# Strategies to Save 50% Site Energy in Grocery and General Merchandise Stores[1]

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## ABSTRACT

This paper summarizes the methodology and main results of two recently published Technical Support Documents. These reports explore the feasibility of designing general merchandise and grocery stores that use half the energy of a minimally code-compliant building, as measured on a whole-building basis.

We used an optimization algorithm to trace out a minimum cost curve and identify designs that satisfy the 50% energy savings goal. We started from baseline building energy use and progressed to more energy-efficient designs by sequentially adding energy design measures (EDMs).

Certain EDMs figured prominently in reaching the 50% energy savings goal for both building types: (1) reduced lighting power density; (2) optimized area fraction and construction of view glass or skylights, or both, as part of a daylighting system tuned to 46.5 fc (500 lux); (3) reduced infiltration with a main entrance vestibule or an envelope air barrier, or both; and (4) energy recovery ventilators, especially in humid and cold climates. In grocery stores, the most effective EDM, which was chosen for all climates, was replacing baseline medium-temperature refrigerated cases with high-efficiency models that have doors.

Additional analyses presented here include specific examples of how 50% savings were achieved in climate zones 1A and 6A with EDM packages; a comparison of the cost effectiveness of different EDMs; and the generation and subsequent comparison of multiple solution sets that all satisfy the 50% energy savings goal.

## Background

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is developing tools to help achieve its vision of market-viable net-zero energy buildings by 2030 (Jarnagin et al. 2008). To this end, ASHRAE, in conjunction with the American Institute of Architects, the U.S. Department of Energy, the U.S. Green Building Council, and Illuminating Engineering Society, has been developing Advanced Energy Design Guides (AEDGs) to chart technically feasible, cost-effective design paths leading to net-zero energy for commercial buildings. Thus far, six AEDGs have been completed, providing prescriptive design recommendations to reach 30% energy savings compared to buildings that meet the minimum requirements of ASHRAE 90.1-1999 (ASHRAE 1999a). Recommendations

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are provided for the eight ASHRAE climate zones defined for the United States. Each AEDG is accompanied by a Technical Support Document that describes the processes and methodologies used to develop the AEDG's recommendations, including detailed descriptions of modeling assumptions and results. A set of 50% energy saving AEDGs is currently under development. This paper summarizes the methodology and results of the Technical Support Documents for two of these studies: medium-box (40,000-50,000 $ft^2$) general merchandise (Hale, Leach, Hirsch & Torcellini 2009) and grocery stores (Leach, Hale, Hirsch & Torcellini 2009).

The following steps were used to select a mathematically optimal design for achieving 50% whole-building site energy savings compared to a minimally code-compliant building as described in Appendix G of ASHRAE 90.1-2004 (ASHRAE 2004):

- Define a prototypical model by specifying design and building program features not addressed by ASHRAE 90.1-2004, from site and layout to miscellaneous electric loads;
- Create baseline energy models that are minimally compliant with ASHRAE 90.1-2004 for each of eight ASHRAE climate zones using weather information for major U.S. cities in those climate zones (1A-Miami, 2A-Houston, 2B-Phoenix, 3A-Atlanta, 3B-Las Vegas, 3C-San Francisco, 4A-Baltimore, 4B-Albuquerque, 4C-Seattle, 5A-Chicago, 5B-Denver, 6A-Minneapolis, 6B-Helena, 7-Duluth, 8-Fairbanks) from the prototype model;
- Assemble a list of energy design measures (EDMs) intended to reduce building energy consumption, specifying performance and cost;
- Conduct industry and peer reviews of the prototypical model and EDMs to strengthen initial assumptions; and
- Use Opt-E-Plus software to run an iterative sequential search optimization to select a combination of design features that produce 50% energy savings at the lowest cost.

