An Investigation of Alternative Energy Efficient Designs for Medium Sized Single Wythe Masonry Buildings

Phase 2 – Supermarket and Low-Rise (Box) Retail

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Revised May 2015

Sponsored by:

International Masonry Institute
Mason Contractors Association of America
Canadian Concrete Masonry Producers Association

INTRODUCTION / BACKGROUND AND SIGNIFICANCE

The demand and cost of energy will increase as the population and economy of the United States continues to grow. For example, Kentucky's energy use is expected to rise more than 40 percent over current levels by the year 2025[1]. Moreover, the rapidly increasing demand for energy by developing nations such as China and India will strain energy production globally, and exacerbate our domestic concerns about energy production, reliability of supply, and cost. China's yearly energy consumption nearly tripled from 36.5 to 90.25 quadrillion Btu between 1999 and 2009, while India's nearly doubled from 13 to 21.7 quadrillion Btu during the same period[2]. These significant increases in energy demand, and thus costs, will negatively impact the US economy and its global competitiveness unless measures are taken domestically to control and mitigate the unfavorable effects.

In recognition of the fact that a significant amount of energy in the US is used to heat, cool and light buildings, a number of code development bodies and standards developing organizations, including The International Code Committee (ICC) and ASHRAE, have been actively developing and updating energy efficiency standards, code requirements, and guidelines for the built environment. As these documents evolved over the past several decades, the required minimum energy efficiencies of the construction permitted by each have been steadily increasing. As a result of these improvements, more energy efficient buildings are now being constructed with higher performance building envelope systems, larger use of day-lighting and occupancy sensors, and more efficient heating and cooling systems.

The International Energy Conservation Code (IECC) is referenced by the International Building Code (IBC), and is generally the basis by which energy related systems within new building construction are designed. Although IECC has its own design provisions, it also allows new designs to meet the requirements of "*ASHRAE 90.1" (ANSI/ASHRAE/IES Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings) [3]*.

The ASHRAE 90.1 provisions define two compliance paths for meeting the energy efficiency goals with each new building design. The first is prescriptive in nature, wherein the minimum energy-related characteristics for all significant elements within a building are defined quantitatively for different system types (such as building envelope and HVAC), space uses, and climates. The prescriptive path effectively defines a minimum baseline energy performance and consumption for a building. The second design compliance path requires a sophisticated whole building energy analysis to be conducted on the proposed building and compared to the same (the virtual, or "budget") building designed using the prescriptive provisions; for compliance, comparable energy performance is required. Additionally, under the Building Envelope Section of ASHRAE 90.1, a building envelope "trade-off option" may be used as an alternative compliance path to the fully prescriptive envelope option. It is used where the energy performance of one or more components in the building envelope of the proposed building does not meet its minimum performance level required under the prescriptive option, yet, other components exceed their minimum. It requires a performance trade-off analysis to be conducted on the building envelope components for both the proposed building and the base envelope design using the concept of an "envelope performance factor". Both buildings are similarly modeled. For compliance, the performance factor of the proposed building must be not less than that of the base building which provides approximately equivalent performance to the fully prescriptive requirement option. Despite the various compliance options provided by ASHRAE 90.1, due to ease of use, presently most buildings are designed using the prescriptive approach. However, increasingly more designs are using whole building energy analysis as new software makes this easier to do and reduces cost, as LEED and other energy efficiency provisions require more detailed analyses, and as building owners and designers demand more flexibility in design and construction to demonstrate equivalent performance and compliance.

In most climates in the US, the code mandated prescriptive envelope requirements would require that single wythe exterior masonry walls be designed with thermal resistances varying from 5.7 ft^2•°F•h/Btu to over 15 ft^2•°F•h/Btu. This requirement, and more specifically, the consequent need to apply continuous insulation on the interior or exterior surfaces of the single wythe wall, greatly impacts the cost of these wall systems and oftentimes detrimentally affects their durability and maintenance costs. Moreover, most design guides developed for energy efficient design begin with the assumption that increases in building envelope thermal resistance are needed to improve whole building energy efficiency. Thus, most designers are conditioned to believe that a building envelope with high thermal resistance is essential for an energy efficient building. A recent study, however, has shown that increasing insulation in a building envelope may have only a minimal effect on the overall energy performance of the building, especially where the building is constructed of walls having a high thermal mass such as concrete block masonry[4]. Providing large increases in the thermal resistance of the building envelope (doubling the R-value from code prescribed minimums) will not necessarily result in a corresponding reduction in building energy use (this study showed that a 50% increase in thermal resistances had less than a 1% effect on overall building energy use in Climate Zone 4). After a certain threshold of resistance, "more is not necessarily better". This type of building energy behavior is quite evident under a whole building energy analysis. Unfortunately, by using the prescriptive methods, designers rarely achieve the most cost effective, or energy efficient building designs. In fact, most designers simply use the prescriptive provisions to design the building systems and these are not always the most cost effective or efficient systems that can be used.

There are similar energy provisions and compliance paths in the Canadian codes, along with the accompanying shortcomings.

There is, therefore, a need to develop guides that describe how to design buildings that offer energy efficient designs that are code-compliant without sacrificing economics. This is particularly true for building envelope components such as single wythe concrete block masonry wall systems which may not comply with the simple prescriptive requirements for thermal resistance in a heating-controlled climate but act to improve energy efficiency as a result of thermal mass, the effects of which are not fully accounted for except by using whole-building analysis. In addition, single wythe masonry walls have traits that make them preferable choices for uses and occupancies where other building performance considerations dominate such as resistance to sound, fire, structure loads, property and personal protection, resistance to mechanical damage, indoor air quality, and durability.

This guide for the design of code compliant energy efficient buildings intends to:

1. Identify representative (archetype/prototype) commercial and light industrial buildings that are commonly constructed with single wythe masonry walls.

2. Develop models for whole building energy analysis for each of the prototype buildings and conduct a series of energy analyses on these models over a range of climates using code prescriptive building configurations.

3. Evaluate the energy used by these prototype building models for a range of alternative building system configurations that produce equivalent performance to the code prescriptive building configurations.

4. Conduct differential cost analyses for the code prescriptive and the alternatively compliant building system configurations.

5. Develop a series of recommendations on how to produce cost effective buildings of a specific archetype/prototype that are code compliant and use single single wythe masonry wall systems.

The investigation is divided into two phases of work. Phase 1 was a proof of concept phase where the process was applied to one archetype (prototype) building (a warehouse). Specially, Phase 1 investigation focused on the effects on energy consumption of various building envelope systems, and heating/cooling and lighting system configurations that can be incorporated practically and economically into typical commercial and light industrial designs that use single wythe masonry wall systems. Phase 2 applied the process developed in Phase 1 to two additional archetype/prototype buildings.

In both phases of this investigation, the design criteria and climates in both the US and Canada were addressed. Because design and building code provisions vary in the US and Canada, the steps described above were applied using the provisions and climates of each country separately.

This report summarizes the results of the second phase of this investigation for both the US and Canada. The first section describes the investigation of cost effective energy efficient single wythe masonry structures used for supermarket and low-rise retail buildings in the US and the second section similarly describes the investigation for single wythe masonry structures in Canada.

PROTOTYPE BUILDING DESIGN AND ANALYSIS – UNITED STATES PHASE 2

Prototype Building and Energy Analysis

The investigation focused on the effects on energy consumption of various building envelope systems, and heating/cooling and lighting system configurations that can be incorporated practically and economically into typical commercial and light industrial designs that use single wythe masonry wall systems. In Phase 1, a prototype warehouse building was identified and detailed. In this second phase, a prototype supermarket and low-rise retail box building is addressed.

Figures 1 and 2 show the prototype supermarket building. The prototype box retail building is similar and will discussed later in the report. The supermarket configuration is based on the 45,000 ft^2 supermarket building that is one of the 16 reference buildings used for the evaluation of energy analysis software by the Department of Energy[5]. The supermarket reference building was configured by the Department of the Energy to be representative of typical supermarkets being constructed in the U.S. This building occupancy was chosen because it commonly uses single wythe exterior masonry wall systems and has substantially different energy use patterns than the warehouse configuration of Phase 1. In addition, the DOE reference building models are accepted as starting points for energy simulation exercises and program calibrations, and are generally accepted by energy design professionals. The prototype supermarket is also well-representative of Canadian construction.

The supermarket building was modeled using the configuration as shown in Figures 1 and 2. The building (260 ft x 173 ft x 20 ft high) has a bakery (33 ft x 70 ft), a deli (33 ft x 74 ft), a dry storage area (227 ft x 29 ft), an office (33 ft x 29 ft), a produce area (53 ft x 144 ft), and a large general sales area (174 ft x 144 ft).

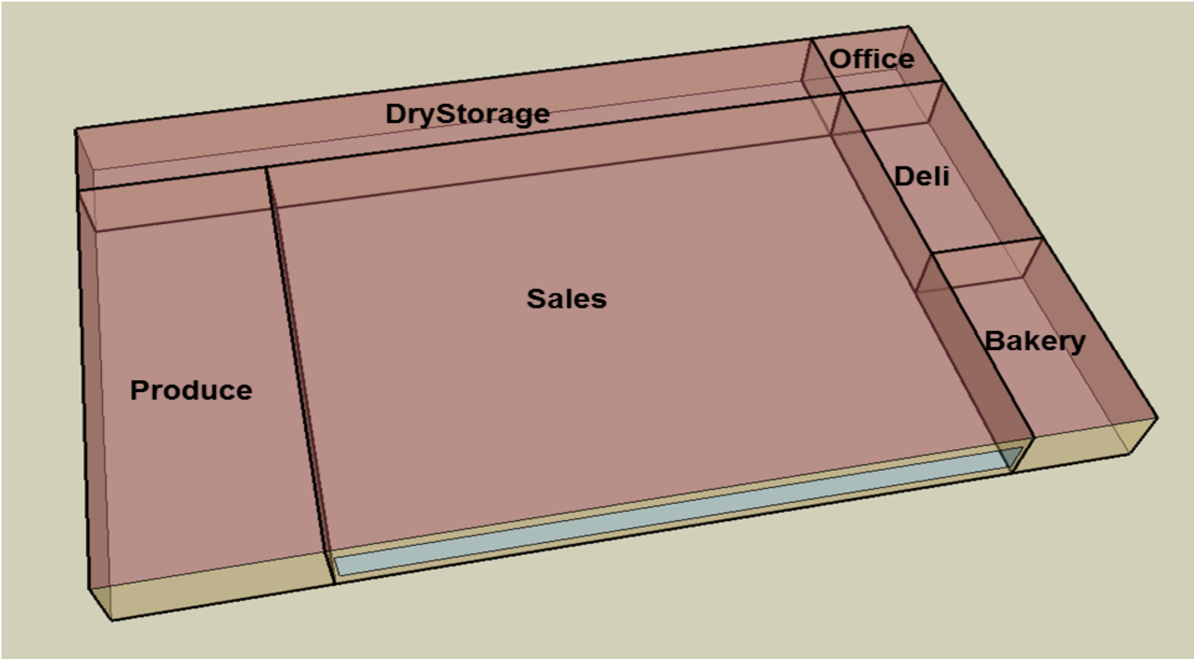

Figure 1. Isometric Floor Plan of Prototype Supermarket Model (45000 ft^2).

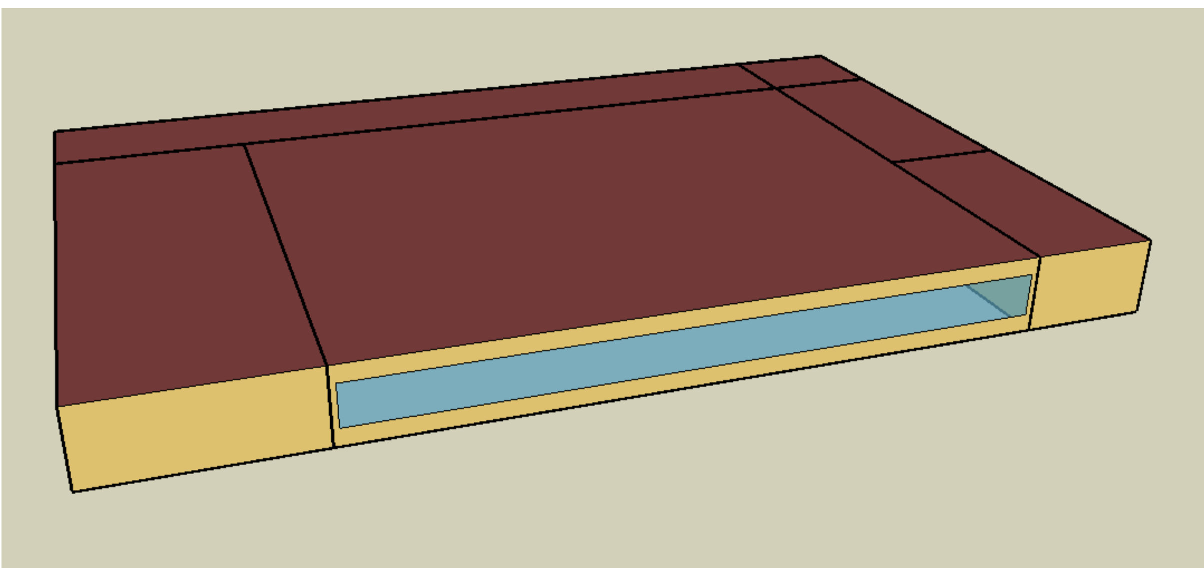

Figure 2. Isometric of Prototype Supermarket Building (45000 ft^2).

Table 1. Summary of Building Zone Data for the Supermarket Prototype.

Zone	Climate	Area (ft^2)
Office	Conditioned	958
Dry Storage	Conditioned	6,695
Deli	Conditioned	2,422
Sales	Conditioned	25,026
Produce	Conditioned	7,653
Bakery	Conditioned	2,250
	Total Area	45,004

The roofing construction included a steel deck with rigid insulation, and a single ply roof membrane system. The occupancy rate for the building was taken from the DOE report [5] as 125 ft^2/ person. This value was based on previous studies, the minimums for this building type, and from the default occupancy rates in the various standards[5]. The bakery was assumed to have a 2500 CFM fan and ovens. The building model, systems, and operating schedules are described more fully in the DOE report on the reference buildings and the DOE Energy Plus supermarket model input files[6].

Typical of this type of building, there are six HVAC climate control zones with each zone served by a single packaged rooftop unit with electric direct expansion (DX) cooling and gas heating, sized to meet the load in each space. Due to its limited scope and based on the recommendations of the reference building groups [5],[6], only packaged gas heating units and electrical DX cooling systems were used in the study. These are the most commonly used systems for this type of building due to their low heating costs. The air conditioning units were operated with setback and setup control strategies, and ventilation air was supplied as required by ASHRAE Standard 62 (ANSI/ASHRAE). Heating and cooling set points are assigned to meet thermal comfort set points. Typical occupancy schedules and operation schedules for the equipment, lighting, heating and cooling were obtained from DOE research and were chosen to be representative of this building type (see Figures 3 through 7). In heating mode, the set points for the building were 73° F (23° C) with a setback of 59° F (15° C). In cooling mode, set points were 75° F (24° C), with a setback of 86° F (30° C).

The exterior walls in the prototype building are a mass wall system that has characteristics consistent with both concrete walls and grouted concrete block walls[5],[6]. The prototype building model included building envelope components and equipment that met the (minimum) prescriptive requirements of ASHRAE 90.1 - 2007.

The sales area has a large glass window in the baseline model. This window has an area of 1884 ft^2 ($175m^2$), or 54% of the front wall area.

