Whole Building Efficiency for Whole Foods

Preprint

Michael Deru, Ian Doebber, and Adam Hirsch

Presented at the 2013 ASHRAE Winter Conference
Dallas, Texas
January 26-30, 2013

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Conference Paper
NREL/CP-5500-56331
February 2013

Contract No. DE-AC36-08GO28308

NOTICE

The submitted manuscript has been offered by an employee of the Alliance for Sustainable Energy, LLC (Alliance), a contractor of the US Government under Contract No. DE-AC36-08GO28308. Accordingly, the US Government and Alliance retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

Whole-Building Efficiency for Whole Foods

Michael Deru, PhD
Member ASHRAE

Ian Doebber
Associate Member ASHRAE

Adam Hirsch, PhD
Associate Member ASHRAE

ABSTRACT

Grocery stores and restaurants are two of the most energy-intensive commercial building types. Some stores combine these under one roof, which creates a challenging combination of spaces and systems. Nevertheless, these buildings also present tremendous opportunities to explore and demonstrate a variety of efficiency measures. The U.S. Department of Energy (DOE) recognized this potential and formed the Commercial Building Partnership (CBP) program to work with companies in retail and commercial real estate to explore and implement energy efficiency measures across a large market. The National Renewable Energy Laboratory partnered with Whole Foods Market under the CBP program to design and implement a new store in Raleigh, North Carolina. The result was a design with predicted energy savings of 40% over ASHRAE Standard 90.1-2004, and 25% energy savings over the standard design. Measured performance of the as-built building showed that it did not achieve the predicted performance. A detailed review of the project several months after opening revealed several construction and control items that were not implemented properly and not fully corrected in the commissioning process. About half the items were noticed during commissioning, but follow-up to correct the problems was very slow. The lessons learned include the efficiency measures used and the need for close communications about performance between the owner, designers, contractors, and commissioning agent. It is very important that the design intent of the building—and of each system—be clearly documented, communicated, and implemented.

INTRODUCTION

The U.S. Department of Energy (DOE) and the DOE research laboratories have been working with commercial building owners to find energy efficiency solutions that work with real buildings and within their business models. The idea is to formulate solutions that provide deep energy savings and that can be replicated by others. Retailers offer many opportunities for energy savings because they own and operate similar buildings and the energy efficiency solutions can be easily replicated. The U.S. Department of Energy's (DOE) Commercial Building Partnerships (CBP) (DOE 2010a) is a public/private cost-shared effort in which DOE representatives, national laboratory staff, and private sector technical experts help partners meet their energy goals with acceptable returns on investment based on their business models. Partners can thus incorporate ideas and strategies into their projects that might otherwise seem too expensive or technologically challenging. The objectives of the CBP projects are to pursue a new construction project with a 50% reduction in energy use over Standard 90.1-2004 and a retrofit project with a 30% reduction over Standard 90.1-2004 or current energy use.

Michael Deru is a senior engineer, Ian Doebber is a mechanical engineer, and Adam Hirsch is a senior engineer with the Commercial Buildings Research Group at the National Renewable Energy Laboratory, Golden, CO.

The CBP projects serve as test beds and training centers for innovative building-related research and demonstrate how energy consumption can be reduced dramatically and cost effectively in commercial buildings. The starting point for the consideration of efficiency measures was a detailed analysis of the energy savings opportunities in the Grocery Store 50% Energy Savings Technical Support Document (Leach et al. 2009). The lessons learned will be shared with the Commercial Building Energy Alliance (DOE 2010b) members and with other interested commercial building professionals.

One of the main goals of this project—beyond achieving a high performance level—was to analyze and test solutions that could be replicated in other Whole Foods stores across the country and in other supermarkets. Several solutions were evaluated and reported on for this and other locations. Lessons learned from other CBP projects were also applied to this project.

THE BUILDING

The building for this project is a 40,000-ft^2 leased facility in a new shopping center in Raleigh, North Carolina (see Figure 1). The developer provided the building shell to the prototype requirements, and Whole Foods provided the interior finishes and systems. Both the shopping center and the grocery store were designed with energy and environmental goals in mind. The shopping center received a LEED 2.0 Core and Shell Silver certification, and the Whole Foods store received a LEED 2.0 New Construction Gold certification. The store was acknowledged by the U.S. Environmental Protection Agency as a Zero Waste business for diverting more than 90% of its waste from landfills. The energy design process for this store was highlighted in a case study (Deru et al. 2010).

