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Regenerative design and adaptive reuse of existing commercial buildings for net-zero energy use

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ABSTRACT

This article discusses feasibility of achieving net-zero energy goals in retrofitting commercial buildings, where a specific case study is presented to illustrate research process, design methods and results. An existing commercial building located in Holyoke, Massachusetts was chosen as the research target to study how to integrate passive design strategies and energy-efficient building systems to improve the building performance and reduce energy consumption. Also, the objective was to investigate how to maximize energy savings and reach net zero energy goals by utilizing renewable energy sources for building's energy needs. Based on extensive energy modeling and simulations, multiple design considerations were investigated, such as material selection, improvements to building envelope, retrofitting of HVAC and lighting systems, occupancy loads, and application of renewable energy sources. Analysis of simulation results was used to determine how specific techniques lead to energy savings, and how to minimize energy consumption. The research results show that this commercial building is able to meet net-zero energy use after appropriate design manipulations and use of multiple renewable energy sources. The strategies and methodologies can be applied to other adaptive reuse and retrofit projects, and improve energy performance of existing buildings. The contribution of this research is that the methodology can be replicated and applied to other retrofit projects in order to improve energy efficiency associated with existing building stock.

1. Introduction and background

In commercial buildings, high demand for energy used for lighting, heating, ventilation, and air conditioning leads to significant amount of carbon dioxide emissions. In 2012, the total end-use emission of carbon dioxide from the commercial building sector in the United States was 897.9 $TgCO_2$ Eq., which accounts for nearly 18% of the total U.S. carbon dioxide emissions (U.S. Environmental Protection Agency, 2014). The energy consumption for commercial buildings is more than 2.3 trillion Btu, and is expected to continue increasing (U.S. Department of Energy, 2008). However, building stock can significantly impact reduction and energy-saving goals if energy-efficiency design strategies are employed. To control this escalating reliance on fossil fuels and tackle future climate change, it is important to apply effective techniques to upgrade the existing commercial buildings. Moreover, taking Net-Zero Energy Building (NZEB) concept into commercial retrofits will improve the energy efficiency levels in existing commercial buildings and apply renewable energy sources in order to reduce their dependence on external energy infrastructure. Since the life of commercial buildings is extended and possible demolition waste is avoided, net-zero energy commercial retrofits also contribute to the development of sustainable and resilient urban environments.

The idea of NZEB has been widely explored during the last decade as a way to achieve energy efficiency in the building sector and encourage renewable energy incorporation on-site. Considering the significant portion that commercial buildings take in the U.S. building stock and their high energy consumption level, involving NZEB concept into commercial retrofits will benefit both the preservation of embodied energy in original construction and the reduction of operational energy. Through reusing and upgrading existing buildings, performance of the existing commercial buildings can be improved, thus bringing more opportunities to reinvigorate the large stock of existing commercial buildings and benefit local economies in the long run. Typically, achieving net-zero energy goals can be realized through implementing passive design strategies, improving building enclosures, installing high performance HVAC systems to reduce heating and cooling loads, reducing lighting and other electric loads, thus making it possible to offset the required energy balance with renewable means, such as solar photovoltaics or wind turbines. Fig. 1 shows appropriate

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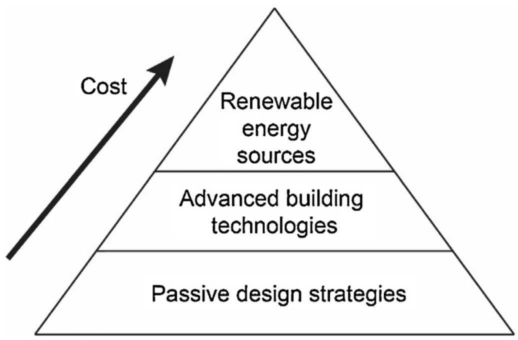

Fig. 1. Methods for achieving net-zero energy goals in buildings and relationship to economic impacts.

steps that should be implemented in achieving net-zero energy buildings, as well as economic impacts. Passive design strategies should be implemented to reduce energy consumption as much as possible, since their costs are relatively low. Advanced building technologies, such as energy-efficient lighting and HVAC systems, as well as high-performance building envelopes should then be employed, since their costs are higher, but they can significantly reduce building's energy consumption. Lastly, renewable energy sources must be used, but only after passive design strategies and advanced building technologies are exhausted, since their initial costs are high (Aksamija, 2010). Achieving net-zero energy goals is a challenging objective, especially when it comes to retrofit projects, because more constraints are typically imposed on existing buildings than new construction. This article presents the effective ways to address those physical and economic constraints in commercial retrofits and investigates applicable strategies to achieve NZEBs. Specifically, a case study is discussed to illustrate the methodology, design strategies and research process. This methodology can be applied to other commercial retrofit projects in order to improve energy efficiency of existing buildings and their dependence on fossil fuels for operation.

