Net-positive Building and Alternative Energy in an Institutional Environment

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ABSTRACT

Net-positive design is one of the frontiers of architecture in the 21st century. However, not a lot of research has been done on this topic; particularly, the contrast between net-zero building and net-positive energy building has not been addressed. The paper will begin with an overview of net-zero building's current status and explain the importance of promoting net-positive institution building. A four-story tall campus building is used as a case study to demonstrate the feasibility of net-positive building design. Then the author details the design principles and technical feasibility. The building system and energy performance targets are shared, expanding on passive renewable and alternative energy systems. The paper uses net-positive design as defined by a European Commission 2012 report. The author addresses the differences and similarities between net-zero and net-positive building before proposing a new framework for evaluating net-positive building as the next research step.

Introduction

In "2014 Getting to Zero Status Update" (NBI, 2014) produced by New Buildings Institute (NBI), a set of rich survey results provides clear evidence that net-zero energy building has established a solid foothold in building design and construction. The update is based on extensive research by NBI, as well as input from many key organizations, states, and design firms leading the net-zero energy market.

The major findings show that between 2012 and 2014 the number of net-zero energy buildings verified and net-zero energy emerging buildings more than doubled. Twenty-four percent of net-zero energy verified projects are renovated existing buildings. "Large net-zero energy buildings are becoming more common; districts are a growing trend toward scaled net-zero energy building; public sector leads but private sector adoption of net-zero energy building is increasing." (NBI, 2014). There are net-zero energy building examples in 16 different building typologies represented in the 2014 updates report. Educational facilities comprise the largest portion of net-zero energy building projects, with kindergarten through 12th grade (K-12), "universities and general education buildings representing about one-third of all net-zero energy buildings, closely followed by offices. Low-rise multifamily buildings are a new trend." (NBI, 2014).

Drivers and the need for net-positive buildings

"There are three major drivers driving the rapid increase of net-zero building development. The first is energy saving incentives and economic return building owners can gain through the setting up high standard at the beginning. The second is the potential increased market value, the recognition of increased market value through green building practice and attention to a label such as net-zero energy building." (European Union, 2009). The third is the educational function, which is particularly valuable for institutional clients. More and more high-performance buildings, net-zero energy buildings, and positive-energy buildings serve as living laboratories for higher education purposes. The three reasons together explain why education/institution buildings represent the largest portion of net-zero energy projects. "Education buildings are 36% of all net-zero buildings. Of the 58 education buildings, 32 are kindergarten through 12th grade, 21 are higher education and five are general education." (NBI, 2014).

Education building could and should move a step beyond to achieve net-positive for the following reasons:

1. Education buildings offer high visibility that can influence community members and the next generation of citizens.
2. Success stories of public funds that return lower operating costs and healthier student environments provide documentation that can be leveraged by others.
3. Education buildings are the fourth largest building floor space in the U.S. with over 10 billion square feet. (CBECS, 2012)
4. This sector offers national and regional forums and associations to facilitate the transfer of best design and operational practices.

Similarity between net-zero building and net-positive building

The steps required to achieve net-zero and net-positive are similar; they both require a reduction of energy consumption to minimal as a prerequisite, afterwards to compensate the energy with on-site renewable energy production. In this sense, both categories are high-performance building and both categories require a comprehensive and integrated design approach. The second similarity between net-zero and net-positive building is that the evaluation is based solely on current energy consumption, regardless of building size and function. The evaluation and calculation method for different types of building is the same. A hospital building will be evaluated the same way as a commercial office building.

Challenges for net-positive building

The challenge for evaluating net-positive building based on net-zero building is that net-positive building's goal goes beyond energy conservation. The goal of net-positive building is to explore the possibility of adding value for users and occupants. The additional value might be increased productivity, occupants' well-being, and energy saving beyond the individual building's boundary. "Rather than considering only the generation of more exported energy versus its importation to individual buildings or the grid, the emphasis shifts to the maximization of energy performance in a system-based approach." (Cole et al., 2015).

The main differences between net-zero building and net-positive building are:

1. Systematic approach

Net-positive building is a system-based approach linking the performance of several buildings. The linkage among the buildings requires well-planned energy infrastructure that involves a series of partnerships—among building owners, operators and users—which makes net-positive building more feasible in large institutions, since the building's owner and operator is essentially one entity.