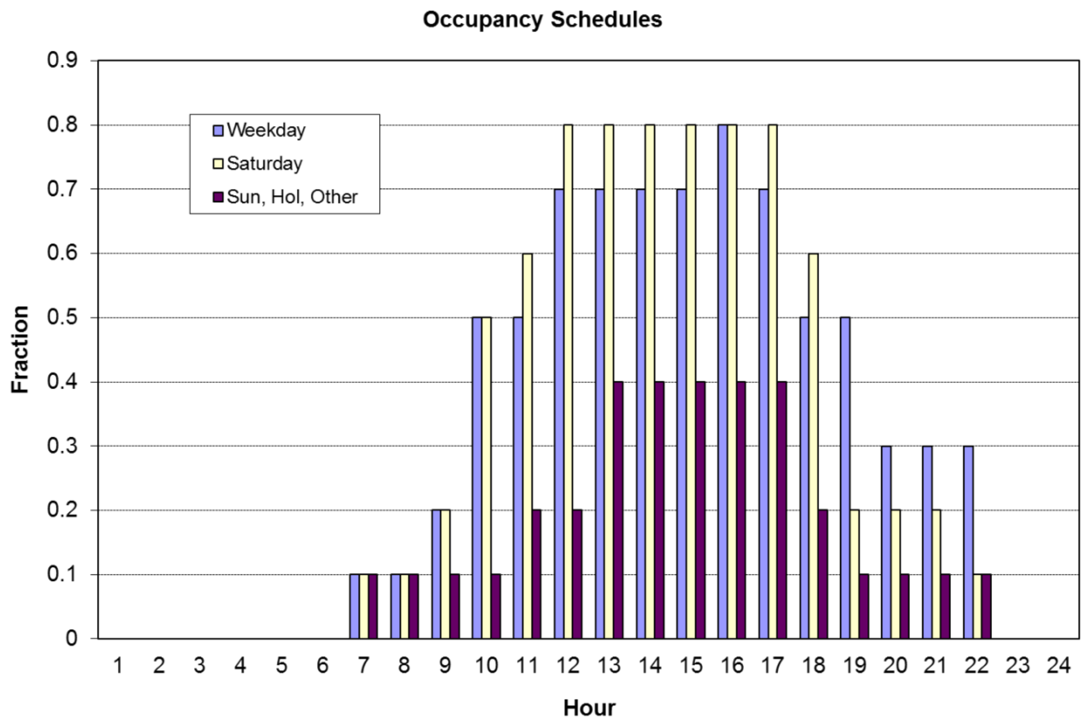

Figure 3. Supermarket Occupancy Schedules from Reference [5].

To be consistent with previously published DOE studies, the weather data from the cities listed in Table 2 were used to represent the various zones. The listed cities were determined to be representative of the corresponding climate zone and known to contain significant numbers of buildings[5]. In accordance with ASHRAE 90.1, the climate zones are based on heating degree days, annual precipitation and mean daily temperatures.

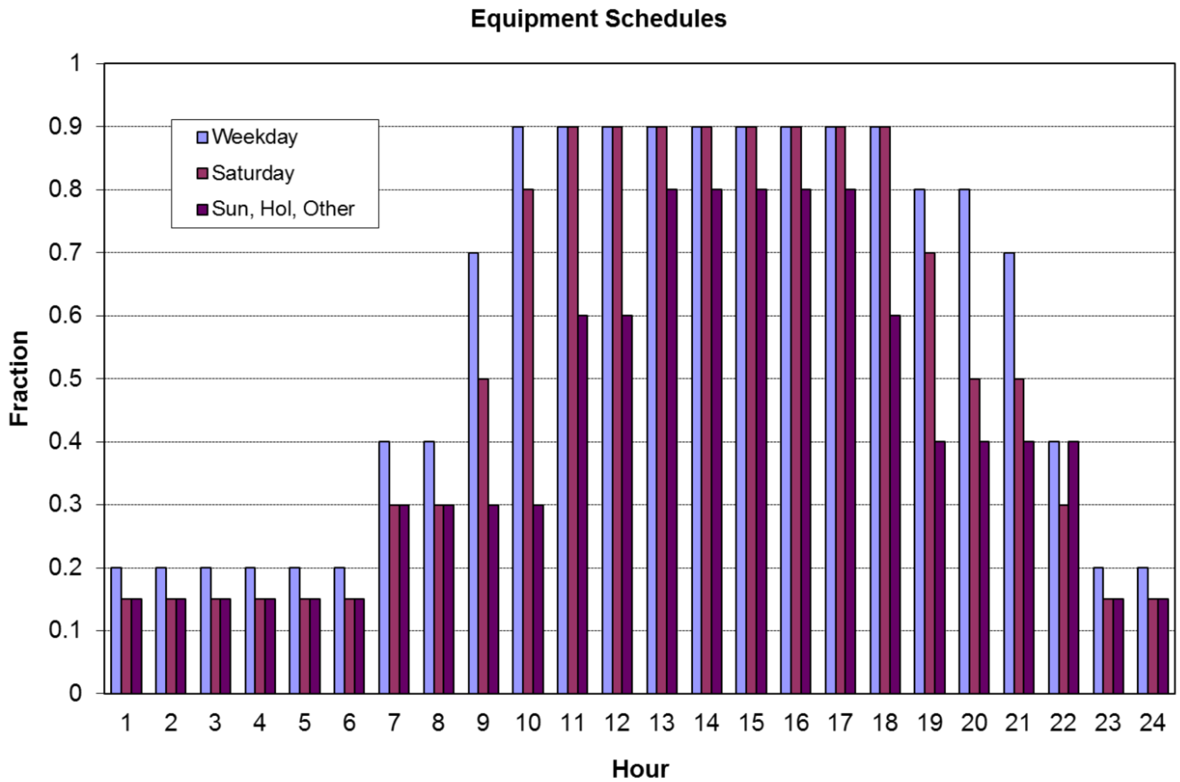

Figure 4. Supermarket Equipment Schedules from Reference [5].

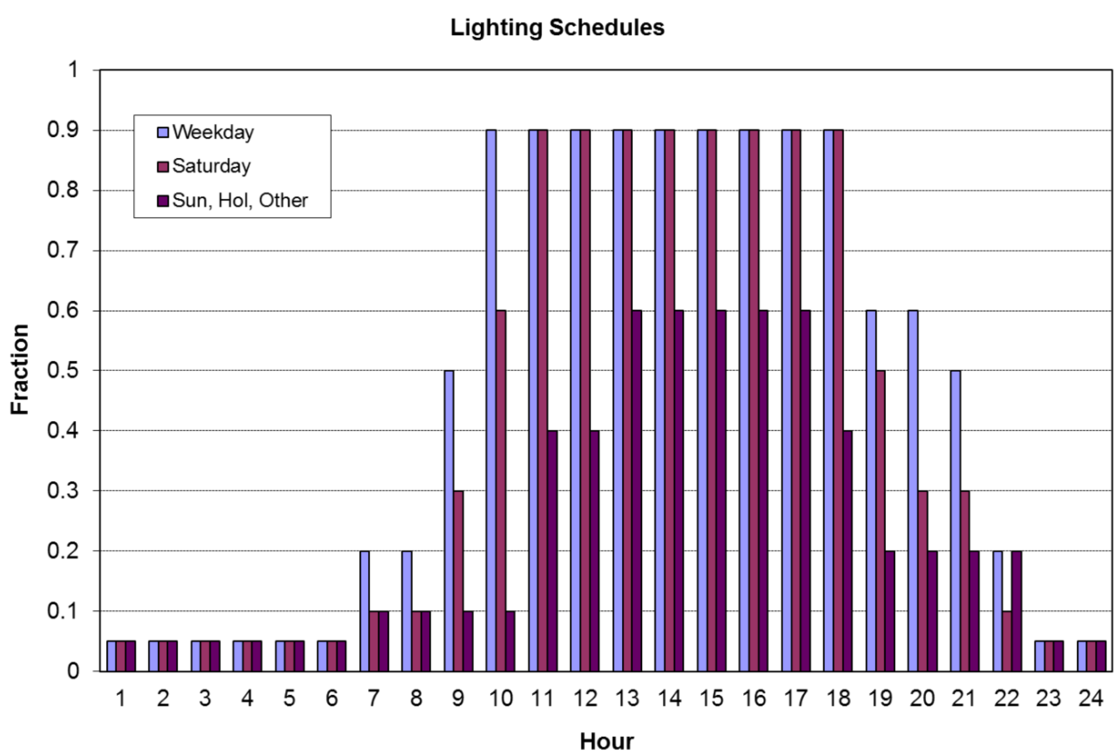

Figure 5. Supermarket Lighting Schedules from Reference [5].

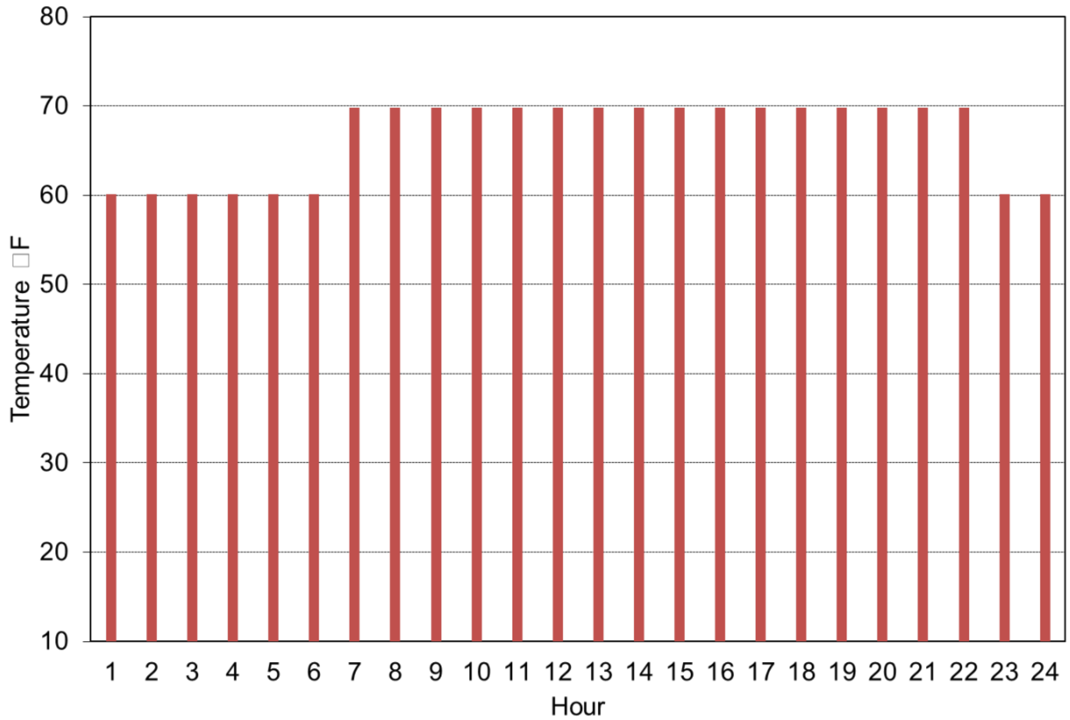

Figure 6. Supermarket Cooling Schedules from Reference [5].

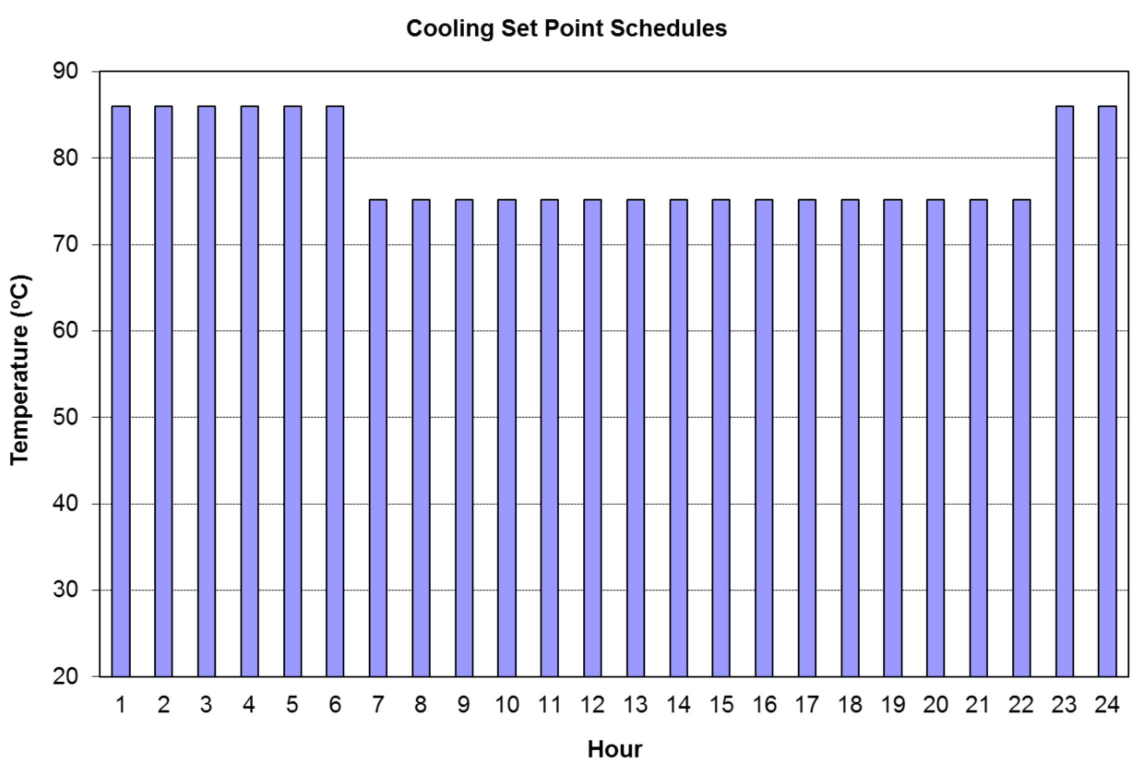

Figure 7. Supermarket Heating Schedules from Reference [5].

Table 2. Cities and Climate Zones 3-7.

City	State	Zone	Climate
Atlanta	Georgia	3A	hot, humid
Las Vegas	Nevada	3B	hot, dry
San Francisco	California	3C	hot, marine
Baltimore	Maryland	4A	mild, humid
Albuquerque	New Mexico	4B	mild, dry
Seattle	Washington	4C	mild, marine
Chicago	Illinois	5A	cold, humid
Boulder	Colorado	5B	cold, dry
Minneapolis	Minnesota	6A	cold, humid
Helena	Montana	6B	cold, dry
Duluth	Minnesota	7	cold, dry

The AECOsim Energy Simulator software by Bentley was used for this study. This software uses the latest and more advanced EnergyPlus energy modeling software. Although this program is more difficult to use than other energy analysis software, such as eQuest, it has been found to give a more realistic evaluation of the thermal response of mass wall systems and thus, is more suitable for modeling buildings using masonry wall systems.

In Phase 1, a building energy model for the warehouse prototype was developed and analyzed in order to validate the model and ensure that the energy use predicted by the AECOsim program was accurate. This validation was not repeated in Phase 2 since the building systems, and thus models, were similar. It should be noted that the results predicted by the prototype base line models were very close to those published for supermarket prototype, and the prototype supermarket model was deemed sufficiently accurate for comparison purposes.

Supermarkets have large freezers and these freezers so dominate the yearly energy use that changes in energy use by the other building systems are largely overshadowed[5]. The energy analysis on the building model was therefore conducted with and without refrigeration. This was done to better assess the effects of changes in the other building systems on the overall energy consumption of the building.

The AECOsim program had limited refrigeration modeling capabilities and could not be adjusted to configurations that were representative of a typical supermarket without significant additional development. However, review of the energy analysis data published for the DOE supermarket building model [5] showed that energy used by the refrigeration systems is quite constant over a very large variation in climate zones (see

Figure 8 and Table 3). Thus, in this study, the energy used by the refrigeration systems was accounted for by adding the annual refrigeration energy predicted by the simulations on the DOE model for each climate zone. This was believed to produce a sufficiently accurate assessment of the effects of the refrigeration on the overall performance of the building. Table 3 lists the yearly electrical energy used by typical refrigeration units operating in the DOE prototype building for the cities listed in Table 2, under the same operating schedules that are used for the comparison analyses.

Table 3 DOE. Supermarket Prototype Annual Electrical Refrigeration Energy [6].

Location	State	Climate Zone	Annual Refrigeration Electrical Energy (kBtu)	Annual Refrigeration Electrical Energy (kWh)
Atlanta	Georgia	3A	3494120	1024127
Las Vegas	Nevada	3B	3122270	915137
San Francisco	California	3C	3187300	934198
Baltimore	Maryland	4A	3265350	957074
Albuquerque	New Mexico	4B	2987290	875575
Seattle	Washington	4C	3035660	889752
Chicago	Illinois	5A	3121660	914959
Boulder	Colorado	5B	2869800	841138
Minneapolis	Minnesota	6A	3057500	896153
Helena	Montana	6B	2778400	814349
Duluth	Minnesota	7	2835900	831202

The DOE prototype supermarket building configurations were modified to meet the minimum prescriptive baseline requirements defined in ASHRAE Standard 90.1 for each climate zone (3 through 7). This modification was required because the building configuration used for the DOE studies [5],[6],[7] did not use code minimum configurations in all cases. These baseline supermarket building models were designed to meet the minimum prescriptive requirements of ASHRAE 90.1 2007 for each climate and humidity zone. The baseline buildings all had the same floor plan and area, thermal mass, and schedules as the DOE model but all exterior walls were changed to a single wythe masonry wall system. Mechanical systems were also adjusted to meet ASHRAE 90.1 minimums. Figures 9 through 13 show the prescriptive requirements specified for building envelopes in Climate Zones 3 through 7 from the ASHRAE 90.1 ANSI/ASHRAE/IESNA Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings[3]. (These provisions are the same as those of ASHRAE 90.1 -2010).