Supermarkets and restaurants are two of the highest energy-consuming building types, and Whole Foods combines both in one building, leading to very high energy intensities. The average annual site energy use intensity (EUI) for a supermarket from the 2003 Commercial Buildings Energy Consumption Survey is 214 kBtu/ft^2 (2,270 MJ/m^2) and the average EUI food sales building constructed after 1990 is 360 kBtu/ft^2 (4,087 MJ/m^2) (EIA 2006). An area-weighted average EUI aligning with the space distribution of a Whole Foods store would be 250 kBtu/ft^2 (2,838 MJ/m^2). A typical Whole Foods store for the southern region consumes more than 300 kBtu/ft^2 (3,406 MJ/m^2). The higher energy intensity for Whole Foods stores results from their significant refrigeration loads, several hot and cold food displays, and specialty lighting systems that create distinct shopping environments.

Figure 1: Front view of the North Raleigh Whole Foods store (credit: Whole Foods Market).

Raleigh has an elevation of 1366 ft (127 m) and is in climate zone 4A with hot humid summers and cold winters. The typical conditions from the Typical Meteorological Year 3 data files are 4729 cooling degree days base 50°F (2627 base 10°C) and 992 heating degree days base 50°F (551 base 10°C) (NREL 2004). The 0.4% cooling design day conditions are 94°F (34.5°C) dry bulb temperature and 76°F (24.4°C) wet bulb temperature. The 99.6% winter design day condition is 18.7°F (-7.4°C) dry bulb temperature.

FINDING SOLUTIONS

Extensive energy simulations with EnergyPlus version 5.0 (DOE 2012) were used to investigate energy efficiency solutions. Energy analysis started at the conceptual design phase; results were provided to the design team throughout the design process. The team evaluated the energy efficiency solutions to see if they were suitable for the store design, met the economic constraints, and could be maintained within the current maintenance framework. Many solutions were incorporated; others were rejected or saved for consideration in future projects. Table 1 provides a summary of the energy efficiency measures (EEMs) over the baseline assumptions for each system.

The energy modeling software and modeling techniques were also advanced during this project. As the building design progressed, more advanced technologies were considered, some of which were beyond the capabilities of the modeling software. New modeling techniques and new model algorithms were developed to support this project and related future projects. Baseline modeling rules were established with industry experts for the kitchen and refrigeration systems. A new method for creating the refrigeration energy model was developed that saves time and improves accuracy and consistency. The refrigeration algorithms were improved based on findings from this and related projects. New performance data were gathered and a new modeling approach was used for the main HVAC unit to fully capture its performance; however, this was completed after the building was finished.

The initial energy model was based on the design of a recently constructed nearby store and calibrated with utility data. A baseline model was then created to meet the minimum requirements of ASHRAE Standard 90.1-2004 (ASHRAE 2004), which was used as the reference point to explore several energy efficiency options. Analyses were completed for other lighting, HVAC, and refrigeration tools. The energy models evolved to match the evolving store design.

The envelope was investigated first for insulation levels, roof reflectivity, window types, and vestibule design. The prototype insulation design was already significantly higher than 90.1-2004 and no cost-effective changes could be implemented. The most significant change in the early design phase was to add a vestibule with side exit doors to the main exit. (The prototype design includes a vestibule on the entry, but not on the exit.) The new design reduced infiltration through the exit by as much as 50% (Stein and Kung 2012). Another early change was to reduce the glazing on the front of the store and include a higher performance glass. The main benefit of these changes was to reduce the direct solar thermal gain and glare from the morning sun, as the front of the store faces southeast.

Whole Foods includes several lighting systems to highlight the merchandise and create a unique shopping experience. Several approaches to the lighting design were implemented that incrementally improve the energy performance. We wanted to see how far we could go and still maintain the store's look and feel. The initial design for the sales floor area had an average lighting power density (LPD) of 1.2 W/ft^2 (12.9 W/m^2), which is lower than the 1.7 W/ft^2 (18.3 W/m^2) allowed by 90.1-2004 (ambient plus accent lighting). A target goal of 0.8 W/ft^2 (8.6 W/m^2) was set. Daylighting controls were also included to further reduce the lighting energy consumption. A detailed lighting model was created to investigate the impacts of various ceiling, skylight, and luminaire combinations. This model helped us to understand the implications of various design approaches and the performance of the final design. We completed additional simulations to understand the implications of lighting control strategies and to generate hourly input for the whole building energy model for more accurate energy simulations. The results were used to recommend the best combination of lighting fixtures and daylight controls for different areas of the store. The final design had an average LPD for the whole building of 1.0 W/ft^2 (10.8 W/m^2) with daylighting in the front and over the dry goods sales area. The design included a mix of ceramic metal halide lamps, T-8 linear fluorescent lamps, and LED track lights. The combination of lamps was carefully designed to be efficient and have the desired illuminance levels and color rendering to provide a unique shopping experience.

