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ABSTRACT

Retail buildings are responsible for approximately 18% of energy consumed by commercial buildings in the United States (EIA 2008). They offer a great opportunity for energy savings because retail stores have many similarities, and because large companies can implement successful energy efficiency strategies across their portfolios. Recognizing this potential, the U.S. Department of Energy (DOE) formed the Commercial Building Partnership (CBP) program to work with select companies in retail and commercial real estate to reduce energy consumption by 30% in existing buildings and 50% in new construction versus ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004a). The National Renewable Energy Laboratory partnered with Target under the CBP program to design and implement a retrofit of a SuperTarget in Thornton, Colorado. The result was a retrofit design that predicted 37% energy savings over ASHRAE Standard 90.1-2004, and 29% compared to existing (pre-retrofit) store consumption. Energy simulations of each efficiency measure played a key role in determining a mix of solutions that would provide the best value and yield the highest savings. The largest savings came from energy-efficient lighting and cooling systems, improved refrigeration, and better control of plug loads. The results of this effort will be carried forward to inform the retrofit of other stores across the nation. Other companies will also be able to use these results to achieve DOE's energy efficiency goals.

INTRODUCTION

Over the past few years, Target and the National Renewable Energy Laboratory (NREL) have collaborated as part of the U.S. Department of Energy (DOE)-sponsored Commercial Building Partnership (CBP) program to reduce energy use in new and existing buildings by 30% and 50%, respectively, compared to ASHRAE Standard 90.1-2004 requirements. The existing Thornton, Colorado store was chosen as a pilot project with the aim to design and implement a retrofit that met or exceeded CBP program goals.

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Since the 1990s, Target has had an in-house engineering team that regularly tracks energy use and examines energy efficiency measures (EEMs) to implement in its stores. EEMs that show significant savings and make economic sense are incorporated into prototypical store designs, reducing energy consumption across the portfolio. For instance, the company has aggressively lowered its lighting power density throughout many of its stores by retrofitting lamps, ballasts, and reflectors in sales floor fixtures. Another example is the company's unique ventilation strategy. Using ASHRAE Standard 62.1 (ASHRAE 2004b) performance-based compliance path, the company conducted research to determine a strategy that, by understanding and reducing sources of air contaminants, greatly reduces the amount of ventilation air that needs to be brought into the space during occupied hours, while maintaining good indoor air quality. Further, the company centrally monitors and manages its stores' energy use from its headquarters. In this management structure, the company can track individual stores and corporate energy use in real time and identify areas where energy can be saved.

EEMs that show significant savings and reliable performance are incorporated into retrofit projects in older stores; a typical retrofit project currently tracks at 27-28% lower than consumption defined by Standard 90.1-2004. To meet the 30% energy reduction goal of the CBP program, Target and NREL worked together to determine the best mix of solutions to achieve even higher savings. The team used energy simulation software (DOE 2011a) to evaluate EEMs, and found a solution that exceeded the CBP program goals, predicting 37% energy savings.

The project, completed in fall 2011, is now being submetered to determine if the predicted energy savings match the store's actual energy savings. If successful, the store will save more than 2 million kWh of electricity and more than 7,000 therms (703 MMBtu) of natural gas annually. This equates to approximately 3.1 million pounds (1.4 million kilograms) of carbon dioxide emissions avoided each year.

Consistent with the intent of the CBP program, the company plans to incorporate EEMs considered in this pilot into multiple upcoming retrofit projects. Lessons learned will be shared with other members of the commercial retail building sector to encourage a wider adoption of energy efficiency solutions.

BUILDING DESCRIPTION

The store in Thornton, Colorado was built in 2001. It is a single-story, 173,000 ft² (16,072 m²) store, and like other super stores, it sells general merchandise and features a full grocery selection that includes fresh produce, a bakery, and a deli. The building is normally occupied from 8:00 a.m. to 10:00 p.m., Monday through Saturday, and 8:00 a.m. to 9:00 p.m. on Sundays. Figure 1 shows the floor plan and thermal zoning used in the energy simulation model.

