# Net-zero energy retrofits for commercial buildings

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ABSTRACT: This paper explores feasibility for achieving net-zero energy goals in retrofitting commercial buildings. An existing commercial building 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 modeling and simulations, multiple design considerations were investigated, such as material selection, improvements to building envelope, retrofitting of HVAC and lighting systems, occupancy loads, as well as application of renewable energy sources. The comparative analysis of simulation results was used to determine how specific techniques lead to energy saving and cost reductions. The research results show that this commercial building is able to meet net-zero energy use after appropriate design manipulations and use of renewable energy sources. The strategies and methodologies can be applied to other adaptive reuse and retrofit projects, and to improve energy performance of existing buildings.

KEYWORDS: Commercial Retrofits, Net-Zero Energy, Building Performance, Renewable Energy

## 1.0 INTRODUCTION

### 1.1. Background

Buildings exert great influence on greenhouse gas emissions, and can significantly impact their reduction and energy-saving goals if energy-efficiency design strategies are employed. In commercial buildings, high demand of energy for lighting, heating, ventilation, and air conditioning leads to significant amount of carbon dioxide emissions. In 2012, the total end-use sector emission of carbon dioxide from the commercial sector in the United States was 897.9 TgCO2 Eq., which accounts for nearly 18% of the total U.S. carbon dioxide emission (EPA 2014). The energy consumption for commercial buildings is more than 2.3 trillion Btu, and the increasing trend is expected to continue until the energy produced in the buildings themselves is able to make up for their growing energy needs (DOE 2011). To control this escalating reliance upon fossil fuels and tackle future climate change, it is important to apply effective techniques to upgrade the existing commercial buildings, developing energy efficient commercial buildings based on the integration of advanced energy saving concepts and adaptive reuse methods. On one hand, taking Net-Zero Energy Building (NZEB) concept into commercial retrofits will improve the energy efficiency levels in existing commercial buildings, exploring the possibilities of involving renewable energy sources in order to reduce their dependence on external energy infrastructure. On the other hand, 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 a sustainable urban regeneration form.

The idea of NZEB has been widely explored and implemented during the last few years as a way to achieve energy efficiency in the building sector and encourage renewable energy incorporation on-site. Department of Energy (DOE) in the United States has been working on creating technologies and design approaches to develop marketable zero-energy commercial buildings by 2025. 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 improving building enclosures, implementing passive design strategies, 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. 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 paper presents the effective ways to address those physical and economic constraints in commercial retrofits and investigates applicable strategies to achieve NZEBs.

### 1.2. Literature review

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 2006). For those buildings with electric grid connection, when the energy balance between energy sold and energy used turns out to be zero, they can be qualified as NZEBs (Hootman 2012). 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 2006). For Net-Zero Site Energy, renewable energy which is accounted for at the site can 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 gets paid 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 2012). Recent research towards the definition of NZEB extends its concept to include the consideration of the building's embodied energy and components, thus integrating life cycle energy balance into 'net energy' concept (Hernandez 2010). In this way, it is possible to acquire the true environmental influence that the building has exerted based on the evaluation of both its operating energy use and the energy which is embodied in its structure, materials, and technical installations (Marszal 2011). The life cycle energy balance calculation method can be widely applied to preservation and retrofits projects. In the existing research projects, most NZEB cases use annual balance to support their applied methodologies (Voss 2011), so this paper will still use a balanced annual energy budget to study the achievement of net-zero energy use in commercial retrofits. Net-Zero Source Energy definition is applied in this exploration to investigate the effective ways to generate as much renewable energy as the building needs in a year, thus reducing the electricity consumption of the building to zero.

### 1.3. Research questions and methods

Through investigating the feasible retrofitting techniques for building performance upgrading, this study explores applicable passive design approaches that can be integrated to achieve energy savings, and the ways to combine the renewable energy generation installations in the limited usable space to provide enough on-site renewable energy for the building. 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 paper:

- 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 in old constructions?
- What is the appropriate way to improve the HVAC systems in existing buildings and make it possible that the newly added system 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. Building energy models in eQuest were used to assess the impact of energy-efficient design strategies and to explore effective energy saving measures. 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, 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.

## 2.0 CASE STUDY: ENERGY EFFICIENCY DESIGN STRATEGIES

The building that was chosen as the target for this research is a 200,000 sf old paper mill, located in Holyoke, Massachusetts. As part of the revitalization plan of south Holyoke, retrofits of commercial buildings will contribute to the development of a stable, healthy and desirable neighborhood in Holyoke in the next ten years, bringing more open space, public facilities, and job opportunities to people who reside in this area. Different energy efficiency design strategies were integrated into the redesign of this building, which are discussed in detail in this section (Fig. 1).