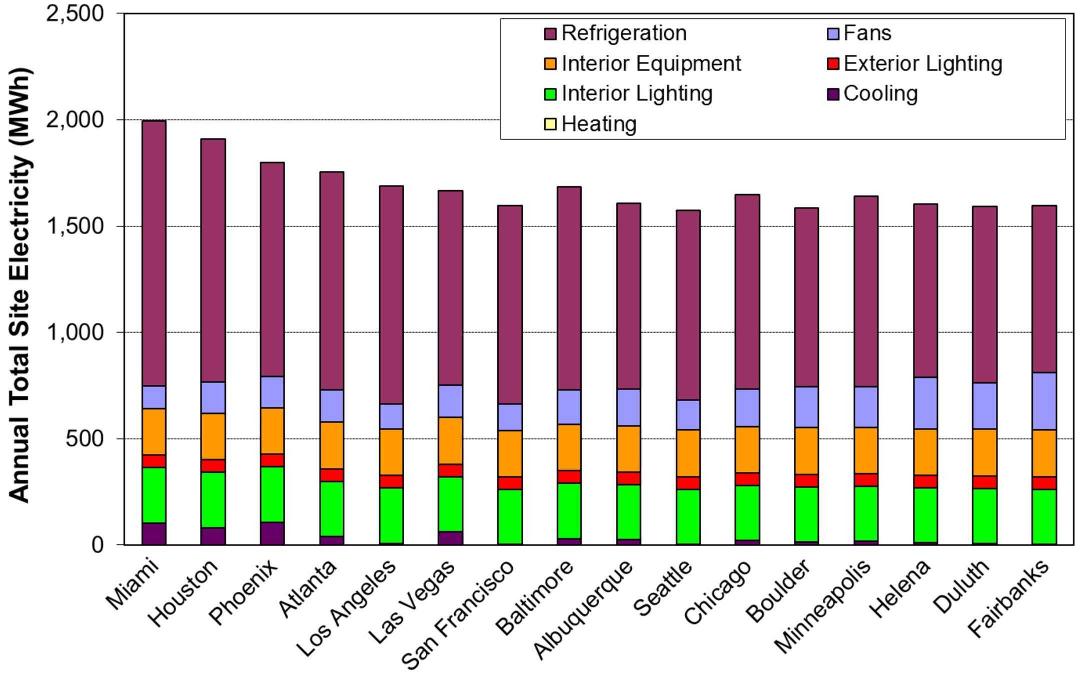

Figure 8. Annual Electrical Energy used in DOE Energy-Plus Supermarket Model Reference[6].

TABLE 5.5-3 Building Envelope Requirements for Climate Zone 3 (A, B, C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.173	R-5.0 c.i.
Metal Building[a]	U-0.055	R-13.0 + R13.0	U-0.055	R-13.0 + R13.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.123	R-7.6 c.i.	U-0.104	R-9.5 c.i.	U-0.580	NR
Metal Building	U-0.084	R-19.0	U-0.084	R-19.0	U-0.113	R-13.0
Steel-Framed	U-0.084	R-13.0 + R-3.8 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.089	R-13.0	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-1.140	NR	C-1.140	NR
Floors						
Mass	U-0.107	R-6.3 c.i.	U-0.087	R-8.3 c.i.	U-0.322	NR
Steel-Joist	U-0.052	R-19.0	U-0.052	R-19.0	U-0.069	R-13.0
Wood-Framed and Other	U-0.051	R-19.0	U-0.033	R-30.0	U-0.066	R-13.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.730	NR	F-0.730	NR
Heated	F-0.900	R-10 for 24 in.	F-0.900	R-10 for 24 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Nonswinging	U-1.450		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.65	SHGC-0.25 all	U-0.65	SHGC-0.25 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.60		U-0.60		U-1.20	
Metal framing (entrance door)[d]	U-0.90		U-0.90		U-1.20	
Metal framing (all other)[d]	U-0.65		U-0.65		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}–1.17	$SHGC_{all}$–0.39	U_{all}–1.17	$SHGC_{all}$–0.36	U_{all}–1.98	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.17	$SHGC_{all}$–0.19	U_{all}–1.17	$SHGC_{all}$–0.19	U_{all}–1.98	$SHGC_{all}$–NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}–1.30	$SHGC_{all}$–0.65	U_{all}–1.30	$SHGC_{all}$–0.27	U_{all}–1.90	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.30	$SHGC_{all}$–0.34	U_{all}–1.30	$SHGC_{all}$–0.27	U_{all}–1.90	$SHGC_{all}$–NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}–0.69	$SHGC_{all}$–0.39	U_{all}–0.69	$SHGC_{all}$–0.36	U_{all}–1.36	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.69	$SHGC_{all}$–0.19	U_{all}–0.69	$SHGC_{all}$–0.19	U_{all}–1.36	$SHGC_{all}$–NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance doors.

Figure 9. Prescriptive Requirements for Zone 3 from ASHRAE 90.1-2007[3].

TABLE 5.5-4 Building Envelope Requirements for Climate Zone 4 (A, B, C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.173	R-5.0 c.i.
Metal Building[a]	U-0.055	R-13.0 + R-13.0	U-0.055	R-13.0 + R-13.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.104	R-9.5 c.i.	U-0.090	R-11.4 c.i.	U-0.580	NR
Metal Building	U-0.084	R-19.0	U-0.084	R-19.0	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.064	R-13.0 + R-3.8 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-1.140	NR	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.087	R-8.3 c.i.	U-0.074	R-10.4 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.038	R-30.0	U-0.069	R-13.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.066	R-13.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.540	R-10 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.860	R-15 for 24 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.40		U-0.40		U-1.20	
Metal framing (curtainwall/storefront)[d]	U-0.50	SHGC-0.40 all	U-0.50	SHGC-0.40 all	U-1.20	SHGC-NR all
Metal framing (entrance door)[d]	U-0.85		U-0.85		U-1.20	
Metal framing (all other)[d]	U-0.55		U-0.55		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}–1.17	$SHGC_{all}$–0.49	U_{all}–0.98	$SHGC_{all}$–0.36	U_{all}–1.98	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.17	$SHGC_{all}$–0.39	U_{all}–0.98	$SHGC_{all}$–0.19	U_{all}–1.98	$SHGC_{all}$–NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}–1.30	$SHGC_{all}$–0.65	U_{all}–1.30	$SHGC_{all}$–0.62	U_{all}–1.90	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.30	$SHGC_{all}$–0.34	U_{all}–1.30	$SHGC_{all}$–0.27	U_{all}–1.90	$SHGC_{all}$–NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}–0.69	$SHGC_{all}$–0.49	U_{all}–0.58	$SHGC_{all}$–0.36	U_{all}–1.36	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.69	$SHGC_{all}$–0.39	U_{all}–0.58	$SHGC_{all}$–0.19	U_{all}–1.36	$SHGC_{all}$–NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

Figure 10. Prescriptive Requirements for Zone 4 from ASHRAE 90.1-2007[3].

TABLE 5.5-5 Building Envelope Requirements for Climate Zone 5 (A, B, C)*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	**Insulation Min. R-Value**	**Assembly Maximum**	**Insulation Min. R-Value**	**Assembly Maximum**	**Insulation Min. R-Value**
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.119	R-7.6 c.i.
Metal Building[a]	U-0.055	R-13.0 + R-13.0	U-0.055	R-13.0 + R-13.0	U-0.083	R-13.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.090	R-11.4 c.i.	U-0.080	R-13.3 c.i.	U-0.151[b]	R-5.7 c.i.[b]
Metal Building	U-0.069	R-13.0 + R-5.6 c.i.	U-0.069	R-13.0 + R-5.6 c.i.	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.064	R-13.0 + R-3.8 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.074	R-10.4 c.i.	U-0.064	R-12.5 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.038	R-30.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.540	R-10 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.860	R-15 for 24 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.35	SHGC-0.40 all	U-0.35	SHGC-0.40 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.45		U-0.45		U-1.20	
Metal framing (entrance door)[d]	U-0.80		U-0.80		U-1.20	
Metal framing (all other)[d]	U-0.55		U-0.55		U-1.20	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-1.17	$SHGC_{all}$-0.39	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-1.10	$SHGC_{all}$-0.77	U_{all}-1.10	$SHGC_{all}$-0.77	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.10	$SHGC_{all}$-0.62	U_{all}-1.10	$SHGC_{all}$-0.62	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-0.69	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

Figure 11. Prescriptive Requirements for Zone 5 from ASHRAE 90.1-2007[3].

TABLE 5.5-6 Building Envelope Requirements for Climate Zone 6 (A, B)*

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	Residential Assembly Maximum	Residential Insulation Min. R-Value	Semiheated Assembly Maximum	Semiheated Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.093	R-10.0 c.i.
Metal Building[a]	U-0.049	R-13.0 + R-19.0	U-0.049	R-13.0 + R-19.0	U-0.072	R-16.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.034	R-30.0
Walls, Above-Grade						
Mass	U-0.080	R-13.3 c.i.	U-0.071	R-15.2 c.i.	U-0.151[b]	R-5.7 c.i.[b]
Metal Building	U-0.069	R-13.0 + R-5.6 c.i.	U-0.069	R-13.0 + R-5.6 c.i.	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.051	R-13.0 + R-7.5 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.064	R-12.5 c.i.	U-0.057	R-14.6 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.032	R-38.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.540	R-10 for 24 in.	F-0.520	R-15 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.688	R-20 for 48 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.35	SHGC-0.40 all	U-0.35	SHGC-0.40 all	U-0.65	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.45		U-0.45		U-0.60	
Metal framing (entrance door)[d]	U-0.80		U-0.80		U-0.90	
Metal framing (all other)[d]	U-0.55		U-0.55		U-0.65	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-0.98	$SHGC_{all}$-0.46	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-1.17	$SHGC_{all}$-0.49	U_{all}-0.98	$SHGC_{all}$-0.36	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-0.87	$SHGC_{all}$-0.71	U_{all}-0.74	$SHGC_{all}$-0.65	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.87	$SHGC_{all}$-0.58	U_{all}-0.74	$SHGC_{all}$-0.55	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.58	$SHGC_{all}$-0.49	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.58	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

Figure 12. Prescriptive Requirements for Zone 6 from ASHRAE 90.1-2007[3].

TABLE 5.5-7 Building Envelope Requirements for Climate Zone 7*

Opaque Elements	Nonresidential		Residential		Semiheated	
	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value	Assembly Maximum	Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.093	R-10.0 c.i.
Metal Building[a]	U-0.049	R-13.0 + R-19.0	U-0.049	R-13.0 + R-19.0	U-0.072	R-16.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.034	R-30.0
Walls, Above-Grade						
Mass	U-0.071	R-15.2 c.i.	U-0.071	R-15.2 c.i.	U-0.123	R-7.6 c.i.
Metal Building	U-0.057	R-19.0 + R-5.6 c.i.	U-0.057	R-19.0 + R-5.6 c.i.	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.042	R-13.0 + R-15.6 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.051	R-13.0 + R-7.5 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.092	R-10.0 c.i.	C-1.140	NR
Floors						
Mass	U-0.064	R-12.5 c.i.	U-0.051	R-16.7 c.i.	U-0.107	R-6.3 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.032	R-38.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.520	R-15 for 24 in.	F-0.520	R-15 for 24 in.	F-0.730	NR
Heated	F-0.843	R-20 for 24 in.	F-0.688	R-20 for 48 in.	F-0.900	R-10 for 24 in.
Opaque Doors						
Swinging	U-0.500		U-0.500		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Max. U**	**Assembly Max. SHGC**
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.35	SHGC-0.45 all	U-0.35	SHGC-NR all	U-0.65	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.40		U-0.40		U-0.60	
Metal framing (entrance door)[d]	U-0.80		U-0.80		U-0.90	
Metal framing (all other)[d]	U-0.45		U-0.45		U-0.65	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}–1.17	$SHGC_{all}$–0.68	U_{all}–1.17	$SHGC_{all}$–0.64	U_{all}–1.98	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.17	$SHGC_{all}$–0.64	U_{all}–1.17	$SHGC_{all}$–0.64	U_{all}–1.98	$SHGC_{all}$–NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}–0.87	$SHGC_{all}$–0.77	U_{all}–0.61	$SHGC_{all}$–0.77	U_{all}–1.90	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.87	$SHGC_{all}$–0.71	U_{all}–0.61	$SHGC_{all}$–0.77	U_{all}–1.90	$SHGC_{all}$–NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}–0.69	$SHGC_{all}$–0.68	U_{all}–0.69	$SHGC_{all}$–0.64	U_{all}–1.36	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.69	$SHGC_{all}$–0.64	U_{all}–0.69	$SHGC_{all}$–0.64	U_{all}–1.36	$SHGC_{all}$–NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

Figure 13. Prescriptive Requirements for Zone 7 from ASHRAE 90.1-2007[3].

The model for the baseline building for each climate zone typically involved minor changes in building envelope configuration. Interior use schedules, lights and loads were kept consistent with the calibrated models since these were developed to be representative of typical supermarket configurations. Figure 14 shows the AECOsim model for the baseline supermarket and Table 4 shows some of the important building configuration information for each climate zone. Note that only important system characteristics that were changed for each climate zone are shown in the table.

Air leakage through the walls was addressed using the recommendation in ASHRAE 90.1 and was chosen to be representative of typical air tightness of this type of construction [5], [6]. The baseline supermarket analysis used a general infiltration rate of 0.25 ACH for the exterior walls. There was also a 2500 cfm fan used in the bakery intermittently. All energy analyses were run with the single constant infiltration rate since it would produce the greatest (and thus conservative) effect with changes in the opaque envelope. This configuration was conservatively used for all equivalent performance comparisons.

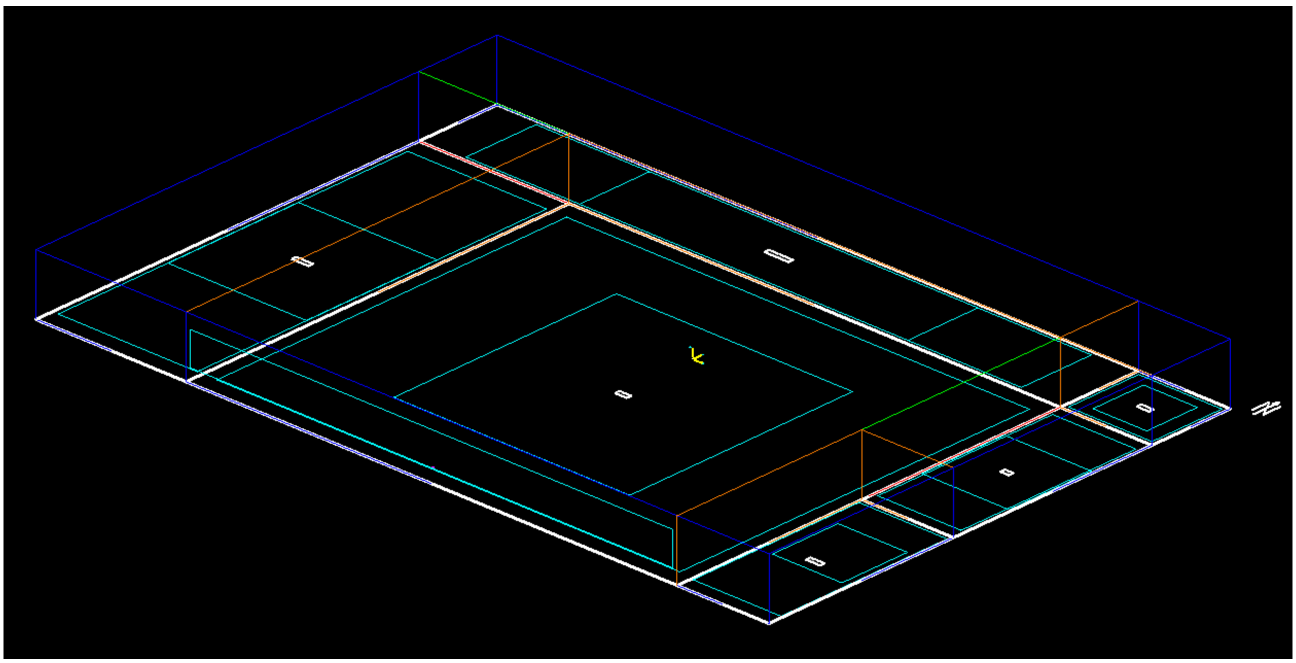

Figure 14. Isometric View of the Baseline Supermarket Model.