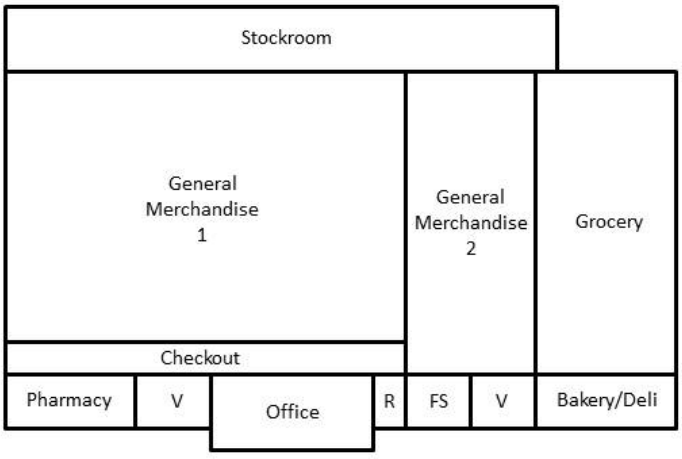

Figure 1: *Thermal zoning of the Thornton store. (The letters V, R, and FS stand for vestibule, restroom, and food service, respectively.)*

Table 1 and Table 2 describe baseline building characteristics of the store before renovation. These characteristics were used as baseline model inputs, which served as a starting point for the energy studies presented in this paper.

Table 1: Building Description

Building Component	Baseline Building Model
Area	173,474 ft² (16,116 m²)
Floors	1
Fenestration type	Standard 90.1-2004 windows
Wall construction	Precast concrete
Wall insulation	13 + 3.8 ci ft²·h·F/Btu (2.29 + 0.67 ci m²·C/W)
Roof construction	Flat built-up roof
Roof insulation	15 ci ft²·h·F/Btu (2.64 ci m²·C/W)
Temperature set points	68°F (20°C) heating; 74°F (23°C) cooling – set back when unoccupied to 59°F (15°C) heating; 81°F (27°C) cooling
HVAC	Packaged single zone system with direct expansion air-conditioning (11.6 EER/3.4 COP) and natural gas heating

Table 2: Baseline Building Zone and Internal Load Characteristics

Zone	Area ft² (m²)	Volume ft³ (m³)	Lights W/ft² (W/m²)	Electric Equipment W/ft² (W/m²)	Gas Equipment W/ft² (W/m²)
General Merchandise 1	722,847 (6,768)	1,651,209 (46,757)	1.42 (15.28)	0.28 (3.05)	-
General Merchandise 2	24,960 (2,319)	565,765 (16,021)	1.03 (11.09)	0.03 (0.34)	-
Grocery	26,520 (2,464)	601,126 (17,022)	1.13 (12.16)	0.02 (0.19)	-
Stockroom	19,834 (1,843)	449,576 (12,730)	1.30 (13.99)	0.25 (2.69)	-
Checkout	7,493 (696)	169,849 (4,810)	1.42 (15.25)	-	-
Pharmacy	3,320 (308)	75,254 (2,131)	0.58 (6.24)	0.48 (5.18)	-
West Vestibule	2,000 (186)	45,334 (1,284)	1.24 (13.35)	2.86 (30.82)	-
Office	7,700 (715)	174,535 (4,942)	2.43 (26.16)	1.14 (12.24)	-
Restroom	880 (82)	19,947 (565)	1.38 (14.85)	-	-
Food Service	1,840 (171)	41,707 (1,181)	1.43 (15.39)	58.86 (633.58)	-
East Vestibule	2,000 (186)	45,334 (1,284)	1.24 (13.35)	1.35 (14.57)	-
Bakery/Deli	4,080 (379)	92,481 (2,619)	0.85 (9.15)	33.40 (359.57)	31.39 (337.86)
Total	**173,474 (16,116)**	**3,932,116 (111,344)**	**228,401 W**	**290,231 W**	**128,059 W**

ENERGY SIMULATION

The team used EnergyPlus energy simulation software (DOE 2011a) to evaluate EEMs. A baseline model used original as-built drawings to represent actual energy use before the retrofit. The model was calibrated to measured utility data from the Thornton store and submetered data from another store of the same vintage in a similar climate zone.

A second baseline model for the store represented compliance with ASHRAE Standard 90.1-2004 (ASHRAE 2004a). The ASHRAE model was used to benchmark energy performance for the CBP program; the calibrated model was used to validate modeling assumptions and to understand the actual effects of EEMs on energy use.