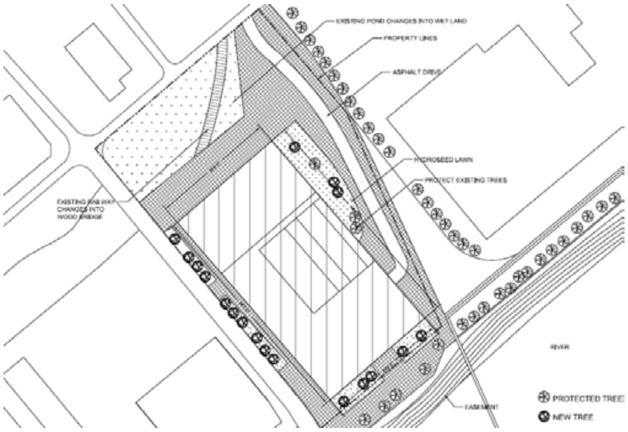


**Figure 1**: Site plan of the existing building.

### 2.1. Building envelope

The first step in adaptive redesign was to analyze massing of the existing building, structure, and spatial organization, and to determine how exactly the building form will be changed and improved. It was determined that parts of the building will be demolished (mainly, parts of the second and third floor), and that two additional floors will be added to accommodate new building program, which includes offices, classrooms, museum, retail space, and a restaurant. The middle part of the building was redesigned into a courtyard, which allowed the building to get back to its appearance when it was first built in 1895 (the initial interior courtyard was closed off in 1960's). With this retrieved courtyard, daylighting and natural ventilation are integrated as passive design techniques to reduce the electricity consumption. Extraction of the existing building mass and addition of a new building mass create several roof gardens, which offer public space for occupants, provide an area for placement of photovoltaics panels, and bring potential building energy reduction benefits (Fig. 2). Adding green roofs to different levels of the building also improves the thermal performance of the roof, hence leading to decreased heat gain during the summer and heat loss during the winter. Also, annual internal temperature becomes more stabilized because green roof add thermal mass to the building (Castleton 2010).

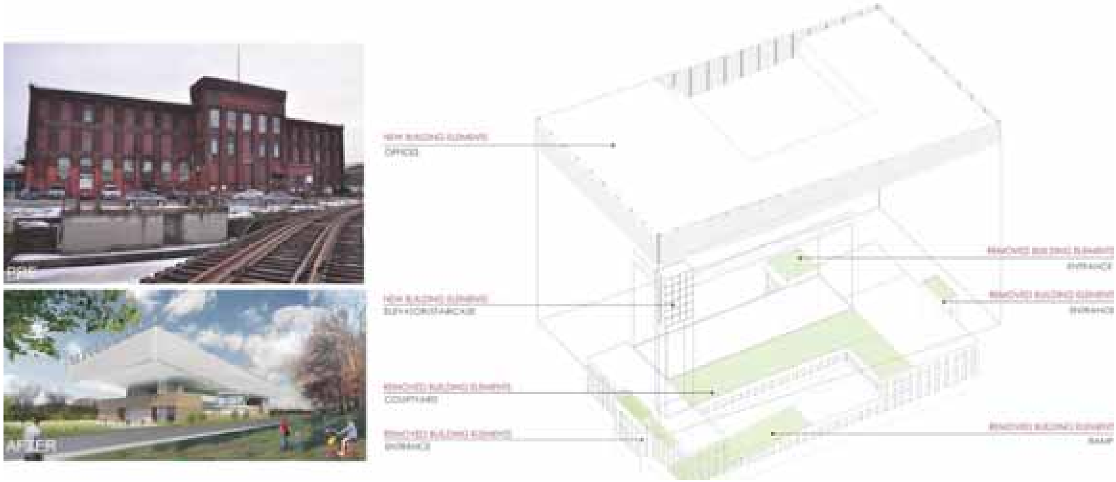


**Figure 2**: Pre and post retrofit views of the building.

Building envelope upgrade was also achieved by improving the exterior wall insulation to control the heat, air, and moisture transfer between the wall assemblies and the exterior environment. Newly added thermal insulation, air barrier, and vapor retarder help the building acquire improved insulating and air sealing performance, and at the same time, ensure that the moisture problem can be addressed adequately. Expanded polystyrene (EPS) rigid insulation panels and fiberglass batt insulation within the framing cavity were added to resist the heat flow and increase the R-value of the wall assemblies. Based on both energy efficiency and moisture control considerations, this facade retrofit design improves the thermal envelope of the existing building, providing an effective way to improve energy efficiency and maintain the moisture