2. Energy offset

Current net-zero building focuses on the balance between energy consumed and energy produced on the site. The ultimate goal is independence from an external energy supply. The building could be off grid and self-sustained, based on renewable energy sources on site, such as solar, wind, and hydro. The net-positive building might not be able to completely cut off the external power supply; however, by utilizing the minimal amount of external energy, individual building within a net-positive network could generate a large quantity of clean power to offset the energy consumption needed from other buildings within the same network. The author will illustrate one such example in the case study below.

3. Broader impact

The current emphasis of net-zero energy building relates to the performance and energy benefits accrued by an individual building. While a net-positive building network considers a broader frame, broader potential benefits include shared resources, less energy-use intensity per capita rather than per square foot, and time allocation. In an institutional environment, buildings represent different use functions and operating schedules. For instance, a classroom/teaching facility will be used predominantly between 8am–6pm, while the adjacent dormitory building/student center will be occupied between 6pm–8am. Working with a larger network and taking advantage of different operating schedules would enable the individual building to provide benefits to adjacent buildings beyond its own boundary.

Definition of net-positive energy building

Net-positive energy buildings are technically feasible. The European Commission defines a net-positive energy building as one that "on average over the year produces more energy from renewable energy sources than it imports from external sources. This is achieved using a combination of small power generators and low-energy building techniques, such as passive solar building design, insulation and careful site selection and placement." (European Commission, 2012.) This definition is comparable to net-zero energy building, but without boundary limitation. While following many of the same principles and technologies as net-zero building, the notion of net-positive energy building introduces two new perspectives: network or district; alternative energy resources other than renewable energy.

Case study

Rochester Institute of Technology (RIT) has constructed a new 88,000 gross square foot educational and research building on its Rochester, NY campus. The four-story building includes office, laboratory, classroom and meeting space. The building was constructed with levels of insulation and glazing-performance characteristics that exceed the minimum prescriptive requirements of the Energy Conservation Construction Code of New York State (ECCC) and ASHRAE Standard 90.1-2007 – Energy Standard for Buildings Except Low Rise Residential Buildings. For example, a typical exterior wall consists of three-inch insulated metal panels with polyisocyanurate insulation (nominal R21) and two-inch bio-base cavity insulation (nominal R5.3 effective). This compares to minimum R7.5 continuous and R13 cavity insulation as per ASHRAE Standard 90.1-2007 in Climate Zone 5A.

Figure 1. Bird's-eye view of the building.

Building systems and energy performance target

Key features that reduce energy requirements are:

- Contribution of central plant equipment to the energy performance of the building
- 400 kW fuel cell cogeneration system
- High-efficiency air-side HVAC systems, including active chilled beam terminal units
- Exhaust air energy recovery (ERV-1)
- Variable flow/speed chilled and hot water pumping systems
- Variable air volume laboratory supply and exhaust system
- Nominal 10-ton geothermal heat pump system with water-to-water heat pump to supplement the building's chilled and hot water loops
- Control enhancements through the building automation system (BAS)
- Improved levels of building envelope insulation over the prescriptive requirements of ASHRAE Standard 90.1-2007
- High-performance window glazing
- High-efficiency lighting and controls with lighting power density lower than the maximum ASHRAE Standard 90.1-2007 prescriptive limit
- Daylighting controls.

Figure 2. Illustration of building system. *Source*: SWBR Architect

Renewable energy resources

The building includes a variety of distributed and integrated energy systems:

- 400 kW phosphoric acid fuel cell
- 40 kW photovoltaic array
- Vertical-axis wind turbines with a combined capacity of 3 kW
- 56 kWh lithium-ion battery storage system
- Eight geothermal wells
- Electric-vehicle charging stations.

These energy systems are complemented by a number of energy-conserving features, including high R-factor insulating roof and wall panels, “chilled beam” room heating and cooling units that provide local temperature control of ventilation air, and office windows with transparent three-heater films for temperature control and minimization of heat loss. The building is also outfitted with a microgrid and computer datacenter that offer opportunities for real-world testing of electrical supply and demand management. The nearly 1500 sensors deployed throughout the building provide insight into real-time performance for educational and research purposes.