Once the baseline models were developed, NREL worked with the company to determine a list of potential EEMs to save energy. The calibrated energy model showed 8% savings compared to the ASHRAE baseline, identifying a large potential for whole-building energy improvement. The current retrofit prototype already incorporates a number of EEMs into the design, estimating 27-28% energy savings over ASHRAE standards. NREL used the typical retrofit package as a starting point and determined additional measures to further increase energy savings cost effectively. The EEMs considered in this project are listed in Table 3 and Table 4.

Table 3: Recommended Envelope, Lighting, and Kitchen Energy Efficiency Measures for the Thornton Store. EEMs that are new additions to the retrofit package are noted with an asterisk (*).

EEM	Implemented in Thornton Store?	Will Consider for Future Projects?	Climate Dependent?
Envelope			
Increase roof insulation to R-25 $ft^2 \cdot h \cdot F/Btu$ (4.4 $m^2 \cdot C/W$)	No	Yes	Yes
Reduce infiltration in cart vestibule area	No	Yes	Yes
Lighting			
*Upgrade 114-Watt sales floor fixtures to 59-Watt fixtures	Yes	Yes	No
Remove neon decorative lights throughout sales area	Yes	Yes	No
Remove all backlighting from panels in the electronics section	Yes	Yes	No
Upgrade display and vendor lighting to light-emitting diode (LED) or higher efficacy fluorescent lamp/ballast combinations	Partial	Yes	No
Upgrade valence (concealed) accent lighting to lower wattage, higher efficacy linear fluorescent lamps on the sales floor	Yes	Yes	No
*Upgrade lights in walk-in coolers and freezers to LEDs	Yes	Yes	No
*Upgrade from 32-Watt T8 lamps to 25-Watt T8 lamps in offices and storage areas	Yes	Yes	No
Use daylight sensors to dim electric lighting in vestibules	No	Yes	No
Reduce the number of auxiliary lighting fixtures, such as those installed above refrigerated cases	Partial	Yes	No
Improve distribution and reduce the number of fixtures in the back of house and office area	No	Yes	No
Manage lighting schedules on the sales floor by turning off all lights during unoccupied hours	Yes	Yes	No
Kitchen			
Use high-efficiency kitchen equipment	No	Yes	No
Consider close proximity exhaust hood designs and temperature and particulate-driven control strategies to lower exhaust flow rates	No	Yes	No

Table 4: Recommended HVAC, Refrigeration, and Plug Load Energy Efficiency Measures for the Thornton Store. EEMs that are new additions to the retrofit package are noted with an asterisk (*).

EEM	Implemented in Thornton Store?	Will Consider for Future Projects?	Climate Dependent?
HVAC			
Use performance-based ventilation strategy - continuous rate of 0.08 cfm/ft² (0.00041 [m³/s]/m²)	Yes	Yes	No
*Increase HVAC fan efficiency and control by changing from constant air volume to variable air volume	Yes	Yes	No
Widen temperature dead band set points throughout store	Yes	Yes	No
*Add energy recovery ventilators to the rooftop units that bring outside air into the building in the main sales, checkout, and grocery areas	Yes	Yes	Yes
*Add evaporative condensing to the HVAC system	Yes	Yes	Yes
Operate the grocery section at the traditional 53°F (11.7°C) dew point temperature and the rest of the store at 55°F (12.8°C) to 57°F (13.9°C) dew point temperature	Yes	Yes	Yes
Indirect evaporative condenser and/or ventilation air precooling	No	Yes	Yes
Refrigeration			
*Add evaporative condensing to the refrigeration system	Yes	Yes	Yes
Add LED fixtures to all low- and medium-temperature refrigerated cases and walk-in freezers	Yes	Yes	No
Replace all evaporator fan motors in cases with electronically commutated motors	Yes	Yes	No
*Include strip curtains on all walk-in cooler and stocking doors	Yes	Yes	No
Add night curtains to open produce cases	No	Yes	No
Add doors to open medium-temperature cases. Add variable frequency drives to condensers	No	Yes	No
Add microchannel condensers	No	No	No
Capture waste heat from refrigeration system for air and service water heating	Yes	Yes	No
Use anti-sweat control strategies	Yes	Yes	No
Allow suction temperature to float in response to ambient and store conditions	No	Yes	No
Allow condensing temperature to float in response to ambient and store conditions	Yes	Yes	No
Plug Loads			
Set all computers to standby mode when not in use	Yes	Yes	No
*Use a load managing device on drink machines and turn them off at night	No	Yes	No
Eliminate personal printers, copiers, fax machines, and scanners; replace with two multifunction print stations	No	No	No
Replace desktop computers with laptop computers	No	No	No
Identify energy efficiency strategies for stockroom charging stations	No	No	No
Choose checkout stands and registers with standby mode and turn off cash registers and checkout stands during unoccupied hours	Yes	Yes	No
Turn off electronics products during unoccupied hours	Yes	Yes	No
Replace all 32 cathode ray tube monitors in the store with liquid crystal display monitors	Yes	Yes	No