For the top two floors, a new facade system was designed to provide appropriate visual environment for the office areas and make full use of daylight to reduce energy consumption for lighting. Curtain wall system and exterior horizontal sunshades system are combined together to achieve environmental optimization and energy efficiency. The sunshades system is made of 12” wide aerofoil-shaped blades connected to the framing system with mounting arms and mounting brackets (Fig.4). This shading system controls the direct solar exposure and glare, making interior daylighting environment ambient and comfortable.

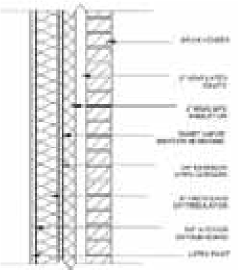


**Figure 3:** Facade system.

**Figure 4**: Curtain wall and shading system.

## 2.2. Passive design strategies

Involvement of passive design strategies plays an important role in achieving energy savings in this commercial retrofit design. Passive design strategies improve energy consumption by designing the building form that responds to the environment, thus making it possible that to achieve high interior environmental quality and low-energy demand at the same time (Hootman 2012). One of the most important applications of passive design strategies that was applied to this building is to make full use of daylight. Since most activities occurring in this building are during the daytime, using natural light can greatly reduce the reliance upon artificial lighting. Also, cooling loads can be reduced if daylight is widely used in the building, because even energy-efficient lighting fixtures can bring significant amount of heat during use (Aksamija 2013). Approaches developed for maximizing exposure to natural light and controlling incoming daylight are based on the comprehensive thinking towards the redesign of the building’s programs, layout, mass, and facade. Daylighting design is developed based on the function of the space, requirement towards lighting quality, and aesthetic value of the building facade. To better daylighting performance and improve the interior lighting quality, manipulation towards the building mass was combined with integrated shading devices to minimize direct daylight and encourage reflective daylight in order to achieve diffusive lighting performance. Plus, building mass’s redesign also facilitated passive wind driven ventilation to reduce cooling loads in the building. These design strategies are portrayed in Figure 5.

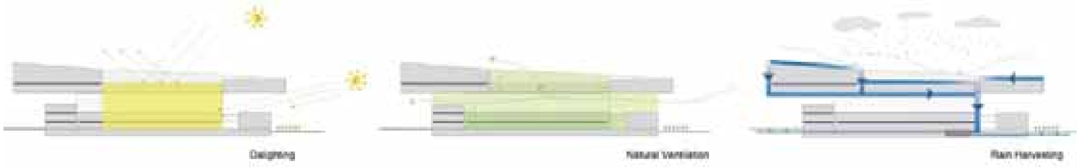


**Figure 5**: Passive design strategies.

## 2.3. HVAC systems

Efficient HVAC systems can improve human comfort and air quality in the building with application of advanced heating, ventilation, and air conditioning technologies. Integrated HVAC systems in this retrofit project were used to reduce the energy demand of the primary equipment and ensure low-energy distribution. Biomass heating system is integrated into the building’s HVAC system by combusting biomass fuels, which add to significant cost-saving, environmental, and social benefits. Since wood, agriculture residues, and crops are the most common fuels for biomass energy systems, easy accessibility to these organic matters in western Massachusetts area leads to reduced delivery and storage cost (Salameh 2014). Compared to emissions related to combusting of coal or oil, pollutants linked to biofuel combustion, such as nitrogen oxide and sulphur dioxide, are within lower amount (Fabrizio 2014).

Delivery of heating, cooling, and ventilation services to each part of the building effectively and energy-efficiently is critical in low-energy HVAC system design. Smart control systems for temperatures management in HVAC system can successfully save energy during the operation. By using modest temperatures instead of extreme temperatures in the working fluids, it is possible to make better use of natural resources for heating and cooling, protect the primary equipment, and minimize reheat energy. Commercial HVAC smart control system is taken into the HVAC system retrofit to facilitate intelligent integration and optimization of HVAC system components in the building. Wireless temperature monitoring system was considered as a strategy to improve HVAC control in the building, allowing that temperatures in rooms with different functions can be adjusted intelligently according to their occupancy, human activities, and specific requirements. Advanced wireless sensor technology allows required real-time data in the building to be collected efficiently by the sensors. After the data is recognized by the main computer monitoring system, signals can be sent based on the analysis of the collected data to control the supply air temperatures and speed of the fan coil units. Reliable wireless monitoring system can effectively reduce energy consumption during the operation of HVAC system and keep room temperature appropriately to ensure human comfort. Also, compared to conventional wire solution, wireless installation is cost-effective for retrofit application with significantly reduced labor cost. This type of system was considered for this project.