Table 4. Baseline Building Envelope and Mechanical System Configurations for the Prototype Supermarket.

Location	Atlanta	Las Vegas	San Francisco	Baltimore	Albuquerque	Seattle	Chicago	Boulder	Minneapolis	Helena	Duluth
State	Georgia	Nevada	California	Maryland	New Mexico	Washington	Illinois	Colorado	Minnesota	Montana	Minnesota
Climate Zone	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Supermarket											
Exterior Walls											
Construction	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)	Medium Weight CMU (Filled)
Insulation Thickness (in.)	1.5	1.5	1.5	2	2	2	2	2	2.5	2.5	2.5
Insulation R-Value (ft^2-h-F/Btu)	7.2	7.2	7.2	9.6	9.6	9.6	9.6	9.6	12	12	12
Required U (Btu/ft^2-h-F)	0.123	0.123	0.123	0.104	0.104	0.104	0.090	0.090	0.078	0.078	0.071
Construction U (Btu/ft^2-h-F)	0.112	0.112	0.112	0.088	0.088	0.088	0.088	0.088	0.070	0.070	0.070
Roof											
Construction	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof	Metal Roof
Insulation Thickness (in.)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Insulation R-Value (ft^2-h-F/Btu)	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7
Required U (Btu/ft^2-h-F)	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Construction U (Btu/ft^2-h-F)	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	1.045	2.045	3.045
Floor											
Construction	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated	Slab Unheated
Insulation Thickness (in.)	0	0	0	0	0	0	0	0	0	0	0
Insulation R-Value (ft^2-h-F/Btu)	0	0	0	0	0	0	0	0	0	0	0
Required U (Btu/ft^2-h-F)	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730	0.730
Construction U (Btu/ft^2-h-F)	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635
HVAC											
Coils											
Bakery Heating (η)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Bakery Cooling (COP)	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67
Bakery Fans (η)	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Deli Heating (η)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Deli Cooling (COP)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Deli Fans (η)	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Dry Storage Heating (η)	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Dry Storage Cooling (COP)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Dry Storage Fans (η)	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Office Heating (η)	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Office Cooling (COP)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Office Fans (η)	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
Produce Heating (η)	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
Produce Cooling (COP)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Produce Fans (η)	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Sales Heating (η)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sales Cooling (COP)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Sales Fans (η)	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57

Annual energy use was calculated for each of the baseline configurations of the supermarket prototype using the AECOsim software. The baseline systems were compliant with the prescriptive code provisions but did not include refrigeration. The results are summarized in Table 5, and expressed using Energy Usage Intensity (EUI). EUI, the annual energy used per square foot of building foot print, is a convenient way to display energy use in a building and allows easy comparisons. EUI will be used throughout this report to compare building energy consumption.

When excluding the refrigeration systems, the energy analyses clearly show that heating is a large portion of the total energy consumption, especially in the colder climates (Zones 5, 6, and 7). However the electrical energy used for lighting also is a significant portion of the annual energy used. These effects can be more readily seen in Figure 15.

Only gas heating and electrical cooling were addressed by this study. In each climate zone, yearly energy costs for electricity and natural gas use were calculated for the baseline building (reported in Table 7) using state average unit energy costs for 2012 (shown in Table 6).

Table 5. Baseline Supermarket Building Energy Use Results by Location for Zones 3-7 (Without Refrigeration).

City	Climate Zone	Heating (MBtu)	Cooling (MBtu)	Lighting (MBtu)	Electric Equip. (MBtu)	Gas Equip. (MBtu)	Fans (MBtu)	Total (MBtu)	EUI (kBtu/ft^2)
Atlanta	3A	534.0	80.9	618.8	751.3	190.4	273.3	2448.8	54.42
Las Vegas	3B	335.8	155.2	640.4	751.3	190.4	272.5	2345.8	52.13
San Francisco	3C	545.9	22.4	632.5	751.3	190.4	218.9	2361.5	52.48
Baltimore	4A	841.6	64.6	637.1	751.3	190.4	284.1	2769.1	61.54
Albuquerque	4B	576.7	69.1	630.0	751.3	190.4	303.0	2520.6	56.01
Seattle	4C	843.7	20.7	655.0	751.3	190.4	251.1	2712.2	60.27
Chicago	5A	1098.4	49.1	645.6	751.3	190.4	335.2	3070.0	68.22
Boulder	5B	926.4	39.1	636.2	751.3	190.4	179.7	2723.3	60.52
Minneapolis	6A	1410.0	44.8	633.7	751.3	190.4	364.8	3394.9	75.44
Helena	6B	1173.2	34.2	638.4	751.3	190.4	383.9	3161.4	70.25
Duluth	7	1747.6	21.6	638.4	751.3	190.4	389.2	3738.6	83.08

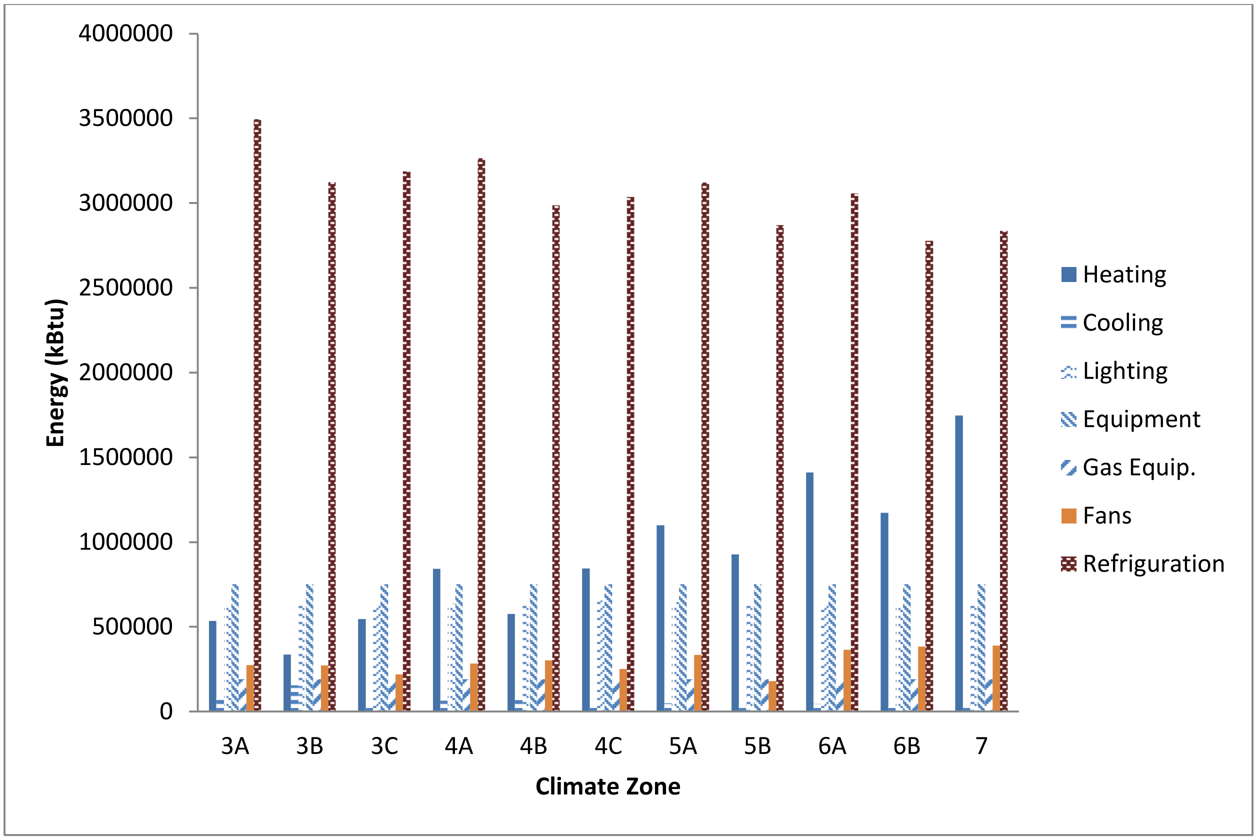

Figure 15. Baseline Supermarket Building Energy Use Results by Location for Zones 3-7. (Without and with Refrigeration).

Table 6. State Average Unit Energy Costs (2012). [8], [9]

State	Electricity ($/kWh)	Gas ($/1000 ft^3)
Georgia	.096	4.18
Nevada	.095	5.13
California	.129	3.46
Maryland	.117	5.67
New Mexico	.086	3.70
Washington	.075	4.48
Illinois	.085	4.11
Colorado	.089	4.26
Minnesota	.081	4.26
Montana	.091	5.11

When the refrigeration energy is added to the annual energy used, there is a significant jump in yearly energy use and costs. As show in Table 8 and Figure 15, the refrigeration energy dominates the annual energy use. These data suggest that any effort to significantly reduce yearly energy use in a typical supermarket needs to be first directed at refrigeration. However, ASHRAE 90.1 does not treat refrigeration as fixed equipment and additional efficiencies in refrigeration cannot be used achieve code compliance.

Table 7. Baseline Supermarket Building Annual Energy Costs by Location for (2012) (Without Refrigeration).

City	Climate Zone	Gas Cost	Electricity Cost	Total Annual Cost
Atlanta	3A	$2,942.91	$48,518.40	$51,461
Las Vegas	3B	$2,623.73	$50,663.68	$53,287
San Francisco	3C	$2,475.98	$61,449.37	$63,925
Baltimore	4A	$5,686.56	$59,570.23	$65,257
Albuquerque	4B	$2,758.29	$44,199.60	$46,958
Seattle	4C	$4,502.27	$36,888.35	$41,391
Chicago	5A	$5,147.83	$44,376.03	$49,524
Boulder	5B	$4,623.80	$41,904.00	$46,528
Minneapolis	6A	$6,624.96	$42,606.49	$49,231
Helena	6B	$6,771.79	$47,949.95	$54,722
Duluth	7	$8,023.22	$42,746.63	$50,770

Table 8. Baseline Supermarket Building Annual Energy Use Results by Location for Zones 3-7 (With Refrigeration).

City	Refrig. Energy (MBtu)	Total Annual Energy without Refrig. (MBtu)	EUI with Refrig. ($kBtu/ft^2$)	Total Annual Cost
Atlanta (3A)	3494.1	2448.8	132.1	$149,777
Las Vegas (3B)	3122.3	2345.8	121.5	$140,225
San Francisco (3C)	3187.3	2361.5	123.3	$184,437
Baltimore (4A)	3265.4	2769.1	134.1	$177,234
Albuquerque(4B)	2987.4	2520.6	122.4	$122,257
Seattle (4C)	3035.7	2712.2	127.7	$108,122
Chicago (5A)	3121.7	3070.0	137.6	$127,295
Boulder (5B)	2869.8	2723.3	124.3	$121,389
Minneapolis (6A)	3057.5	3394.9	143.4	$121,820
Helena (6B)	2778.4	3161.4	132.0	$128,828
Duluth (7)	2835.9	3738.6	146.1	$118,097

Incremental Analysis on Supermarket Prototype

A study of the effects of incremental changes of building systems was conducted on the warehouse prototype in Phase 1. This was done to establish sensitivity of yearly energy consumption to the various changes in the building systems and to determine which changes have the greatest effect on yearly building energy use. The supermarket prototype was similar to the configuration of the warehouse prototype building so the results from the sensitivity analysis of warehouse prototype should be generally applicable to the supermarket prototype as well.

To confirm the applicability of the Phase 1 results, changes were made to the thermal resistance of the exterior concrete block masonry walls of the supermarket prototype. For each city, the annual energy use for the prototype building was evaluated using four different levels of wall insulation and included: (a) the code prescriptive level (ASHRAE baseline), (b) double the code prescriptive level required for wall insulation, (c) no wall insulation, and (d) by introducing foam insulation into the cores of the concrete block masonry walls, a thermal resistance value between "no insulation" and the "code prescriptive level". Figure 16 shows the baseline exterior CMU wall configuration with continuous internal insulation. The EUI values determined for the supermarket prototype using each of these wall configurations are shown in Table 9. These EUI values are for annual energy use, neglecting refrigeration.

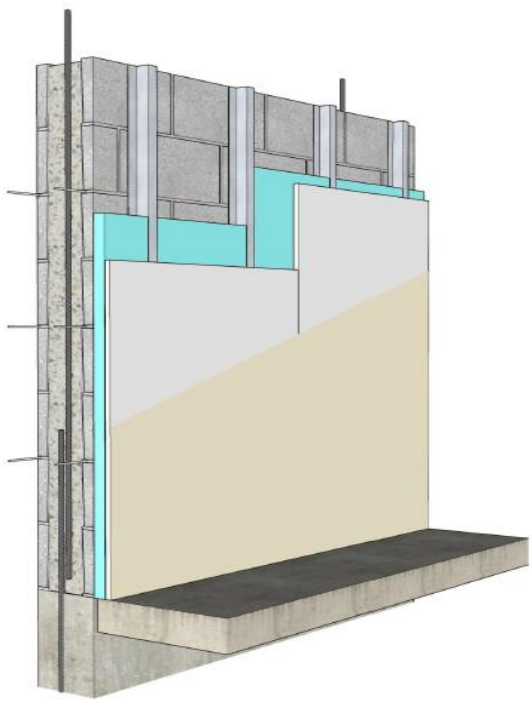

Figure 16. Surface Insulated Exterior Masonry Wall Section - Baseline Configuration.

The exterior walls of the baseline building configurations were modified to use an 8 inch CMU wall, partially grouted and reinforced vertically at 48 inches on center with all other cores filled with foam insulation (Figure 17). This wall was incorporated in the AECOsim model to evaluate the effects of this wall construction on the building energy use. The procedures described in NCMA TEK Note 6B [10] were used to calculate the effective U- and R-values for this partially grouted/partially foamed wall, these being, 0.287 Btu/ft^2-h-F and 3.48 ft^2-h-F/Btu, respectively (assuming 80:20 grouted and un-grouted area ratios with some allowance for horizontal grouting). This is a significant decrease in thermal transmittance when compared to the bare masonry wall (with U-value of 0.580 Btu/ft^2-h-F- partially grouted) but it offers a much higher thermal transmittance than does an 8" CMU wall having a continuous insulation of R-7.2 ft^2-h-F/ Btu (U-value of 0.125 Btu/ft^2-h-F). The U-values for the exterior CMU walls with insulation are listed in Table 4.

Figure 17. Exterior Masonry Wall Sections With Core Insulation.

Examination of the data in Table 9 shows that there is a diminishing return for energy savings as the thermal resistances of exterior walls are increased. However, the uninsulated concrete block masonry mass wall configuration uses more energy than the baseline configurations, especially when significant heating is needed. In Climate Zone 7, when comparing to the baseline configuration, there is a 15% increase in annual energy use when no insulation is used in the exterior walls but only a 1.7% decrease in energy use when the insulation is doubled from code prescribed minimums. This effect is even less if the refrigeration energy is included in the energy total. In this case, the increase in energy use in Climate Zone 7 for uninsulated CMU walls is only 8.5% (EUIs-146.1 kBtu/ft^2 baseline vs 158.5 kBtu/ft^2 for bare CMU walls). The maximum difference between the EUI of the foamed core walls and the baseline configuration is 9.0% without refrigeration and 5.1% when accounting for refrigeration energy (Climate Zone 7). The effects of envelope changes in all other climates appear to be minimal and less than the effects seen for similar changes in the warehouse building in Phase 1.

Table 9. Energy Use Intensity (kBtu/ft^2) for Variations in Wall Insulation levels (no Refrigeration- Supermarket).

