A Case-Study Comparison Towards Quantifying

Energy Saving Strategies in Big-Box Retail Stores

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Abstract

This research focuses on energy-related initiatives implemented by one big-box retail chain in Canada. Through analysis of energy reduction strategies, the study compares the energy performance of two stores, one of which operated with conventional design features and the other which was operated with energy-related upgrades.

The results of this research conclude that the store constructed with advanced technological solutions outperformed the other in terms of energy-use intensity by 44%. The research also reveals that premium costs related to the advanced technologies were effective choices. For example, the upgraded mechanical strategy showed an ROI of 52% and a simple payback of 2 years.

Finally, the research analyzes initiatives that are currently under evaluation by some of North America's largest retail companies. The results show further energy efficiency opportunities in areas such as retail lighting and plug load reduction strategies, with each offering further reductions of 3% and 2-4% respectively.

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1 Introduction

The North American retail landscape has changed dramatically over the past 50 years. Prior to World War II, retail stores were isolated to individual communities in the form of general stores and “mom-n-pop” shops (Smyth LLC, 2011). Such stores were frequently family run and offered a variety of products that catered to the needs of the local community. By the early 1960’s, Walmart, K-Mart, and Target all opened their first large discount stores and the era of big-box retail was born (Welch, Burritt, and Coleman-Lochner, 2012). These stores were generally attached to shopping malls, and represented a new way for consumers to purchase goods. Big-box retail development boomed in the 1990’s and began to dominate suburban landscapes with the now familiar stand-alone big-box store (Welch, Burritt, and Coleman-Lochner, 2012). It is now very common to see these large retail developments in both urban and suburban settings.

Fundamentally, these types of buildings are constructed with one main goal; to provide a facility where consumers can choose from a selection of goods and services that satisfy their needs profitably (Burke, 2005). While this remains a standard goal for any retail store, additional elements have become more prevalent in recent years with respect to the design and operation of these buildings. The reduction of energy consumption in big-box stores has become an important component for many retailers. Energy-efficient retail building design can add value in addition to direct expense reduction, including the ability to publicize a corporate commitment for sustainability, linking to a corporate sustainable mission, higher employee morale, and maintenance cost savings when properly implemented (ASHRAE, 2011).

1.1 Objectives and Scope of Research

The objective of this Major Research Project (MRP) is to identify and evaluate practical solutions regarding energy reduction for big-box retail stores. This is not a building type that is inherently intriguing, but it is a building type that gets constructed with some degree of regularity in North America. A recent announcement from one multi-national retailer, for example, confirmed that they will add 35 new supercentres in Canada in 2014 (Strauss, 2014). There are practical opportunities through this research to identify, analyze, and recommend strategies that will have positive results towards the design and operation of these facilities.

This research is presented in the form of a case study analysis of one newly constructed retail store in eastern Ontario. This store was constructed by a large Canadian retail organization and a number of non-traditional 'sustainable' technologies were incorporated into this building. The newly constructed store, Store B, replaced a traditional store in the same market located on an adjacent lot, Store A. Store A was built in 1999 using traditional building design strategies common in big-box retail design. Through analysis and comparison of performance data of Store B to the more traditional Store A, the research aims to quantify the energy impacts of these non-traditional technologies.

In addition to the analysis of the case study buildings, the research aims to provide an overview of future developments with respect to energy performance in big-box retail stores. An understanding of the industry trends with respect to this building type is an important component in moving the dialogue forward. To aide in this analysis, an eQuest energy model was created for Store B was used as a baseline to assess possible scenarios for future store designs. Details pertaining to this energy model are explained throughout the report.

Finally, given the fact that the retail industry is acutely conscious of decisions involving capital and operational expenditures, understanding energy performance initiatives from a life-cycle cost perspective is critical. The findings of this report will present the specific strategies in these terms.

1.2 Research Questions

The basis of this research lies in two fundamental research questions:

1) How did Store A and Store B compare in terms of energy performance based on the utility data available for each location, and what were the energy and life-cycle cost benefits of the specific building efficiency improvements?

2) Looking forward, what are the most favourable technologies currently being evaluated in the big-box design community in terms of life-cycle costs as they pertain to future big-box store designs?

2 Literature Review

In order to answer the research questions posed as the basis for this work, a thorough literature review was performed to present the current state of research related to big-box energy efficiency and to identify gaps in that research. The objective of the literature review was as follows:

- To provide a background on big-box retail buildings
- To understand the extent of energy and sustainable strategies that exist in the big-box retail industry in terms of building designs
- To identify existing scientific research and practical examples that pertain to the energy reduction strategies which were implemented in the case study building (Store B)
- To develop an understanding of major trends in the design community as they relate to future construction of big-box stores
- To identify existing research in the area of life-cycle cost analysis as it pertains to the energy-reduction strategies presented throughout this research.

2.1 Background: Big-box Retail Stores

ASHRAE defines medium to big-box stores as having gross floor areas (GFA) between 3,700 m^2 (40,000 ft^2) and 9,300 m^2 (100,000 ft2) (ASHRAE, 2011). Typical big-box architectural design has changed very little over time. The buildings themselves are ubiquitous and are largely indistinguishable from retailer to retailer. From the author's own experience as a big-box retail building designer, retail organizations are frequently altering interior store designs and layouts, however the base-building design features of these facilities have remained largely unchanged. These buildings are frequently single-storey structures with large footprints. Floor-to-ceiling heights between 6 and 7 meters are common. The result is a large volume space that requires illumination, heating, cooling, and ventilation. Big-box stores are often constructed of similar materials, conditioned in similar ways, and illuminated using common lighting designs. They are most often individual buildings, and often part of larger shopping developments, or Power Centres.

In recent years, with increased competition in the marketplace and the amplified importance of maximizing share value, retailers have started to invest in operational cost-saving strategies. Such strategies are typically presented on many large retailer's corporate websites as achievements towards their sustainability targets. Given that many retailers operate hundreds of stores and millions of square meters of floor space globally, the opportunity to reduce energy consumption has become a significant source of investment. Furthermore, with an increasingly environmentally conscious consumer, there are significant goodwill benefits for companies that invest in energy reduction strategies and environmentally responsible building design. New consumer buying patterns are impacting retail sales per square foot across many retail environments (Jamieson and Hughes, 13).

Energy costs are typically the second largest cost for retailers beyond labour (ASHRAE, 2011). After the financial downturn in 2008, energy consumption and its associated cost received as much scrutiny as did traditional supply-chain expenditures (Ecova, 2013). Over the past few years, leading retailers have added sustainability leaders to their executive teams, established and publicly reported on energy-reduction targets, improved the energy performance of their stores and real estate assets, and actively managed the sustainability of their supply chains to ensure a lower impact on the environment (Jamieson and Hughes, 2013).

One of the biggest impacts on energy use comes from finding efficiencies in the retail buildings themselves. In companies where big-box stores represent the overwhelming number of retail locations, finding improvements in the building's operations is critical to any energy reduction strategy.

As shown in Table 1, the number of big-box stores in Canada increased by almost 20% between 2006 and 2010 (Hernandez, 2011).

Table 1: *Canadian Power Centres, 2006–2010. (Hernandez, 2011)*

Year	Number of Power Centres	Number of Big Box Stores
2006	451	2,929
2007	461	3,139
2008	474	3,305
2009	484	3,429
2010	487	3,511
Change from 2006 to 2010		
Number	36	582
Percent	8.0%	19.9%

Historically, the majority of these buildings have been designed and constructed using similar systems and technologies. Large footprint, single-storey, open volume buildings have always been relatively inexpensive to build. They are straight forward to construct, which is appealing because construction schedules can be maintained and controlled and they are relatively durable in terms of the typical building envelope. The result is a building that is known in terms of its life expectancy, its maintenance requirements, and its expected operational nuances. Owners have a relatively good understanding of the replacement requirements of the systems and equipment over the building's expected life span. There is value in being able to predict operational expense, and in most cases, this factor along with the relatively inexpensive capital costs have dictated design decisions for prototypical store designs.

A number of factors over the past several years have contributed to the industry's willingness to implement strategies for building and operating more efficient stores. Primarily, cost savings has been the driving factor, but a review of some large multi-national retail organization websites reveal that newly created corporate social responsibility (CSR) platforms have also played a role. Leading retailers have added sustainability leaders to their executive leadership teams, established and publically reported on targets, improved the efficiency of their facilities, invested in renewable energy, improved product lifecycles, and actively managed the sustainability of their supply chains to ensure a lower impact on the environment (Jamieson and Hughes, 2013).

According to the US Environmental Protection Agency, on average 30% of the energy used in commercial buildings is wasted (EPA, 2010). This is largely due to inefficiencies in the design and operation of the building. Energy-use reduction and improved efficiency literally translates to millions of dollars in savings, improved asset performance for owners, and increased profits (Ecova, 2013).

Energy costs are expected to increase in the coming years and like most companies, retail organizations are looking at ways to reduce energy consumption and save on those costs (Jamieson and Hughes, 2013).

2.2 Retail Sustainability

Retailers are in a unique position to benefit from environmentally conscious strategies. A 2009 report sponsored by Smart Centres and the Toronto and Region Conservation Authority (TRCA) titled *Greening Retail: Best Environmental Practices of Leading Retailers from Around the World* (Evans & Denney, 2009) pronounced that virtually all Canadians are impacted by retail, whether by their weekly visit to food stores, to fashion stores, home furnishings stores, the corner convenience store, or the country general store. Corporately, retailers can define environmentally oriented purchasing requirements and, at the store level, they can educate consumers. Retail businesses act as the gatekeeper for the goods and services offered to consumers and, as such, have the ability to influence behaviour and consumption patterns (Evans & Denney, 2009). In essence the report asserts that retailers are afforded access to the public in ways that other organizations are not. Work that they engage in to reduce their energy consumption can be publicized directly to their desired target – the consumer.

The Retail Sustainability Report (RILA, 2013) discusses a number of factors related to retailer willingness to engage in energy reduction strategies. Through the research, RILA has identified how retailers all attempt to identify the highest payback opportunities for energy-efficient retrofits and new construction opportunities. The research shows that most retailers focus on: (i) high-efficiency lighting systems with significantly improved lifetimes and energy performance, (ii) motion sensors and other automation systems to control the artificial lighting, and (iii) the retrofitting of HVAC systems. Strategies such as the incorporation of daylighting (mainly through skylights) are discussed as a way of saving energy and improving the customer experience in stores (RILA, 2013).

The report identifies fundamental elements within the retail environment related to sustainability (RILA, 2013):

- Most companies' sustainability budgets are not increasing
- Most companies act on sustainability investments that are expected to generate a two- to three-year payback.
- Companies see the primary benefits of sustainability as reduced costs, brand enhancement, and risk management.
- Sustainability programs target the management of reputational risks and energy and fuel price risks.

Overall, the research results of the RILA survey conclude that large budgets are not typically set aside strictly to experiment with building energy improvements. The process of evaluating strategies from a life-cycle cost analysis is important. If capital costs can be recovered and a desirable return on investment (ROI) be achieved in a timely fashion through operational, maintenance, and equipment replacement efficiencies, then it becomes more likely that capital budgets will be made available and that specific technological advancements will be implemented.

Many retail companies have also produced case studies that identify successes with new technologies. In conjunction with the U.S. Department of Energy (DOE), one multi-national retailer constructed a new store in California that incorporated several new energy-efficient strategies (Klettke, 2013). Focusing on all areas of new store design, the retailer was looking to make improvements in their energy performance through the inclusion of improved lighting technology, efficient HVAC strategies, and building envelope improvements. The report listed all energy reduction strategies considered and presented the data to identify energy saved (kWh/a) and simple payback period in years. While this information is useful, it did not discuss the strategies in terms specifically related to life-cycle costing. As such, significant aspects that should inform corporate decision making, such as maintenance and capital replacement were not identified.

In recent years, many large North American retailers have begun to collaborate as part of a DOE initiative in the United States called the Commercial Building Energy Alliance (CBEA) (Holuj et. al. 2010). A number of industries are represented and work in sub-groups specific to their building type. In the case of the retail group many of America's largest retailers are represented. Members of the CBEA collaborate with regularity and discuss energy savings initiatives and strategies. A review of CBEA annual reports indicate that this group has made significant progress in terms of developing energy reduction programs (DOE, 2012). Through 2013, member organizations accounted for over 900 million square meters of floor area, and reported energy savings, on average, of 2% across their portfolios as a result of DOE-related initiatives. The DOE estimates that if the commercial building sector at-large were to implement the strategies developed through the relevant technology specifications and other energy-related campaigns, energy consumption would be reduced by 12% across the commercial portfolio of buildings in the U.S (DOE, 2012).

Facilitation and technical support for the CBEA is provided by the DOE's supporting national labs: National Renewable Energy Laboratory (NREL), the Pacific Northwest National Laboratory (PNNL), Lawrence Berkely National Laboratory (LBNL, and Oak Ridge National Laboratory (ORNL) (Holuj et. al. 2010). Through this alliance big-box retailers have access to scientific research focussed on commercial and retail building design and operation. The energy reduction goal established by the DOE through the work of the retail alliance is significant, as illustrated in Table 2.

Table 2: *Energy Performance Goals for New Commercial Buildings (DOE, 2010)*

	2015	**2020**	**2025**
DOE Enabling RD&D Goal for New Construction	65% improvement in energy performance with 5-year payback relative to ASHRAE Standard 90.1-2004	70% improvement in energy performance (zero-energy buildings with renewable energy technologies) with 5-year payback relative to ASHRAE Standard 90.1-2004	75% improvement in energy performance (zero-energy buildings with renewable energy technologies) with 5-year payback relative to ASHRAE Standard 90.1-2004

Of the literature published either by or in conjunction with the CBEA, a number of building technologies have been (or are being) analyzed. These include:

- LED Lighting (DOE, 2013)
- High Efficiency Roof-top Units (Wang, 2013)
- Windows and Building Envelope Research: Emerging Technologies (EERE, 2014)

The results and key findings of these reports are presented further in Section 2.3.

For the past several years one large multi-national corporation has been an active member of the DOE's CBEA program (Langner et. al. 2013). Through this collaboration, the corporation has developed a strategy whereby energy efficiency measures (EEMs) implemented in retrofit projects are measured and monitored for their energy-related performance. The corporation has evaluated such strategies as reducing lighting power density through lamp, ballast, and reflector retrofits, as well as ventilation strategies that result in significantly less ventilation being required in a store (Langner et. al. 2013). The results of these initiatives are then studied and, where suitable, are implemented in future retrofit and new construction programs.

An interesting piece of this strategy relates to the review process the corporation has developed that identifies each strategy, its results, and the probability of use in future projects based on a number of factors, including climate dependence. As the case study notes, strategies such as increased roof insulation, the addition of energy recovery ventilators (ERVs), and mitigation of air infiltration are all climate dependant, whereas strategies related to aspects such as plug-loads, fan efficiencies, and lighting control, for example, are not (Langner et. al. 2013). For retailers that operate a network of big-box stores across a variety of climates and geographical regions, understanding the applicability of specific energy reduction-related approaches is important. Also worth noting is that the case study refers to strategies "that make economic sense" but it does not offer any insight into the specific meaning of that term nor does it go into specifics related to specific program costs (Langner et. al. 2013).

2.3 Energy Reduction Strategies

The newly constructed big-box retail store used as the basis for this MRP, to be referred to as Store B throughout this report, was designed using a number of strategies which will be explained in detail in Section 4. In order to provide context as to how the building design compares to the literature, Table 3 highlights key elements that were used as guidelines throughout the design process. The literature identified existing research in these specific areas.

Table 3: *Critical Design Elements for Case Study Building B*	
Building Envelope	• Opportunities for improved thermal performance • Reduce infiltration/exfiltration through assembly • Understand potential control measures to verify adherence to design and construction details • Evaluate White Roof Benefits
Electrical System	• Evaluate lighting technology and provide lowest possible lighting power density without sacrificing store light levels • Determine suitable control strategies
Mechanical System	• Evaluate opportunities to isolate heating, cooling, and ventilation strategies • Investigate hydronic heating solutions • Establish understanding of ERV, DCV technologies for this building type • Evaluate strategies to reduce fan/motor energy consumption

2.3.1 Building Envelope

Two separate studies (Haves et.al, 2008 and EDR, 2004) both conclude that due to the large floor area of a typical big-box store, energy-use loads are very core dominant and are not greatly affected by building envelope performance. Haves et. al. (2008) used energy modelling software to simulate performance and create an energy benchmark for a chain retailer across a number of climate zones. Subsequent energy modelling using various store locations showed minimal improvements in overall energy performance as a result of upgrading the thermal resistance in the respective building envelopes. The study concluded that the much smaller efficiency gains predicted for insulation improvements reflect both the core-dominated nature of the loads and the diminishing returns from insulation (Haves et. al. 2008).

An additional report authored by Energy Design Resources (EDR), an organization funded by California utility customers with the support of the California Public Utilities Commission, also concluded that building envelope upgrades in big-box retail stores yielded insignificant results in terms of energy efficiency improvements (EDR, 2004).

