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Economic analysis on energy saving technologies for complex manufacturing building

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ABSTRACT

Energy saving strategies are vital for long term viability and commercial success of buildings. Buildings in the US today consume 41% of the total primary energy. Complex buildings consume significantly higher energy than typical office buildings and present challenges to energy savings due to their operational requirements. This paper presents an economic analysis on energy saving technologies implemented in a complex manufacturing building. The return on investment is determined by using the payback analysis and life cycle cost analysis. The results indicate that energy saving technologies achieved a total energy cost savings of 14%. The savings were achieved by using high efficiency HVAC equipment and advanced fluorescent lighting systems. When applied to similar types of buildings, energy saving strategies considered will increase economic and environmental benefits to owners.

1. Introduction

The world's energy consumption is expected to increase by 33% between the years of 2010–2030 (Abdelaziz et al., 2011). Energy consumption in buildings accounts for 20–40% of the total energy consumption in developed countries. For example, in the US during 2010, the building sector consumed 41% of the total primary energy (DOE, 2011). Fossil fuels are the main source of primary energy consumption making upward of 82% (EIA, 2011). These energy resources are limited and are major contributors to carbon dioxide (CO_2) emissions, which are rising globally at more than 2% per year (DOE, 2011). Global carbon dioxide emissions exceeded 31 billion metric tons in 2010 with the US contributing more than 5 billion metric tons (EIA, 2011). The rises of carbon dioxide emissions are attributed to increasing energy consumption and inefficient energy use (Abdelaziz et al., 2011).

Energy demand is significantly magnified in a complex building where energy consumption is five to ten times greater than a typical office building (Reilly and Walsh, 2012). Complex buildings may be defined as buildings that "have special or unusual functional requirements (e.g. health and safety) that directly and significantly impact sustainability criteria" (Mathew et al., 2004). Therefore, improving energy efficiency in complex buildings has a great potential for reducing energy consumption and associated negative environmental impacts. The associated negative environmental impacts of greenhouse gas emissions have been linked to global warming (Kessel, 2000) and increased risk of natural disasters (Van Aalst, 2006). In addition, energy cost savings play a significant role in a building's long term viability and commercial success (Orlitzky et al., 2003).

Energy efficiency efforts in buildings have been focused towards improving energy consumption in air conditioning and lighting systems. Heating, Ventilation, and Air Conditioning (HVAC) systems account for almost half of a building's energy consumption (Vali et al., 2009), followed by artificial lighting which consumes about one-fifth of a building's total energy (Kozminski et al., 2006). Energy saving measures for HVAC and lighting systems have potential energy savings of 20% or more. However, research thus far has not offered energy saving strategies for a complex manufacturing building. Therefore, this paper focuses on energy saving technologies for a biotech manufacturing building because this type of a complex building requires special health and safety code regulations, which result in much higher energy consumption than that of a typical commercial building.

The main objective of this study is to evaluate energy saving technologies, and costs and benefits of implementing such technologies. The methodologies utilized to achieve the study goals include: identifying the energy saving technologies implemented in the project; calculating the energy consumption cost of these

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technologies as compared to those of a baseline building per the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard 90.1–2007 (ASHRAE, 2007); and determining the return on investment from these technologies based on their energy cost savings.

2. Background studies and literature review

This section presents a literature review that focuses on laboratories and hospitals, which are specific examples of complex buildings. A laboratory facility is an example of a complex building with special requirements for health and safety, which directly impacts energy requirements (Mathew et al., 2004). According to various code regulations and due to health and safety reasons, laboratories require 100% ventilation at specific rates, measured in air changes per hour (ACH). Therefore, the energy consumption of an HVAC system in a laboratory is higher than that of a typical commercial building (Reilly and Walsh, 2012). In complex buildings that require 100% outside air ventilation, HVAC energy consumption exceeds 50%. Ventilated air accounts for 20–40% of HVAC energy consumption (Vali et al., 2009). In addition, laboratory lighting consumes 8–25% of the total electricity (Kozminski et al., 2006). Due to such high energy consumption rates, the US Environmental Protection Agency and the US Department of Energy have jointly sponsored a program, Laboratories 21 (Lab 21), in order to improve the energy performance of laboratories (Mathew et al., 2004).