## 3.0 MODELING AND SIMULATIONS

### 3.1. Energy modelling

Using simulation software eQuest to build and analyze energy model of this commercial complex allowed us to understand the energy consumption quantities, explore the energy saving potentials, evaluate different sustainable design alternatives, and assist decision making process for choosing feasible and reliable approaches (Fig. 6).

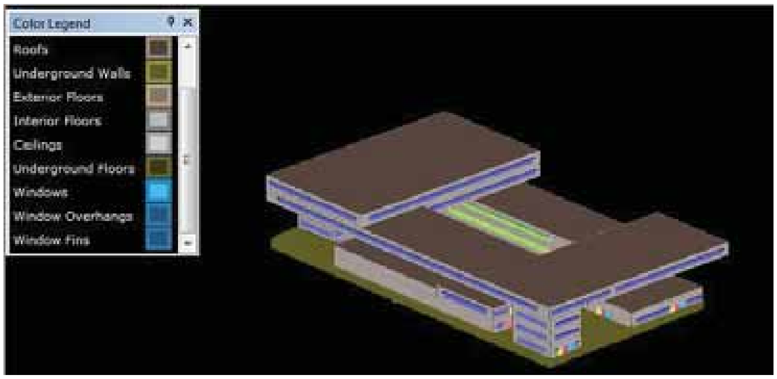
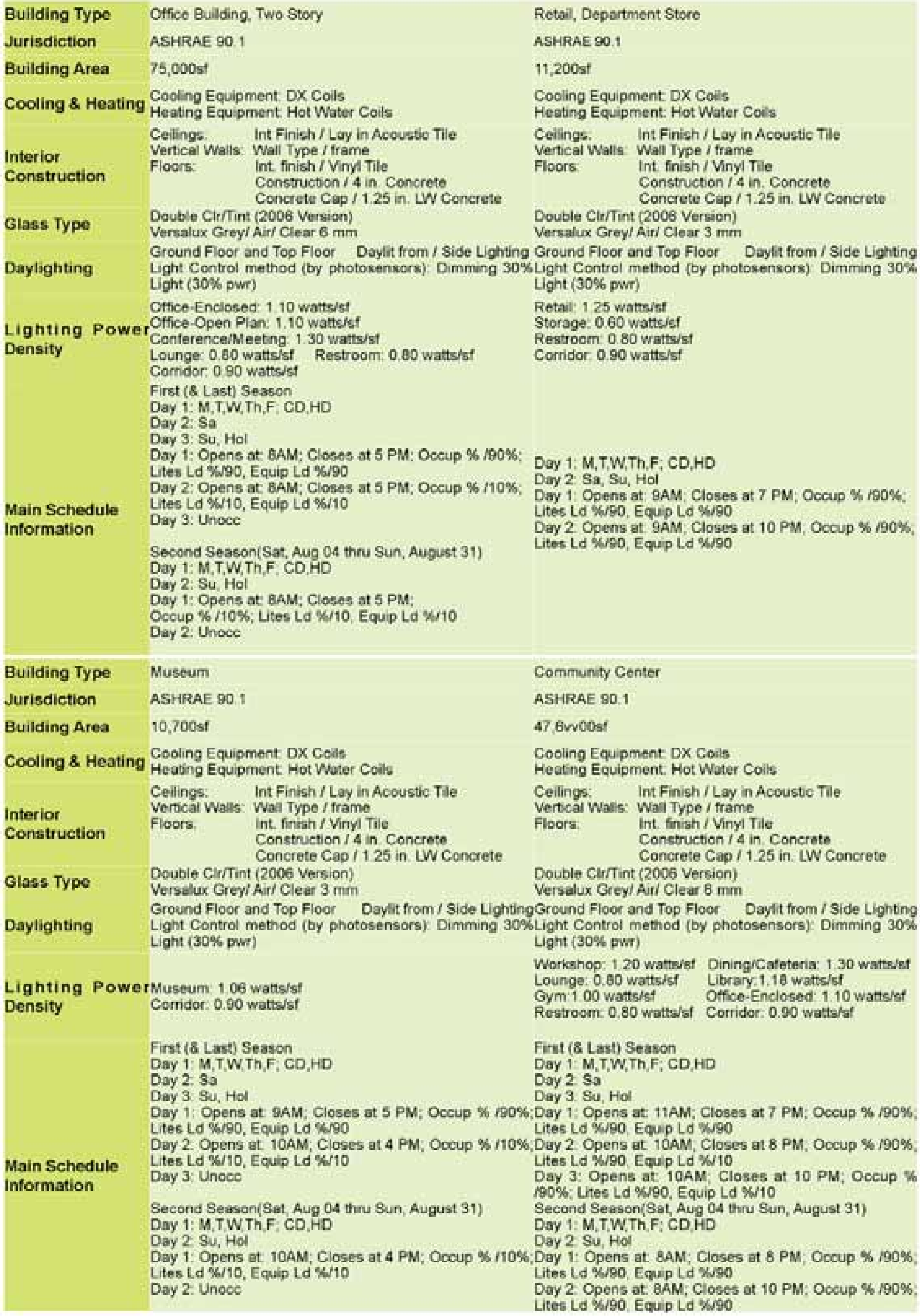