EEMs were modeled and evaluated individually to estimate each measure's energy savings. The results were provided to the company's management, who then determined the net present value (NPV) and payback period, and considered other financial factors such as tax incentives, utility rebates, capital costs, installation costs, operation and maintenance costs, and energy costs. In general, EEMs with a positive NPV were retained for further consideration; however, measures that pay back within five years and emerging technologies with large savings potential were also considered.

Once determined to be economically feasible, the best mix of EEMs were combined into two "proposed design" models, developed to estimate total energy savings. Savings from individual EEMs are not additive; interactions between the measures play a key role in final energy savings estimates. The two proposed design models reflect EEMs that were implemented in the store (Proposed Design 1), and measures that were implemented in the store plus additional measures that the company hopes to consider in the future (Proposed Design 2). The additional measures in the Proposed Design 2 model include new technologies in the marketplace that have not yet been fully adopted, or are measures that the company would like to incorporate into remodel designs, but could not determine market, economic, and/or operational feasibility at this time.

MODELING RESULTS

Whole-building energy use was estimated for the baseline and proposed design models. A side-by-side comparison of these results shows significant energy savings of the proposed design models compared to the ASHRAE 90.1-2004-compliant baseline. The Proposed Design 1 model shows 37% energy savings, exceeding the energy savings goal of the CBP program. Going a step further, the Proposed Design 2 model estimates even greater savings, reaching 49% compared to the ASHRAE baseline. These savings can be attributed to a more aggressive lighting power reduction, plug load reductions, highest efficiency kitchen equipment, doors on all medium-temperature refrigeration cases (except produce), night curtains on produce cases, and HVAC equipment designed to meet the specifications of the DOE High Performance Rooftop Unit Challenge (DOE 2011b). Figure 2 compares energy use intensity and energy savings for each building model. Table 5 compares energy use and percent savings by end use between the models.

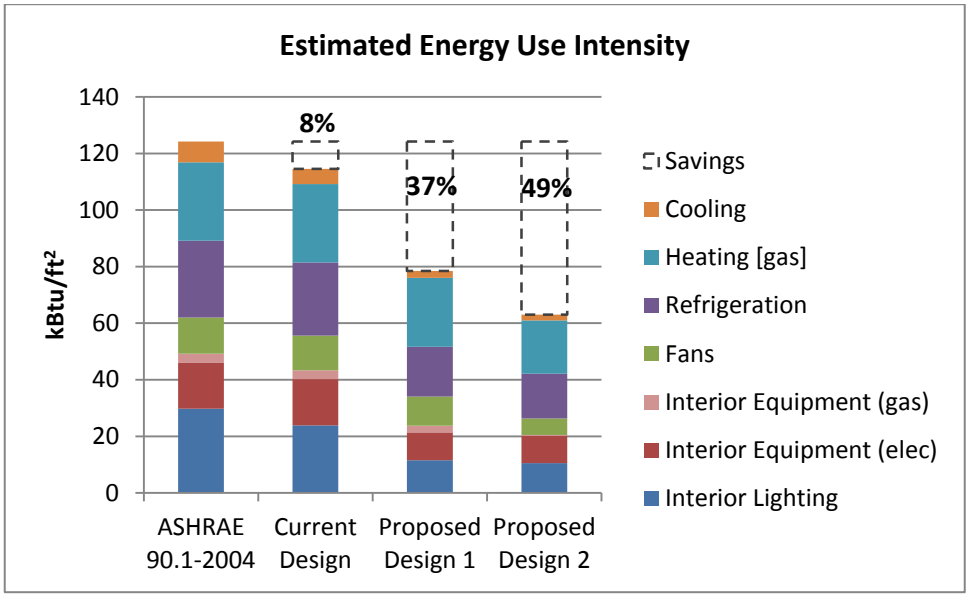

Figure 2: *Estimated energy use intensity of the ASHRAE-compliant baseline, existing store, and two proposed design models.*