Exterior Wall Insulation	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
8" CMU None[1]	56.7	54.3	54.4	66.7	59.9	65.7	75.4	66.5	85.1	78.9	95.6
ASHRAE Baseline[2]	54.4	52.1	52.5	61.5	56.0	60.27	68.2	60.5	75.4	70.2	83.1
8" CMU Foamed Cores[3]	56.1	53.4	53.6	64.6	58.5	63.50	72.4	64.2	81.2	75.4	90.6
Double Insulation[4]	53.8	51.6	52.1	60.7	55.4	59.5	66.6	59.8	74.4	69.2	81.7
12"CMU Foamed Cores[5]	55.0	52.6	52.9	63.1	57.2	61.8	70.3	62.4	78.7	73.0	87.2

[1]- 8" CMU wall - No surface or core wall insulation (bare masonry wall U = 0.580 Btu/ft^2-h-F) - All other building systems at ASHRAE baseline levels including the roof insulation.
[2]- ASHRAE Baseline values (U Varied from 0.112 to 0.070 Btu/ft^2-h-F - Zone 3A Zone 7)
[3]- No external wall insulation – 8" Internally foam insulated CMU walls with grout at 48" OC (U = 0.278 Btu/ft^2-h-F) - All other building systems at ASHRAE baseline levels including the roof insulation.
[4] - Double ASHRAE wall insulation – External wall insulation increased by 100% (R-values are double the prescribed ASHRAE values listed in Table 4) (U Varied from 0.060 to 0.022 Btu/ft^2-h-F- Zone 3A Zone 7).
[5]- No external wall insulation – 12" Internally foam insulated CMU walls with grout at 48" OC - All other building systems at baseline levels including the roof insulation. (U = 0.209 Btu/ft^2-h-F).

To confirm that the warehouse analysis presented in Phase 1 is consistent with the trends with that of the supermarket prototype, the supermarket baseline configuration was also adjusted to include 12 in. CMU walls with foam insulation in the cores and grout at 48 inches on center. For all climate zones, a very small reduction in annual building energy use was realized when the foamed CMU walls were increased in thickness from 8 to 12. This is consistent with the results of the Phase 1 study.

Clearly, increasing the wall insulation R-value above the code prescribed minimums does not have a significant effect on building energy use. This also suggests that the minimum thermal insulation values prescribed by the code for opaque wall systems have been “optimized”, and therefore, the designer should seek alternative means to economically improve the energy efficiency of a building other than by increasing the thermal performance of opaque wall systems.

There are large increases in building energy use associated with using low R-value uninsulated concrete block masonry exterior walls (having large envelope surface area), and diminishing returns on energy use offered by incremental increases to the thermal resistances of building envelope components beyond the prescribed code minimums. Together, they identify why the envelope insulation trade-offs allowed under Section 5 of ASHRAE 90.1 are not particularly effective in colder climates when seeking compliance for use of low R-value envelope components (having relatively large envelope areas). Indeed, it is common that roof and fenestration R-values cannot be increased sufficiently to off-set the heat loss and to compensate for the larger increase in building energy consumption caused by the uninsulated walls, even in the warmer Climate Zones 3 and 4. Because the trade-off relationships are based on only envelope components (a subset of whole building analyses) this trade-off was not considered during the investigation; it was known beforehand, qualitatively, that simple building envelope trade-off would not be effective in the climate zones and building configurations addressed in the study. This is consistent with the findings in Phase 1.

Results from Phase 1 suggested that higher efficiency heating systems will have a greater effect on energy used than changes in the thermal resistance of the building envelope. However these analyses also suggest that an even greater effect on annual energy use and costs can be obtained from addressing the electrical energy used by the lighting systems.

Lighting Analysis

Similar to the warehouse prototype in Phase 1, lighting was shown to be a significant portion of the yearly energy used in the supermarket prototype building.

As required by the ASHRAE 90.1 standard, the lighting systems of the supermarket baseline building model were defined by a maximum power budget in watts per unit area. This did not define the actual lighting systems in the building but simply described the basic lighting type and energy use. Thus, to define equivalent alternative systems, an estimate of the baseline lighting configuration first had to be made. Using data gathered from Lighting Design Lab [11], it was reasonably established that the baseline building used T8 high performance fluorescent fixtures (with 3100 lumen lamps). The number of lighting fixtures for each baseline configuration was determined using the building layout, an assumed configuration for the light fixtures, and the code lighting power density. The supermarket baseline configuration required 18 fixtures in the bakery, 5 fixtures in the office area, 19 fixtures in the Deli, 25 fixtures in the storage area, 60 fixtures in the

Produce area and 196 fixtures in the Sales area. Each fixture was assumed to consist of six, T8, high performance lamps (a total of 217 W per fixture). This results in a total of (332) T8 fixtures for the supermarket.

Methods of reducing lighting energy consumption, while still meeting minimum lighting standards, were investigated and analyzed for their overall impact on building energy consumption in a manner similar to that described in Phase 1. It should be noted that more efficient lighting also reduces the waste heat provided by the lights and thus increases heating demand. This effect is accounted for by whole building energy analysis programs. Although many options are possible, only two alternative lighting configurations are addressed in this investigation. These two systems involved only minor system changes and were judged to be the simplest and most cost effective.

The first system alternative used a common approach to reduce lighting energy wherein the (baseline) ballast unit is replaced with one having a lower ballast factor. The electrical ballast limits the amount of current allowed into the lighting fixture, and decreases both the light output and the electrical usage. According to Lighting Design Lab [11],[12], lowering the ballast factor would reduce the watts/fixture down to 167 W from 217. Given a set number of lighting fixtures, and by reducing the ballast factor for the light fixtures from 1.15 to 0.88, light power density was reduced in each of the building areas shown in Table 1. Note that the reduction of the ballast factor also causes a drop in the effective lumens produced by each fixture, as described in Phase 1. The lower ballast factors reduced the effective lighting budget from 1.7 watts/ft^2 in the main areas (Deli, Produce Area, Bakery and Sales Area) to 1.31 watts/ft^2, 1.1 watts/ft^2 in the office area to 0.85 watts/ft^2 and 0.8 watts/ft^2 in the storage area to 0.64 watts/ft^2. These calculations are summarized in Table 10.

Table 10. Lighting Power Density with Lower Ballast Factor.

		Baseline	Lower BF
Deli, Bakery, Sales, Produce	LPD (W/ft^2)	1.7	1.1
	Footcandles	26.5	20.0
	Minimum Footcandles	10-50	10-50
Storage	LPD (W/ft^2)	0.8	0.64
	Footcandles	17.1	10
	Minimum Footcandles	10	10
Office	LPD (W/ft^2)	1.1	0.85
	Footcandles	52.3	45.
	Minimum Footcandles	30-50	30-50

In Phase 1, occupancy sensors and LED lighting were also investigated as alternatives to the T8 Lighting. However, because the lights are expected to remain on in almost all areas of the supermarket during occupied periods, little reduction in energy use is expected by using occupancy sensors. Thus, the occupancy sensor alternative was not addressed for the supermarket prototype. The second alternative for lowering lighting energy consumption replaced the T8 fluorescent lamps with much more efficient LED lights. LED lighting technology produces low energy consumption with high lumen output. GE's IP series LED lighting systems were chosen for the simulation and GE's lighting design tool was used to obtain the light output of specific IP series lamp configurations[13]. This information was used to determine how many fixtures would be required to reach the IES minimum lumen level in each of the areas of the supermarket [11]. This revised lighting design resulted in light power densities of 0.47 W/ft^2 in the main areas Deli, Produce Area, Bakery and Sales Area, 0.3 W/ft^2 in the office area, and 0.147 W/ft^2 in the storage area. A total 232 LED fixtures were needed for the supermarket prototype.

The cost effectiveness of implementing energy efficient lighting designs will be discussed in the following sections.

<u>Low-Rise (Box) Retail Prototype</u>

The 45,000 ft^2 supermarket prototype building is similar in configuration to a number of other building types that have successfully used single wythe exterior masonry walls. These include low-rise (box) retail entities such as Walgreens, CVS and Best Buy. With the exception of the bakery, these entities have similar operating hours, occupancy schedules, equipment and configurations to those used for the supermarket prototype.

Using the basic configuration of the supermarket prototype including, zoning, storage configuration, and schedules, (but removing refrigeration and the bakery equipment) a new low-rise (box) retail prototype was developed. This prototype was assumed to have the same physical characteristics as the supermarket prototype (see Table 4), as it must meet the same code prescriptive minimums, including lighting power densities.

The AECOsim software was used to conduct whole building energy analyses on the low-rise retail prototype and the annual energy use for this prototype is shown in Table 11 for each climate zone. As a comparison, the baseline supermarket prototype EUI values without refrigeration are also listed. The data shows that the removal of the bakery equipment has a small but consistent impact on annual energy use.

Often box retail buildings have smaller area of front glass than supermarkets. For the previous energy analyses, both the supermarket prototype and the box retail prototype were assumed to have glass over 54% of the storefront wall area. To evaluate the effect that a lower front fenestration area will have on the energy use, the box retail prototype was also analyzed using a storefront glass area of 25%. The EUI values for this configuration are also listed in Table 11. The data shows that reducing the front glass area by 50% has less than a 0.8% effect on the annual energy use.

Table 11. Energy Use Intensity (kBtu/ft^2) for the Low-Rise (Box) Retail Prototype Baseline Configurations and Lower Front Glass Area.

Exterior Wall Insulation	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Supermarket Baseline- No Refrigeration- (54% Front glass Area)	54.4	52.1	52.5	61.5	56.0	60.3	68.2	60.5	75.4	70.2	83.1
Box Retail Baseline- (54% Front Glass Area)	49.3	46.3	48.2	57.2	51.2	56.7	64.2	56.6	71.8	66.8	80.2
Box Retail Baseline - (25% Front Glass Area)	49.2	46.2	48.2	56.9	51.1	56.4	63.9	56.4	71.4	66.3	79.6

Lighting Analysis

The low-rise (box) retail configuration has the same lighting power densities and light level requirements as the supermarket, and as such, was assumed to use the same number of T8 florescent lamps (332) in its base configuration.

As with the supermarket configuration, occupancy sensors were not addressed because the lights are expected to remain on in this building during occupied hours and thus, the use of occupancy sensors would not impact energy use significantly.

It was also assumed that the reduced ballast factor analysis and the LED lighting design presented for the supermarket are applicable to the low-rise (box) retail prototype as well.

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COST ANALYSES - UNITED STATES

As noted earlier, there are three energy design compliance paths permitted for use in ASHRAE 90.1[3]. The energy cost budget method is the most sophisticated, and for a compliant energy design, this path requires that:

"...the design energy cost [of the proposed design], as calculated in Section 11.3, does not exceed the energy cost budget as calculated by the simulation program described in Section 11.2…".

Thus, to determine if a proposed design is compliant, it must produce the same or lower energy cost as that of the proposed building modeled with the same set points, schedules, etc., but complying with the prescriptive minimum code requirements (baseline or reference building). Using this compliance path, energy cost analyses were run on building configurations that were expected to give substantially lower construction costs than the baseline building, but which used single wythe exterior wall systems with no externally applied insulation systems. Results are presented later in the report.

To further evaluate the design variations addressed in the earlier sections of this report (variations in lighting, insulation, HVAC efficiency, and wall construction) and to choose which of these different configurations might be the more cost effective alternatives to explore further, construction costs for the various building configurations were estimated, and their construction cost differences were calculated. To determine the payback time (if applicable) and overall cost savings gained from using these various energy efficient technologies, construction cost differences were then compared to the whole building annual energy cost savings.

Building Costs

The various wall configurations analyzed in this project all have different costs associated with their construction and these costs vary depending on the city in which they are built. These cost variations were necessarily accounted for in each of the cost analyses undertaken.

Wall construction cost data were provided by the International Masonry Institute (IMI) and are based on the RSMeans data base. The unit prices for the various CMU wall configurations are listed in Tables 12, 13, and 14. These Tables provide construction and material costs for the baseline wall configuration (partially grouted, externally insulated 8 in. CMU, with insulation and furring ranging from 1.5 to 2.5 inches in depth depending on climate zone), the partially grouted 8 inch foam filled CMU wall configuration, and the partially grouted, 12 inch foam filled wall configuration.

Using these wall unit costs, the total exterior wall construction costs for the various supermarket and box retail prototype configurations were calculated; these are provided in Table 15 (based on a 15,436 sq. ft. total wall area , excluding the 54% front glass area). Both the supermarket and box retail prototype buildings have identical exterior wall configurations and thus costs. There were three exterior wall configurations used in the study: (a) code baseline, (b) 8 in. foam cored, and (c) 12 in. foam cored. Costs for the baseline were calculated using the externally/internally insulated walls (as required by code, and illustrated in Figure 16) for all opaque exterior wall areas. These opaque insulated walls were replaced by foamed walls (Figure 17) for the other two cost determinations. It is clear that the partially grouted 8 inch foamed CMU wall is less costly to construct in all zones than the baseline wall profile. This is perhaps best illustrated by the bar chart in Figure 18. This is not the case for the 12 inch foamed CMU wall where these wall costs exceed those of the baseline configuration. Therefore, where sufficient to meet energy requirements, it is most cost effective to use an 8 inch foamed in place CMU wall because the incremental cost of installing insulation over either the exterior or interior surface of a bare CMU wall is much higher than using foamed cores. The use 12 inch foam CMU walls are not cost effective unless the larger unit size is needed for other reasons (such as structural demand) and moreover, when compared to the 8 inch foam CMU wall configurations, it reduces the yearly energy used only by about 4%.

Table 12. Unit Cost Estimate for the Baseline Supermarket and Low-Rise (Box) Retail Prototype Walls.

Wall Profile	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
8" CMU, EXT - reinf alt crs, tool 2 sds, norm wt	8.60	12.05	15.35	9.30	8.80	11.70	14.80	9.00	13.45	10.30	12.90
#7 rebar @ 48" o.c.	0.33	0.40	0.47	0.35	0.31	0.38	0.48	0.33	0.44	0.32	0.41
Grout	0.48	0.54	0.72	0.50	0.46	0.57	0.73	0.50	0.66	0.48	0.54
Bond beam/cmu+rebar+grout	0.15	0.23	0.26	0.18	0.18	0.21	0.27	0.18	0.24	0.19	0.24
Exterior Paint -2 coats, rolled	0.67	0.90	0.83	0.68	0.49	0.71	1.10	0.60	0.96	0.45	0.80
Galv Z Strip, 1.5 to 2.5"	0.09	0.12	0.17	0.11	0.1	0.13	0.19	0.12	1.39	0.79	1.23
1.5" to 2.5" XP Rigid Insul	1.17	1.46	1.72	1.54	1.52	1.66	1.86	1.62	2.40	1.98	2.30
1/2" GWB, taped Fin L4	1.20	1.57	2.1	1.18	1.01	1.45	2.14	1.33	1.82	1.05	1.62
Interior paint, 2 cts - rolled	0.62	0.84	1.04	0.62	0.45	0.63	1.06	0.54	0.89	0.39	0.76
Total $/ SF	13.31	18.11	22.66	14.46	13.32	17.44	22.63	14.22	22.25	15.95	20.80

Table 13. Unit Cost Estimate for the Partially Grouted, 8 in. Foam Filled CMU Wall.

Wall Profile	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
8" CMU, EXT - reinf alt crs, tool 2 sds, norm wt	8.60	12.05	15.35	9.30	8.80	11.70	14.80	9.00	13.45	10.30	12.90
#7 rebar @ 48" o.c.	0.33	0.40	0.47	0.35	0.31	0.38	0.48	0.33	0.44	0.32	0.41
Grout	0.48	0.54	0.72	0.50	0.46	0.57	0.73	0.50	0.66	0.48	0.54
Bond beam/cmu+rebar+grout	0.15	0.23	0.26	0.18	0.18	0.21	0.27	0.18	0.24	0.19	0.24
Foamed cores / Drill & Patch	0.50	0.59	0.70	0.55	0.52	0.59	0.70	0.56	0.72	0.54	0.69
Exterior Paint -2 coats, rolled	0.67	0.90	0.83	0.68	0.49	0.71	1.10	0.60	0.96	0.45	0.80
Interior Paint, 1 prm-1fin-rolled	0.82	1.12	1.37	0.83	0.58	0.85	1.39	0.73	1.19	0.52	1.02
Total $ / SF	**11.55**	**15.83**	**19.70**	**12.39**	**11.34**	**15.01**	**19.47**	**11.90**	**17.66**	**12.80**	**16.60**

Table 14. Unit Cost Estimate for the Partially Grouted, 12 in. Foam Filled CMU Wall.