**Figure 6**: Energy model in eQuest.

Building energy performance assessment was developed based on the creation of a virtual environment of the building within its geometric configuration. Input data about building materials allows building envelope system to be simulated accurately, and by varying the layers in the assemblies and parameters, it is possible to understand the energy consumption fluctuations and determine solutions to maximize energy saving potentials. Since this building has a complex form and different functions, the whole building energy model was developed by building four shells and organizing them together in one model. Input data for every shell was determined according to its size and program, building envelope treatment and system loads (Table 1). By manipulating building materials, lighting power density, occupancy schedules, cooling, heating, and lighting loads in the building were lowered significantly to acquire maximized energy savings.

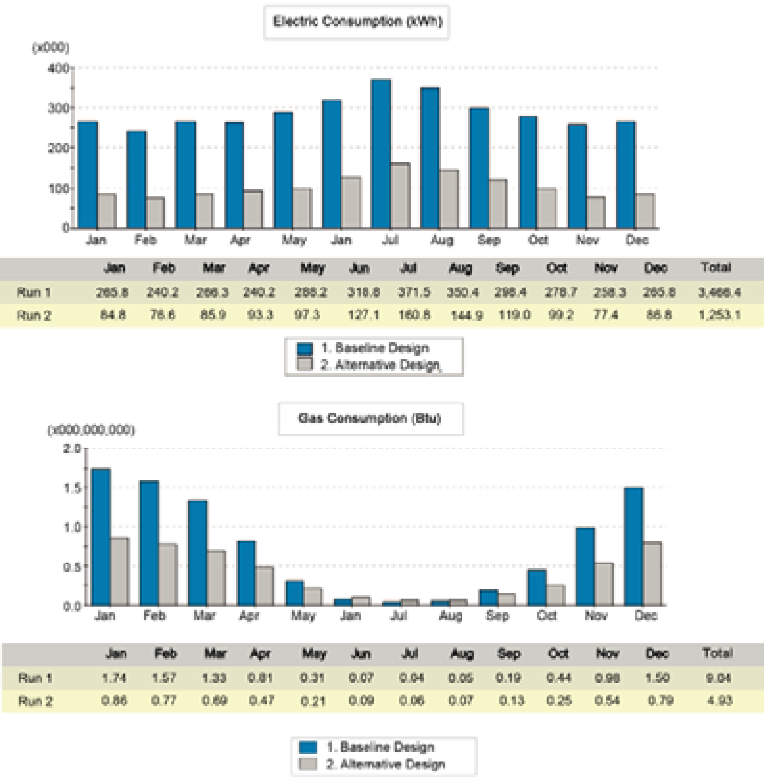
The baseline simulation showed high annual energy consumption, with Energy Use Intensity (EUI) of 120 kBtu/ft$^2$. Deep retrofit measures designed to address this problem incorporated control of internal loads and operating schedules, lighting, and improvement in the building envelope. For museum, classrooms, stores, and offices, different demand for interior lighting environment and occupancy schedules were taken into consideration in energy modeling improvement process. Lighting power density (LPD), which is an important value associated with energy efficient lighting design was reduced for all spaces in the building. In addition, planning and rescheduling work time for every functional room made it possible that significant lighting energy can be saved according to real occupancy situation, and accompanied occupancy sensors design ensured that waste lighting electricity for unoccupied rooms is minimized. After applying all the possible energy saving strategies, an alternative simulation run in eQuest was conducted to acquire a comparison analysis, lowering the EUI value to 52 kBtu/ft$^2$. By comparing baseline run and alternative run, it was evident energy performance improvement can be acquired after implementation of available and effective approaches (Fig. 7).