To further illustrate this notion, a review of the DOE's report on emerging technologies with respect to building envelopes reveals that in terms of insulation upgrades, the payback period is heavily dependent on installed cost of the insulation as opposed to its energy performance. The analysis concludes that performance targets cannot be met unless new insulation materials are cost effective from a supply and installation perspective (EERE, 2014).

This is not to conclude that the building envelope is not a critical component in terms of big-box store energy efficiency. The literature simply ascertains that financial benefits in terms of energy savings are often lost due to the capital cost related to providing higher levels of insulation. Furthermore, energy modelling that was developed as part of this research revealed that increased insulation in the envelope had diminishing returns in terms of energy saved versus capital investment required. Essentially, the literature is showing that other energy reduction options are currently more financially viable before increasing thermal resistance values in the building envelope.

Areas that were identified as having energy reduction benefits related to air leakage and thermal bridging within the envelope assembly. The ASHRAE Advanced Energy Design Guide (ASHRAE, 2011) identified a number of considerations with respect to thermal bridging and air leakage issues. The guide identified strategies across all climate zones and made recommendations on detailing the critical components and junction points within the envelope. The guide identifies ideal vestibule configurations, overhead door strategies, and other applicable areas within the envelope that typically result in air infiltration and/or thermal bridging (ASHRAE, 2011).

To further emphasize the importance of providing a thermally efficient, air-tight building envelope, Straube (2014) identified the top ten strategies for designing low-energy commercial and industrial buildings in cold climates. Included in his recommendations are noted improvements with respect to envelope insulation as it pertains to air-leakage (Straube, 2014). The report notes that in many commercial building enclosures, the majority of lost R-value is due to thermal bridging around insulation materials. It goes on to say that air leakage can also bypass poorly detailed insulated assemblies, rendering the envelope ineffective (Straube, 2014).

In big-box store construction, there are advantages to using envelope systems such as insulated metal panels (IMP's), the system selected as the primary building envelope for Store B. From a thermal perspective, IMP's perform well for this building-type. An independent report (Building Science Corporation, 2011) concludes that IMP's outperform a number of well-known envelope assemblies in terms of thermal performance and thermal bridging. Insulated metal panels combine structural rigidity with superior insulation and air/water barrier performance, are custom engineered to project requirements and are produced in a factory controlled environment (Zabcik, 2013). For big-box store buildings, they can be installed quickly on site which reduces construction times.

2.3.2 Electrical

2.3.2.1 Lighting

Retail lighting is critical to the ability to sell merchandise. Consequently, measures to reduce energy consumption through lighting can affect sales (Galvez-Martos, 2013); lighting devices should be defined per lighting zone that will give the proper illuminating requirements. The most important parameter is to control the amount of light per unit of power, or lighting power density (Galvez-Martos, 2013).

Traditionally, lighting has represented 30 to 50 percent of energy use for retail stores and has long been considered the best opportunity to improve efficiency, while increasing quality and productivity in most facilities (Rogers & Fredizzi, 2002). Lighting energy can generally be reduced by 40 to 80 percent by installing more efficient lighting fixtures, improved lighting controls and taking advantage of daylight where available (Rogers & Fredizzi, 2002).

The ASHRAE Advanced Energy Design Guide for Medium to Big Box Retail Buildings recommends the use of high-performance T8 fluorescent lamps and high-performance electronic ballasts for general lighting usage in big-box retail environments (ASHRAE, 2011). The guide notes that high performance T8 fixtures are available in 30W, 28W, and 25W instant start lamps.

In big-box retail design, where a consistent blanket-like lighting profile is desired, T8 fixtures have been a preferred choice for many years across the industry. In the early 2000's, one multi-national corporation was building stores using T8 fluorescent lighting. According to one published report, the change to T8 technology with electronic ballasts from high-intensity discharge (HID) fixtures saved this organization approximately 250 million kWh per year (Rogers and Fredizzi, 2002).

2.3.2.2 Motors and Pumps

Beyond lighting, other areas in big-box stores that result in electrical reduction relate to power consumption through the operation of fans, blowers, and pumps. Air that is brought into a store for heating, cooling, or ventilation purposes is moved by a fan or blower. Hydronic systems that circulate hot water for heating rely on pumps.

Wang et. al. (2011) evaluate opportunities to retrofit existing commercial HVAC units with advanced control strategies. The study analyzes energy-related benefits of retrofitting the control component of existing roof-top units (RTU's) that are used for heat, cooling, and ventilation. The main goals of the study were to determine the energy savings achievable by retrofitting existing RTU's with control strategies not historically used for packaged rooftop equipment. The second objective was to quantify the complete cost of a replacement controller in different climate zones in order to help owners understand the respective payback periods. This study is one of the few discovered that presents cost-related data for such an initiative.

Even though the study is presented from a retrofit perspective, the concepts identified help support an argument that similar design strategies would be beneficial in new construction as well. According to the study, packaged air-conditioners and heat pumps serve over 60% of the commercial building floor space in the U.S (Wang et. al. 2011). This illustrates the dominance of packaged RTU's in traditional commercial building design. The retrofit initiative evaluated a number of control strategies that can be retrofit into an existing RTU to improve the operational efficiency of packaged heating, ventilation and air-conditioning (HVAC) equipment. The results from detailed simulation analysis show significant energy (24% to 35%) and cost savings (38%) from fan, cooling and heating energy consumption when packaged units are retrofitted with advanced control packages (Wang et. al. 2011).

The premise of the Wang et. al. (2011) study is relevant in that it identifies technological advancements that can be applied to traditional mechanical designs. Improved control of systems and equipment does result in energy reduction simply based on decreased run-times and overall electrical draw during operation.

Technological advancements in fan and motor power consumption have grown in recent years. Goetzler et. al. (2013) address a number of issues relative to the amount of energy consumed through the operation of fans and motors to move air. The study addresses current motor technology and identifies opportunities for energy savings in commercial and residential applications. The report states that electric motor-driven systems and motor-driven components in appliances and equipment account for more than 25% of the primary energy consumption in both the residential and commercial sectors (Goetzler et. al. 2013). In the commercial sector, the HVAC and refrigeration categories together account for 93% of motor-driven energy use (Goetzler et. al. 2013). Reduction in energy consumption related to motor-driven fans, blowers, and pumps, can have significant benefit to the overall energy profile of a building. In traditional big-box stores, packaged roof-top units, gas-fired unit heaters, make-up air units, and exhaust fans all rely on fans and blowers to move air and hot water for hydronic systems. As the study asserts, reduction in this consumption can have significant energy-related performance benefits.

In addition to presenting specific strategies and technologies with respect to motor types, Goetzler et. al. (2013) emphasize the importance of understanding the overall cost and energy implications by using life-cycle analysis. Given the capital investment required in such technology, the report notes that additional cost of advanced motor technology can deter owners who do not consider payback periods or total lifecycle costs (Goetzler et. al. 2013).

The study also includes an analysis of motor technology and efficiency as it pertains to hydronic heating systems; the heating system being used in the newly constructed case study building (Store B) that forms the basis of this MRP.

2.3.3 Mechanical

Strategies related to mechanical design and energy efficiency are numerous and published literature in this area is abundant. With respect to big-box retail design, significant areas of development have occurred in recent years in order to bring these buildings up to a higher standard in the way they are heated, cooled, and ventilated.

Wang et. al. (2011) cite that packaged roof-top units (RTUs) serve over 60% of the commercial floor space in the U.S. A common theme with RTU's is that they are almost always oversized to meet peak design-load conditions (Felts et al. 2000). As a result, single-speed RTU supply fans often provide air at a higher rate than what is actually required. Consequently, energy is used to move, heat, and/or cool a volume of air that isn't needed to meet the specific zone requirement.

A fundamental approach that was taken by the national retailer in this MRP was to separate the function of heating, ventilation, and cooling from one traditional RTU into separate packages. By separating the three functions, maximum efficiency could be established within each individual component (ASHRAE, 2011).

Mechanical design is a critical component in the energy efficiency of a building. Straube (2014) asserts that second only to the design of the enclosure, ventilation, heating, and cooling strategies are fundamental to building's energy performance. Within the top ten design strategies he recommends for commercial and institutional buildings, four of them are specific to the mechanical design. From a mechanical perspective, he advises on the following (Straube, 2014):

- Separate ventilation from the heating and cooling systems
- Don't over-ventilate the space. Use strategies like demand controlled ventilation
- Increase boiler/chiller efficiency and recover waste heat through energy recovery or heat recovery ventilators
- Use variable speed controls (VFD's) for all large pumps and fans.

These strategies are all evaluated from a retail big-box perspective as part of this MRP. The case study Store B implemented three of the four recommendations from Straube (2014).

2.3.3.1 Demand Control Ventilation

All buildings need to be ventilated with fresh, outdoor air to meet the specific code requirements as outlined in ASHRAE 62.1 (ASHRAE, 2011). In order to do that, traditional designs involved packaged RTUs using fans to bring outdoor air into a space on a continuous basis. Traditional big-box retail design has historically relied on a constant supply of fresh air, resulting in continuous fan operation. In months where outside air is either too warm or too cool to bring directly into a space, that air needs to be treated by the air handling unit which results in additional energy consumption either through the cooling process (electricity) or the heating process (natural gas). By eliminating the need for constant ventilation, energy reductions can be significant because there are benefits to both the electricity and natural gas consumption.

Krepchin et. al. (2006) explain how demand control ventilation(DCV) saves energy by using building occupancy indicators, such as CO_2 levels, to regulate the amount of outside air that is brought into the space to satisfy the ventilation requirements. Demand Controlled Ventilation allows fresh, outdoor air to be brought into the store when required, rather than on a continuous basis. In big-box stores, the continuous supply of air has historically resulted in over ventilation, particularly during periods of low occupancy (Krepchin et.al, 2006). The report further stated that DCV has the greatest savings potential and financial benefit in climates with large heating and/or cooling loads and in buildings that have high variable and unpredictable occupancy levels, like retail stores and post-secondary institutions.

ASHRAE (2011) also recommends DCV implementation in big-box retail buildings. Identifying conditions that warrant specific types of control, the report itemizes specific ventilation rates that need to be met. In a big-box retail store, this is relevant because even though the dominant space is the large volume of the retail floor, office areas and support spaces may require specific and isolated ventilation strategies. Office areas, for example, may be best suited by implementing time-of-day schedules or occupant sensors rather than straight CO_2 levels (ASHRAE, 2011).

Evaluation of a strategy such as DCV should be done in combination with the use of a typical RTU economizer. Economizers save energy by providing free cooling when the exterior temperatures are suitable to meet part or all of the cooling load (ASHRAE, 2011). Both DCV and an economizer function rely on the use of modulating outdoor air dampers in the roof-top unit, and combining the two strategies to operate together can be an additional energy saving opportunity (Lawrence, 2004).

2.3.3.2 Energy Recovery Ventilators

In keeping Straube's (2014) recommendation to isolate the ventilation from the heating/cooling systems, the implementation of an energy recovery ventilator (ERV) is appropriate.

Hastbacka et.al (2013) evaluates the significant developments that have been made in ERV technology and notes how the technology continues to emerge into the commercial mainstream. ERVs use air-to-air energy recovery heat exchangers to capture latent and sensible heat before it exits the building. The design captures energy from the building's exhaust air and uses that energy to pre-heat outdoor air supply in winter months, which results in decreased heating requirements. In warmer months, heat from the outdoor air supply is transferred to waste exhaust, resulting in decreased air-conditioning demand. Both of these scenarios result in decreased energy use.

Buildings that have the following characteristics were identified as good candidates for incorporating ERV's (Hastbacka et.al, 2013):

- Located in climates with moderate to extreme cooling and heating requirements
- Require large amounts of outdoor ventilation air
- New construction in order to take advantage of “first cost” reduction

The study goes on to characterize some other benefits of ERV systems by citing examples of projects where the overall size of respective HVAC systems was reduced by 30% as a result of implementing the ERV strategy to meet ventilation requirements (Hastbacka et.al, 2013).

Depending on the building size, one ERV can provide the ventilation function that was traditionally provided by several conventional roof-top units. This can result in a reduction in the number of RTUs that would typically be required. As a result, a single fan provides ventilation air as opposed to the traditional design of several fans providing the same function. Additionally, fewer roof-top units equals fewer roof-top penetrations. This is desirable from a number of perspectives including roof framing, roof loading, roof maintenance and leak avoidance. A decrease in the number of roof-top units also translates to decreased maintenance cost and improved operational performance.

An additional case study explained that ERVs could help reduce the first costs associated with a new chiller and boiler by requiring smaller units (HPAC, 2007). Smaller units result in decreased capital cost and decreased operating costs. The study notes that a series of newly constructed schools in a hot and humid environment, the lack of an isolated ventilation strategy had led to indoor air quality issues. This led to future projects implementing an ERV strategy, which resulted in significant reductions in cooling and heating loads on the buildings, and consequently a reduction in the sizing of other HVAC equipment.

2.3.3.3 High Efficiency Condensing Boilers

A space heating boiler is a pressure-rated vessel consisting of a fuel burner, furnace chamber, heat-transfer fluid chamber, heat exchanger, exhaust system, and controls (Parker and Blanchard, 2012). A boiler fundamentally works by transferring heat energy generated through combustion to a hydronic fluid (usually water) that is then distributed through a series of pipes to specific terminal equipment. The terminal equipment may be various types of radiators, or individual fan-coil units. The current literature such as DOE (2012) and Wang et. al. (2011), would lead one to conclude that boiler technology is not a common solution for heating applications in big-box retail stores.

High-efficiency condensing boilers are more efficient than forced air systems by a considerable margin. Modern condensing boilers have efficiencies in the mid-90's, whereas traditional non-condensing boilers or forced air systems are closer to 80 percent efficient (Parker and Blanchard, 2012). Hydronic heating technology is not new, however advances in the energy efficiency of such systems have increased in recent years to the point where it is now an attractive technology for buildings such as big-box retail stores.

A 2012 study assessed the implementation of condensing boilers in a U.S. federal building in Atlanta, Georgia. Among its findings, the study presented a number of relevant technological explanations on the efficient operation of condensing boilers. As noted in the Parker and Blanchard (2012) report, condensing boilers are equipped with high-efficiency heat exchangers to recover sufficient heat energy from the products of combustion, which results in the temperature of the combustion gases dropping below the condensing temperature of the water vapor. As the water vapor condenses, the latent heat energy is released and absorbed by the heat transfer fluid. The result is an increase in the thermal efficiency of the heating system (Parker and Blanchard, 2012).

There are a number of advantages to a heating system that uses boilers versus a traditional heating system relying on forced air. Among the advantages are:

- Heat exchangers are made of high-quality materials and designed to drain freely, which allows them to withstand years of condensing operation with no significant corrosion (Pilaar, 2007).
- Fewer roof-top penetrations through a reduction in the requirement for typical packaged rooftop units
- Reduction in fan power as hydronic systems do not require outdoor air
- Fewer maintenance checks (once per year versus 4-6 times per year for conventional roof-top units)
- Longer life-span – boilers have been known to last in excess of 50 years with proper maintenance. Traditional RTU's rarely last beyond 15 years (Oregon DOE, 2004).

ASHRAE's Advanced Energy Design Guide for Medium to Big Box Retail Buildings identifies certain characteristics of hydronic heating systems that make it a desirable choice for efficient space heating. One critical piece is that condensing boilers can operate efficiently at partial load, meaning they don't have to run at full power to be efficient. The modulating ability of the burner may satisfy the space heating requirements effectively and efficiently without having the advance to a higher level of flame output. In the case of the case-study building design, supply temperatures are established at 77℃ and the loop design ΔT is 20℃ (REF). This matches the optimal range that ASHRAE prescribes in order to maximize the system's efficiency (ASHRAE, 2011). Higher ΔTs result in smaller piping and less pumping energy (ASHRAE, 2011). The design of the hydronic system in the Store B meets these specified criteria.

In terms of preference over a traditional heating solution using packaged RTUs, condensing boilers have been shown to be better investments over the long term aspect of building operation and maintenance. A study published by the Oregon Department of Energy titled *Case Study: Rooftop Units V. Central HVAC* identified savings and benefits of converting from traditional RTUs to a more efficient boiler system. From a number of perspectives, including maintenance and energy savings, the boiler system has shown to be a considerable cost saver since installation. The study estimates that preventative maintenance is three times higher on RTUs in comparison to a central hydronic heating system (Oregon DOE, 2004). The study also notes that while capital costs of the boiler system were higher, when factoring in life expectancies of the different systems, over the life of the building, boilers are a better investment.

2.4 Future Developments

Throughout the DOE's collaborative research efforts with retailers and other commercial building owners, a driving mantra remains that research and development of new technologies and systems will not alone dramatically reduce energy performance in buildings (Holuj et.al, 2010). The market must implement the technologies on a large enough scale in order to realize any substantive reduction in energy use.

With this in mind, part of this research is to identify and analyze the key technologies that retailers are looking towards in terms of reducing energy consumption in the near future. Focusing specifically on advancements in energy efficiency specific to big-box retail stores, the respective participants working with the DOE are involved in a number of pilot programs to test and measure specific strategies as discussed below.