Whole Foods prepares and sells a significant amount of food throughout the day, which requires considerable energy. The energy efficiency solution included selecting recommendations for the best in class (highest efficiency) kitchen equipment, minimizing the exhaust air requirements with proper hood design and demand ventilation control, linking the make-up air to the exhaust air, using minimal conditioning of the make-up air, and using some transfer air from the store's main air handling unit (AHU). It was also important to minimize the humidity transfer from the cooking and food sales area to the refrigerated food sales area.

The baseline energy model showed that refrigeration was the largest end use and was responsible for more than one third of the total energy consumption. Various strategies were suggested and simulated to estimate performance. The largest energy saver was adding doors to all medium-temperature cases and night curtains to the produce cases. The decision to add doors to cases represents a balance between saving energy and impacting sales. In the end, it was decided to add doors to the packaged produce, packaged seafood, cheese, and dairy cases and add night curtains to the produce cases. In addition to the energy performance requirements, the owners wanted to reduce the charge of hydro fluorocarbon refrigerants to lessen the potential for leakage of potent greenhouse gases. To find the best solution, a request for proposals was sent to several manufacturers to request the most cost-effective low-energy design for the refrigeration system. Four manufacturers presented their designs, which allowed side-by-side comparisons. The selected manufacturer continued to iterate on the design to improve its performance. The final design included a secondary glycol loop on the medium-temperature racks, which offers substantial reductions in the refrigerant charge, but it comes with a slight energy penalty because it requires a heat exchanger and pumps. The other features of the final system are listed in Table 1.

The HVAC design focused on finding the most efficient method to provide the ventilation air at the optimal dew point to minimize the HVAC and refrigeration energy consumption. Another major consideration was the interaction with the kitchen exhaust/make-up air unit. A common design strategy for supermarkets is to use one high-efficiency AHU that provides ventilation air and dehumidification. Another good general supermarket design strategy in humid climates is to separate the ventilation air from the space conditioning and further separate the latent cooling from the sensible cooling. A driving design consideration is determining the optimal dew point set point and the most efficient dehumidification technology. A standard supermarket operation is to maintain indoor conditions at 72°F (22.2°C) dry bulb and below 55°F (12.8°C) dew point. Standard Whole Foods operation is to maintain the 74°F (23.3°C) dry bulb and 53°F (11.7°C) dew point. Going to a lower dew point set point can reduce refrigeration energy but increased the HVAC system loads. What is the optimal balance point? The answer depends somewhat on the relative efficiency of the HVAC dehumidification system and the impact of humidity on the anti-sweat, defrost, and energy efficiency of the refrigeration system. Based on analysis of this project and information from other projects, a supply air set point of 72°F (22.2°C) dry bulb and 45°F (7.2°C) dew point was recommended. The design set point for the project was selected to be 72°F (22.2°C) dry bulb and 50°F (10°C) dew point.

Several options for HVAC dehumidification systems with different efficiencies and a wide range of costs were evaluated. The system selected for this project included an active desiccant wheel with condenser reheat. This system has a higher pressure drop across the desiccant wheel, but it can provide very dry air while maintaining a relatively high energy efficiency. A bypass damper is used when dehumidification is not needed to avoid the pressure drop penalty.