**Table 1**: Input for shells.



| | | |
|---|---|---|
| **Building Type** | Office Building, Two Story | Retail, Department Store |
| **Jurisdiction** | ASHRAE 90.1 | ASHRAE 90.1 |
| **Building Area** | 75,000sf | 11,200sf |
| **Cooling & Heating** | Cooling Equipment: DX Coils<br>Heating Equipment: Hot Water Coils | Cooling Equipment: DX Coils<br>Heating Equipment: Hot Water Coils |
| **Interior Construction** | Ceilings: Int Finish / Lay in Acoustic Tile<br>Vertical Walls: Wall Type / frame<br>Floors: Int. finish / Vinyl Tile<br>Construction / 4 in. Concrete<br>Concrete Cap / 1.25 in. LW Concrete | Ceilings: Int Finish / Lay in Acoustic Tile<br>Vertical Walls: Wall Type / frame<br>Floors: Int. finish / Vinyl Tile<br>Construction / 4 in. Concrete<br>Concrete Cap / 1.25 in. LW Concrete |
| **Glass Type** | Double Clr/Tint (2006 Version)<br>Versalux Grey/ Air/ Clear 6 mm | Double Clr/Tint (2006 Version)<br>Versalux Grey/ Air/ Clear 3 mm |
| **Daylighting** | Ground Floor and Top Floor Daylit from / Side Lighting<br>Light Control method (by photosensors): Dimming 30% Light (30% pwr) | Ground Floor and Top Floor Daylit from / Side Lighting<br>Light Control method (by photosensors): Dimming 30% Light (30% pwr) |
| **Lighting Power Density** | Office-Enclosed: 1.10 watts/sf<br>Office-Open Plan: 1.10 watts/sf<br>Conference/Meeting: 1.30 watts/sf<br>Lounge: 0.80 watts/sf Restroom: 0.80 watts/sf<br>Corridor: 0.90 watts/sf | Retail: 1.25 watts/sf<br>Storage: 0.60 watts/sf<br>Restroom: 0.80 watts/sf<br>Corridor: 0.90 watts/sf |
| **Main Schedule Information** | First (& Last) Season<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Sa<br>Day 3: Su, Hol<br>Day 1: Opens at: 8AM; Closes at 5 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90<br>Day 2: Opens at: 8AM; Closes at 5 PM; Occup % /10%; Lites Ld %/10, Equip Ld %/10<br>Day 3: Unocc<br>Second Season(Sat, Aug 04 thru Sun, August 31)<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Su, Hol<br>Day 1: Opens at: 8AM; Closes at 5 PM; Occup % /10%; Lites Ld %/10, Equip Ld %/10<br>Day 2: Unocc | Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Sa, Su, Hol<br>Day 1: Opens at: 9AM; Closes at 7 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90<br>Day 2: Opens at: 9AM; Closes at 10 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90 |