2.4.1 Electrical

2.4.1.1 Lighting

Advances in lighting technology dominate electricity-reduction discussions. According to a DOE survey , most retailers have been retrofitting existing stores and building new ones using T8 fluorescent lighting technology over the past several years (EREE, Jan 2012). By 2010, 79% of the retail market incorporated linear fluorescent technology for their main lighting needs (EREE, Jan 2012). Some of the largest multi-national companies, for example, converted to T8 lighting several years ago and reported significant savings immediately in comparison to previous HID lighting systems (Fedrizzi and Rogers, 2002).

Advancements in lighting have been trending towards solid state, also known as light emitting diode (LED), technology for some time. According to Shuler (2013) most industry experts agree that LED technology will inevitably replace incandescent and fluorescent lighting in most common lighting applications over the next few years. The study identifies significant benefits associated with LED fixtures that include reduced energy consumption, reduced maintenance costs, and mercury-free technology.

ASHRAE (2011) identifies cost as being a prohibitive factor to the widespread implementation of LED technology. The author's observations suggest historically this has been accurate, and to some extent continues to be a factor, however there are cases of implementation in big-box retail environments. Information published about one of the largest multi-national retail corporation's latest efforts report they have experimented with LED lighting on its main retail floors in several locations (EERE, 2013). In a store in Wichita, Kansas, they claim that the implementation of LED reduced power use compared to linear fluorescent lights by 29% (EERE, 2013). While the study notes this corporation has not committed to the technology as a standard in new construction, two additional stores opened in 2013 using LEDs; cost data was not provided.

The DOE cites advancements in LED technology as one of the key emerging technologies with respect to buildings and reduced energy consumption (DOE, 2013). The organization along with industry partners have invested over $70 million to-date on the advancement of the technology.

In addition to improved energy performance, LED technology has the benefit of long lamp-life and zero maintenance (DOE, 2013). LED fixtures have varying lifespan ratings but it is not uncommon for fixtures to be rated for 100,000 hours. For retail stores that operate lighting for approximately 4,500 hours per year, this equates to over twenty years of use from LED technology without incurring any maintenance or lamp replacement costs (DOE, 2013).

2.4.1.2 Plug and Process Loads

Beyond lighting, another area specific to electrical consumption that is becoming more popular relates to energy consumed through plug and process loads (PPLs); loads that are not related to general lighting, heating, ventilation, or cooling. These loads typically do not provide comfort to the occupants (Sheppy and Lobato, 2011). Equipment such as computers, monitors, photo-copiers, fax machines, appliances, cash registers, and point of sale terminals are all examples of PPLs. The NREL estimates plug load consumption to account for approximately 33% of the energy consumed in commercial buildings (Sheppy and Lobato, 2011). While data specific to retail was not identified in the NREL study, the report does conclude that significant energy savings are available through reductions in PPL.

ASHRAE (2011) states plug load control strategies can be even more important than minimizing connected wattage in reducing overall plug load energy consumption. A case study published by one multi-national retail corporation identifies plug load reductions as being one of the key areas that retailers can focus on in their energy reduction strategies (Langner, et.al, 2013).

Metzger et. al. (2012) identified an array of new technologies available that meter and control plug-loads. Control strategies that match plug-load energy use to user work schedules can save considerable energy and are replicable for most commercial buildings. The report also notes that plug-load control strategies are effective in minimizing peak electricity demand (Metzger et.al, 2012).

There are a number of specific control measures available that are designed to mitigate the impact of plug loads. Research at the NREL on control and behaviour patterns concluded the largest savings were on loads that run continuously, such as printers (27%-69% reduction, depending on the type of control) and miscellaneous equipment (51%-81% reduction, depending on the type of control) (Metzger et. al., 2012).

Inviro (2013) provides a number of general recommendations such as turning equipment off when not in use, and shifting non-critical loads away from peak times. For example, charging of various batteries for equipment could occur overnight rather than in the peak daytime hours. Additionally, the use of Energy Star (Inviro, 2013) rated equipment is desirable wherever possible. More specifically, use of LED fixtures for any retail display is recommended, as well as the inclusion of motion sensors in areas that require illumination for certain product. Most general merchandise retailers have assortments of energy-consuming display products. Often, these items remain "on" throughout the day, resulting in significant amounts of energy being wasted. The addition of timer switches or motion sensors would contribute to a notable reduction in energy consumption from those items.

In terms of identifying plug-load factors for energy modelling purposes, eQuest modelling software establishes default plug loads at 0.5W/ft^2 (Inviro, 2013). It is challenging to determine the accuracy of this setting as numerous assumptions are made when estimating plug load value. The report concluded that accurate electrical use based on plug loads alone was impossible to obtain without further long-term monitoring with meters or data loggers in place (Inviro, 2013). The report also concluded, however, that reductions can be attained and that they are potentially significant.

2.4.2 Mechanical

Advancements in roof-top unit (RTU) technology, boiler efficiency, and variable frequency drives (VFDs) are all areas with considerable ongoing research (DOE, 2013).

2.4.2.1 Advanced Roof-Top Units

Wang et. al. (2013) evaluates advancements in packaged roof-top units (RTUs) which are very common with big-box retail store design. Comprising a key initiative sponsored by the DOE, the study analyzes the energy saving potential of the first commercially available advanced RTU that meets specific energy performance requirements as prescribed by the DOE. The 'RTU Challenge', as it was called, challenged manufacturers to develop high-performance RTU's with capacity ranges between 10 and 20 tons (Wang et.al, 2013). This initiative was spawned by the fact that an estimated 40,000 10-ton RTU's are sold in the United States every year and these typical packaged RTU's use approximately 50% of the cooling energy annually in the United States commercial buildings (Bouza, 2012). The challenge had the following criteria:

- Efficiency from baseline 11.0 SEER to 18 SEER
- Decrease air flow by specifying variable air volume over constant air volume
- Increase fan efficiency from 45% to 60% (minimum) with variable volume or multi-stage operation capability

In 2012, a dominant manufacturer in the HVAC market became the first to produce a commercially available unit to meet the specifications established in the RTU Challenge (Wang et. al. 2013). The Wang et. al. (2013) study uses detailed energy modelling to compare the results of this unit to a series of pre-defined baseline conditions with older and less efficient technology. The study concluded that in all scenarios and climate zones the advanced unit showed significant reductions in energy consumption (Wang et.al. 2013). Where the study falls short, however, is in the area of cost and potential payback. The report states that "no attempt was made to estimate the potential payback periods associated with any of the three reference scenarios" (Wang, et.al, 2013). This represents another case of technology being analysed from a performance perspective only. By ignoring associated cost premiums and other economic factors, it becomes difficult to fully understand the specific strategy.

Wang et. al.(2013) concluded that the through testing of the advanced unit, energy reductions are significant in a number of scenarios. When compared to existing HVAC equipment on the market that meets current U.S. requirements for equipment efficiency, the unit shows reductions of 29% in cold climates such as Chicago (Wang, et.al. 2013). The report states that 50% of that reduction is attributable to electricity use.

2.5 Life-Cycle Cost Analysis (LCCA)

This research is focussed on providing analysis of specific energy-related strategies from a life-cycle cost analysis (LCCA) perspective. The methodology used to achieve this is discussed in detail in Section 3. In terms of the published literature that focuses on LCCA as it relates to the design, implementation, and operation of specific energy-saving technologies, the topic is well covered. What is not so well covered, however, are specific examples of energy-related improvements and the life-cycle costs associated with those advances. Contributing to filling that gap is a goal of this research.

A significant study in LCCA was published in 2005 as the result of a United States executive order through the U.S. Department of Energy (Fuller, 2005). The purpose of the study was primarily to assist agencies in ensuring that all project cost estimates, bids, and agency budget requests for design, construction and renovation of facilities were based on life-cycle costs. The study identified a formula for calculating life-cycle costs of a specific initiative. Additionally it qualified the difference between LCCA and simple payback (SPB) analysis. The study explains how SPB analysis evaluates the time required to recover the initial capital investment. In the case of energy-related building strategies, the SPB strategy calculates the number of years required to offset the capital investment through annual energy cost savings. This strategy ignores costs or savings that are incurred over the remaining life of a specific project. Fuller (2005) concludes that SPB is an inappropriate tool for understanding life-cycle costs.

Fuller (2010) produced additional research on LCCA that outlined specific criteria that need to be considered in order to obtain useful results. Costs associated with acquiring, operating, maintaining, and disposing of a building or building system usually fall into several main categories (Fuller, 2010). These categories are:

- Initial Costs—Purchase, Acquisition, Construction Costs
- Energy Costs
- Operation, Maintenance, and Repair Costs
- Replacement Costs
- Residual Values—Resale or Salvage Values or Disposal Costs
- Non-Monetary Benefits or Costs

In terms of implementing specific energy-saving systems, initial costs refer to the cost of the system or equipment. In the case of this research, initial or capital costs are presented as premiums costs relative to traditional or typical designs. The literature confirmed that detailed estimates at an early stage of design are not necessary for the initial analysis of a system or piece of equipment (Fuller, 2010). As

Fuller (2010) notes, detailed estimates are usually not available until the design is quite advanced and the opportunity for cost-reducing design changes has been missed. The study goes on to assert that LCCA can be repeated throughout the design process if more detailed cost information becomes available (Fuller, 2010). In terms of relevance to this research, this point is significant as many of the potential strategies that retailers may pursue are in early stages and cost data is preliminary at best.

Fuller (2010) goes on to qualify other areas of LCCA which are highly relevant to this research. Energy costs, for example, are challenging to predict. Fuller also notes that operation and maintenance costs can be difficult to estimate until the building is occupied and its performance requirements and characteristics are better understood. With respect to big-box retail stores this may be somewhat easier to ascertain at an early stage simply because the building type is understood given that hundreds of stores are currently in operation for any given large national retail corporation. Operating hours are generally known in advance, as are the major processes and end-use energy requirements of the building. Where there may be some challenge is with the implementation of new technology that is not standard for that retailer, predicting specific maintenance schedules may require some room for flexibility once the store is operational.

2.6 Summary

The literature review reveals areas of significant investment on the part of North America's largest retail organizations in terms of energy performance. The largest retail corporations understand that energy reduction strategies are important, as evidenced by the initiatives developed and implemented over the past several years. Furthermore, there is ample evidence to suggest that future strategies are being developed as retailers continue to invest in energy-saving and sustainable technologies.

It is clear from the research, however, that reliable, cost-based analysis is required. Many retailers have engaged in a variety of programs related to the reduction of energy in their respective stores, both new and existing, but information relative to the success of many of these programs is often high-level in the form of case-studies. There is a gap with respect to appropriate cost-benefit analysis of various initiatives, particularly from a life-cycle cost perspective. As noted in a recent report published by The Retail Council of Canada (RCC, 2012), retailers are historically averse to sharing information relative to energy performance and associated costs due to the competitive nature of the industry and the investment in acquiring expertise and knowledge.

3 Methodology

3.1 MRP Organization

This research is presented in three main parts. The first is an analysis comparing the utility data and energy performance of two big-box retail stores. The second focuses on trends and possible strategies going forward that are applicable to big-box design. The third evaluates the respective strategies, both implemented and potential, from a life-cycle cost analysis perspective.

3.2 Comparative Analysis of a National Retailer's Implemented Energy Reduction Strategies for Big-Box Retail Stores

A case study comparing two big-box retail stores belonging to one national retailer was performed as part of this research. Using utility (electricity and natural gas) consumption data for each location, a comparison between the traditional building and a newly constructed building was performed in order to evaluate specific energy-saving initiatives. The data provided was specific to a national retail organization which owns and operates a large network of big-box stores across the country. This company has requested anonymity for the purposes of this research. This retailer had an existing store in eastern Ontario that was in need of replacement, primarily to increase the size of the store to satisfy a growing population in that area. The decision was made to construct a new store adjacent to the existing one and to outfit the new location with several systems and technologies that fundamentally varied from more traditional store designs. The store which was being replaced (Store A) was initially constructed in 1999. The new store (Store B) was occupied in the spring of 2011.

Store B was constructed on a parcel of land adjacent to Store A's former location. Climate data is therefore the same, which is preferable for comparative purposes. ASHRAE defines the geographic location as being in Climate Zone 6, as noted in Figure 1.

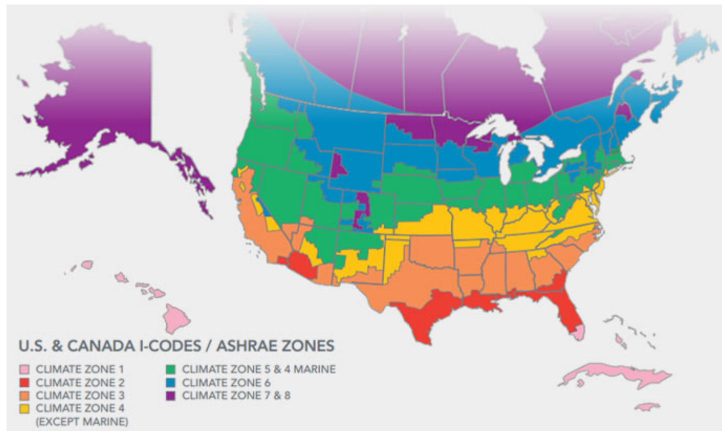


Figure 1: *ASHRAE Climate Zones (www.greenzone.com)*

Utility data from electricity and natural gas bills was secured for Store A for its last 12 months of operation. After the first year of operation for Store B, utility bills were collected and analyzed for that location. As a part of this research, data from each store was weather normalized, compared and analysed. The weather-normalized data is presented in Section 4, and the figures used to perform the weatherization calculations are included in the appendices of this report. Utility bills used for comparative purposes were dated June 2010 to May 2011 for Store A, and June 2011 to May 2012 for store B. Given that the data available was for the final year of operation at Store A and the first year of operation at Store B, it should be noted that the data may have been potentially inaccurate, most likely for Store B. Discussions with the store operator confirmed that the final year of Store A's operation did not fundamentally vary from previous years, so the data for Store A was assumed to be accurate. Store B data, however, may have inflated or deflated values. The way in which Store B was heated and cooled was fundamentally different than that of Store A, and as a result, operational and maintenance variations away from the ideal performance levels may have contributed to increases or decreases in the expected levels of natural gas and electricity consumption. In other words, learning the new systems may have contributed to energy consumption that would not be repeated after learning the nuances of the system. Additional data was not available, however, to attempt to isolate this possibility further.

The fundamental differences between Store A and B from a mechanical, electrical, and building envelope design perspective are identified in Section 4. Each major component in Store B was analysed in comparison to the equivalent technology or system that was used in Store A. For items such as lighting, run-time calculations were performed based on operating hours of the respective stores in conjunction with the kilowatt consumption difference of the respective lighting systems. This same process has been used for other electrical components, such as fans and motors. Exterior lighting has been quantified and subsequently removed from the overall performance assessment of each location as it was deemed to be external to the fundamental goal of this research which focuses on the building. As a note, the thermal resistance values presented throughout the report are all to be considered nominal values.

For the purpose of this research, it was not enough to simply perform a direct comparison between the two stores in terms of energy use intensity. The respective building sizes vary significantly (Store B is more than double the size of Store A in overall area) and an attempt needed to be made that accounted for this difference in terms of overall performance. In order to address this issue, the energy model developed for the design of Store B was adjusted to reflect design conditions and parameters that were equal to Store A. In other words, the Store B footprint was modelled with mechanical, electrical, and envelope designs that were equivalent to those found in Store A. This allowed the research to identify the energy performance in the same building using fundamentally different building inputs. The results of this exercise were then compared to the actual performance of the two buildings to determine if the respective end-uses were similar to the modelled results. This removed the uncertainty of building size from having a significant input on the overall energy performance

The energy model developed for Store B was an integral part of the retailer’s strategy when initially designing the building. Various systems and strategies were analyzed through the energy model. Going forward, the model developed for Store B will form the baseline scenario from which future design strategies for this retailer will be developed.

3.3 Potential Future Strategies in Big-Box Retail Design

Based on the corporation’s experience and the pertinent literature, technological trends and advancements that may be applicable to big-box store design were identified as part of the literature review and will be explored in detail to assess their potential energy-related benefits. It is important to note that future potential strategies currently being evaluated across the industry are, in some cases, preliminary. In cases where energy modelled data is not suitable or quantifiable, data specific to ongoing studies and analysis is presented.

3.4 Life-Cycle Cost Analysis (LCCA)

The inclusion of financial data related to energy efficiency strategies is a fundamental part of this research. In practical terms there is little value in identifying energy saving strategies that are beyond what owner's will realistically pay. Nor is there value in simply looking at the initial capital investment required for a specific technology. An understanding of costs from a life-cycle perspective is critical to ensuring decision makers are well informed on the choices they make with respect to energy conservation.

It is important to note that the approach taken in this research does not include a full life-cycle assessment (LCA). A full life-cycle assessment is a formal process of examining the environmental effects of a material or product through its entire life cycle, from raw resource or material acquisition through manufacture and use to waste disposal (Lucuik and Meil, 2004). A life-cycle cost analysis is an economic method of project evaluation in which all costs arising from owning, operating, maintaining, and disposing of a project are considered important to the decision (Fuller, 2005). As such, this research does not focus on the environmental aspects of the selected systems, products, materials, or strategies.