Table 1. Summary of Energy Efficiency Measures

System	Component	Baseline	EEM
Envelope	• Main exit	No vestibule	Vestibule with side entry doors
	• Front of store glazing	Prototype design and 90.1-2004 properties	Reduced glazing, U-value = 0.28 Btu/ft²·h·°F (1.6 W/m²·K), SHGC = 0.27, VLT = 0.64
	• Skylights	90.1-2004 properties	U-value = 0.50 Btu/ft²·h·°F (2.8 W/m²·K), SHGC = 0.60, VLT = 0.50
Lighting	• Average LPD	1.34 W/ft² (14.4 W/m²)	1.0 W/ft² (10.8 W/m²)
	• Glare control in front of the store	Prototype design	Smaller windows, better shading
	• Daylighting	None	Optimize skylight and luminair layout, bi-level (plus off) switching
	• Stocking light levels	Full power	Half power
Kitchen	• Exhaust flow rate	Standard industry design practices	Reduced flow rate with side panels and efficient layout of equipment
	• Exhaust flow rate control	Constant	Demand control ventilation
	• Make-up air	Air supplied diffusely to the kitchen space	60% of make-up air supplied at the face of the hood with heating and cooling set points of 65°F (18.3°C) and 85°F (29.4°C)
	• Kitchen equipment	Standard efficiency	ENERGY STAR or best-in-class equipment
Refrigeration	• Doors on medium-temperature cases	None	Doors on packaged produce, packaged seafood, cheese, and dairy
	• Produce cases	No night curtains	Night curtains
	• Dew point set point	55°F (30.6°C)	50°F (10°C) with aggressive anti-sweat control
	• Case lights	Linear fluorescent	LED
	• Evaporator fan motors	Permanent split-capacitor motors	Electrically commutated motors
	• Saturated condensing temperature	Fixed at 75°F (23.9°C)	Floating down to 55°F (12.8°C) with electronic expansion valves
	• Condenser fans	Constant speed	Variable speed drives
	• Medium-temperature loop	Full refrigerant loop	Secondary glycol loop
	• Heat recovery	None	Heat recovery for water and space heating
HVAC	• Sales floor airflow rate	1.0 cfm/ft² (5.1 l/s/m²)	0.6 cfm/ft² (3.0 l/s/m²)
	• Main AHU dehumidification	No active dehumidification	Active desiccant wheel with condenser reheat and a bypass when not in use
	• RTU efficiency	90.1-2004 levels	Increased efficiency (11-12.5 EER and 15 SEER for small units)
	• Gas unit heaters	80% efficient	94% efficient

Figure 2 shows the results of the preconstruction energy simulations. Energy simulations are important at this stage to clarify opportunities for energy savings and to estimate the relative energy performance of design options. They do not predict the actual energy performance of the final constructed building to a high degree of accuracy. The preconstruction energy simulations predicted 16% site energy savings for the standard design over 90.1-2004 and 41% site energy savings with all the EEMs developed for this project. These energy savings did not reach the 50% target for CBP new construction projects. It was determined that we could not reach 50% in a cost-effective way within the solutions accepted by the owners. A significant challenge was the high fraction of energy consumption that was "unregulated" or not included in 90.1-2004. The unregulated loads in the baseline model were 56%, and increased to 65% in the energy-efficient design. A cost-effective 50% energy savings design may be achievable as the costs of advanced technologies decrease and other new technologies become available.