The guide to Laboratories 21 presents several strategies for reducing energy consumption of HVAC and lighting systems. One possible strategy, in particular, for reducing HVAC energy consumption is a heat recovery system, which recovers wasted heat from one air stream and transfers it to another air stream by using heat from internal conditioned air to warm external incoming air. The system consists of ducts, heat exchangers, and blower fans (Mardiana-Idayua and Riffat, 2012). Other strategies for energy recovery systems include enthalpy wheel, heat pipes, and run-around loops. In addition, building envelope design and proper insulation contributes to the reduction of heating and cooling loads (Kaynakli, 2012). This particular strategy has the potential to save energy and may result in downsizing of the equipment required for buildings (Reilly and Walsh, 2012). The second highest user of energy in laboratories is lighting systems. The Lab 21 guide for lighting systems recommends energy saving strategies; such as daylight integration into lighting plans, energy efficient lamps and ballasts, bi-level lighting controls, and occupancy sensors (Kozminski et al., 2006). Ryckaert et al. (2010) specifically mentions the use of T5 or T8 fluorescent lamps in lighting systems for energy efficiency.

In addition to general recommendations offered by the guide, the Lab 21 program includes case studies detailing specific energy strategies employed in actual laboratory buildings, such as the Whitehead Research Building in Atlanta, Georgia and the Fred Hutchinson Center in Seattle, Washington. These case studies offer a complete picture of the integration of various guide recommendations with actual energy saving costs. The first case study assesses the Whitehead Biomedical Research Building located at Emory University. This building employed energy recovery measures that had resulted in an overall energy savings of 22%, or rather $167,300 in energy costs, as compared to a baseline building meeting ASHRAE standard 90.1–1999. One of the energy saving measures that have been implemented in the Whitehead Building is the installation of four enthalpy wheels. This energy recovery system mixes return air back with supply air to reduce outside supply air from 100% to 75%, and reduces energy cost for air conditioning by 25%. In addition, the condensate from the cooling system is recovered and recycled to the cooling towers. For daylight integration, the Whitehead Building was designed so that 90% of the offices and lab spaces have windows in order to receive natural light. The lighting system is programmed to turn off when adequate natural lighting is available. Energy efficient lamps and ballasts were also installed with motion sensors so that lights will turn off when the area is not occupied (Carlisle et al., 2005).

The second case study reviews the energy saving measures in the Fred Hutchinson Cancer Research Center, which have resulted in energy savings of 26%. The building's energy saving strategies included the installation of high efficiency equipment, such as motors with variable speed drives (VSD), chillers, and pumps. For the HVAC system, variable volume/variable pressure controllers were installed to allow for the savings of 1/3 of the energy, as compared to a constant pressure/constant volume design. High efficiency lamps and ballasts with programmable controls and motion sensors were also installed to reduce lighting energy consumption, which allows for the lights to automatically be turned off at 9:00 pm if the area is unoccupied. In addition, temperature settings can be setback for heating and set up for cooling for occupied and unoccupied hours. As for the building's glazing, low emissivity glass was installed in 20% of the wall space in order to conserve energy (Walker et al., 2001).

Hospitals are another example of complex buildings. Santamouris et al. (1994) conducted a study on the energy consumption of 33 healthcare facilities (24 hospitals and 9 clinics) in Greece. The total electrical and thermal consumption for each building was collected. Energy for the individual systems, such as heating and lighting, was then calculated based on equipment specifications and estimated hours of usage. The calculations showed the average annual energy consumption to be 407 kWh/m^2 (31.81 kWh/ft^2) and 274.7 kWh/m^2 (25.52 kWh/ft^2) in hospitals and clinics, respectively. An analysis of this data shows that the majority of energy consumption is due to space heating (73% in hospitals and 65% in clinics), followed by lighting (12.8% in hospitals and 9.4% in clinics).

Santamouris et al. (1994) recommends several energy saving measures to reduce the amount of energy consumed by heating and lighting systems in healthcare facilities; such as proper orientation of the building, improved thermal insulation, and use of higher efficiency combustion systems. For improvements in lighting systems, this study recommends the installation of higher efficiency fluorescent lamps, electronic ballasts, occupancy sensors, and the use of natural lighting. This study's energy saving measures for healthcare facilities has the potential to reduce energy consumption by 20% (Santamouris et al., 1994). The same conclusion is made for laboratory buildings when classifying HVAC and lighting systems as the two top end users of building energy and applying the same energy saving strategies.

3. Research objective and methodology

In regards to energy consumption in buildings, the literature review has revealed that HVAC systems account for almost half of a building's energy consumption, followed by artificial lighting consuming about one-fifth of the total energy. Although energy saving measures for HVAC and lighting systems have potential energy savings, no research thus far has offered energy saving strategies for complex manufacturing buildings. Therefore, the intended contribution of this paper is to evaluate the benefits from energy saving technologies and strategies for implementation in complex manufacturing buildings. The suggested energy reduction technologies—air handling units, chillers, and lighting systems—are selected as a result of interviews with practitioners. In addition, a financial analysis is presented to determine if the added cost of energy saving equipment is economically viable.

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