In terms of analyzing the strategies implemented in Store B from a life-cycle cost perspective, it is important to clearly identify the critical factors required to quantify the energy reduction strategy. In the case of capital investment, understanding the premium cost associated with the particular strategy is essential. Costs related to new technologies are typically over and above what would traditionally be designed. For example, typical retailers operate multiple store locations and as a result have prototypical design standards that are used in new store construction projects (ASHRAE, 2011). Re-designing and constructing these stores with new technologies and improved standards may have premium costs over and above a more prototypical design. Beyond the increased capital cost, one must understand the implications in terms of operation and maintenance and end-of-life replacement costs.

The process for developing a useful LCCA approach is to establish the economic conditions related to inflation and expected energy cost trends. Such analysis allows for the development of a more complete financial picture and gives overall benefits in terms of net present value (NPV), internal rate of return (IRR), and cash flows (Betterbricks, 2012). By accounting for these factors, future savings are converted into “todays” dollars through the concept of “time value of money”. In doing so, total cost of ownership of a specific strategy is better projected and understood.

This research has compiled cost related data and has considered rates of inflation, estimated increases in energy rates, as well as discount rates for the value of money. The LCCA analysis for this research used a spreadsheet calculator that required inputs related to first costs, projected annual energy savings, projected rates of inflation and energy cost increases, as well as operation and maintenance costs. By providing these specific values to each strategy, detailed IRRs and NPVs of the initial investment have been quantified.

Regarding potential future strategies, the same concepts apply. Evaluation of cost premiums (if any) relative to the operational and maintenance aspects of a technology form the basis from which corporate executives make decisions on particular investments. Although it is more challenging to estimate the applicable costs of technology and systems that are currently in development, research and discussions with industry personnel have aided in understanding the costs associated with potential energy-savings strategies.

4 Store A and B Designs and Energy Data

4.1 Store A and B Comparison

Figure 2 reveals the locations and proximities of Store A and Store B.

Figure 2*: Aerial Photo Showing Store A and Store B Locations (*https://maps.google.ca/*)*

The fundamental design differences between Store A and Store B in terms of architectural, electrical, and mechanical components are noted in Table 4.

Table 4*: Design Comparison of Store A and Store B*

Discipline	Item	Store A	Store B
Architectural	Areas		
	Total Building Area (m^2)	2,695	6,000
	Retail Floor (m^2)	1,485	3,900
	Warehouse (m^2)	665	1,035

	Offices and Misc (m^2)	545	1,065
	Insulation		
	Roof (W/m^2K)	RSI 3.52	RSI 3.52
	Walls (W/m^2K)	RSI 2.47	RSI 3.52 & RSI 2.47**
	Floor (W/m^2K)	none	none
	Envelope Details	None	Thermal Breaks Aligned ++
	Envelope Materials		
	Floor	Slab on grade	Slab on grade
	Walls	Metal siding	Insulated Metal Panel
	Roof	Ballasted EPDM	White TPO
Electrical	Retail Lighting Fixtures	HID 400 Watt lamps	6-lamp T-8 Fluorescent - 28 Watt lamps
	Warehouse Lighting	32 Watt fluorescent	32 Watt fluorescent
	Office Lighting	32 Watt fluorescent	54 Watt LED
	Lighting Power Density W/m^2	26.9	8.9
Mechanical	HVAC Capacities		
	Retail Heating Capacity (kW)	700,000	300,000
	Retail Cooling Capacity (kW)	300,000	160,000
	HVAC Systems	Standard Efficiency RTUs	High Efficiency RTUs
		80% Efficient unit heaters (warehouse)	Hydronic Heaters w/ Condensing Boilers
			High Efficiency RTUs in offices w/ HRV

			Dedicated ERV in retail
	HVAC Features	None	DCV
			Floor level return air to improve ventilation effectiveness

** Higher insulation value (RSI 3.52) along front façade only
++ Continuous and unbroken thermal barrier throughout envelope

The fundamental design differences between Store A and Store B are discussed in more detail throughout Section 4 of this report. In order to provide some context for ongoing reference, however, the respective energy-use intensity (EUI) figures are presented in Table 5. The EUI for each building has been established using the following equation $EUI = ekWh/A$, where ekWh is the annual energy use and A is the building area.

Table 5: *Store A and B Energy Use Intensity (EUI)*

	Store A	Store B
Normalized Energy Use (ekWh)	1,235,146	1,549,774
Store Area (m^2)	2,695	6,000
EUI ($ekWh/m^2$)	**458.3**	**258.3**

Discussion related to the respective EUI's is provided throughout Section 4 of the report.

4.2 Store A Design Details

4.2.1 Building Envelope

Store A was constructed using building assemblies that met all code requirements from a thermal resistance value. There was one predominant exterior wall assembly (W1) with slight variations in some areas of the building.

Exterior walls were primarily constructed using a pre-finished metal siding assembly with an overall thermal resistance of RSI 2.47 W/m^{2}K, as follows:

Table 6: *Store A Wall Assemblies*

W1	W2	W3
• Prefinished metal siding • 102mm steel z-girts • Fibreglass Batt insulation • Prefinished Metal Liner	• 90mm Split-face Concrete Block • 18mm air space • 102mm steel z-girts • Fibreglass Batt Insulation • Prefinished Metal Liner	230mm Insulated Precast Concrete Panels

There was one typical roof assembly, and a standard slab-on-grade floor throughout the building. The roofing was a conventional loose laid system with an overall thermal resistance of 3.52 W/m^{2}K, as identified in Table 7.

Table 7: *Store A Roof Assembly*

- Washed riverstone ballast
- Single Ply EPDM membrane
- Polyisocyanurate rigid insulation (150 mm)
- Metal decking

This roofing system was typical throughout the building and was not replaced over the course of the store's life.

4.2.2 Mechanical System

The mechanical system in Store A was designed using standard efficiency equipment. Packaged rooftop units (RTUs) provided heating, cooling, and ventilation for the retail and office areas. These units were manufactured by York and ranged between 7.5 and 20 tonnes in capacity. Additional heating requirements in warehouse and receiving-areas were met using gas-fired ceiling-suspended unit heaters. Programmable thermostats were located throughout the store as the control mechanisms for heating and cooling set points. Table 8 reveals the heating and cooling set points for specific spaces within the store.

Table 8: *Store A Heating and Cooling Set Points (Case Study Retailer Construction Documents, 1999)*			
		Heating	**Cooling**
Retail and Offices	Occupied Hours	22°C	23°C
	Unoccupied Hours	15°C	31°C
Warehouse	Occupied	22°C	NA
	Unoccupied	15°C	NA

A dedicated outdoor air system was not part of this building design. Consequently, the building was ventilated continuously during occupied hours through the packaged RTUs. Roof top unit blowers could be operated in two stages for heating purposes, but in cooling or ventilation mode, the blower operated at full capacity when running. Fans of this nature were either on or off. Variable speed fans and drives were not part of this building, and therefore the fans drew the maximum amount of power whenever mechanical ventilation or cooling was operational. Exhaust fans were typically found throughout the building in areas such as washrooms, computer rooms, and lunchroom facilities.

4.2.3 Electrical System

4.2.3.1 Lighting

The retail floor of Store A was illuminated using high intensity discharge (HID) metal halide light fixtures. Each lamp was 400 Watts, which resulted in significant energy consumption attributable to the retail lighting. Operating hours for this store were typically 4,500 hours per year. Using the equation $akWh = kW\ x\ t$, where akWh is annual kilowatt hours, kW is total kilowatts, and t is time in hours, annual electrical consumption attributed to interior lighting is identified in Figure 3.

$$akWh = kW \; x \; t$$

$$akWh = 76kW \; x \; 4{,}500hrs$$

$$akWh = 341{,}000kWh$$

Figure 3: *Store A Annual Lighting Consumption*

Estimated annual electricity use in Store A attributable to lighting was 341,000 kWh. According to the Ontario Energy Board, non-residential electricity rates for consumers above 750kWh of consumption are approximately $0.10 per kWh. At this rate, annual lighting costs attributable to the retail fixtures alone would be approximately $34,100. 00.

The estimated lighting consumption in Store A represented 48% of the total electricity used in the store. This is on the high end but within the estimated range of 30-50% presented by Rogers & Fredizzi (2002).

It should be noted that exterior lighting also contributes to the electrical consumption of the building. Exterior parking lot light standards and building morality/security lights are common for all retailers throughout North America. For the purpose of this research, site lighting has been quantified and removed from any calculations of energy performance comparisons between the two stores. Quantification of the exterior lighting load is included in Appendix B. While improvement in exterior lighting technology is significant, this type of lighting is generally independent of the building operation and therefore not relevant to this research.

4.2.3.2 Motors, Fans and Blowers

Although lighting was the dominant electrical load for Store A, the operation of mechanical equipment and components resulted in significant electrical consumption. Using the same 4,500 hours of operation, consider the cost of operating a typical 7.5-horsepower (HP) fan for a year.

$$AC = (P)(r)(C)$$

$$AC = (7.5 \ x \ 0.746) \ x \ 4500 \ x \ 0.10$$

$$Annual \ Cost = \$2{,}517.75$$

AC = annual cost, P = power (kW), r = runtime (hrs), C = Cost (per kWh)

Figure 4: *Sample Annual Cost RTU Fan Operation (note: 1-HP = 0.746kW)*

Having a number of fans throughout the store, one can see the potential for decreasing these costs and consumption figures through effective fan-power mitigation strategies. Using the formula from Figure 4, Table 9 below identifies motor consumption per item on an hourly basis. The calculations are based on the motors running at full capacity.

Table 9: *Store A Mechanical Schedule and hourly kW impacts (Case Study Retailer Construction Documents, 1999)*

Item	**Qty**	**Details**	**Hourly kW consumption per motor**
Rooftop AC Units	2	20 ton heating/cooling RTU 7.5 HP Blower Motor EER 8.5, 2.4888 COP	5.60
	1	7.5 ton heating/cooling RTU 2.0 HP Blower Motor EER 8.9, 2.605 COP	1.49
	1	7.5 ton heating/cooling RTU 3.0 HP Blower Motor EER 9.0, 2.635 COP	2.24
Unit Heaters	4	0.75HP fan motor 320 MBH Heating	0.56
	3	1/6 HP fan motor 240 MBH Heating	0.12
	2	3.0 HP fan motor	2.24

			320 MBH Heating		
	Make-up Air Unit	1	3.0 HP fan motor 410 MBH Heating	2.24	
	Exhaust Fans	11	1/3 HP fan motor	0.25	
	Destratification Fans	12	100Watts	0.75	

4.3 Store A Energy Consumption

Twelve months of energy bills were collected for Store A for the period starting June 2010 and concluding in May 2011. Electricity and natural gas consumption data for this 12 month period was then weather normalized which accounts for variations in weather patterns over a specific period of time. By using readily published data that tracks heating degree days (HDD) and cooling degree days (CDD), weather normalization adjusts energy-consumption figures to factor out the variations in outside air temperature (Bizee, 2013). Figure 5 shows the formula used to create normalized weather data.

$$NekWh = \left(\frac{ekWh}{DDt}\right) x\ DDavg$$

NekWh = normalized ekWh, DDt = total degree days, DDavg = 5-year average total degree days.

Figure 5: *Weather Normalization Formula*

Table 10 identifies the normalized data and associated consumption of electricity and natural gas over the 12-month time frame. For the purpose of this research, exterior lighting has been removed from these 12-month consumption figures. Calculations showing exterior lighting statistics are included in Appendix B. For reference, throughout this report natural gas consumption has been converted to equivalent kilowatt hours using a conversion factor prescribed by the National Energy Board. One cubic meter ($1m^3$) of natural gas is equivalent to 10.28 kWh of energy consumption (NEB, 2011). Full utility data is included in Appendix C.

Table 10: *Store A– Normalized Energy Consumption Data (HDD, CDD, and 5-yr Avg DD taken from http://ottawa.weatherstats.ca)*

	12 Months Total Energy Consumption (ekWh)	**Total Degree Days (HDD and CDD)**	**kWh/Degree day**	**5-year Avg Degree Days**	**Normalized ekWh**	**EUI (ekWh/m^2)**
Store A	1,315,081	4711	279.15	4424.65	1,235,146	458.3

The United States Department of Energy (DOE) estimates annual energy-use intensity in this type of building to be approximately 233.1 ekWh/m^2 for climate zone 6A , which is approximately 52% less than Store A's energy intensity figure for one year (DOE, 2012).

To provide some additional context related to energy-use intensity figures for this building-type, ASHRAE estimates an EUI of 320 ekWh/m^2 for traditional designs in climate zone 6A (ASHRAE, 2011). The National Research Council of Canada (NRCAN) published a collection of energy data from commercial and industrial buildings across Canada. This report identifies a more modest EUI of 263.8 ekWh/m^2 for similar sized big-box stores (NRC, 2012).

The results from Store A show that electricity accounts for approximately 53% of the total energy used. Those figures will vary based on respective climates, however the differences noted between the U.S. DOE figures and Store A results are significant. For Store A, this may be the result of inefficient HID lighting in the building, given that the lighting accounted for 48% of the overall electricity consumption. Additionally, operational factors including lack of reliable lighting control measures could also have contributed to the high electrical usage.

The energy performance and subsequent energy-use intensity of Store A was very poor and well below the ASHRAE figures. The goal of this research, however, is not to offer an explanation for the poor performance of Store A, but rather to identify critical changes made with respect to the building systems and technologies and to quantify those improvements from an energy performance and LCCA perspective. By understanding the energy used by the individual systems in Store A, comparisons can then be made identifying improvements in the respective upgrades to Store B.

4.4 Store B Design

Construction on Store B began in 2010 and the store commenced operation in 2011. When the design of the store began, the timing coincided with the implementation of an overall energy strategy for this retailer who had recently established a number of energy reduction targets for its new store construction projects. As a result, Store B became the test location for design strategies aimed at significantly reducing the energy consumption of new stores in comparison to stores previously constructed. Using an integrated design approach, the design team identified, analysed, and made recommendations to senior executives on the technologies and strategies that were deemed to be most suitable in terms of life-cycle cost-effectiveness and overall energy reduction.

Throughout the process, design consultants and stakeholders engaged in a series of design meetings that allowed each discipline to voice opinions, concerns, and challenges related to the new store design. It was determined early on through this process that decisions made by one discipline often directly impacted the approach of another. For example, changes to lighting designs impacted heat gain in the building which in turn translated to different heating and cooling requirements. In order to thoroughly understand the implications of all the particular design decisions, ongoing energy simulations were performed by the design team which became the basis for making informed design decisions. Throughout the process, cost estimates were created and adjusted on an ongoing basis. By the time the final design was established, life-cycle costs had been estimated based on inputs from the design team and other stakeholders.

The baseline model was created in eQuest software using the prototypical design standards in place at the time of design, 2010. The primary baseline conditions and model inputs are summarized in Table 11.

Table 11: *Store B Baseline Working Model Inputs (Case Study Retailer Prototypical Design Parameters, 2010)*	
Building Envelope	• RSI 3.52 W/m^{2}K Composite panels on storefront • RSI 2.47 W/m^{2}K insulation in remaining exterior walls • All thermal breaks aligned • RSI 3.52 W/m^{2}K ballasted EPDM roof • Double glazed, low-e clearstory windows on 3 elevations of store

Electrical	• 8-lamp T-8 Fluorescent fixtures. Lighting power density 15.1 W/m^2 • Daylight and Occupancy Sensors throughout building • Plug load 5.4 W/m^2
Mechanical	• High Efficiency Lennox Energence RTUs in retail area (SEER Rating – 15.5) • Gas-fired unit heaters in warehouse (83% thermal efficiency) • CO2 sensors to utilize DCV

Misc	<u>Set-points</u>
	• Retail/Offices
	  o Occupied heat at 21*C, cool at 25*C
	  o Unoccupied heat at 15* C, cool at 31*C
	• Warehouse and Miscellaneous space
	  o Occupied heat at 21*C
	  o Unoccupied heat at 15*C
	
	Hours of operation - M-S – 10am to 9pm, Sunday 10am to 7pm

The total annual energy consumption for the Store B baseline model was identified in eQuest as 1,579,520 ekWh. This consumption equated to an estimated energy-use intensity of 263.3 eKwh/m^2. From this baseline model, end-use energy figures were established, as shown in Figure 6.

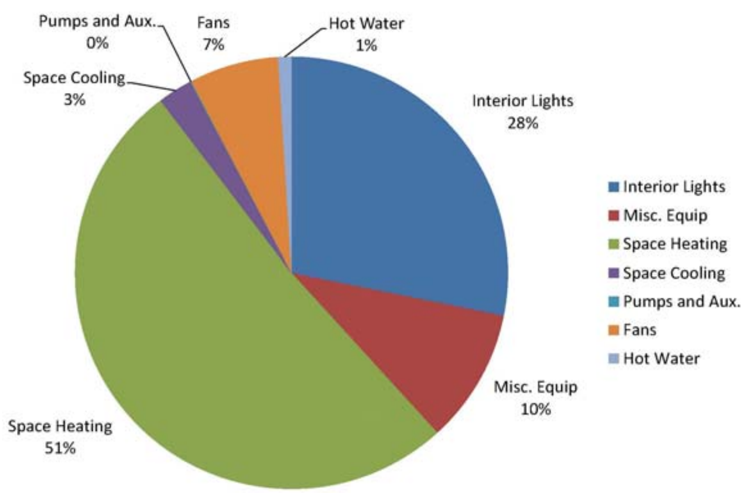


Figure 6: *Store B Baseline Working Model, Energy End Use Summary (eQuest Store B Baseline Energy Model, 2010)*

The baseline energy model developed for Store B allowed the design team to experiment with various inputs in order to produce an energy efficient design. All areas of the design were evaluated and potential improvements were identified and evaluated through energy modelling and life-cycle cost analysis.