Wall Profile	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
12" CMU, EXT - reinf alt crs, tool 2 sds, norm wt	12.75	18.20	23.50	13.80	12.80	17.60	23.00	13.45	20.50	15.15	19.75
#6 rebar @ 48" o.c.	0.24	0.29	0.35	0.26	0.23	0.28	0.36	0.24	0.32	0.24	0.30
Grout	0.60	0.73	0.86	0.64	0.58	0.70	0.88	0.64	0.80	0.60	0.63
Bond beam/cmu+rebar+grout	0.22	0.28	0.37	0.24	0.23	0.28	0.33	0.22	0.32	0.25	0.30
Foamed cores / Drill & Patch	0.80	0.93	1.11	0.89	0.83	0.94	1.12	0.89	1.15	0.86	1.09
Exterior Paint -2 coats, rolled	0.67	0.90	0.83	0.68	0.49	0.71	1.10	0.60	0.96	0.45	0.80
Interior Paint, 1 prm-1fin-rolled	0.82	1.12	1.37	0.83	0.58	0.85	1.39	0.73	1.19	0.52	1.02
Total $ / SF	16.10	22.45	28.39	17.34	15.74	21.36	28.18	16.77	25.24	18.07	23.89

Table 15. Total Exterior Wall Cost for Supermarket and Low-Rise (Box) Retail Prototype Walls.

	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Baseline	$205.4k	$279.5k	$349.8k	$223.2k	$205.6k	$269.2k	$349.3k	$219.5k	$343.4k	$246.2k	$321.1k
8 in. Foam	$170.6k	$235.2k	$293.3k	$182.8k	$167.0k	$222.6k	$289.7k	$175.0k	$261.5k	$189.2k	$245.6k
12 in. Foam	$245.1k	$342.2k	$432.6k	$264.0k	$239.4k	$325.4k	$429.9k	$255.5k	$384.7k	$275.2k	$364.1k

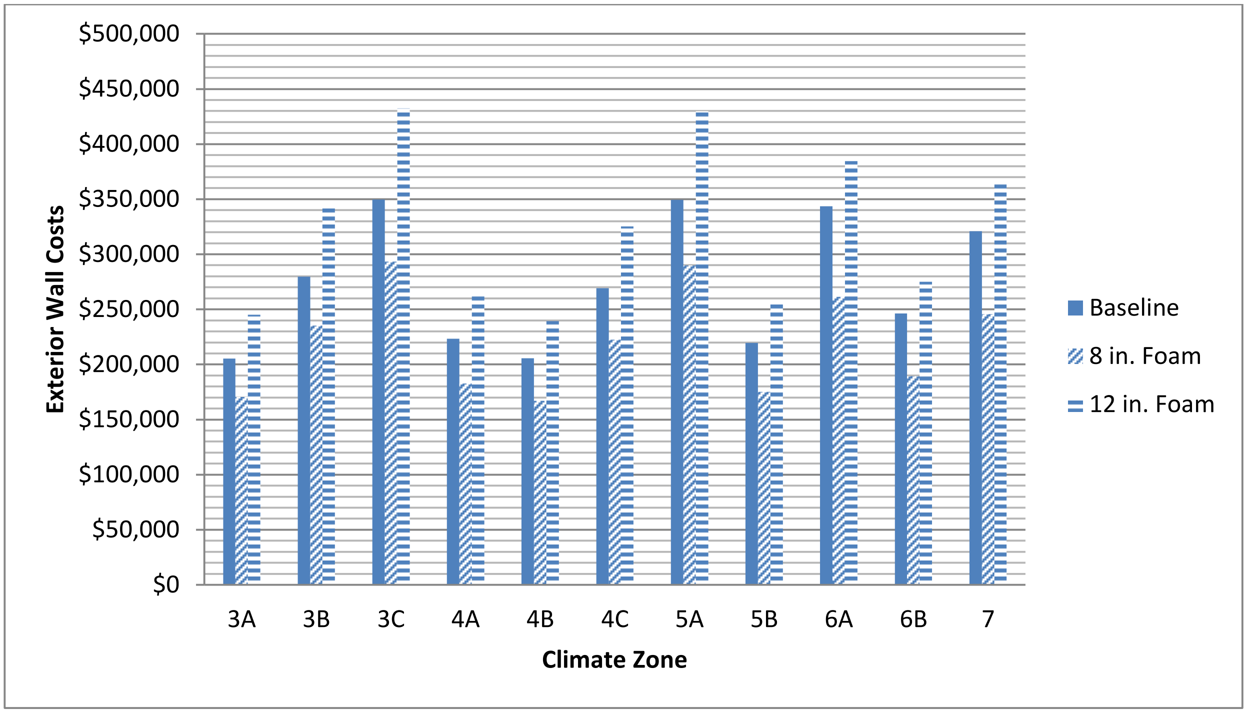

Figure 18. Wall Configuration Costs for the Supermarket and Low-Rise (Box) Retail Prototype.

HVAC System Costs

The AECOsim energy simulator auto-sized the HVAC equipment to meet heating and cooling demands for the climate in each city and building configuration analyzed.

The analysis in Phase 1 showed that changes in heating systems had an effect on the overall energy used by the building. However, because the heating was provided by lower cost gas, improving the energy efficiency of the heating systems was not as cost effective as improving the energy performance of the building lighting due to relatively high costs for electricity. This was the case for both the box retail and the supermarket prototype buildings, and the effects were exacerbated when refrigeration energy (which is electrical) was included. Improvements to the heating systems simply cannot affect energy cost savings in amounts needed to demonstrate code compliance and were not addressed in this phase of the study.

Lighting

Lighting costs are dependent on the type and the number of lights required in the building. This varies with the building floor plan and the intended use of each of the floor areas. For example, the lighting level required at ground level is higher in the Sales area versus the storage area. Since these levels changed little between different building configurations, the cost analysis was confined to the cost difference between traditional lighting and any lighting energy conservation measures. It should be noted that, in practice, most building lighting is designed using the prescriptive method rather than performance-tradeoff lighting analysis[11].

Based on RSMeans cost data [14], there is no significant price difference between ballasts with variable ballast factors. Thus, for the alternative lighting configuration that used reduced ballast factors, since the number of fixtures used remains fixed and the cost of ballast with lower ballast factors are the same, there is no difference in cost for this alternative design when compared to the baseline configuration.

The lighting analysis showed that the LED light design required fewer numbers of fixtures than the T8 baseline design. The baseline design produced (332) T8 fluorescent light fixtures and the LED design produced (232) LED fixtures. The per fixture cost of the baseline fluorescent lamps were obtained from RSMeans [14] at $220 per fixture. The LED fixture material costs were obtained from the Granger product catalog [15] and the labor cost obtained from RSMeans [14] for a similar fixture. The total cost for the LED fixture was $520. These values were also adjusted for location using the MEANS procedures.

Building Configuration Analysis and Code Compliance

Using the results of the analyses presented in Phase 1, and the construction cost estimate data and the energy analysis results presented earlier in the report, a number of building configurations were selected and further analyzed to determine which configuration(s) provided the most cost effective means to meet code minimum energy efficiency [essentially, identifying that building configuration having minimum (construction + energy) costs].

To facilitate this comparison and to determine code compliance, the yearly energy costs for the baseline supermarket prototype (from Table 7 and 8) were used to establish the reference (baseline) performance levels and to calculate any annual energy cost savings offered by the alternate building configurations. Code compliance was evaluated with and without refrigeration.

A variety of alternative building configurations were evaluated. All these configurations used 8 inch CMU walls with internal insulation since this wall system was shown to be low cost and provide significantly better energy performance than bare CMU walls. Initially a number of building configurations were evaluated with lower ballast factor T8 lights. However, unlike the Phase 1 warehouse archetype, use of lower ballast factor lighting and 8 inch foamed CMU walls did not produce annual energy costs below baseline values even with large increases of roof insulation. Because the lower ballast light configuration could not be readily made code compliant, LED light configurations were then combined with the internally insulated masonry walls.

Table 16 shows the annual energy costs for the alternative building configuration having partially grouted 8 inch foamed CMU walls and LED lighting (including the break down between gas and electric costs) . Also listed in Table 16 are the total annual energy costs for the baseline supermarket prototype building. In all climate zones, the annual energy costs for the alternative building configuration are less than the corresponding costs for the baseline configuration, and thus, the alternative configuration is code compliant for all climate zones. Note that there are significant yearly energy cost savings predicted for the foamed CMU wall configuration over the code prescriptive baseline configuration for all climate zones (as much as $16k/per year in Climate Zone 3C).

Table 16. Yearly Energy Costs for Supermarket Prototype (No Refrigeration) having 8 in. Foam Filled CMU Walls and LED lighting.

Climate Zone	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Proposed Supermarket Configuration – 8in. Foam filled CMU walls with LED Lighting											
Gas Cost	$3,616	$3,236	$3,199	$7,154	$3,512	$5,927	$6,429	$5,946	$8,461	$8,866	$10,309
Electricity Cost	$35,452	$37,247	$43,904	$43,838	$32,541	$26,563	$33,103	$29,950	$31,095	$35,295	$31,426
Total Yearly Energy Cost	$39,068	$40,483	$47,104	$50,992	$36,053	$32,490	$39,532	$35,896	$39,556	$44,162	$41,735
Baseline (reference) Configuration (from Table 7)											
Total Yearly Energy Cost	$51,461	$53,287	$63,925	$65,257	$46,958	$41,391	$49,524	$46,528	$49,231	$54,722	$50,770
Cost Difference	($12,393)	($12,804)	($16,822)	($14,265)	($10,905)	($8,901)	($9,992)	($10,632)	($9,676)	($10,560)	($9,035)

() denotes energy cost savings

The supermarket prototype was also evaluated with the refrigeration energy accounted for and a summary of these results for the baseline and alternative configurations are shown in Table 17.

Table 17. Yearly Energy Costs for Supermarket Prototype (With Refrigeration) having 8 in. Foam Filled CMU Walls and LED lighting.

Climate Zone	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Proposed Supermarket Configuration – 8in. Foam filled CMU walls with LED Lighting											
Gas Cost	$3,616	$3,236	$3,199	$7,154	$3,512	$5,927	$6,429	$5,946	$8,461	$8,866	$10,309
Electricity Cost	$133,769	$124,185	$164,416	$155,816	$107,841	$93,295	$110,875	$104,812	$103,684	$109,401	$98,753
Total Yearly Energy Cost	$137,385	$127,421	$167,615	$162,970	$111,352	$99,221	$117,303	$110,757	$112,145	$118,268	$109,062
Baseline (reference) Configuration (from Table 8)											
Total Yearly Energy Cost	$149,777	$140,225	$184,437	$177,234	$122,257	$108,122	$127,295	$121,389	$121,820	$128,828	$118,097
Cost Difference	**($12,393)**	**($12,804)**	**($16,822)**	**($14,265)**	**($10,905)**	**($8,901)**	**($9,992)**	**($10,632)**	**($9,675)**	**($10,560)**	**($9,035)**

() denotes energy cost savings

As can be seen from the cost data listed in Tables 16 and 17, the difference in the total annual energy costs, proposed versus baseline, is the same for a given climate zone whether the refrigeration energy is accounted for or not. However, the 18% to 26% decrease in energy costs offered by the alternative configuration is reduced to approximately 8% when refrigeration energy is accounted for. Clearly, efficiency improvements to refrigeration systems will have a significant impact on the energy performance of the building but since this does not impact code compliance, addressing the performance of these systems was beyond the scope of this study.

Low-Rise (Box) Retail Prototype

The baseline low-rise (box) retail prototype having surface insulation over exterior masonry walls (Figure 16), and an alternative configuration having exterior 8 inch CMU walls with core insulation (Figure 17) and LED lights, were also evaluated for energy efficiencies, energy costs, and ASHRAE 90.1 compliance. Table 18 summarizes the yearly gas, electrical and total energy costs for the proposed alternative configuration, as well as the total yearly energy costs for the baseline configuration. Savings similar in amount to those for the supermarket prototype were also realized for the box retail prototype building by using the alternative wall and light configurations. The alternative configuration was ASHRAE 90.1 compliant for all climate zones.

Although low-rise (box) retail buildings typically have smaller amounts of front glass area than supermarkets, the analysis discussed earlier (see Table 11 and related discussion) showed that decreases in storefront glass area had very little effect on the annual energy used. Thus, analysis on both the baseline and proposed low-rise retail building configurations conservatively used the larger glass area (54% storefront glass area). The energy savings for lower front glass configurations will be almost the same as that shown in Table 18.

Table 18. Yearly Energy Costs for Low-Rise (Box) Retail Prototype cost having 8 in. Foam Filled CMU Walls and LED lighting.

Climate Zone	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Proposed Low-rise Retail Configuration – 8in. Foam filled CMU walls with LED Lighting											
Gas Cost	$3,500	$3,004	$3,188	$7,116	$3,421	$5,950	$6,459	$5,967	$8,620	$9,015	$10,631
Electricity Cost	$30,100	$31,451	$37,259	$37,542	$27,865	$22,810	$28,637	$25,336	$26,879	$30,671	$27,317
Total Yearly Energy Cost	$33,600	$34,455	$40,447	$44,658	$31,286	$28,760	$35,096	$31,303	$35,499	$39,686	$37,948
Baseline (reference) Configuration											
Total Yearly Energy Cost	$45,812	$47,091	$57,441	$58,869	$42,015	$37,706	$45,015	$41,857	$45,044	$50,137	$46,890
Cost Difference	**($12,212)**	**($12,636)**	**($16,994)**	**($14,210)**	**($10,729)**	**($8,947)**	**($9,919)**	**($10,554)**	**($9,545)**	**($10,451)**	**($8,942)**

() denotes energy cost savings

Construction Costs

As a further comparison between alternative configurations and baselines, the differential construction costs for the various building configurations were determined. As shown previously (see Table 15), the alternative configurations constructed with an 8 inch foam filled CMU wall have significantly lower wall costs than code prescribed wall configurations.

As was discussed earlier, the supermarket and low-rise (box) retail prototype have the same wall and lighting configurations for both the baseline and the proposed alternative building configurations. They will therefore have the same differential construction costs. The following discussion is therefore applicable to both the supermarket and box retail archetypes.

Table 19 summarizes the differential construction costs associated with the alternative prototype building configurations (as compared to the code prescriptive baseline configurations), for both the supermarket and low-rise retail prototypes. Examining the data in Table 19 shows that, for climate zones below Zone 5, there is generally a slight increase in the initial cost associated with the alternative design configuration. However, the annual energy savings are much greater than the initial construction costs. In every case, the additional construction costs had paybacks that are significantly less than one year.

Table 19. Differential Construction Costs for Alternative Configuration with 8 inch Foam Filled CMU Wall and LED lights (In Contrast to Code Prescriptive Box Retail and Supermarket Prototype Baseline Configurations).

	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Wall	($34,885)	($44,301)	($56,496)	($40,442)	($38,590)	($46,617)	($59,583)	($44,456)	($81,965)	($56,959)	($75,482)
Lighting	$41,936	$50,408	$54,883	$44,078	$42,031	$49,980	$55,787	$43,697	$53,550	$42,554	$50,361
Total Savings	**$7,050**	**$6,107**	**($1,613)**	**$3,635**	**$3,441**	**$3,363**	**($3,796)**	**($759)**	**($28,415)**	**($14,404)**	**($25,121)**

() indicates that there is a net savings associated with the alternative design configuration.

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US Study Summary

The results of this study showed that holistic energy analyses can be used to demonstrate US energy code compliance for both the supermarket and low-rise (box) retail prototypes constructed with single wythe masonry walls without continuous external insulation. Moreover, when compared to the US code prescriptive configurations (externally insulated walls), benefits of the single wythe masonry wall configurations with integral foam insulation include both substantial yearly energy cost savings, and in most cases, significant construction costs savings (see Tables 16, 18 and 19). By using the foamed CMU walls and LED lighting, the predicted yearly energy cost savings for the proposed building configurations ranged from $9,000 to $17,000. In climates where building energy costs are dominated by heating costs, the construction cost savings for the proposed building configurations ranged from $800 to $25,000.

PROTOTYPE BUILDING DESIGN AND ANALYSIS – CANADA

The prototype building design and analyses described in the previous sections were extended to examine alternative energy solutions for supermarket and low-rise (box) retail buildings in a number of Canadian Cities using the energy requirements of the 2011 edition of the National Energy Code for Buildings (NECB)[16]. The climates investigated were restricted to Climate Zones 4 through 7B since these zones cover the vast majority of the climates in Canada and also represent those geographical areas for nearly all construction activity. The Canadian cities investigated, and basic climate data, are shown in Table 20.

Table 20. Canadian Cities for Zones 4 Though 7B.