1.1. Research questions and methods

This study explores applicable passive and active design approaches that can be integrated to achieve energy savings through investigating feasible retrofitting techniques for building performance upgrading. Also, the study investigates the ways to combine renewable energy generation installations to provide on-site renewable energy to meet net-zero energy goals. Different energy saving methods are studied and applied in this commercial retrofit project to propose a framework which combines passive design techniques and active design techniques, accompanied by energy modeling and energy simulations to evaluate potential energy savings. Several research questions are addressed in this article:

- How to manipulate building mass/volume and building envelope to maximize the embodied energy preservation and reduce energy consumption?
- How to use advanced facade system to ensure human comfort and save operating energy? How can we control thermal and lighting loads?
- What is the appropriate way to improve building systems in existing buildings and make it possible that the newly added systems will be well adapted to the building?
- How to involve renewable energy sources on site to change the fact that commercial buildings have heavy reliance on external energy infrastructure?

In order to evaluate energy saving performance in retrofit projects accurately, research methodologies included data gathering, adaptive redesign of a case study building, energy analysis, and application of renewable energy systems. Information about the original building was obtained and analyzed to develop redesign strategies that would facilitate the achievement of net-zero energy goals. Energy modeling was used to drive design decisions, where initial energy model was built that assessed the impact of retrofitting design strategies, such as change in building massing, impacts of daylight, improvement in building envelope, and retrofitting of lighting and HVAC systems. Then, alternative energy model was developed which investigated the maximum energy savings that could be achieved by the combined design strategies. Different parameters within energy models were varied to perform comparison of base case and alternative runs. Based on the calculation of annual energy balance and consideration of local climate and available resources, specific types of renewable energy generation installations were selected and integrated in the retrofit design program to ensure that enough energy can be generated on-site to offset the annual energy balance in the building to zero. The next sections describe existing literature, as well as a detailed case study building, applied energy-efficiency retrofitting strategies, results of simulations and modeling, and discussion of potential for reaching net-zero energy goals in commercial retrofits. Although the results of simulations and modeling are applicable only to the discussed case study building, the methods are applicable to any retrofit design project. The procedure for reaching net-zero energy in retrofitting projects must include these following steps:

- Determination of passive design strategies that can be applied to improve energy savings.
- Determination of methods for upgrading building systems and their effect on energy consumption.
- Extensive energy modeling to determine maximum energy saving potentials.
- Determination of applicable renewable energy sources and their effect on energy consumption.

2. Literature review

2.1. Definitions of NZEB

In the concept of NZEB, the fundamental idea is to make buildings meet all their energy requirements by using low-cost, locally available, nonpolluting, renewable sources (Torcellini, Pless, & Deru, 2006). Net-Zero Site Energy, Net-Zero Source Energy, Net-Zero Energy Costs, and Net-Zero Energy Emissions are four accounting methods that are commonly used (Torcellini et al., 2006). For Net-Zero Site Energy, on-site renewable energy should offset the annual energy consumption of the building. A Net-Zero Source Energy building is able to provide enough renewable energy to support its annual usage. The energy that is utilized to extract, process, generate, and deliver the energy to the site is considered as source energy in the calculation. Net-Zero Energy costs means that the amount that the building owner receives by exporting renewable energy from the building should be equal to or more than the amount of the purchase that the owner made with external energy service utilities. And in Net-Zero Emissions building, emissions from its annual energy consumption should be equal to the emissions-free renewable energy that the building produces or purchases.

Even though there is a general understanding towards the NZEB idea, a widely agreed definition that can be consistent with the principles behind the practice of designing and constructing NZEBs internationally is still lacking (Sartori, Napolitano, & Voss, 2012).

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