Among the numerous strategies that were evaluated, revisions to the baseline model did not show significant energy-performance results when the thermal value of the building was upgraded. As a result, the building envelope was not altered in terms of its thermal value above the baseline design.

However, changes to the mechanical design of the building were significant. Where the baseline eQuest energy model used a conventional design strategy of packaged roof top units for the majority of the HVAC needs, the final design moved away from that solution to one that was more efficient from an energy consumption perspective and also more cost effective over the life of the building.

In terms of significant electrical changes, a simple strategy with respect to lighting yielded positive results in terms of energy reduction. The lighting design adopted for Store B was a solution that required lower capital investment and also had immediate benefits in terms of the amount of energy consumed. This strategy revealed that energy reduction solutions do not always require significant investment, but are the result of creative and collaborative design.

There were synergies in some of the design solutions that resulted in lower electrical consumption through the implementation of a more efficient mechanical design. By eliminating the packaged RTUs from the design, electrical consumption through a reduction in the number of fans and blowers was also reduced.

Key architectural, electrical, and mechanical elements implemented in the design of Store B are summarized in Table 12.

Table 12: *Summary of Implemented Strategies in Store B*

Item	Notes	Capital Premium*	Energy Implications
Building Envelope	Combination of IMPs and precast concrete panels • RSI 3.52 W/m^{2}K (R-20) metal siding on storefront • RSI 2.47 W/m^{2}K (R-14) insulation in remaining exterior walls • All thermal breaks aligned	No	Same as baseline
	Double glazed, low-e clearstory windows along 3 elevations of store	No	Same as baseline
	Mechanically fastened, white TPO roofing membrane • RSI 3.52 W/m^{2}K (R-20) white TPO roof	10%	Savings during cooling season due

			to minimization of heat gain through roof assembly
Elec. Design	6-lamp T-8 fluorescent retail fixtures rotated 45 degrees to long axis of store • Fixture hung at 5.2m (17') which wsa 450mm lower than conventional design. This gave an equivalent light level but did so with 25% fewer lamps. See Appendix F for lighting layout.	No (savings)	LPD reduction from 15.1 W/m^2 to 9.2 W/ m^2
	LED office lighting	15%	Estimated to reduce office lighting load by 10% from baseline
	Photocell on interior perimeter lights adjacent to clearstory windows • Permits perimeter retail T8 fixtures to shut off when ambient light level are sufficient	No	Same as baseline
	Occupancy sensors in offices, washrooms, warehouse spaces	No	Same as baseline
	High-Efficiency Condensing Boilers • The primary source of heating in Store B is through a hydronic (hot water) heating system. Using high-efficiency condensing boilers, hot water is distributed through a combination of in-floor systems and overhead unit heaters with fan coils. This is a closed loop system - the hot water that is distributed throughout the network of pipes is returned to the boiler and re-heated as required. Appendix F shows a schematic of the system layout.	15-20%	Estimated energy savings of 10% over baseline, but significant savings expected in terms of maintenance and replacement costs.
Mech. Design	Energy Recovery Ventilators • Prime building ventilation provided by ERVs. Benefits include: o Pre-heating of cool outdoor air in winter time with heat captured from exhaust air of building interior o Pre-cooling of outdoor air in summer months by exhausting hot-air before it enters the building	Y**	Estimated significant energy savings in summer and winter months
	Dedicated High-Efficiency AC units	N	
	Demand Control Ventilation (DCV) • In conjunction with ERV, ventilation air only provided when required by CO^2 levels in building	N	Estimated significant energy savings year round due to fans not running continuously to satisfy ventilation requirements

	Increased ventilation effectiveness • Conditioned and ventilated air is supplied at a high level and returned at a low level. By improving the ventilation efficiency in the store, the outdoor air requirements are reduced resulting in lower energy demands for both heating and cooling. Floor level return increases the efficiency in which outdoor air is distributed to occupants.	Y**	Estimated 25% reduction in outdoor air requirements are reduced
	Destratification Fans • Ceiling level fans operate continuously to avoid stratification of warm air at the higher levels of the building. This keeps a more consisten temperature throughout the building volume and lowers the heating and cooling demands on the building.	N	Same as baseline
* Capital premium estimates provided by design consultants as guideline estimates for budgeting purposes ** ERV and Ventilation strategy cost premiums were included in the 15-20% premium noted for high-efficiency boilers. Since the HVAC strategy was fundamentally being changed, cost premiums were identified as an overall HVAC premium of 15-20%, not on individual components.			

Figure 7 identifies the updated energy end-use breakdown as a result of the fundamental envelope, electrical, and mechanical strategies implemented in the final eQuest model for Store B.

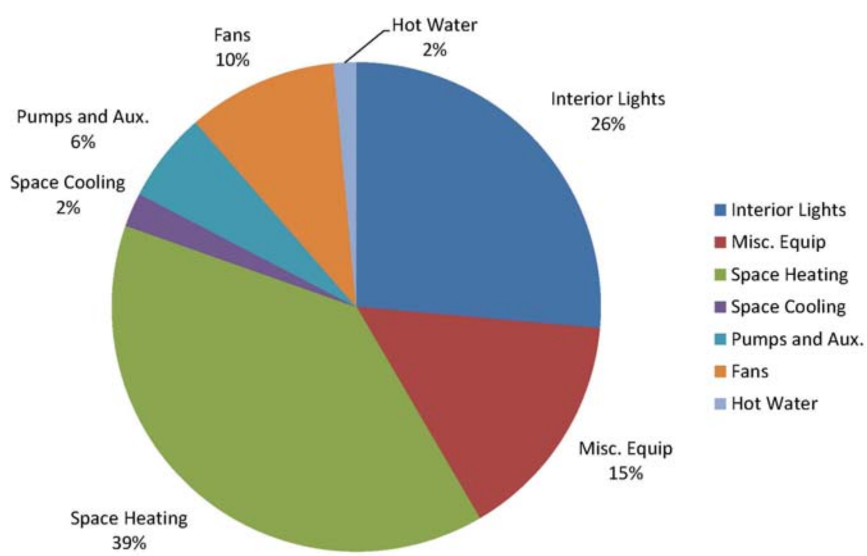


Figure 7: *Store B Final Design, Energy End Use Summary (eQuest Store B Final Energy Model, 2010)*

The total energy consumption for the Store B final eQuest model was identified as 1,005,970 ekWh. This consumption equated to an estimated energy-use intensity of 167.7 eKwh/m^2. When compared to the baseline model created for Store B, the energy consumption reduction between the two was 573,550 ekWh, or 36%.

To validate the energy impact of the lighting installed in Store B, an inventory of fixtures was completed and energy consumption was calculated. Figure 8 shows the annual electrical consumption attributed to interior lighting.

$$akWh = kW \ x \ t$$

$$akWh = 52kW \ x \ 4{,}500hrs$$

$$akWh = 234{,}000kWh$$

akWh = annual kilowatt hours, kW = total kilowatts, and t = time in hours

Figure 8: *Store B Annual Lighting Consumption*

At a rate of $0.10 per kWh, the first 12 months of lighting cost approximately $23,400.00. Details of these calculations are included in Appendix A.

Based on data provided by the electrical engineer of record, estimated lighting power density (LPD) in Store B is 8.9 W/m^2. This represents a decrease in LPD between Store A and Store B of 67%.

Similar to the approach taken in Store A, exterior lighting costs have been calculated and removed from the analysis of Store B. Appendix B identifies exterior lighting consumption statistics for reference.

4.5 Store B Energy Consumption

Energy consumption of Store B over its first 12-months of operation was established through the collection of natural gas and electricity utility data. This data was adjusted to normalize the information relative to specific climate data. Normalized energy use was calculated using the same formula used for Store A: $NekWh = \left(\frac{ekWh}{DDt}\right)\ x\ DDavg.$

Additionally, exterior lighting impacts were calculated and removed from the overall store electrical consumption totals. The normalized energy consumption data for Store B is presented in Table 13.

Table 13: *Store B – Normalized Energy Consumption Data (HDD, CDD, and 5-yr Avg DD taken from http://ottawa.weatherstats.ca)*

	12 Months Total Energy Consumption (ekWh)	**Total Degree Days (HDD and CDD)**	**kWh/Degree day**	**5-year Avg DD**	**Normalized ekWh**	**EUI (ekWh/m^2)**
Store B	1,445,765	4127.7	350.26	4424.65	1,549,774	258.3

5 Results and Analysis

A direct comparison of the data between Store A and Store B shows that the energy use intensity between the two stores is markedly different.

Table 14: *Energy Use Intensity (EUI) Comparison of Store A and Store B*

Store A	Store B
2,695 m^2	6,000 m^2
458.3 ekWh/m^2	258.3 ekWh/m^2

Store B showed an EUI that was a 44% improvement in comparison to Store A. Prior to identifying the specific design elements that contributed to this reduction, an appreciation of the differing building areas is required. In order to understand any impact of floor area difference on EUI, the Store B energy model was used to model the building specifications from Store A. The results of this are shown in Table 15.

Table 15: *Modelled Performance of Store A and B Using Same Building Area (eQuest Energy Models, 2010)*

	Store A Model	Store B Final Model
Total ekWh	2,003,300	1,005,970
EUI ekWh/m^2	333.9	167.7

The energy-use intensity results are very close in terms of percentage differences to the actual performance of the two buildings presented in Table 14. From this analysis, it can be concluded the floor area difference between Stores A and B, did not have a significant impact on the overall performance improvements observed in Store B.

The variation in modelled performance and actual performance of Store B is significant. Even though the focus of this research is not to quantify this variation, it is important to offer a brief explanation of this in order to provide some context. Significant time was spent analysing the initial 12 months of data for Store B and then comparing that information back to the assumptions in the final energy model. Audits of the store were also done. As a result of these audits and detailed analysis, several factors were identified as contributing to the actual energy consumption being higher than expected. Among the findings were the following:

- Store hours of operation varied from the assumptions in the energy model
- Set points for heating and cooling were not being adhered to with strict regularity
- The modulating function of the boilers was not being used which resulted in the boilers firing at full output at all times
- Additional energy-consuming equipment had been added to the store that was not accounted for in the model

These items collectively contributed to the variation in energy performance of Store B.

Table 16 identifies end-use consumption between the energy models developed for Store A, the Store B Baseline, and the Store B final design for the major electrical and mechanical components in the respective buildings.

Table 16: *Annual End-Use Energy Consumption Comparison (eQuest Energy Models, 2010)*

Electricity End-use	Store A Model ekWh/m²	Store B Baseline Model ekWh/m²	Store B Final Model ekWh/m²	% decrease from A to B Final	% decrease from B Model to B Final
Lighting	107.93	71.39	44.34	58.92%	37.89%
Misc. Equipment	25.53	25.54	25.54	nil	nil
Ventilation	20.75	16.93	16.66	19.73%	1.59%
Cooling	11.87	6.60	3.77	68.23%	42.88%
Pumps and Misc	0.13	0.14	10.02	Increase	Increase
Water Heating	2.50	2.50	2.50	nil	nil
Space Heating	165.17	140.17	64.83	60.75%	53.75%
Final	333.88	263.25	167.66	49.78%	36.31%

These figures highlight some significant improvements in all areas of the Store B design. In terms of electrical initiatives, overall there is a 39% decrease in consumption, primarily in the areas of lighting and cooling. From the Store A to Store B lighting designs, lighting power density dropped from 26.9 to 8.9 W/m^2 as a result of changing to T8 fluorescent fixtures and then from further design choices of rotating the fixtures 45-degrees and hanging them closer to the floor. Based on calculations by the electrical engineer and by floor observations upon completion, light levels were not impacted.

From a space heating perspective, there is a 61% reduction in natural gas consumption in Store B as a result of moving to hydronic heating and away from conventional packaged roof-top units.

While the critical areas of lighting, ventilation, cooling, and natural gas consumption all saw significant decrease in energy consumption, there is an increase in consumption with regard to pumps. The reason for this is due to the fact that the previous store design did not have pumps which circulated hot water through the hydronic loop. Of the total electricity consumed in Store B, pumps account for a 9% increase from the baseline condition.

The strategy to isolate the ventilation function proved to be a positive decision also as efficiency has improved through the implementation of energy recovery ventilators, demand controlled ventilation, and floor-level return- air strategies.

There is not any change in consumption relative to miscellaneous equipment or domestic hot water heating. Miscellaneous equipment typically includes plug and process loads, which is an area that is addressed in Section 6. Domestic hot water is heated using electric hot water tanks. Engineering calculations related to water consumption reveal that big-box stores do not use significant amounts of water. As a result of this, the decision was made to maintain individual hot water tanks for domestic hot-water purposes and to not link this service to the hydronic loop.

From the energy models, comparison of electrical consumption from the Store B baseline model to the Store B final model showed a decrease by 16.4%. In terms of natural gas, the same comparison yielded a reduction of 53.7%. Had Store B been constructed using the traditional systems and equipment, electricity costs would have been approximately $12,000 higher and natural gas costs would have increased by $110,000.00.

6 Evaluating Future Energy Reduction Strategies in Big-Box Store Design

There are a number of areas that offer potential improvements moving forward in big-box retail store design. The literature review identified strategies that many large retail organizations are actively evaluating. For the purpose of this research, the energy model developed for Store B is an effective tool to assist in an analysis of some specific energy-saving initiatives. Energy reduction measures presented as part of this research were modelled and analyzed in an attempt to qualify their potential for adoption within the big-box retail store community.

6.1 Building Envelope

Building envelope upgrades by way of improved thermal performance are challenging in this building type. An upgrade of the roof insulation in Store B from RSI 3.52 W/m^{2}K to RSI 5.28 W/m^{2}K yields a minimal performance improvement from an energy perspective, just over 2%. Capital costs, which will be presented in Section 7 are prohibitive given the return in energy savings.

Table 17: *Roof Insulation Upgrade (eQuest Energy Models, 2010)*

Energy-use Intensity (ekWh/m^2)	**Store B Final Model** (RSI 3.52 W/m^{2}K)	**Roof Upgrade** (RSI 5.28 W/m^{2}K)	**% Reduction**
Lighting	44.34	44.35	
Misc. Equipment	25.54	25.54	
Ventilation	16.66	16.66	
Cooling	3.77	4.41	
Pumps and Misc	10.02	9.92	
Water Heating	2.50	2.50	
Heating	64.83	60.50	
Total ekWh/m^2	167.66	163.88	2.26%

As the overall “energy pie” shrinks through the implementation of mechanical and electrical strategies, the building envelope will become a more prevalent factor in developing future reduction strategies. Given that lighting and mechanical systems are to the point where the current industry alternatives are not at the point of offering further consumption reductions, upgrades to building envelopes with respect to thermal performance and air leakage will need to be an important part of the discussion moving forward. Big-box store design has not evolved in a significant way with respect to envelope design, but a continued progression toward the next level of energy efficiency will require envelope strategies to be re-evaluated, regardless of the cost, if the intent is to reduce energy consumption.

6.2 Mechanical Strategies

6.2.1 Advanced Roof-top Units

In order to understand the potential energy performance impacts that may be achieved through the implementation of advanced RTUs, it was determined to use the energy model that was developed as the Store B baseline model for comparative purposes. The reason for the comparison to the baseline energy model as opposed to the energy model that represents the actual as-built condition is twofold. Primarily, the literature review established energy saving calculations attributable to the advanced RTUs in comparison to a series of baseline conditions, all of which had existing RTU designs. The data available to aide in the quantification of the advanced RTU performance is relative to more conventional RTU performance. The evaluation of advanced RTUs is being done through this research as an alternative to conventional RTU design, not hydronic-based solutions.

The results of this analysis use data from the Wang (2011) report that characterize energy savings of 29% when the advanced RTU is implemented in a cold climate. Of the 29% energy reduction, Wang's research concludes that 50% of that figure is attributable to electrical savings (Wang et.al, 2013).

When the Store B baseline model is analyzed and adjusted to reflect a 29% decrease in energy use attributable to the mechanical system, the annual energy cost decrease amounts to approximately $5,500.00 per year. Capital costs related to the advanced unit have shown to carry a premium of approximately 20% in comparison to other commercially used RTUs (ref). Further understanding of this aspect is presented as part of the life-cycle cost analysis.

The advanced RTU is the first commercially available unit to meet the specific energy-efficiency requirements as prescribed by the U.S. DOE. As more units continue to be developed to meet this specification, improved capital cost and possibly further advances in energy performance will make it a more attractive solution for big-box retail design.