City	Climate Zone	HDD
Victoria, BC	4 (<3000 HDD)	2650
Windsor, ON	5 (3000 to 3999)	3400
Montreal (City Hall), QC	6 (4000 to 4999)	4200
Edmonton, AB	7A (5000 to 5999)	5120
Ft. McMurray, AB	7B (6000 to 6999)	6250

Changes to the Prototype Supermarket and Low-Rise (Box) Retail Buildings

The prescriptive requirements of the NECB 2011 [16] differ from those in the ASHRAE 90.1 standard, and thus, changes to the US prototype building baseline configurations were needed for all of the climate zones investigated. For instance, under the prescriptive requirements of the NECB, for a given climate zone, the various components of the building envelope such as a wall, floor, roof, or fenestration are each prescribed a maximum overall thermal transmittance (minimum thermal resistance) that does not vary with construction type. Thus, both mass walls and light frame walls are required to meet the same maximum thermal transmittance. Furthermore, for all climate zones, the prescribed maximum permissible thermal transmittances for the various building envelope components (walls, roofs, floors, fenestrations) are significantly lower in the NECB-11 than in ASHRAE 90.1. The differing prescriptive limits required significant changes to the reference building configurations for each prototype.

In addition, unlike ASHRAE 90.1, the holistic energy analysis option for code compliance described in Part 8 of NECB-11(Building Energy Performance Compliance) requires that the yearly energy use (not energy *cost*) of the proposed building not exceed that of a reference building designed to meet the prescriptive code requirements. This is a more stringent requirement than the ASHRAE Standard.

Tables 21 through 23 list the changes made to the ASHRAE baseline prototype supermarket and low-rise (box) retail configurations in order to meet minimum requirements set forth in NECB 2011[16]. There were required increases in wall thermal resistances (reduction in thermal transmittances), and also reductions in lighting system energy budgets and a slight increase in HVAC system efficiencies.

Table 21. Building Envelope Component Prescribed Maximum Thermal Transmittances (U-value) (NECB 2011)[16].

Climate Zone	4	5	6	7A	7B
SI units					
Wall (W/m^{2}K)	0.315	0.278	0.247	0.210	0.210
Roof (W/m^{2}K)	0.227	0.183	0.183	0.162	0.162
Floor (W/m^{2}K)	0.227	0.183	0.183	0.162	0.162
Floors in contract with ground (W/m^{2}K)	0.757 for 1.2 m	0.757 for 1.2 m	0.757 for 1.2 m	0.757 for 1.2 m	0.757 for 1.2 m
Windows(W/m^{2}K)	2.4	2.2	2.2	2.2	2.2
Doors (W/m^{2}K)	2.4	2.2	2.2	2.2	2.2
US Standard Units					
Wall (Btu/ft^2-h-°F)	0.055	0.049	0.043	0.037	0.037
Roof (Btu/ft^2-h-°F)	0.040	0.032	0.032	0.028	0.028
Floor (Btu/ft^2-h-°F)	0.040	0.032	0.032	0.028	0.028
Floors in contract with ground (Btu/ft^2-h-°F)	0.133 for 4 ft.	0.133 for 4 ft.	0.133 for 4 ft.	0.133 for 4 ft.	0.133 for 4 ft.
Windows (Btu/ft^2-h-°F)	0.422	0.387	0.387	0.387	0.387
Doors (Btu/ft^2-h-°F)	0.422	0.387	0.387	0.387	0.387

Table 22. Lighting Energy Minimum Requirements (Lighting Power Densities) in NECB 2011[16].

Space Type	W/ft^2	W/m^2
Main Areas	0.95	10.2
Storage	0.59	6.3
Office	1.02	11.0

Table 23. HVAC Minimum Efficiency Requirements in NECB 2011.

	Coefficient of Performance (COP)
Heat Pump	3.1

When using the whole building analysis compliance path, one notable difference between NECB-11 and ASHRAE 90.1 is the NECB provision that allows the fenestration+door area to gross wall area ratio (FDWR) of the reference building to be increased under certain conditions independent of FDWR of the proposed building configuration. The FDWR of the reference building is not required to “track” the FDWR of the proposed building where the FDWR of the proposed building is below a prescribed maximum value. Thus, for the purposes of analyses and compliance, the reference building may be assigned the maximum FDWR permissible even though the proposed building uses its design FDWR. The FDWR limit varies with HDD, and is equal to 40% where HDD < 4000, 20% where HDD > 7000, and varies linearly between these HDD limits. Because fenestration and doors typically have higher U-values compared to opaque envelope components, this code provision aids in qualifying proposed buildings where the FDWR is low, such as a warehouse, supermarket or box retail building. This is particularly true in building configurations where exterior walls have higher opaque wall thermal transmittance than that prescribed by the code. These provisions also allow the reference building to be assigned a total skylight area of 5% of the gross roof area, and like FDWR, may be used where the proposed building has less than a 5% skylight area, however this effect is much smaller.

The FDWR for the proposed supermarket prototype configuration is below 11%, and because this is below the maximum allowable FDWR for the HDD of all climate zones, the reference buildings used for holistic analysis comparisons were adjusted so that the fenestrations in each conditioned area met the percentages shown in Table 24. The fenestrations were assumed to be uniformly distributed in each wall area. Due to the small limit on roof area (5%), the effect of a skylight on energy use is small and this was not added to the reference building configurations.

Table 24. Adjusted FDWR Values for the Reference Supermarket and Box Retail Configurations.

City	Climate Zone	FDWR (%)
Victoria	4	40%
Windsor	5	40%
Montreal	6	38.6%
Edmonton	7A	32.5%
Fort McMurray	7B	25%

Energy Analysis

To produce the Canadian prototype baseline supermarket and box retail buildings, the US-based ASHRAE prototypes were suitably modified to comply with the NECB-11 minimum performance levels prescribed for the building envelope components, lighting, and HVAC systems. For each city, the reference building prototypes were also adjusted to maximum permissible FDWR. These baseline building configurations were otherwise identical to those described for the US analyses. And as discussed earlier under the U.S. ASHRAE analysis, the refrigeration energy dominates the annual energy use for the supermarket. Notwithstanding, analyzing the prototypes without the refrigeration energy allows for a better evaluation of the effects of the other building systems on total energy use, and moreover, the ASHRAE-based analyses undertaken for the U.S. prototypes show that differences in building annual energy use are consistent with and without the refrigeration (that is, energy used by the refrigeration systems is quite constant over a very large variation in climate zones; see Figure 8 and Table 3). Thus, all of the Canadian simulations were conducted without including refrigeration.

Supermarket Prototype

Energy simulations for the supermarket (and box retail) buildings were undertaken using baseline configurations having the FDWR adjusted to the maximum area permitted by NECB-11. The results of the supermarket prototype (the reference buildings) analyses are shown in Table 25. In addition, the Canadian NECB supermarket baseline configurations were also analyzed with no increase in FDWR, and the resulting EUI values are also shown in Table 25. To allow for comparisons with earlier analyses, the results of the energy analyses are presented in both SI and US standard units.

Table 25. Yearly Energy Consumption and EUI Values for NECB 2011 Reference Baseline Supermarket Prototype Configurations (NECB Prescriptive Configurations, With and Without Adjusted FDWR, No Refrigeration).

Location	**Victoria**	**Windsor**	**Montreal**	**Edmonton**	**Ft. McMurray**
Province	**BC**	**ON**	**QC**	**AB**	**AB**
Climate Zone	**4**	**5**	**6**	**7A**	**7B**
SI Units					
Heating (GJ)	1157.6	1376.2	2022.8	1999.7	2328.7
Cooling (GJ)	15.7	47.7	19.7	20.0	22.9
Interior Lighting (GJ)	609.9	609.9	609.9	609.9	648.2
Interior Equip. Electric (GJ)	792.7	792.7	792.7	792.7	792.7
Interior Equip. Gas (GJ)	200.9	200.9	200.9	200.9	200.9
Fans (GJ)	285.1	353.5	271.0	415.6	427.6
Total (GJ)	**3061.9**	**3380.9**	**3917.1**	**4038.7**	**4421.0**
EUI (GJ/m^2) (Reference Building with max FDWR)	**0.732**	**0.809**	**0.937**	**0.966**	**1.057**
EUI (GJ/m^2) (Reference Building No increase in FDWR)	**0.687**	**0.679**	**0.738**	**0.736**	**0.806**
US Standard Units					
Heating (kBtu)	1097160	1304348	1917257	1895312	2207192
Cooling (kBtu)	14904	45185	18676	18919	21677
Interior Lighting (kBtu)	578102	578102	578102	578102	614342
Interior Equip. Electric (kBtu)	751294	751294	751294	751294	751294
Interior Equip. Gas (kBtu)	190431	190431	190431	190431	190431
Fans (kBtu)	270188	335092	256883	393883	405301
Total (kBtu)	**2902079**	**3204452**	**3712643**	**3827941**	**4190237**
EUI (kBtu/ft^2) (Reference Building with max FDWR)	**64.49**	**71.21**	**82.50**	**85.07**	**93.12**
EUI (kBtu/ft^2) (Reference Building No increase in FDWR)	**60.5**	**59.8**	**65.0**	**64.8**	**71.0**

Comparing the EUI values of the Canadian NECB baseline supermarket without refrigeration configurations (no increase in FDWR) to the U.S. ASHRAE 90.1 baseline configuration (Table 5), suggests that they are lower than ASHRAE 90.1 baseline values for the corresponding climate zones. Also note that Seattle has an EUI of 60.3 kBtu/ft^2 whereas Victoria has an EUI of 60.5 kBtu/ft^2 for the unadjusted FDWR and 64.5 kBtu/ft^2 for the adjusted FDWR (both cities have similar climates). This suggests that the significantly lower envelope thermal transmittances (higher thermal resistances) mandated by the NECB (as compared to this in the ASHRAE provisions) do not have a significant effect on energy use in warmer climates. However, an increasing difference between corresponding EUI is seen in the colder climates. Additionally, the EUIs for the reference buildings having adjusted (increased) FDWR are considerably higher than those with unadjusted FDWR and higher than those resulting from ASHRAE analyses. This clearly demonstrates the effect of FDWR adjustment on building energy use, and the advantage offered using Part 8 compliance under the NECB in lieu of the prescriptive compliance path.

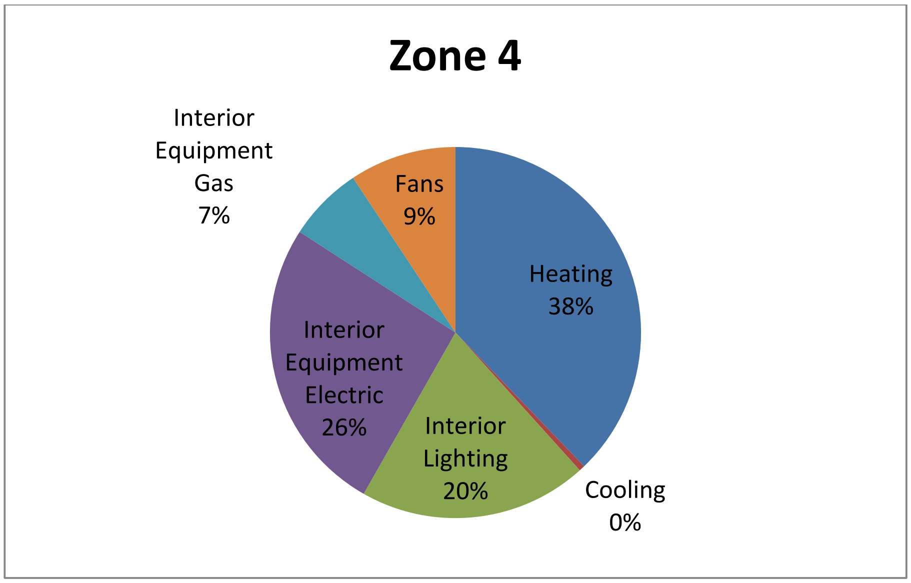

Figure 19. Annual Energy Use of the Canadian Baseline Supermarket Prototype Configuration - the Reference Building (NECB Prescriptive Configuration – With Adjusted FDWR – No Refrigeration) - Zone 4.

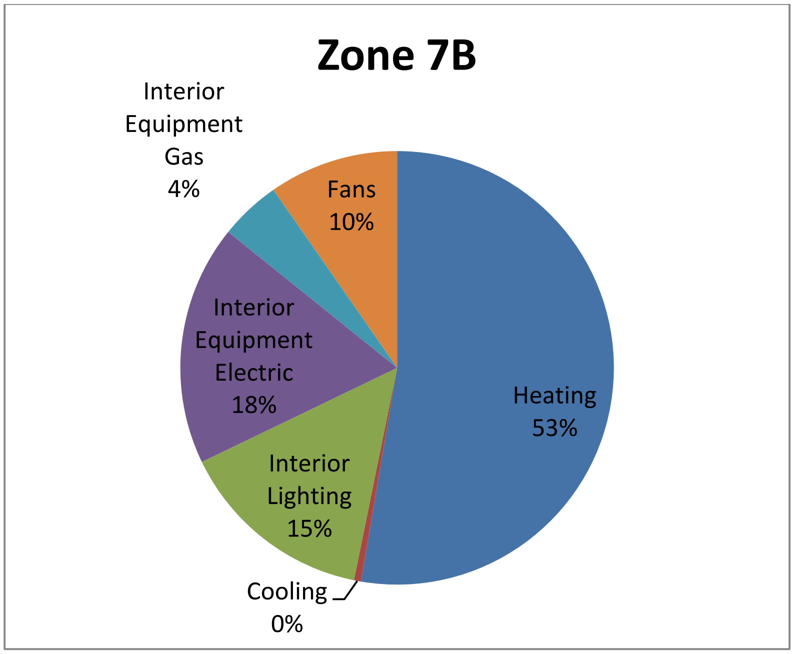

Figure 20. Annual Energy Use of the Canadian Baseline Supermarket Prototype Configuration - the Reference Building (Code Prescriptive Configuration – With Adjusted FDWR – No Refrigeration) – Zone 7B.

The reference buildings (with the adjusted FDWR) were used as the baseline for the holistic building energy compliance path defined in Part 8 of the NECB ("Building Energy Performance Compliance"). A number of energy conservation measures were investigated for the proposed buildings. To keep the construction cost of the alternative opaque masonry wall system low, 8" (20 cm) exterior CMU walls with foamed cores were used [with vertical reinforcement at 48 inches on center (1200 mm) to satisfy structural demand]. Overall thermal transmittance was calculated accordingly. In response to the comparatively more stringent HVAC systems and lighting requirements in the NECB, more efficient LED lights were expected to provide significant improvements in building energy performance and were investigated as an alternative lighting configuration.

LED lighting technology produces low energy consumption with high lumen output. As described previously for the ASHRAE-based U.S. supermarket model, the baseline light design was revised to use LED lights which resulted in light power densities of 0.47 W/ft^2 (5.0W/m^2) in the main areas, 0.147 W/ft^2 (1.56 W/m^2) in the storage area, and 0.3 W/ft^2 (3.2W/m^2) in the office area. These lighting power density levels were well below the maximum lighting power density limits listed in Table 22 for the respective area use, but the LED fixtures are able to provide light levels consistent with good illumination design practices.

For Climate Zones 4 through 7B, Table 26 shows the results of analysis for yearly energy use by the prototype supermarket configuration (the proposed building) having 8" (20 cm) core insulated exterior CMU walls and energy efficient LED lights without refrigeration energy included. The table also shows the EUI value for the baseline configuration (the reference building) for each climate zone and the calculated differences in EUI between the proposed building alternative and the reference building baseline configuration. To allow for comparisons with earlier analyses, the results of the energy analyses are presented in both SI and US standard units.

As shown in Table 26, the proposed building configuration meets or exceeds the NECB 2011 requirements for Climate Zones 4 through 7A. The yearly energy use predicted for the proposed building configuration is lower than that of the reference building configuration for all but Climate Zone 7B. To achieve compliance in Zone 7B, a small adjustment to the efficiency of the heating system is sufficient to reduce the energy use below that of the reference building; by using gas heaters with improved heating coil efficiencies of 0.9, the analysis produced an EUI of 87.15 kBtu/ft^2 (0.990 GJ/m^2) for Climate Zone 7B. It should be noted that the EUI of the proposed and reference buildings are very close without the increase in heating coil efficiency in Climate Zone 7B. An argument could be made that the proposed configuration (without increased heating coil efficiency) would be acceptable and code compliant, especially in light of typical inaccuracies in energy use modelling.

For each Canadian city, the yearly energy cost for the proposed building configuration was then calculated using natural gas prices from the Canadian Natural Gas Association (yearly average) and electricity rates from www.hydroquebec.com[17],[18]. These yearly costs are listed in Table 27. Electrical rates vary with power demand and the 500 kW-200,000 kWh electrical rates were used for the analysis. As not all Canadian cities are listed in the above summaries, the unit cost for Vancouver was used for Victoria, Edmonton rates were used for Fort McMurray, and Toronto rates were used for Windsor. This was judged to be reasonable since this is for comparison purposes only and because actual energy prices vary with demand and location. Also calculated are the yearly energy costs for the Canadian baseline supermarket prototype without adjusted FDWR.