| | | |
|---|---|---|
| **Building Type** | Museum | Community Center |
| **Jurisdiction** | ASHRAE 90.1 | ASHRAE 90.1 |
| **Building Area** | 10,700sf | 47,6vv00sf |
| **Cooling & Heating** | Cooling Equipment: DX Coils<br>Heating Equipment: Hot Water Coils | Cooling Equipment: DX Coils<br>Heating Equipment: Hot Water Coils |
| **Interior Construction** | Ceilings: Int Finish / Lay in Acoustic Tile<br>Vertical Walls: Wall Type / frame<br>Floors: Int. finish / Vinyl Tile<br>Construction / 4 in. Concrete<br>Concrete Cap / 1.25 in. LW Concrete | Ceilings: Int Finish / Lay in Acoustic Tile<br>Vertical Walls: Wall Type / frame<br>Floors: Int. finish / Vinyl Tile<br>Construction / 4 in. Concrete<br>Concrete Cap / 1.25 in. LW Concrete |
| **Glass Type** | Double Clr/Tint (2006 Version)<br>Versalux Grey/ Air/ Clear 3 mm | Double Clr/Tint (2006 Version)<br>Versalux Grey/ Air/ Clear 6 mm |
| **Daylighting** | Ground Floor and Top Floor Daylit from / Side Lighting<br>Light Control method (by photosensors): Dimming 30% Light (30% pwr) | Ground Floor and Top Floor Daylit from / Side Lighting<br>Light Control method (by photosensors): Dimming 30% Light (30% pwr) |
| **Lighting Power Density** | Museum: 1.06 watts/sf<br>Corridor: 0.90 watts/sf | Workshop: 1.20 watts/sf Dining/Cafeteria: 1.30 watts/sf<br>Lounge: 0.80 watts/sf Library:1.18 watts/sf<br>Gym:1.00 watts/sf Office-Enclosed: 1.10 watts/sf<br>Restroom: 0.80 watts/sf Corridor: 0.90 watts/sf |
| **Main Schedule Information** | First (& Last) Season<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Sa<br>Day 3: Su, Hol<br>Day 1: Opens at: 9AM; Closes at 5 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90<br>Day 2: Opens at: 10AM; Closes at 4 PM; Occup % /10%; Lites Ld %/10, Equip Ld %/10<br>Day 3: Unocc<br>Second Season(Sat, Aug 04 thru Sun, August 31)<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Su, Hol<br>Day 1: Opens at: 10AM; Closes at 4 PM; Occup % /10%; Lites Ld %/10, Equip Ld %/10<br>Day 2: Unocc | First (& Last) Season<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Sa<br>Day 3: Su, Hol<br>Day 1: Opens at: 11AM; Closes at 7 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90<br>Day 2: Opens at: 10AM; Closes at 8 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/10<br>Day 3: Opens at: 10AM; Closes at 10 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/10<br>Second Season(Sat, Aug 04 thru Sun, August 31)<br>Day 1: M,T,W,Th,F; CD,HD<br>Day 2: Su, Hol<br>Day 1: Opens at: 8AM; Closes at 8 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90<br>Day 2: Opens at: 8AM; Closes at 10 PM; Occup % /90%; Lites Ld %/90, Equip Ld %/90 |



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run 1 | 265.8 | 240.2 | 266.3 | 240.2 | 288.2 | 318.8 | 371.5 | 350.4 | 298.4 | 278.7 | 258.3 | 265.8 | 3,466.4 |
| Run 2 | 84.8 | 76.6 | 85.9 | 93.3 | 97.3 | 127.1 | 160.8 | 144.9 | 119.0 | 99.2 | 77.4 | 86.8 | 1,253.1 |

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run 1 | 1.74 | 1.57 | 1.33 | 0.81 | 0.31 | 0.07 | 0.04 | 0.05 | 0.19 | 0.44 | 0.98 | 1.50 | 9.04 |
| Run 2 | 0.86 | 0.77 | 0.69 | 0.47 | 0.21 | 0.09 | 0.06 | 0.07 | 0.13 | 0.25 | 0.54 | 0.79 | 4.93 |

**Figure 7**: Results of energy modeling (annual electricity and gas consumption) simulations.

Other energy efficiency approaches involved in the improvement of energy model included using materials that have high thermal mass and durability, such as stone, as well as applying better insulated glazing. Since windows account for most energy loss in the building and glazing is so crucial to window energy efficiency, improving glazing is an effective way to reduce energy transfer through the windows. Double glazing with low-e coating and argon gas fill was selected to substitute glazing for windows, thus significantly reducing heat transfer through the building envelope significantly. And the three critical properties in evaluating the glazing's energy performance – visible light transmittance, solar heat gain coefficient, and insulating performance – were also taken into consideration during the decision making process.

### 3.2. Renewable energy systems

According to the simulation results for monthly energy usage, it was evident that renewable energy sources are necessary to achieve net-zero energy goals. Comprehensive thinking towards energy conversion ratio, feasibility, accessibility, and cost contributed to the decision of selecting four types of renewable energy systems to work together, generating enough energy to support the operation of the building system (Fig. 8).