6.3 Electrical Strategies

6.3.1 LED Lighting

Of the more promising strategies in the area of big-box design is the advancement in LED lighting technology. The literature review identified examples of retailers that have experimented with LED lighting in their retail areas, however very little information relative to cost or energy performance has been made available.

Calculations using appropriate lighting software have determined that a building of this size could be illuminated using LED's without sacrificing any lighting quality (H&J, 2014). By lighting the retail area of Store B with LED technology, the lighting power density drops to 6.13 W/m^2 which represents a decrease in LPD in this store by 27% over the previous T8 design (H&J, 2013). Table 18 identifies the results of adding the reduced LPD numbers to the eQuest energy model and presents the figures in terms of energy intensity. Under this scenario the area lighting consumption decreases by 19%. The heating energy increases by 6% to compensate for the loss of heat output of the traditional fluorescent fixtures. In all, energy-use intensity decreases by approximately 3%.

Table 18*: LED Lighting Upgrade to Store B Model (eQuest Energy Model, 2014)*

Energy-use Intensity (ekWh/m^2)	**Store B Final Model**	**Change to LED** (6.13 W/m^2)	**% Reduction**
Lighting	44.34	35.92	
Misc. Equipment	25.54	25.54	
Ventilation	16.66	16.82	
Cooling	3.77	3.25	
Pumps and Misc	10.02	10.08	
Water Heating	2.50	2.50	
Heating	64.83	68.83	
Total ekWh/m^2	167.66	162.95	2.81%

6.3.2 Plug and Process Load

Another evolving strategy aimed at reducing electrical consumption is in the area of plug and process loads (PPLs). In the Store B energy model, miscellaneous equipment accounts for approximately 19 % of the electricity consumed in the store. Based on the model, reducing the PPL in this store by 50% would yield a 12.6 % reduction in electricity consumption (Refer to Table 19), and an overall energy-use intensity reduction of nearly 4%. Beyond reducing the actual plug loads, reductions in these areas result in some cooling savings as well as a result of less heat being emitted from idle, yet powered, equipment. To achieve a 50% reduction would be a challenge, although strategies are available to assist in that goal. A more modest 25% reduction in plug-load would still yield an electricity reduction of 6%, and an overall energy-use intensity reduction of 2.1%.

Table 19: *Plug-Load Reduction Results (eQuest Energy Model, 2014)*

Energy-use Intensity (ekWh/m^2)	Store B Final Model	Store B Reduced Plug Load by 50%	% Reduction	Store B Reduced Plug Load by 25%	% Reduction
Lighting	44.34	44.35		44.35	
Misc. Equipment	25.54	12.77		19.16	
Ventilation	16.66	16.97		16.81	
Cooling	3.77	3.15		3.47	
Pumps and Misc	10.00	10.00		10.00	
Water Heating	2.50	2.50		2.50	
Heating	64.83	71.33		67.83	
Total ekWh/m^2	167.66	161.14	3.89%	164.11	2.12%

7 Life-Cycle Cost Analysis (LCCA)

Companies invest in strategies that improve the energy performance of their buildings for a number of reasons, not the least of which is the financial benefit from such investments. Energy saving technologies inherently result in lower energy costs which translates into an improved bottom line. The savings associated with reducing energy consumption can be substantial, especially in cases where owners build and operate a number of buildings and have a large portfolio of real estate assets.

In this research, the energy consumption differences between Store A and Store B have proven to be significant. In all major areas, the comparison of the two stores from an energy performance perspective has shown Store B to be outperforming Store A in all major categories, including the lighting performance as well as the heating, cooling, and ventilation performance. The final piece of the research analyzes the costs of these strategies from a life-cycle perspective and seeks to develop a true understanding of each initiative and its overall financial performance. Simple payback and ROI numbers are presented through Section 7. Details relating to these figures have been included in Appendix E.

7.1 Life-cycle Cost Analysis of Strategies Evaluated for Store B

For a big-box retailer that constructs and operates a wide portfolio of buildings, stores are generally constructed to a prototypical standard (ASHRAE, 2011). Even though each building has specific nuances that are unique to its design, there are common elements that are consistent from store to store. These include but are not limited to lighting technologies, mechanical equipment, and envelope construction materials. The costs of these components are basically understood from a unit perspective and it is generally understood through proper budgeting and forecasting ahead of time what the capital costs related to these building elements are going to be. Additionally, standard equipment that has been used over a long period of time comes with a degree of certainty regarding the maintenance requirements and costs that can be expected on an annual basis.

The LCCA performed for this research has made a number of reasonable assumptions related to rates of inflation, discount rates, and projected energy cost increases. As a standard set of figures for consistency, rates of inflation for maintenance and repair have been set at 2%, which is the Canadian Central Bank's target rate (McKenna, 2014). Energy costs are more difficult to predict given the volatility in the market, but for the purpose of this research, 2% annual increases have been estimated. The discount rate, which accounts for the future value of money, has been set at 10%, which falls within rates typically used in Canada for LCCA (Betterbricks, 2012).

Beyond these financial variables, incremental costs of the specific technologies have been established using cost information gathered from industry professionals, design engineers, and contract documents. A variety of sources have been used to quantify the costs associated with capital investment and maintenance and repair expenses. The author's own expertise has aided in this assessment as a result of years of work within the big-box design community. As a general rule, premium costs have been identified as the extra capital required for the implementation of different technologies beyond the prototypical design decisions.

The following analysis outlines the strategies that were implemented in Store B and presents a life-cycle cost analysis of those same strategies. The analysis shows capital cost premiums (incremental cost), annual energy savings, annual maintenance costs, and also rates of inflation and discount rates. For ease of reference, some of the mechanical strategies have been bundled together, which according to the DOE is an acceptable practice (Fuller, 2005). Furthermore, the report states that energy managers should take an integrated systems approach when defining the scope of a building retrofit or other energy-related project. In many cases, a decision about one ECM will directly affect the scope or type and thus the cost-effectiveness of other ECMs (Fuller, 2005).

Bundling of strategies becomes important in one particular case. Traditional store design across the big-box retail industry generally relies on packaged rooftop units to provide heating, cooling, and ventilation requirements for the building (Studer et.al. 2012). There are variables in the replacement of the traditional HVAC system that need to be understood. For example, the design of Store B resulted in the removal of typical packaged RTUs and replaced these units with three separate systems. It would not be practical to do a calculation showing a straight one-for-one replacement in this case because, in fact, the entire system was different and three separate systems replaced one. If roof-top equipment was being replaced with new roof-top equipment on a one-for-one basis, then a direct comparison of each unit could be performed. In the case of this research, however, analysis from a system-level perspective is a more reliable method and the LCCA on the mechanical design has been bundled into one analysis.

The LCCA has been completed using a simple, generic life-cycle energy savings calculator (Betterbricks, 2012)

7.1.1 Building Envelope

7.1.1.1 Insulation

Increasing the thermal performance of the building envelope represents a significant cost. Data obtained from contractor pricing and industry catalogues (i.e. Yardsticks) estimates costs to be in the region of $5.38/m^2 ($0.50/ft^2) for an increase of RSI 0.88 W/m^2. For a building the size of Store B, that represents a capital premium of in excess of $60,000.00 for a modest increase in thermal performance. Energy modelling was performed on the Store B baseline that increased the roof insulation from RSI 3.52 W/m^2 to RSI 5.28 W/m^2. When analyzed using the actual utility data from Store B, the modest improvement of 2% in energy performance would yield annual heating cost reductions of approximately $3,000.00. This is based on natural gas price of $0.30/m^3 and electricity costs of $0.10/kWh (Inviro, 2012). For a capital premium of $60,000.00 improving the thermal resistance value of the roof carries a significant payback.

Table 20: *LCCA of Thermal Increase to Store B Roof*

Simple Payback Years (SPB)	30.00
Simple Return on Investment (ROI)	5.00%
Net Present Value of Savings (NPV)	$ (40,768)
Internal Rate of Return (IRR)	-2%

The study period for the increased roof insulation LCCA was set at 20 years. The simple payback was calculated at 30 years, with an ROI of only 5%. The total cost of ownership over the 20 year period of this investment based on the NPV of the savings is a cost in excess of $40,000.00

7.1.2 Electrical

7.1.2.1 Lighting

The lighting strategy implemented in Store B did not require a LCCA as there was less capital required as well as immediate energy savings in comparison to the previous lighting design. For point of reference, however, Table 21 was included to identify a negative simple payback and ROI. The lighting strategy for Store B used the same technology, T8 linear fluorescent fixtures, as the baseline model for Store B. The advancement in performance, however, was in the strategy to lower the mounting height of the fixtures, turn them on a 45-degree angle, and use 2-fewer lamps per fixture. Capital costs decreased, annual energy costs decreased, 5-year re-lamping costs decreased, and end-of-life replacement costs decreased relative to the baseline case. A breakdown of these figures are included in Appendix C .

Table 21: *LCCA of 8-lamp to 6-lamp T8 fixture*

Simple Payback Years (SPB)	-8.00
Simple Return on Investment (ROI)	-
Net Present Value of Savings (NPV)	$ 22,137

7.1.3 Mechanical

7.1.3.1 HVAC Design

The fundamental change of the mechanical system from a packaged solution to individual components resulted in a significant overall reduction in annual energy costs. Worth noting is that due to the addition of hydronic heating, electrical consumption actually rose slightly between the Store B baseline model and the Store B final design. This is not particularly surprising given the fact the hydronic system is specific to heating the building and the pumps required to circulate hot water resulted in an increase to the electrical consumption. The natural gas savings, however, was significant and far exceeded any losses incurred as a result of the electrical consumption increase.

The net annual energy costs savings that can be attributed to the HVAC design, which includes the hydronic heating, energy recovery, and dedicated cooling units, amounts to approximately $87,000. This figure was established by using data from the utility bills and then assigning the specific reduction (or increased) percentages from the Store B final energy model.

To put these figures into perspective from an LCCA viewpoint, Table 22 identifies a comparison between the traditional RTU design in comparison to the new, energy efficient system with Store B as the building. Financial parameters include incremental capital costs, annual maintenance and anticipated repairs, energy savings, and end-of-life replacement and disposal costs.

Table 22: *LCCA of Mechanical Strategy Comparing Store B Baseline to Store B Final*

Simple Payback Years (SPB)	2.04
Simple Return on Investment (ROI)	51.58%
Net Present Value of Savings (NPV)	$ 613,077
Internal Rate of Return (IRR)	52%

The study period for this strategy was estimated to be 15 years, since that is when most traditional HVAC equipment requires replacement. Using this timeline, the results of the analysis show that the simple payback is slightly over 2 years. The ROI is nearly 52%, and at the end of 15 years the NPV is in excess of $613,000.00

By analyzing the HVAC strategy from an LCCA perspective, the numbers clearly reveal a significant benefit to the new hydronic system. If the changes to the design had of been evaluated on initial capital costs alone, the decision perhaps would not have been made to invest in this energy-efficient method providing the appropriate thermal requirements to this store given the capital premium associated with the change.

7.2 LCCA of Future Strategies in Big-box Store Design

To evaluate the benefits of potential strategies going forward from an LCCA perspective, the same principles apply that were used to evaluate the strategies implemented in Store B.

7.2.1 Lighting

Solid State Lighting (SSL), or LED as it is more commonly known, is certain to become the next standard lighting type in big-box retail stores. Cost of the technology varies, but discussions with industry personnel and information gathered through research have identified some fairly consistent pricing with respect to big-box retail applications. The energy modelling performed as part of this research identified a 38% reduction in lighting consumption when comparing the 6-lamp T8 fluorescent fixture with the proposed LED alternative. As a result of that output, if Store B were to be constructed using the LED technology, annual electricity costs would decrease by approximately $5,000.00.

Table 23: LCCA of LED versus T8 Lighting

Simple Payback Years (SPB)	3.67
Simple Return on Investment (ROI)	27.27%
Net Present Value of Savings (NPV)	$ 37,603
Internal Rate of Return (IRR)	30%

The expected lifespan of the LED lighting is 20 years. Over that period of time, the LCCA reveals a simple payback of 3.67 years, and an ROI slightly above 27%. The NPV of the projected savings is just over $37,000.00.

Two distinct advantages to LED technology are in the energy savings as well as in the life-time maintenance costs. Essentially LED fixtures don't require maintenance for their lifespan, which in the case of Store B would be just over 20 years.

7.2.2 Plug Load Reductions

Strategies aimed at reducing plug loads have a wide range of applications starting with simple solutions such as educating owners to turn equipment when not in use, to the implementation of timers and controls, to the purchasing of more efficient equipment. Each strategy carries with it specific and wide ranging costs.

Educational strategies aimed at providing owners with a set of best-practices can easily be implemented without the incurrence of capital. Small control strategies through advanced power strips and timers can be added to office equipment and floor-area monitors and sales-related equipment for minimal investment. Larger control strategies aimed at more significant components such as energy consuming sales product do carry higher capital costs, but payback times are estimated to be less than two years in most cases (Inviro, 2012). Cost estimates for the various control strategies are in the range of $10,000 to $15,000 per location (Inviro, Personal Communication, 2013). This may include a combination of strategies ranging from controllable outlets to advanced power strips to education around electricity use of equipment.

In terms of the energy saving potential of a well-planned plug-load reduction strategy, energy modelling revealed significant potential opportunity. Through energy modelling, a 25-percent reduction in plug load contributed to a 2-percent reduction in electrical consumption, or approximately 20,000 kWh in Store B's measured electrical use. This translates to an annual energy savings of $2,000.00 based on estimated costs of $0.10 per kWh and results in a payback of 7.5 years. In terms of the LCCA related to such an initiative, maintenance costs would be minimal, if anything.

Table 24: *LCCA of Plug-load Reduction Strategies*

Simple Payback Years (SPB)	7.50
Simple Return on Investment (ROI)	13.33%
Net Present Value of Savings (NPV)	$ 1,648
Internal Rate of Return (IRR)	12%

The relatively small capital premium associated with plug load reduction strategies makes it potential strategy, even though the simple payback is higher than some of the other approaches. However, the ROI of 13% is attractive, and as the cost of energy increases, strategies such as this do become increasingly appealing.

7.2.3 Advanced Roof-top Units

The success of the HVAC strategy implemented in Store B using hydronic heating, energy recovery ventilators, and dedicated cooling resulted in significant energy savings and a very attractive solution from an LCCA perspective. In order to assess alternative strategies and understand where the industry at large might be going, however, a review of the results from the DOEs RTU challenge is appropriate.

The advanced RTU was not specifically modelled as part of this research. There was data discovered in the literature review, however, that provided some insight into potential energy performance of this new, high-efficient equipment. Using the published figures as a guideline, it is possible to assess the Daikin units from an LCCA perspective in an attempt to quantify likelihood of mass acceptance of these units.

The research report by Wang (2013) reported an energy reduction of 29% when compared to existing RTU equipment that met the U.S. federal requirements for equipment energy performance (Wang, et.al. 2013). Of the 29% reduction, 50% of that was attributed to electricity use. Using these figures as guidelines, the energy costs from the baseline Store B energy model could have been reduced by $5,500.00 per year. Table 25 identifies the LCCA associated with this potential strategy.

Table 25: *LCCA of Advanced Rooftop Strategies*

Simple Payback Years (SPB)	32.00
Simple Return on Investment (ROI)	18.75%
Net Present Value of Savings (NPV)	$ (23,994)
Internal Rate of Return (IRR)	-7%

The advanced RTU analysis is examined over a 15 year lifespan as that is a standard timeframe for packaged RTUs to remain in working order. Based on the analysis, the simple payback at this point is 32 years. The NPV of the associated savings over this period is a negative number, meaning the cost of the system is greater than the savings over its 15 year lifespan. At this point, this strategy does not appear to offer a financial return that would make it attractive to most retailers as an upgrade to their existing HVAC design strategies.

8 Conclusions

Big-box retail buildings, like all retail stores, are constructed with the main goal of providing a shopping environment that encourages consumers to purchase goods. In recent years, large retail organizations have started to pursue energy reduction strategies as a way of curbing operating expenses as well incurring some goodwill with consumers as being good environmental stewards. Many retailers have been experimenting and implementing technologies for the past several years aimed at reducing the energy consumption of their stores. Through a number of individual and collaborative efforts, strategies in lighting, heating and cooling, and ventilation have been tested using a number of different technologies along the way. These strategies have all been developed while maintaining the overarching goal of not negatively impacting the sales environment. Energy savings at the expense of decreased sales is not a viable solution.

This research sought to provide answers to the following research questions:

1) How did Store A and Store B compare in terms of energy performance based on the utility data available for each location, and what were the energy and life-cycle cost benefits of the specific building efficiency improvements?

2) Looking forward, what are the most favourable technologies currently being evaluated in the big-box design community in terms of life-cycle costs as they pertain to future big-box store designs?

Performance results specific to the technological advancements made in Store B were proven to be significant and beneficial from both energy and life-cycle cost perspectives. Furthermore, the research reaffirmed that even ubiquitous building types, such as big-box retail, can benefit financially and environmentally through the use of good engineering practices and design strategies.