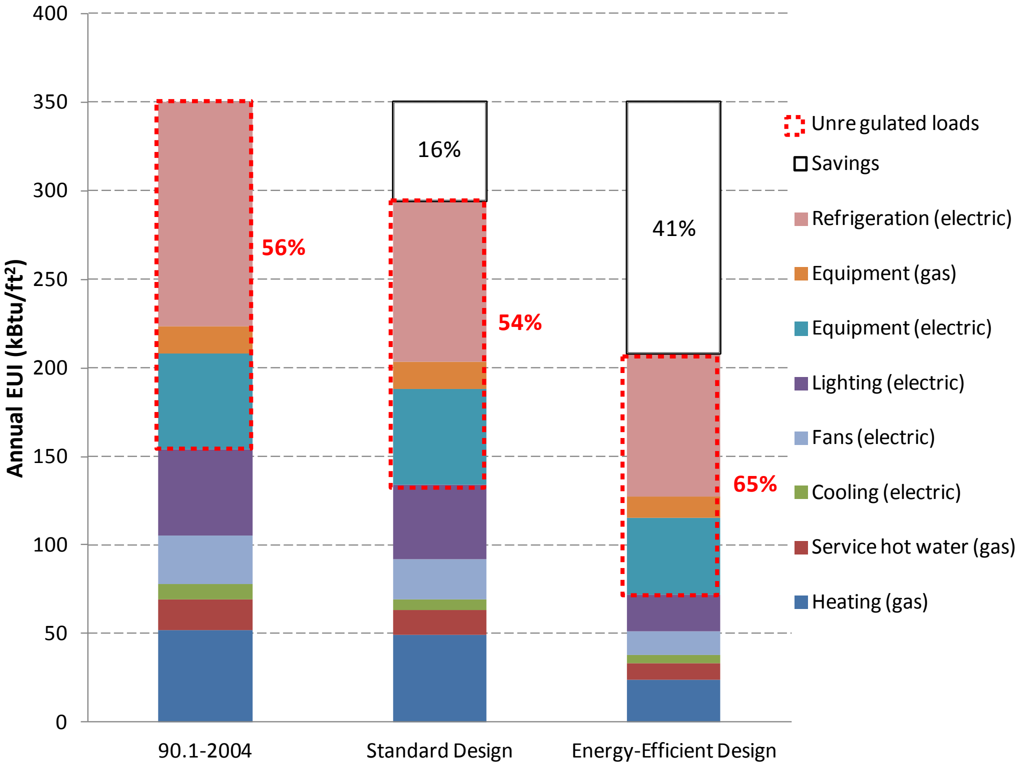

Figure 2: Preconstruction estimated energy consumption by end use for the baseline, standard design, and the energy-efficient design.

MEASURED PERFORMANCE

The store was completed in February 2011, and the grand opening was held on March 16, 2011. Monitoring consisted of utility bills and submeters. Submeters were installed on the electricity, gas, and water systems. However, these systems had problems that were slowly discovered and corrected over several months, making it difficult to evaluate the performance of all the systems.

Figure 3 shows the average daily gas and electricity consumption from the utility bills from the store opening in March 2011 through June 2012. The month-to-month energy consumption pattern is consistent. The annual EUI is also very consistent, with a value of 294 kBtu/ft^2 (3,338 MJ/m^2) (starting with the first 12 months and moving forward each month). A revised energy baseline (90.1-2004) energy model was created to match the actual store construction and operation. The revised baseline energy model estimated the annual energy use to be 412 kBtu/ft^2 (4,677 MJ/m^2). The as-built energy performance compared to the as-built baseline model provides 29% site energy savings. This is good performance but not equal to the 41% energy performance predicted from the preconstruction energy simulations.

Analysis of the submetered data with detailed energy modeling revealed operational issues and opportunities for improvements. Improvements to lighting, HVAC, and kitchen load controls for additional savings were developed. Some control changes were part of the design intent but were never fully implemented because of hardware constraints (lighting contactors not connected), set points not fully implemented, and some overrides of controls that were never restored. A detailed analysis of the refrigeration system showed additional savings opportunities through changes to the control setting for defrost, anti-sweat heaters, and condenser fans. These changes together are predicted to provide annual energy savings of approximately 300 MWh and energy cost savings of $18,000. With these savings, the annual EUI would be 262 kBtu/ft^2 (2,974 MJ/m^2), which would be 36% savings over the 90.1-2004 baseline. This is close to the predicted savings of 41%. Further analysis may reveal additional savings opportunities and allow the store to match the predicted energy savings.