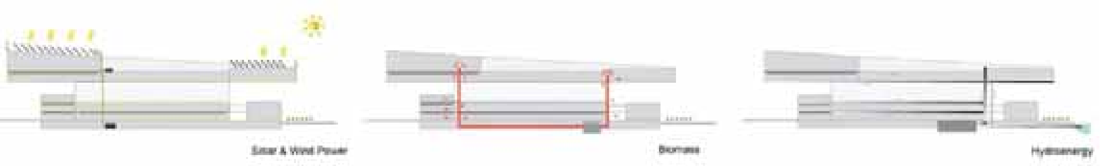


**Figure 8**: Integrated renewable energy system.

High efficiency commercial photovoltaics were considered to be placed on the roofs. Since the applied photovoltaics are integrated in a grid-connected system, direct current power which is generated by the PV arrays is converted into alternating current by the power conditioning unit to satisfy the building's energy demand (Masters 2014). Applying this grid-connected PV system in commercial retrofit project has a number of benefits. With relatively simple configuration, it is easy to install and maintain the devices. Also, considering the limited site around the existing building, high efficiency PV panels with desirable power demand. In addition, the working schedule for most spaces in the building are during the daytime, so PV system can deliver power during the peak time when utility rates are relatively high. The design of PV arrays involved a series of 240 PV panels, covering 50,000 sf roof areas to provide approximately 4,000,000 kBtu energy annually. In addition, wind turbines were considered to be installed on top of the building to capture wind energy on site. Medium vertical axis wind turbines which are 4ft wide and 8ft high with 2KW generator were selected to be installed on the roof to generate about 1,800,000 kBtu energy per year. The reasons for choosing this type of wind turbines included their high efficiency, possibility to catch wind from all directions and simplicity in mechanical configuration. Since vertical axis wind turbines are without downwind coning, rudders, and yaw mechanisms and their electrical generators are positioned close to the base, they are easy to install and maintain.

Biomass and hydropower were also used in the design of renewable energy systems based on the consideration of the accessibility towards the resources. Holyoke is located in western Massachusetts area, which has rich agricultural resources, so it is cost-efficient to collect and deliver biomass materials. The last renewable energy source that was considered for the retrofit design of the building's energy system is hydropower. The location of this building was the primary reason for including hydropower. Right beside an important canal of Holyoke, this building can integrate the hydropower system in it with easiness. Although site-based hydropower is not widely used in commercial buildings due to specific site requirements and access to water, this particular building has a great potential due to its proximity to canal and existing hydropower turbines in the City of Holyoke. Different from solar power, which only works during the daytime with enough solar radiation, hydropower's availability is very flexible, so it is possible to get a long-term, stable, and dependable payback with one-time investment. For this building scale, a micro hydro system is suitable for placement, and a turbine can be applied to transform potential energy from the water flow into mechanical energy first, and this mechanical energy can be transformed into electric power later for building usage. Incentives for micro system applications are widespread, which can offset a significant part of the cost for equipment purchase and instalment (Jenkins 2013).

The renewable energy systems that incorporate solar energy, wind energy, biomass, and hydroenergy made it possible to achieve net-zero energy goals, thus meeting the energy demand of the building with renewable energy sources on site. The breakdown of the supplied energy by renewable sources is shown in Figure 9, where solar energy accounts for 45% of the total renewable energy support, satisfying the energy needs of the building as the major renewable energy source (Fig. 10). Hydroenergy, biomass, and wind energy systems work together to make up for the rest energy need, generating more than 5 million kBtu energy annually.

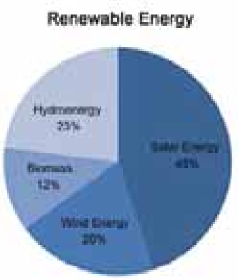


**Figure 9**: Renewable energy sources.

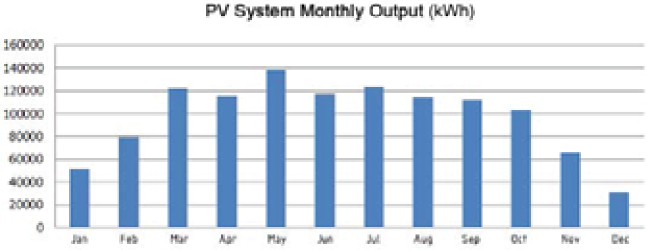


**Figure 10:** PV system energy output.

## 4.0 CONCLUSION

In exploring the applicable net-zero energy design approaches for commercial retrofits, rethinking towards the NZEB concept and all the possible strategies that can be integrated into an existing building must be taken into account. It is necessary to consider comprehensive methods for sustainable design, adaptive reuse, and new energy systems. Achieving net-zero energy goals in commercial retrofits with available technologies is challenging. However, with careful attention to adaptive design strategies, building envelope treatment, passive design approaches, appropriate HVAC systems and utilization of renewable energy sources it is possible to achieve that goal. Energy modelling and simulations, which uncover the energy saving potentials in every energy-saving measure, are beneficial tools in retrofit design and should be widely applied. Local resources, environment, and human activity should be considered during the decision making process, contributing to develop an integrated building system that enables new opportunities for energy saving and building performance improvements.

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