Photovoltaic arrays

The building is equipped with three separate photovoltaic arrays, including two 20 kW arrays on the main roof, along with a small 5 kW experimental array installed on the lower-level green roof. When combined, the arrays have a maximum capacity of 40 kW, although due to various factors including weather, an average sunny-day output is expected to be around 35–40 kW. The peak output for the PV systems occurs between 9 am and 5 pm daily, which coincides with many of the high-usage times. At certain points throughout the day, the solar performance of the arrays is able to match the lighting load for the entire building.

Vertical axis wind turbines

On the north side of the building, three separate 1 kW vertical axis wind turbines have been installed. The turbines are intended primarily for academic study, although at high wind speeds they are expected to generate up to a total of 3 kW of power. However, the performance of three wind turbines has never met the original target set during the design phase.

Lithium-ion battery storage

A collection of 56 kWh of lithium-ion battery storage is housed inside the microgrid laboratory on the first floor of the building. The batteries are charged by the wind and solar inputs to the microgrid, and may discharge some of their electric power if the building load requires additional power. Battery storage is also useful for peak-shaving applications, in which the battery may be discharged to supply other buildings on the campus in order to reduce the total electricity delivered to campus from the external utility.

Alternative energy resource: Fuel cell

The building was constructed with the ability to supply all its own electricity through a combination of distributed energy systems in, on and around the building, powered by a fuel cell installed in the basement. The fuel cell power makes it possible for the building to become net-positive. The ClearEdge PureEdge fuel cell installed on the east side of the building uses natural gas as fuel and is rated at 400 kW. The fuel cell system is also equipped with high- and low-grade heat capture systems, allowing the fuel cell to run at around 90 percent efficiency. The fuel cell will run continuously, meeting the building's entire electricity demand and providing excess electricity to the main campus grid.

Because there is no combustion in a fuel cell, fuel is converted to electricity more efficiently than it would be by any other electricity-generating technology available today. In this building, with 50MJ/kg nature gas input, the converter could produce 400kW electricity. In addition, 537 kW thermal heat generated as a by-product of electrical generation will help warm the 4-story high hall and other buildings on the campus. Any excess electricity goes into the campus grid. The fuel cell contributes significantly to the building's energy efficiency, which is expected to be more than 50 percent higher than a conventional structure.

Conclusion and proposed framework

This building adopted a variety of advanced building technologies to reduce energy consumption. With the high-performance fuel cell, this building is producing, and will continue to produce, electricity/power beyond the building's requirements, so it will continue to power other buildings on the campus. Meanwhile, the by-product heat and hot water is also being cycled back to the campus grid to provide heat to other buildings. However, this building can not be qualified as a net-zero energy building, because the gas needs to come from outside the building site. This raises critical and philosophical questions: Should net-positive building be based on a net-zero building definition and framework? Is net-zero building the ultimate goal of good design? How do we determine the boundary of energy consumption and regeneration?

Does the net-zero balance within the building's boundary constrain innovation and the application of advanced technology in the design and construction industry?

"Net-positive energy approaches open a host of new technical, behavioral, policy, and regulatory issues and opportunities not currently evident with net-zero energy buildings." (Cole et al., 2015). Instead of using the existing criteria of net-zero building to evaluate net-positive building, we should explore an alternative design and evaluation framework. Two key factors should be considered: 1) the network, instead of "individual" buildings; 2) the dynamic energy offset within the network, instead of static balance. In a net-positive building network, we don't expect each and every building to achieve a net-zero performance goal; instead, we focus on overall impact.

The following model is proposed to represent the possible approach to the new framework: A net-positive index.

The Net-positive Index = $(E_p - E_c) \times F_b \times F_p$

E_p: Sum of individual buildings' energy consumption

E_c: Sum of individual buildings' energy production

F_b: Boundary factor (defined by numbers of the buildings, total occupancy, and total area)

F_p: Environmental factor (Defined by alternative energy impact, renewable energy impact, infrastructure cost, etc.)

Further research is needed to create a mathematic model that will define an index range based on overall energy performance, the number of the buildings involved, the total building area, functions, occupancy load, and site area, using a lifecycle approach. The index could be created in several tiers to provide fair assessment.

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