Table 5: Annual Energy Use and Percent Savings by End Use

End Use Category	90.1-2004	Current Design		Proposed Design 1		Proposed Design 2	
	Annual EUI kBtu/ft² (kWh/m²)	Annual EUI kBtu/ft² (kWh/m²)	Percent Savings Over 90.1-2004	Annual EUI kBtu/ft² (kWh/m²)	Percent Savings Over 90.1-2004	Annual EUI kBtu/ft² (kWh/m²)	Percent Savings Over 90.1-2004
Heating (gas)	28(88)	28 (88)	0%	24 (76)	12%	19 (60)	32%
Cooling (electric)	7 (22)	5 (16)	28%	2 (6)	67%	2 (6)	73%
Lighting (electric)	30 (95)	24 (76)	20%	12 (38)	61%	11 (35)	65%
Equipment (electric)	16 (50)	16 (50)	0%	10 (32)	40%	10 (32)	41%
Equipment (gas)	3 (10)	3 (10)	0%	2 (6)	24%	0.3 (1)	89%
Fans (electric)	13 (41)	12 (38)	4%	10 (32)	20%	6 (19)	54%
Refrigeration (electric)	27 (85)	26 (82)	5%	18 (57)	35%	16 (50)	42%
Total	**124 (391)**	**115 (363)**	**8%**	**79 (249)**	**37%**	**63 (199)**	**49%**

The Thornton store was extensively submetered. These data are currently being collected and will be compared to modeling results to confirm actual energy savings. If successful, the store will save more than 2 million kWh of electricity and more than 7,000 therms (703 MMBtu) of natural gas annually. The greatest electricity savings can be attributed to lighting power reduction; refrigeration, electric equipment, cooling, and fan power reductions show significant savings as well. Natural gas savings are associated with reductions in heating energy. Table 6 and Table 7 show a breakout of energy savings by end use. The savings equate to approximately 3.1 million pounds (1.4 million kilograms) of carbon dioxide emissions avoided each year.

Table 6: Electricity Savings by End Use

Electricity End Use Category	Energy Savings kWh
Refrigeration	484,748
Interior Lighting	926,519
Fans	128,265
Electric Equipment	329,692
Cooling	251,974
Electricity Total	**2,327,302**

Table 7: Natural Gas Savings by End Use

Natural Gas End Use Category	Energy Savings Therms (MMBtu)
Heating	5,772 (577)
Service Hot Water	N/A
Equipment	1,262 (126)
Natural Gas Total	**7,034 (703)**

IMPLEMENTATION AND APPLICATION TO THE COMMERCIAL BUILDING SECTOR

The CBP program has acted as a platform for testing innovative buildings-related research. The results of this research have been—and will continue to be—formulated into recommendations and lessons learned, checklists, best practices, webinars, and other useful tools that can be shared with the rest of the commercial building sector, supporting those who do not have direct support from national laboratory staff. The goal of this outreach is to encourage other members of the commercial building sector to implement similar cost-effective efficiency measures into store designs, aiming for widespread adoption and replication.

CONCLUSION

NREL partnered with Target under the CBP program to design and implement a retrofit of a SuperTarget in Thornton, Colorado. EnergyPlus was used to evaluate many EEMs and determine energy savings. After determining the best mix of energy efficiency solutions, the team was able to develop a retrofit design that predicted 37% energy savings over ASHRAE 90.1-2004 (ASHRAE 2004a), surpassing the CBP program goal of 30% savings for a retrofit project.

The final retrofit design was determined to be the best value that achieved the highest energy savings. Energy savings were attributed to a reduction in interior lighting power, followed by refrigeration system EEMs, reductions in plug load equipment power, and high-efficiency HVAC strategies.

Results from this study will be shared with the greater commercial building sector in an effort to encourage a wider adoption of EEMs. By communicating the success of the company's participation in the CBP program, we hope to expand the adoption of these cost-effective measures and reduce the energy consumed by the commercial retail building sector.

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