Table 26. Yearly Energy Consumption of the Proposed Supermarket Buildings (Having Foamed in Place 8 in. (20 cm) CMU Walls, with LED Lighting - No Refrigeration).

Location	Victoria	Windsor	Montreal	Edmonton	Ft. McMurray
Province	BC	ON	QC	AB	AB
Climate Zone	4	5	6	7A	7B[a]
SI Units					
Heating (GJ)	1347.8	1567.1	2281.9	2331.0	2810.9
Cooling (GJ)	11.0	34.2	22.3	14.5	17.6
Interior Lighting (GJ)	179.0	174.5	182.7	175.3	177.3
Interior Equip. Electric (GJ)	792.7	792.7	792.7	792.7	792.7
Interior Equip. Gas (GJ)	200.9	200.9	200.9	200.9	200.9
Fans (GJ)	288.1	365.2	278.8	444.6	472.3
Total (GJ)	**2819.4**	**3134.5**	**3759.3**	**3958.9**	**4471.8**
EUI (Proposed Building) (GJ/m^2)	**0.674**	**0.750**	**0.899**	**0.947**	**1.070**
EUI (GJ/m^2) (Reference Building with max FDWR)	**0.732**	**0.809**	**0.937**	**0.966**	**1.057**
Difference	**-0.058**	**-0.059**	**-0.038**	**-0.019**	**0.013**
US Standard Units					
Heating (kBtu)	1277448	1485295	2162857	2209354	2664182
Cooling (kBtu)	10407	32436	21117	13732	16719
Interior Lighting (kBtu)	169672	165356	173152	166108	168090
Interior Equip. Electric (kBtu)	751294	751294	751294	751294	751294
Interior Equip. Gas (kBtu)	190431	190431	190431	190431	190431
Fans (kBtu)	273030	346133	264238	421377	447688
Total (kBtu)	**2672282**	**2970945**	**3563089**	**3752296**	**4238404**
EUI ($kBtu/ft^2$) (Proposed Building)	**59.38**	**66.02**	**79.18**	**83.38**	**94.19**
EUI ($kBtu/ft^2$) (Reference Building with max FDWR)	**64.49**	**71.21**	**82.50**	**85.07**	**93.12**
Difference	**-5.11**	**-5.19**	**-3.32**	**-1.68**	**1.07**

Non code compliant

[a] To achieve compliance in Zone 7B, a small adjustment to the efficiency of the heating system is sufficient to reduce the energy use below that of the reference building; by using gas heaters with improved heating coil efficiencies of 0.9, the analysis produced an EUI of 87.15 $kBtu/ft^2$ (0.990 GJ/m^2) for Climate Zone 7B.

Table 27. Canadian Yearly Energy Costs for the Proposed Building Supermarket Prototype [Having Foamed in Place 8 in. (20 cm) CMU wall and LED lighting].

Location	Victoria	Windsor	Montreal	Edmonton	Ft. McMurray
Province	**BC**	**ON**	**QC**	**AB**	**AB**
Climate Zone	**4**	**5**	**6**	**7A**	**7B**
Gas Cost	$5,358	$6,116	$8,590	$8,759	$10,419
Electricity Cost	$24,992	$36,974	$25,494	$43,881	$44,896
Total Energy Cost (Proposed Building)	$30,349	$43,090	$34,083	$52,641	$55,315
Total Energy Cost Baseline Prototype‡	$33,829	$47,682	$36,845	$57,772	$60,052
Cost Difference	($3,479.)	($4,592.)	($2,762.)	($5,131.)	($4,736.)

Non code compliant (See Table 26: EUI of reference building exceeds that of the proposed building)

() indicates net cost savings; + number denotes an increase in costs

‡The Canadian "Baseline Prototype" (that is, the reference building compliant with the minimum prescriptive requirements of the NECB, and without FDWR adjusted/increased to the permissible limits)

As shown in Table 27, yearly energy use predictions show significant energy cost savings for the proposed building in all climate zones (including for Zone 7B where the proposed building is not compliant with NECB). Zone 7A had yearly energy cost savings of $5,100 compared to the baseline prototype configuration (without FDWR increases).

Not included in Table 27 was a proposed building configuration that also makes use of improved heating coil efficiencies [hence, 8 in. (20 cm) foamed CMU wall, LED lighting, and 0.9 heating coil efficiencies]. This configuration was analyzed under only Climate Zone 7B conditions. The total yearly energy used by this configuration (EUI) was 0.990 GJ/m^2 (87.1 kBtu/ft^2) which is below the adjusted base line value and thus code compliant. Energy cost analyses for this building produced a yearly gas cost of $9,260 and a yearly electrical cost of $44,890 (note little change in fan energy is seen due the effect of the bakery), with a total energy cost of $54,150. This is a savings of $5,880 over the baseline configuration (without FDWR adjustments) in Climate Zone 7B.

Construction cost analyses show similar results to those for the alternative ASHRAE 90.1 supermarket building modelled earlier, with opaque wall costs for the proposed building [8" (20 cm) foamed in place concrete block masonry walls] being much lower than those for the baseline reference building configuration [internally strapped and insulated 8" (20 cm) concrete block masonry walls, Figure 11]. The opaque wall cost differentials are shown in Table 28 for the various climate zones and are based on the prototype building configurations without adjustments to the FDWR.

The LED lighting analysis produced a design with fewer numbers of LED light fixtures than required in the baseline T8 fluorescent design (described previously for the U.S model). By using the (same) prices as identified for the U.S. analysis and adjusting the costs for location (city) using the RSMeans estimating procedures, differential lighting costs (LED vs. fluorescent lamp) were calculated, and are shown in Table 28.

Table 28. Differential Construction Costs, (Proposed Building Cost – Baseline Supermarket Prototype Cost, No FDWR adjustments).

Cities	Victoria	Windsor	Montreal	Edmonton	Ft. McMurray
	4	5	6	7A	7B
Opaque Walls‡	($114,345)	($101,212)	($108,122)	($114,536)	($110,426)
Lighting§	$50,075	$49,171	$52,027	$54,692	$50,075
Total	($64,270)	($52,041)	($56,095)	($59,844)	($60,351)
0.9 Heating coil					$40,000
Total for 7B					($20,351)

() indicates net cost savings; + number denotes an increase in costs

[shaded] Non code compliant (See Table 26: EUI of reference building exceeds that of the proposed building)

‡ 8" (20 cm) CMU foam filled wall (proposed building) vs. 8" (20 cm) internally insulated wall (baseline building)

§ LED lighting (proposed building) vs. fluorescent lamp (baseline building)

The differential construction cost analyses show that the code-compliant alternative designs for the Canadian prototype supermarket are less costly to construct than those meeting the code prescriptive configurations, although in Climate Zone 7B, increasing the heating efficiency to achieve compliance will cost an additional $40,000. However, this cost increase is offset by a $60,351 construction cost savings (wall + lighting) resulting in a next construction cost savings of $20,351, along with a yearly energy cost savings of $5,890.

Clearly, holistic energy analyses can be used to show that supermarkets constructed with single wythe core insulated masonry walls can be code compliant, be built at lower cost than construction configurations that meet code prescriptive requirements, and can offer significant yearly energy savings when compared to prescriptively compliant construction.

Box Retail Prototype

Similar to the analyses for the supermarket prototype, the low-rise (box) prototype building was analyzed for energy use, energy cost, and construction cost using proposed alternative construction configurations consisting of exterior foam filled 8" (20 cm) CMU walls and LED lights.

Table 29 shows the EUI values (in Both US Standard and SI Units) produced from these analyses (EUI, Proposed Building). Also shown in Table 29 are the annual energy use indices (EUI) for the Baseline Prototype configuration with and without adjusted FDWR. Energy performance similar to the supermarket prototype was realized for the box retail prototype building using the alternative wall and LED lighting configuration. Code compliance was demonstrated for all climate zones except Zone 7B, and like the proposed supermarket building, code compliance in Climate Zone 7B will also require improved heating coil efficiency for the box retail building. A heating coil efficiency of 0.9, in combination with the foamed 8” (20 cm) CMU walls and LED lighting, will produce an EUI of 0.961 GJ/m^2 (84.6 $kBtu/ft^2$) for Climate Zone 7B, and thus, will be code compliant. The total yearly energy cost for this configuration in Climate Zone 7B is $48,890.

Typically, low-rise (box) retail buildings have smaller amounts of front glass area than supermarkets. However, the U.S.-based analysis presented earlier showed that the storefront glass area had very little effect on the annual energy used. The energy savings for high-area front glass configurations (54% used in earlier analysis) will be almost the same as those for low-area (25% used earlier). Thus, for all comparisons, code compliance evaluations, and cost analyses, the glass store front was assumed to be 54% of the front wall area.

The construction costs for the Box Retail Prototype are the same as those described for the Supermarket prototype both for the baseline and alternative configurations. The exterior walls and the lighting systems are identical for the supermarket and box retail building configurations.

It is clear that holistic energy analyses can be used effectively to demonstrate energy code compliance for low-rise (box) retail prototypes constructed with single wythe masonry walls. Moreover, when compared to the code prescriptive configurations, the alternative single wythe configurations can produce substantial yearly energy cost savings. In all climates there are also substantial construction cost savings associated with the proposed alternative configurations over configurations that meet the code prescriptive provisions.

Table 29. EUI and Yearly Energy Costs for the Box Retail Prototype Proposed Building [Having 8 in. (20 cm) Foam Filled CMU Walls and LED lighting].

Victoria	Victoria	Windsor	Montreal	Edmonton	Ft. McMurray
Climate Zone	**4**	**5**	**6**	**7A**	**7B**
SI Units					
EUI (GJ/m^2) (Proposed Building)	0.635	0.709	0.872	0.921	1.046
EUI (GJ/m^2) (Baseline Prototype adjusted FWDR)	0.696	0.773	0.913	0.927	1.015
EUI (GJ/m^2) (Baseline Prototype FWDR Not adjusted)	0.650	0.638	0.704	0.690	0.756
EUI (GJ/m^2) (Proposed Building+ Increased HC Efficiency					0.961
US Standard Units					
EUI (kBtu/ft^2) (Proposed Building)	55.9	62.4	76.8	81.1	92.1
EUI (kBtu/ft^2) (Baseline Prototype adjusted FWDR)	61.3	68.1	80.4	81.6	89.4
EUI (kBtu/ft^2) (Baseline Prototype FWDR Not adjusted)	57.2	56.2	62.0	60.8	66.6
EUI (kBtu/ft^2) (Proposed Building+ Increased HC Efficiency					84.6
Yearly Energy Costs					
Gas Cost (Proposed Building)	$ 5,403	$ 6,169	$ 8,826	$ 8,993	$ 10,688
Electricity Cost (Proposed Building)	$ 21,489	$ 31,924	$ 21,878	$ 38,426	$ 39,425
Total Energy Cost (Proposed Building)	$ 26,891	$ 38,093	$ 30,704	$ 47,419	$ 50,113
Total Energy Cost (Baseline Prototype, no FDWR Adjustment)	$ 33,346	$ 44,782	$ 33,365	$ 51,344	$ 52,753
Cost Difference	$(6,454)	$(6,690)	$(2,660)	$(3,925)	$(2,640)
Total Energy Costs (Proposed Building + 0.9HC)					$48,890

Non code compliant (EUI of proposed building exceeds EUI of reference building)

() denotes savings

Canadian Study Summary

The results of this study showed that holistic energy analyses can be used to demonstrate NECB compliance in Climate Zones 4 through 7A for both the supermarket and low-rise (box) retail prototypes constructed with single wythe masonry walls having core foam insulation only (without continuous external insulation) and by trading out traditional fluorescent lights for LED light fixtures. For Climate Zone 7B, additional improvements in heating coil efficiencies are needed to demonstrate compliance. Moreover, when compared to the NECB code prescriptive configurations (externally insulated walls), benefits of the single wythe masonry wall configurations with integral foam insulation include both substantial construction cost savings and yearly energy costs savings (see Tables 27, 28 and 29). The predicted construction cost savings for the proposed building configurations ranged from $20,000 to $64,000. The yearly energy savings for predicted for the proposed building configurations ranged from $2,600 to $6,700.

CONCLUSION

The following conclusions can be made based on the results of this investigation:

1. There are a number of supermarket and low-rise (box) retail building configurations which use exterior single wythe concrete masonry unit (CMU) wall systems (without external insulation) that can be readily shown to comply with ASHRAE 90.1 and NECB-11 when modelled using the whole building analysis compliance path.
2. Supermarkets and box retail buildings constructed with CMU walls (without external insulation) cannot be easily designed for code compliance using only the simple building envelope trade-offs permitted by ASHRAE 90.1 and NECB-11.
3. Under ASHRAE 90.1 in the U.S., in Climate Zones 1 through 7, the whole building energy analysis path shows code compliance (wherein yearly energy cost of the proposed building is not greater than the energy cost for a building designed to code prescriptive requirements) for the super market and box retail archetype models constructed with exterior 8 in. CMU walls (partially grouted, with the ungrouted cores filled with foam insulation) and LED lighting.
4. Refrigeration energy dominates the yearly energy use of supermarket building and any effort to improve energy efficiency should concentrate on these systems first, although these systems are considered process equipment and not addressed as part of the energy code compliance process.
5. For the building configurations and climate zones studied, yearly energy cost determined code compliance under ASHRAE 90.1 In many cases the proposed building configurations used more energy (had higher EUI values) than code prescriptive building configurations, but the trade-off of higher cost electricity with low cost natural gas produced lower overall energy costs and thus code compliance.
6. Lighting and HVAC efficiency have a greater effect on energy use than envelope insulation, provided some increase in thermal resistance over bare CMU walls is realized.
7. In most cases under ASHRAE 90.1, the whole building analysis methodology is effective at producing supermarket and box retail building design alternatives that have significantly lower capital costs than the code prescriptive building configurations, as well as producing significant yearly energy cost savings. Where capital costs are higher than the code prescriptive building configurations, payback periods are significantly less than a year.

8. Viable alternative supermarket and retail box building designs can be produced under the Canadian Energy code (NECB 2011) in Climate Zones 4-7A by using foamed-in-place 8 inch CMU walls coupled with LED lighting systems. In Climate Zone 7B increased heating efficiencies are also required. All alternative designs show significant construction and yearly energy cost savings over code prescriptive building configurations.
9. The comparatively low prescriptive envelope thermal transmittances required under the NECB render building envelope trade-offs less effective because at these low levels further decreases have little, and a progressively less effect, on the overall energy used by the buildings.
10. The NECB provision that allows the fenestration+door area to gross wall area ratio (FDWR) of the reference building to be increased to a maximum permissible value, independent of the proposed building configurations, significantly aids in qualifying proposed buildings (having a higher opaque wall thermal transmittance than that prescribed by the code). This is particularly true where the FDWR is low, such as in a supermarket or box retail building.

RECOMMENDATIONS

The results of whole building energy analyses show that typical supermarket and low-rise (box) retail buildings constructed using single wythe masonry walls without external insulation can be energy code compliant in cost effective construction configurations for most US climate zones and for Canadian Climate Zones 4 through 7B. This methodology should be applied to other building archetypes using single wythe masonry walls systems to determine if similar results can be obtained. Furthermore, additional building systems (such as variable refrigeration systems, passive solar systems and others) appropriate for application to supermarket and box retail use should be investigated to determine if they might produce more cost effective designs.

An effort must be made to encourage holistic energy analysis in building design (use of the “Energy Cost Budget Method” of ASHRAE 90.1, and of “Building Energy Performance Compliance” of the NECB). This will allow the designer and owner to focus on the building systems that meaningfully affect the energy use of the building and help eliminate any tendency to needlessly increase the thermal insulation levels of mass exterior wall systems beyond those where they have no significant effect on the building performance yet significantly increase the cost of construction.

ACKNOWLEDGEMENTS

The author would like to thank The International Masonry Institute, the Masonry Contractors Association of America and the Canadian Concrete Masonry Producers Association for sponsoring this investigation. The efforts of two mechanical engineering students, David Beraun and Brian O'Neal, who conducted the energy simulations are also gratefully acknowledged.

The author would also like thank Gary Sturgeon of CCMPA for his significant review effort and Diane Throop of IMI for her guidance.

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