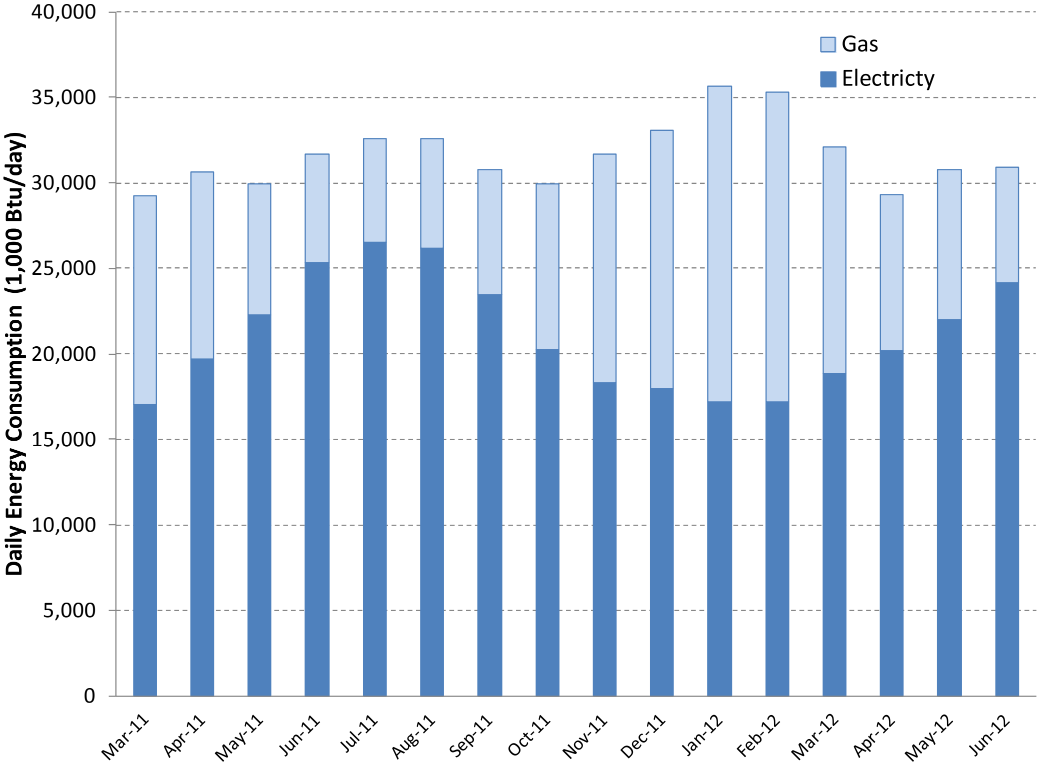

Figure 3: Preconstruction estimated energy consumption by end use for the baseline, standard design, and the energy-efficient design.

CONCLUSIONS

This project was a success on many levels. The finished store is energy efficient, lessons learned are being carried forward, new energy models were developed, and new design process were established that will continue to generate new ideas and lead to more energy savings. The technology-specific lessons are outlined in the body of the paper. Some general lessons that can be carried forward to other projects are discussed here.

Energy simulations played a central role in understanding system performance and in determining the final design. The full system performance and system interactions were difficult to model and were not modeled to the level of accuracy desired, but they were extremely valuable for making design decisions. Extensive energy modeling helped push the design from about 20% to 40% savings by optimizing each system. Additionally, energy modeling and submetered data were used after the store was open to clarify the operational performance and further improve the energy savings.

Manufacturers can be good sources of energy efficiency ideas. This project engaged lighting, HVAC, and refrigeration manufacturers to help determine the best technology applications. The HVAC and refrigeration systems were determined through a competitive request for proposals process, where the manufacturers presented their best solutions to Whole Foods. The design team evaluated the proposals and worked with the winning manufacturer to implement further improvements.

ACKNOWLEDGMENTS

We would like to acknowledge the Kathy Loftus, Mike Farish, and Scot Hewitt from Whole Foods for their enthusiasm and dedication to this project and broader energy efficiency efforts. In addition, the entire design team worked very hard and put in extra hours to make this project a success. We would like to also thank the support from NREL staff, in particular Eric Bonnema, Brent Griffith, Rois Langner, Andrew Parker, Michael Sheppy, and Danny Studer. Lastly, we would like to thank Monica Neukomm and the U.S. Department of Energy for sponsorship of the CBP program.

REFERENCES

ASHRAE. (2004). ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

DOE. (2010a). Commercial Building Partnerships website. www.commercialbuildings.energy.gov/ building_partnerships.html.

DOE. (2010b). Commercial Building Energy Alliances website. www.buildings.energy.gov/ alliances/.

DOE. (2011). EnergyPlus energy simulation software. www.eere.energy.gov/buildings/energyplus/. U.S. Department of Energy, Washington, D.C.

Deru, M.; Bonnema, E.; Doebber, I.; Hirsch, A.; McIntyre, M.; Scheib, J. (2011). Thinking Like a Whole Building: A Whole Foods Market New Construction Case Study. NREL Report No. TP-5500-50056. Golden, CO: National Renewable Energy Laboratory.

EIA (2006). 2003 Commercial Buildings Energy Consumption Survey, Washington, DC: Department of Energy, Energy Information Administration.

Leach, M., Hale, E., Hirsch, A., and Torcellini, P., (2009). Grocery Store 50% Energy Savings Technical Support Document, NREL Report No. TP-5500-46101. Golden, CO: National Renewable Energy Laboratory.

NREL (2004). Typical Meteorological Year-3, Golden, CO: National Renewable Energy Laboratory.

Stein, J. and Kung, F. (2012). Retail Building Guide for Entrance Energy Efficiency Measures. NREL Report No. BK-5500-52290. Golden, CO: National Renewable Energy Laboratory.