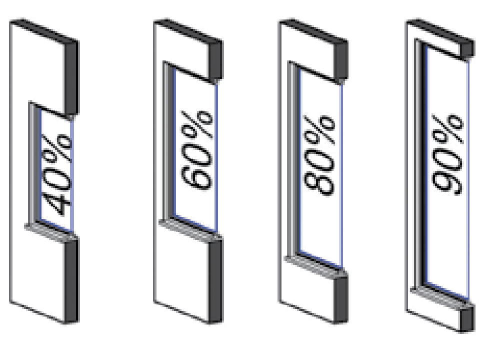
The last technology applied to the building for energy generation is a small-scale dry fermentation anaerobic biodigester (AD). The AD for the Zipper Building was modeled after a similar academic installation at the University of Wisconsin, Oshkosh (UWO). The UWO AD is located on its campus near its administrative offices. The AD has the capacity to ingest up to 7,257 metric tons of organic waste (produce and baked goods only, no meats) to function. When the waste is processed through the AD, the output is a rich fertilizer that can be used for the campus or sold to local community gardens. During a tour of the UWO facility, it was obvious that smell would not be an issue if the AD is properly vented and maintained. The team



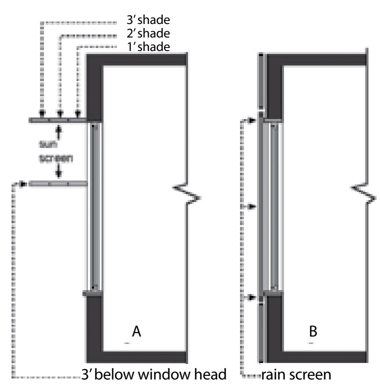
ROOM SIZES
A set of five room sizes ranging from 100 sqf to 1,600 sqf, were used to analyze how orientation glazing percentage and shading devices influence as well as energy consumption and solar heat exchange within each space.



ORIENTATION AND GLAZING LOCATION
To understand the impact of building orientation to fenestration percentages, shading devices, and room size, the research placed glazing in three direction to simulate the climate to energy consumption, and interior comfort. NW, NE, SE, and SW opportunities for efficiency based on true North condition.



GLAZING PERCENTAGE
The percentage of glazing has a tremendous influence on interior comfort, views, energy consumption, and constructability. The smallest glazing (40, 60, 80, and 90%) is to reflect the baseline determined by ASHRAE 90.1–2007.



SUN SHADE AND RAIN SCREEN
The research implemented the use of window shading devices at two specific locations: the first at window head and the second at 3 ft below window head (A). The final stage was to incorporate rain screen to each façade (B).

Figure 7. Climate Impact Analysis.

“A lack of first-hand experience within design and construction firms alike makes use of thermally active surfaces, geothermal and solar thermal technologies incredibly tricky. When professionals feel uneasy about a technology, concerns of liability and performance trump any other benefits.”

proposed a similar strategy to fuel the AD to that which UWO has developed for its facility. That is, NYU could partner with local restaurants, groceries, and farmers markets to take damaged and expired food waste.

Call it Net Zero, Maybe?

When all energy-efficiency and generation options are combined, the overall energy footprint of the Zipper Building is 5,636 MMBTU, a mere 7% of the original baseline (see Figure 8). The overall energy cost savings per year would be more than US$3 million. This is based on no significant changes to the design morphology and without employing specific energy-saving devices such as set points, LED lighting, and daylight sensors. Though the team did not achieve net zero, it was a highly successful exercise in showing just how close and achievable Zero Energy Buildings (ZEBs) are for NYU and for urban high-rise buildings in general. No two sites are the same, and construction cost would fluctuate widely with some of the technologies explored. That said, with such an extensive evaluation having been completed at an early stage of the design, the remaining time with the project could be used to find the best ways to reduce the cost of construction. ■

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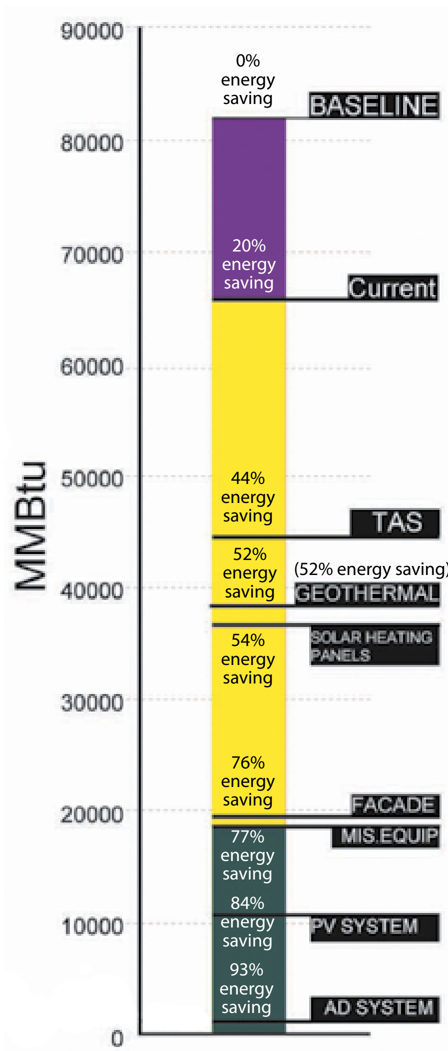

Figure 8. Overall energy footprint after all energy-efficiency options are combined.

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