Among the findings, the research identified fundamental changes to the manner in which a building of this type can be heated, cooled, and ventilated. A number of design decisions resulted in a big-box store that was markedly different from previous stores built by this retailer and others in the industry. Through unique approaches to lighting as well as through the implementation of new heating, cooling, and ventilation strategies, the store demonstrated an energy-use intensity reduction of 44% when compared to an older store that used conventional design solutions.

Beyond energy-related benefits, the research itemized the implemented energy-related initiatives in an attempt to justify them from a life-cycle cost perspective. In each scenario, the results of this LCCA concluded that decisions made with respect to the design of this store were not only environmentally responsible, but they were financially responsible as well. In the case of the alteration to the lighting design from previous generations of stores, the pay-back was instantaneous as the capital investment was less than it had previously been. Regarding the mechanical design, LCCA revealed that in under two years, there was a return on the initial investment and an impressive ROI of 53% was achieved as a result of this design.

In addition to the strategies implemented and analyzed in one store, the research evaluated potential technological advancements regarding the future of big-box design. In areas related to improvements in electricity consumption, new lighting solutions focusing on LED technology are showing signs of industry-wide adoption. The financial benefits of the technology are to the point where increase in capital is recovered in approximately 3 years, and the ROI of such initiatives ranges around XX%.

Beyond lighting improvements, strategies to curb plug loads in retail facilities are gaining momentum and many effective ways of combating this source of consumption are available for little or no cost. In some ways, good practice is as effective at combating plug and process loads as are technological solutions.

Advancements in mechanical design are also getting significant attention from the industry. Currently, the success of the hydronic heating model implemented in Store B appears to have set a new benchmark in big-box store design, however, advancements in RTU technology are ongoing. Recently, advanced RTUs have been developed that meet a higher level of efficiency than previous designs but the LCCA has concluded that the financial benefit does not yet justify the widespread implementation of this technology.

Finally, this research has identified a more collaborative environment than previously assumed. The ongoing collaboration between organizations, industry personnel, and financial stakeholders will continue to yield results in terms of new technologies and strategies that will benefit retailers and other business operators alike into the future.

9 Appendix

Appendix A: Interior Lighting Calculations – Store A and Store B

Store A - Interior Lighting Consumption*

Lighting Type	Fixture Name	Description	No. of Fixtures	No. of Lamps	Wattage (kW)	Estimated Annual Hrs. Operation	Annual kWh
Interior	A	HID Metal Halide	165	1	0.4	4500	297,000
Interior	B	Fluorescent Tube	26	4	0.032	4500	14,976
Interior	C	Fluorescent Tube	18	4	0.032	4500	10,368
Interior	D	Fluorescent Tube	60	2	0.032	4500	17,280
Interior	D1	Fluorescent Tube	11	1	0.032	4500	1,584
Total							341,208

Store B - Interior Lighting Consumption*

Lighting Type	Fixture Name	Description	No. of Fixtures	No. of Lamps	Wattage (kW)	Estimated Annual Hrs. Operation	Annual kWh
Interior	F	T8 Fluorescent	207	6	0.028	4500	156,492
Interior	M	Pot Light	14	1	0.025	4500	1,575
Interior	K	T8 Fluorescent	23	1	0.048	4500	4,968
Interior	D	T8 Fluorescent	174	2	0.028	4500	43,848
Interior	B1	LED	19	1	0.054	4500	4,617
Interior	C3	T8 Fluorescent	34	4	0.028	4500	17,136
Interior	C	T8 Fluorescent	10	4	0.028	4500	5,040
Total							233,676

*source: Case Study Retailer Construction Documents

Appendix B: Exterior Lighting Calculations – Store A and Store B

Store A - Exterior Lighting Consumption*

Lighting Type	Fixture Name	Description	No. of Fixtures	No. of Lamps	Wattage (kW)	Estimated Annual Hrs. Operation	Annual kWh
Exterior	L2	Metal Halide - Pole Mount	6	1	1	2190	13,140
Exterior	L3A	Metal Halide - Pole Mount Flood Light	3	1	0.4	2190	2,628
Exterior	J	Metal Halide Wall Mount	10	1	0.4	2190	8,760
Exterior	G	Metal Halide Wall Mount	5	1	0.175	2190	1,916
Total							26,444

Exterior lights estimated to be on for 6hrs per day, on average

Store B - Exterior Lighting Consumption*

Lighting Type	Fixture Name	Description	No. of Fixtures	No. of Lamps	Wattage (kW)	Estimated Annual Hrs. Operation	Annual kWh
Exterior	L1	LED Pole Mount	16		0.285	1460	6657.6
Exterior	L2	LED Pole Mount	6		0.285	1460	2496.6
Exterior	J	LED Wall Mount	9		0.027	3650	886.95
Exterior	G	LED Wall Mount	9		0.027	3650	886.95
Total							10,928

Exterior Pole lights estimated to be on for 4hrs per day, on average
Exterior Wall Mounts estimated to be on 10 hrs per day, on average

*source: Case Study Retailer Construction Documents

Appendix C: Utility Data – Store A and Store B

Store A - Energy Consumption Data

Electricity	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Total	Ext Lighting	**Total (Ext Lighting Removed)**
kWh	67,098	61,368	63,915	68,753	57,803	52,456	59,968	61,623	52,838	56,148	54,238	57,294	713,502	26,444	**687,058**
Natural Gas															
M^3	717	246	14	144	1,040	3,414	7,966	10,589	14,385	10,881	9,042	2,558	60,996		
ekWh**	7,382	2,533	144	1,483	10,708	35,151	82,019	109,026	148,110	112,032	93,098	26,338	628,023		**628,023**
Total ekWh	74,480	63,901	64,059	70,236	68,511	87,607	141,987	170,649	200,948	168,180	147,336	83,632	1,341,525		**1,315,081**

Store B - Energy Consumption Data

Electricity	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Total	Ext Lighting	**Total (Ext Lighting Removed)**
kWh	56,021	64,424	79,702	58,313	65,188	60,000	60,604	78,429	63,405	75,119	48,127	62,132	771,464	10,928	**760,536**
Natural Gas															
M3	2,663	357	65	181	1,836	5,938	9,830	19,034	11,428	9,025	3,787	2,408	66,552		
ekWh**	27,419	3,676	669	1,864	18,904	61,138	101,211	195,977	117,664	92,923	38,991	24,793	685,229		**685,229**
Total ekWh	83,440	68,100	80,371	60,177	84,092	121,138	161,815	274,406	181,069	168,042	87,118	86,925	1,456,693		**1,445,765**

**ekWh - 1m^3 of natural gas use = 10.28 ekWh of energy consumption (Source: National Energy Board)

Appendix D: Ottawa Weather Data

Ottawa 5-year CDD	http://ottawa.weatherstats.ca/charts/cdd-5years.html			
008 - Q4	0			
2009 - Q1	0	Q1 Avg	Jan-Mar	0
2009 - Q2	50.6	Q2 Avg	Apr-Jun	69.78
2009 - Q3	130	Q3 Avg	Jul-Sept	218.92
2009 - Q4	0	Q4 Avg	Oct-Dec	0.35
2010 - Q1	0	**Total**		**289.05**
2010 - Q2	73.2			
2010 - Q3	270			
2010 - Q4	0			
2011 - Q1	0			
2011 - Q2	75.8			
2011 - Q3	252.7			
2011 - Q4	1.4			
2012 - Q1	0			
2012 - Q2	94.6			
2012 - Q3	260.4			
2012 - Q4	0			
2013 - Q1	0			
2013 - Q2	54.7			
2013 - Q3	181.5			
2013 - Q4	0.7			
2014 - Q1	0			

Ottawa 5-year HDD	http://ottawa.weatherstats.ca/charts/hd			
08 - Q4	1621.3			
2009 - Q1	2289.3	Q1 Avg	Jan-Mar	1966.967
2009 - Q2	566.3	Q2 Avg	Apr-Jun	509.28
2009 - Q3	145.7	Q3 Avg	Jul-Sept	124.92
2009 - Q4	1532.3	Q4 Avg	Oct-Dec	1534.433
2010 - Q1	1905.7	**Total**		**4135.6**
2010 - Q2	408			
2010 - Q3	131.2			
2010 - Q4	1534	Total DD		4424.65
2011 - Q1	2254.9			
2011 - Q2	508.7			
2011 - Q3	57.7			
2011 - Q4	1323.7			
2012 - Q1	1962.7			
2012 - Q2	496.3			
2012 - Q3	135.7			
2012 - Q4	1513.7			
2013 - Q1	2181.7			
2013 - Q2	567.1			
2013 - Q3	154.3			
2013 - Q4	1681.6			
2014 - Q1	1207.5			

Store A Baseline is June 2010 to May 2011

		CDD	HDD	
Jun	Q2 10	7.4	22.2	
July				
Aug	Q3 2010	270	131.2	
Sept				
Oct				
Nov	Q4 2010	0	1534	
Dec				
Jan				
Feb	Q1 2011	0	2254.9	
Mar				
April	Q2 2011	1.1	490.2	
May				
Total		278.5	4432.5	4711

Store B Baseline is June 2011 to May 2012

		CDD	HDD	
Jun	Q2 11	21.9	18.5	
July				
Aug	Q3 2011	252.7	57.7	
Sept				
Oct				
Nov	Q4 2011	1.4	1323.7	
Dec				
Jan				
Feb	Q1 2012	0	1962.7	
Mar				
April	Q2 2012	24.2	464.9	
May				
Total		300.2	3827.5	4127.7

Appendix E: LCCA Supporting Figures

Client	Big Box Retail Store
Project	Replace 8-Lamp T8 fixtures with 6-Lamp T8 Fixtures
Alternative Description	

Inputs		Results	
Study Period (Years)	10	Simple Payback Years (SPB)	-8.00
M&O Inflation Rate	2.0%	Simple Return on Investment (ROI)	-20.83%
Electricity Inflation Rate	2.0%		
Fuel Inflation Rate	2.0%	Net Present Value of Savings (NPV)	$ 22,137
Hurdle (Re-invest) Rate	13.0%	Internal Rate of Return (IRR)	#NUM!
Discount Rate	10.0%	Modified Internal Rate of Return (MIRR)	#DIV/0!
Initial Incremental Cost	$ (12,000)		
Annual M&O Cost	$ 1,000		
Annual Electricity Savings	$ 2,500		
Annual Fuel Savings	$ -	Total Annual Savings (Initial)	$ 1,500

Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ 12,000				$ 12,000	$ 12,000
1		$ (1,020)	$ 2,550	$ -	$ 1,530	$ 1,391
2		$ (1,040)	$ 2,601	$ -	$ 1,561	$ 1,290
3		$ (1,061)	$ 2,653	$ -	$ 1,592	$ 1,196
4		$ (1,082)	$ 2,706	$ -	$ 1,624	$ 1,109
5		$ (1,104)	$ 2,760	$ -	$ 1,656	$ 1,028
6		$ (1,126)	$ 2,815	$ -	$ 1,689	$ 954
7		$ (1,149)	$ 2,872	$ -	$ 1,723	$ 884
8		$ (1,172)	$ 2,929	$ -	$ 1,757	$ 820
9		$ (1,195)	$ 2,988	$ -	$ 1,793	$ 760
10		$ (1,219)	$ 3,047	$ -	$ 1,828	$ 705

Client	Big Box Retail Store
Project	Improve Thermal Resistance in Roof
Alternative Description	Increase Roof Insulation from RSI 3.52W/m^2 to RSI 5.28 W/m^2

Inputs		Results	
Study Period (Years)	20	Simple Payback Years (SPB)	30.00
M&O Inflation Rate	2.0%	Simple Return on Investment (ROI)	5.00%
Electricity Inflation Rate	2.0%		
Fuel Inflation Rate	2.0%	Net Present Value of Savings (NPV)	$ (40,132)
Hurdle (Re-invest) Rate	13.0%	Internal Rate of Return (IRR)	-2%
Discount Rate	10.0%	Modified Internal Rate of Return (MIRR)	6%
Initial Incremental Cost	$ 60,000		
Annual M&O Cost	$ 1,000		
Annual Electricity Savings	$ 1,000		
Annual Fuel Savings	$ 2,000	Total Annual Savings (Initial)	$ 2,000

Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ (60,000)				$ (60,000)	$ (60,000)
1		$ (1,020)	$ 1,020	$ 2,040	$ 2,040	$ 1,855
2		$ (1,040)	$ 1,040	$ 2,081	$ 2,081	$ 1,720
3		$ (1,061)	$ 1,061	$ 2,122	$ 2,122	$ 1,595
4		$ (1,082)	$ 1,082	$ 2,165	$ 2,165	$ 1,479
5		$ (1,104)	$ 1,104	$ 2,208	$ 2,208	$ 1,371
6		$ (1,126)	$ 1,126	$ 2,252	$ 2,252	$ 1,271
7		$ (1,149)	$ 1,149	$ 2,297	$ 2,297	$ 1,179
8		$ (1,172)	$ 1,172	$ 2,343	$ 2,343	$ 1,093
9		$ (1,195)	$ 1,195	$ 2,390	$ 2,390	$ 1,014
10		$ (1,219)	$ 1,219	$ 2,438	$ 2,438	$ 940
11		$ (1,243)	$ 1,243	$ 2,487	$ 2,487	$ 872
12		$ (1,268)	$ 1,268	$ 2,536	$ 2,536	$ 808
13		$ (1,294)	$ 1,294	$ 2,587	$ 2,587	$ 749
14		$ (1,319)	$ 1,319	$ 2,639	$ 2,639	$ 695
15		$ (1,346)	$ 1,346	$ 2,692	$ 2,692	$ 644
16		$ (1,373)	$ 1,373	$ 2,746	$ 2,746	$ 598
17		$ (1,400)	$ 1,400	$ 2,800	$ 2,800	$ 554
18		$ (1,428)	$ 1,428	$ 2,856	$ 2,856	$ 514
19		$ (1,457)	$ 1,457	$ 2,914	$ 2,914	$ 476
20		$ (1,486)	$ 1,486	$ 2,972	$ 2,972	$ 442

Client	Big-box Retail Store
Project	Mechanical Strategy
Alternative Description	Replace conventional HVAC design with high efficiency boilers, ERV, and dedicated cooling

Inputs		Results	
Study Period (Years)	15	Simple Payback Years (SPB)	2.04
M&O Inflation Rate	2.0%	Simple Return on Investment (ROI)	51.58%
Electricity Inflation Rate	2.0%		
Fuel Inflation Rate	2.0%	Net Present Value of Savings (NPV)	$ 613,713
Hurdle (Re-invest) Rate	13.0%	Internal Rate of Return (IRR)	52%
Discount Rate	10.0%	Modified Internal Rate of Return (MIRR)	23%
Initial Incremental Cost	$ 190,000		
Annual M&O Cost	$ 5,000		
Annual Electricity Savings	$ (12,000)		
Annual Fuel Savings	$ 110,000	Total Annual Savings (Initial)	$ 93,000

Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ (190,000)				$ (190,000)	$ (190,000)
1		$ (5,100)	$ (12,240)	$ 112,200	$ 94,860	$ 86,236
2		$ (5,202)	$ (12,485)	$ 114,444	$ 96,757	$ 79,965
3		$ (5,306)	$ (12,734)	$ 116,733	$ 98,692	$ 74,149
4		$ (5,412)	$ (12,989)	$ 119,068	$ 100,666	$ 68,756
5		$ (5,520)	$ (13,249)	$ 121,449	$ 102,680	$ 63,756
6		$ (5,631)	$ (13,514)	$ 123,878	$ 104,733	$ 59,119
7		$ (5,743)	$ (13,784)	$ 126,355	$ 106,828	$ 54,820
8		$ (5,858)	$ (14,060)	$ 128,883	$ 108,964	$ 50,833
9		$ (5,975)	$ (14,341)	$ 131,460	$ 111,144	$ 47,136
10		$ (6,095)	$ (14,628)	$ 134,089	$ 113,366	$ 43,708
11		$ (6,217)	$ (14,920)	$ 136,771	$ 115,634	$ 40,529
12		$ (6,341)	$ (15,219)	$ 139,507	$ 117,946	$ 37,581
13		$ (6,468)	$ (15,523)	$ 142,297	$ 120,305	$ 34,848
14		$ (6,597)	$ (15,834)	$ 145,143	$ 122,712	$ 32,314
15		$ (6,729)	$ (16,150)	$ 148,046	$ 125,166	$ 29,964

Client	Big Box Retail Store
Project	LED Lighting
Alternative Description	

Inputs	
Study Period (Years)	20
M&O Inflation Rate	2.0%
Electricity Inflation Rate	2.0%
Fuel Inflation Rate	2.0%
Hurdle (Re-invest) Rate	13.0%
Discount Rate	10.0%
Initial Incremental Cost	$ 22,000
Annual M&O Cost	$ -
Annual Electricity Savings	$ 6,000
Annual Fuel Savings	$ -

Results	
Simple Payback Years (SPB)	3.67
Simple Return on Investment (ROI)	27.27%
Net Present Value of Savings (NPV)	$ 37,603
Internal Rate of Return (IRR)	30%
Modified Internal Rate of Return (MIRR)	18%
Total Annual Savings (Initial)	$ 6,000

Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ (22,000)				$ (22,000)	$ (22,000)
1		$ -	$ 6,120	$ -	$ 6,120	$ 5,564
2		$ -	$ 6,242	$ -	$ 6,242	$ 5,159
3		$ -	$ 6,367	$ -	$ 6,367	$ 4,784
4		$ -	$ 6,495	$ -	$ 6,495	$ 4,436
5		$ -	$ 6,624	$ -	$ 6,624	$ 4,113
6		$ -	$ 6,757	$ -	$ 6,757	$ 3,814
7		$ -	$ 6,892	$ -	$ 6,892	$ 3,537
8		$ -	$ 7,030	$ -	$ 7,030	$ 3,280
9		$ -	$ 7,171	$ -	$ 7,171	$ 3,041
10		$ -	$ 7,314	$ -	$ 7,314	$ 2,820
11		$ -	$ 7,460	$ -	$ 7,460	$ 2,615
12		$ -	$ 7,609	$ -	$ 7,609	$ 2,425
13		$ -	$ 7,762	$ -	$ 7,762	$ 2,248
14		$ -	$ 7,917	$ -	$ 7,917	$ 2,085
15		$ -	$ 8,075	$ -	$ 8,075	$ 1,933
16		$ -	$ 8,237	$ -	$ 8,237	$ 1,793
17		$ -	$ 8,401	$ -	$ 8,401	$ 1,662
18		$ -	$ 8,569	$ -	$ 8,569	$ 1,541
19		$ -	$ 8,741	$ -	$ 8,741	$ 1,429
20		$ -	$ 8,916	$ -	$ 8,916	$ 1,325

Client	National Retailer
Project	25% Plug and Proces Load Reductions
Alternative Description	

Inputs	
Study Period (Years)	15
M&O Inflation Rate	2.0%
Electricity Inflation Rate	2.0%
Fuel Inflation Rate	2.0%
Hurdle (Re-invest) Rate	13.0%
Discount Rate	10.0%
Initial Incremental Cost	$ 15,000
Annual M&O Cost	$ -
Annual Electricity Savings	$ 2,000
Annual Fuel Savings	$ -

Results	
Simple Payback Years (SPB)	7.50
Simple Return on Investment (ROI)	13.33%
Net Present Value of Savings (NPV)	$ 2,284
Internal Rate of Return (IRR)	12%
Modified Internal Rate of Return (MIRR)	13%
Total Annual Savings (Initial)	$ 2,000

Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ (15,000)				$ (15,000)	$ (15,000)
1		$ -	$ 2,040	$ -	$ 2,040	$ 1,855
2		$ -	$ 2,081	$ -	$ 2,081	$ 1,720
3		$ -	$ 2,122	$ -	$ 2,122	$ 1,595
4		$ -	$ 2,165	$ -	$ 2,165	$ 1,479
5		$ -	$ 2,208	$ -	$ 2,208	$ 1,371
6		$ -	$ 2,252	$ -	$ 2,252	$ 1,271
7		$ -	$ 2,297	$ -	$ 2,297	$ 1,179
8		$ -	$ 2,343	$ -	$ 2,343	$ 1,093
9		$ -	$ 2,390	$ -	$ 2,390	$ 1,014
10		$ -	$ 2,438	$ -	$ 2,438	$ 940
11		$ -	$ 2,487	$ -	$ 2,487	$ 872
12		$ -	$ 2,536	$ -	$ 2,536	$ 808
13		$ -	$ 2,587	$ -	$ 2,587	$ 749
14		$ -	$ 2,639	$ -	$ 2,639	$ 695
15		$ -	$ 2,692	$ -	$ 2,692	$ 644

Client	National Retailer
Project	Advanced RTUs
Alternative Description	

Inputs

Study Period (Years)	15
M&O Inflation Rate	2.0%
Electricity Inflation Rate	2.0%
Fuel Inflation Rate	2.0%
Hurdle (Re-invest) Rate	13.0%
Discount Rate	10.0%
Initial Incremental Cost	$ 32,000
Annual M&O Cost	$ 5,000
Annual Electricity Savings	$ 3,000
Annual Fuel Savings	$ 3,000

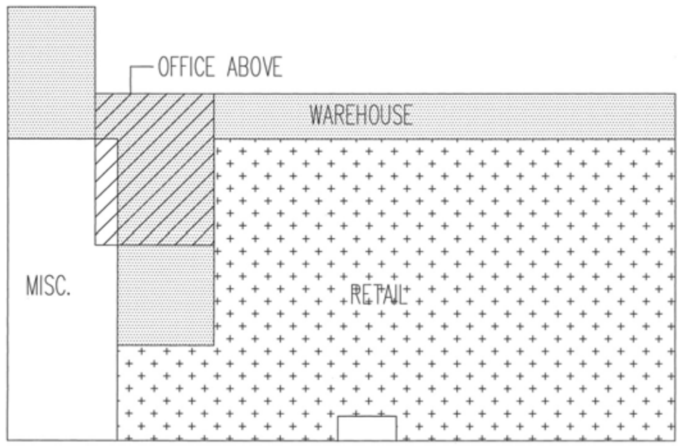
Results

Simple Payback Years (SPB)	32.00
Simple Return on Investment (ROI)	18.75%
Net Present Value of Savings (NPV)	$ (23,358)
Internal Rate of Return (IRR)	-6%
Modified Internal Rate of Return (MIRR)	2%
Total Annual Savings (Initial)	$ 1,000

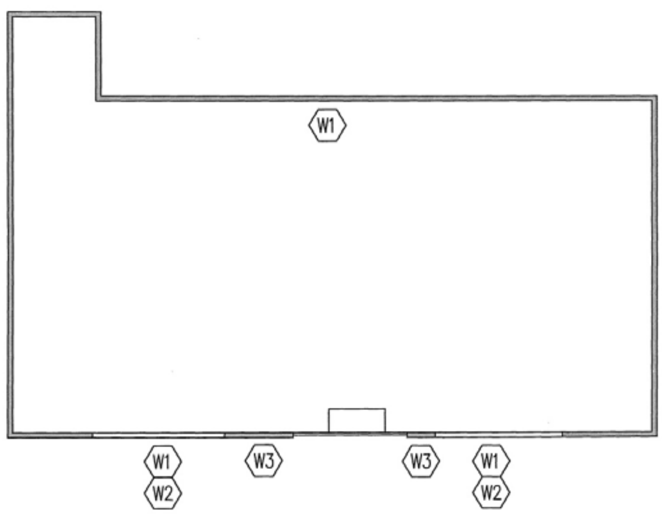
Annual Cash Flow

Year in Study Period	Incremental Costs	M&O Costs	Electricity Savings	Fuel Savings	Total by Year	Present Value in Year 0
0	$ (32,000)				$ (32,000)	$ (32,000)
1		$ (5,100)	$ 3,060	$ 3,060	$ 1,020	$ 927
2		$ (5,202)	$ 3,121	$ 3,121	$ 1,040	$ 860
3		$ (5,306)	$ 3,184	$ 3,184	$ 1,061	$ 797
4		$ (5,412)	$ 3,247	$ 3,247	$ 1,082	$ 739
5		$ (5,520)	$ 3,312	$ 3,312	$ 1,104	$ 686
6		$ (5,631)	$ 3,378	$ 3,378	$ 1,126	$ 636
7		$ (5,743)	$ 3,446	$ 3,446	$ 1,149	$ 589
8		$ (5,858)	$ 3,515	$ 3,515	$ 1,172	$ 547
9		$ (5,975)	$ 3,585	$ 3,585	$ 1,195	$ 507
10		$ (6,095)	$ 3,657	$ 3,657	$ 1,219	$ 470
11		$ (6,217)	$ 3,730	$ 3,730	$ 1,243	$ 436
12		$ (6,341)	$ 3,805	$ 3,805	$ 1,268	$ 404
13		$ (6,468)	$ 3,881	$ 3,881	$ 1,294	$ 375
14		$ (6,597)	$ 3,958	$ 3,958	$ 1,319	$ 347
15		$ (6,729)	$ 4,038	$ 4,038	$ 1,346	$ 322

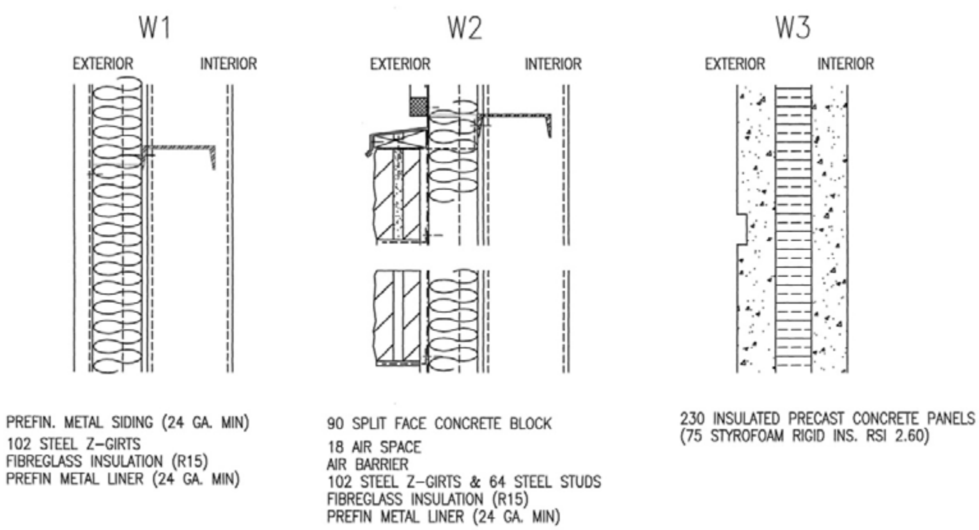
Appendix F: Store Design Diagrams and Details



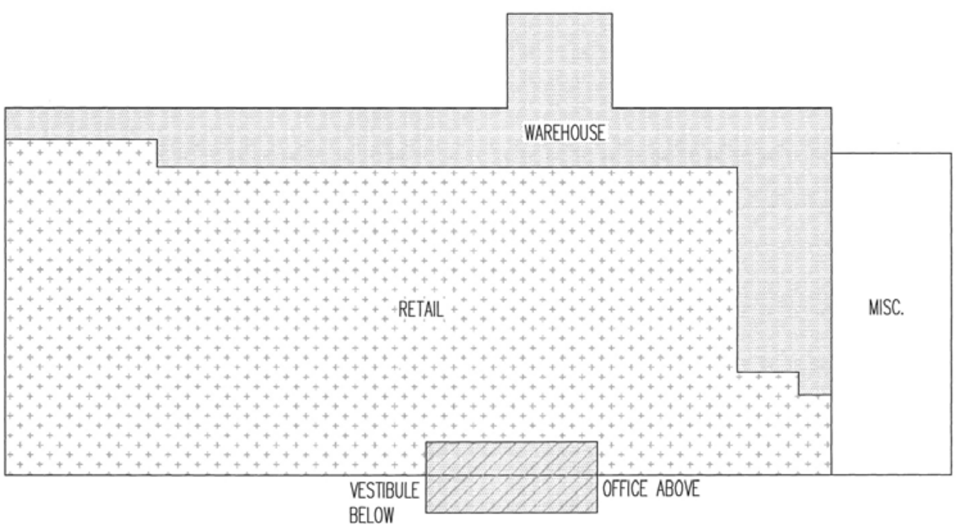
Store A Area Diagram



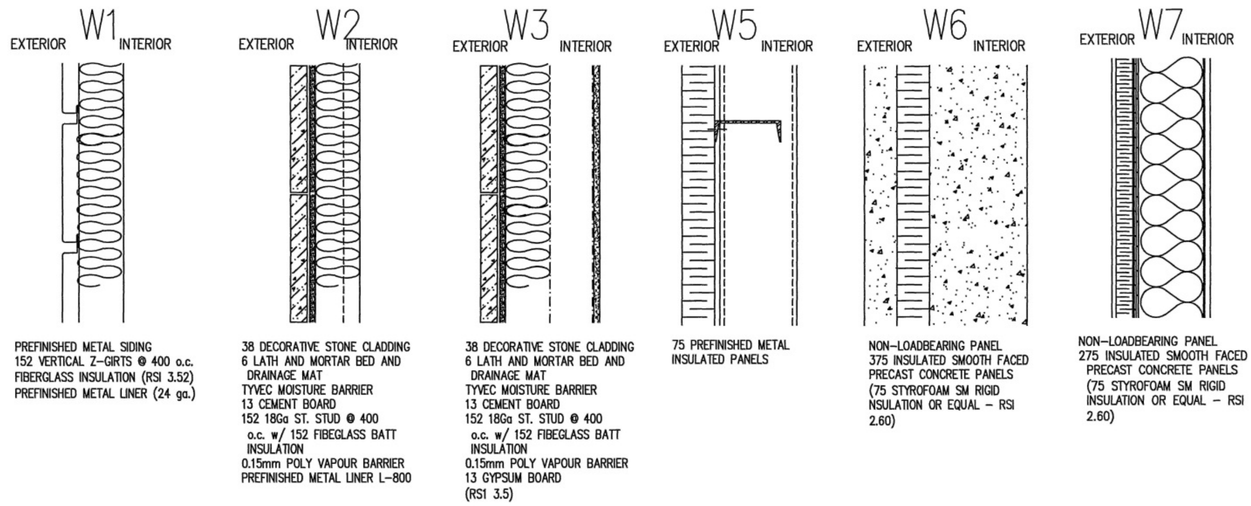
Store A - Floor Plan Showing Wall Types



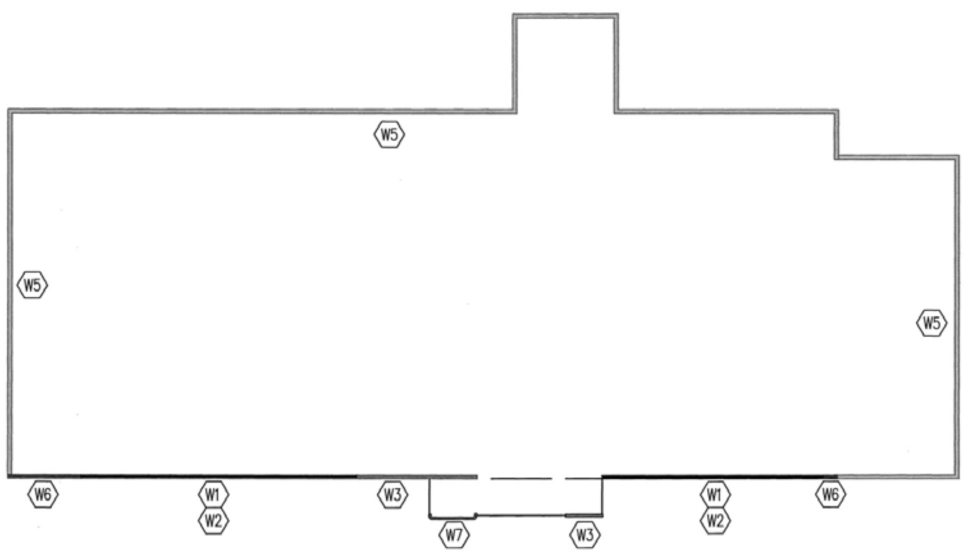
Store A - Wall Assemblies



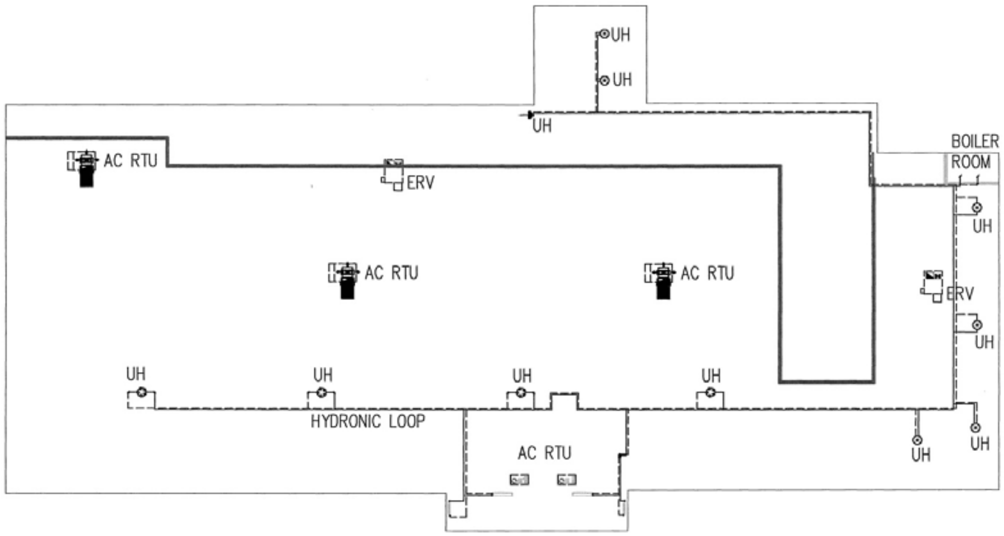
Store B Area Diagram



Store B – Wall Assemblies Types



Store B – Wall Assemblies Locations



Mechanical Schematic of Store B

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