## Prototype Buildings

One grocery store prototype and two general merchandise prototype buildings were developed. The general merchandise prototypes vary only in their plug loads. The prototype grocery store assumptions are drawn mainly from the 2003 CBECS study (EIA 2005) and the U.S. Department of Energy Benchmark Supermarket (Deru 2010). It is a one-story, 45,000-$ft^2$ building with a 1.5 aspect ratio and 20-ft ceiling height. The façade contains 1,400 $ft^2$ of glazing, giving a 27% window-to-wall ratio for that wall and 8% window-to-wall ratio overall. The walls are built from stucco on concrete block with rigid isocyanurate insulation (R-value varies by climate) and gypsum board; the roof is built up with all insulation above deck; and the floors are slab-on-grade 8-in. thick heavyweight concrete. Ten-ton unitary rooftop units (RTUs) with direct expansion coils, natural gas heating, air-cooled condensers, and constant volume fans are used to condition and ventilate the interior space. The grocery store contains 13 thermal zones, dominated by main sales (~55%), produce (17%), deli (5.4%), bakery (5%), and storage (10%). The remaining floor area is taken up by restrooms, meeting rooms, offices, and electrical/mechanical areas. Plug and process loads were taken from Deru et al. (2010), totaling 0.884 W/$ft^2$ and 0.384 W/$ft^2$ for electrical and gas loads, respectively. Operating hours (6:00 a.m. to 10:00 p.m. 7 days/week) and occupancy were taken from ASHRAE 90.1-1989 (ASHRAE 1989). The prototype refrigeration system is adapted from the benchmark supermarket model system (Deru et al. 2010), which is largely based on an example in Westphalen et al. (1996). There are four compressor racks: two low-temperature racks (serving frozen food cases, ice cream cases, and walk-in freezers), and two medium-temperature racks (serving meat cases, dairy/deli cases, and walk-in coolers).

The general merchandise prototypes are smaller (40,500 $ft^2$, 1.25 aspect ratio) than the grocery store prototype and have 1000 $ft^2$ of glazing on the façade. Eighty-five percent of the gross floor area is allocated to sales display, 8% to active storage, 1% to a meeting room, 1% to a dining room, 2% to restrooms, and roughly 3% in total to several other spaces such as an enclosed office, a mechanical room, a corridor, and a vestibule. Stores operate 7:00 a.m. to 9:00 p.m. Monday through Friday; 7:00 a.m. to 10:00 p.m. Saturday; and 9:00 a.m. to 7:00 p.m. Sundays and Holidays. The two prototype models differ in their whole-building plug load densities: the "low plug load" model contains 0.29 W/$ft^2$, and the "high plug load" model contains 1.32 W/$ft^2$ (representing larger amounts of plug-in merchandise and accent lighting).

## Opt-E-Plus and Sequential Search

Most EDMs were shared between the two studies, except that refrigeration equipment measures were limited to the grocery store analysis and plug loads were addressed in the general merchandise store analysis. Detailed costs and performance for each EDM were taken from the literature; please see the original reports for details (Hale, Leach, Hirsch & Torcellini 2009; Leach, Hale, Hirsch & Torcellini 2009). The EDMs that were considered are listed in Table 1.

**Table 1. Categories of EDMs**

| Building Component | Symbol | Description |
|---|---|---|
| Infiltration | IN | Air barrier; vestibule |
| Electric Lighting | LPD | Lighting power density reduction |
| Daylighting | DL | Daylighting controls and skylights |
| Window Area | WA | Reduce glazing on south façade by 50% |
| Wall Insulation | WI | Eight options including baseline |
| Roof Insulation | RI | Fourteen options including baseline and four cool roof options |
| Fenestration Types | FT | Two categories, one for south façade glazing, one for skylights |
| Heating, Ventilation, and Air-Conditioning | HVC | Twelve options based on varying coefficient of performance, fan efficiency, and use of economizers |
| Demand Control Ventilation | DCV | Ventilation control based on occupancy |
| Energy Recovery Ventilator | ERV | Two effectiveness options (50% and 70%) |
| Frozen Food Cases | FFC | Six types of frozen food cases |
| Ice Cream Cases | ICC | Six types of ice cream cases |
| Meat Cases | MC | Eight types of refrigerated meat cases. |
| Dairy/Deli Cases | DDC | Five types of refrigerated dairy/deli cases. |
| Solar Photovoltaic Generation | PV | 10% efficient panels installed on 60% of net roof area (gross roof area-skylight area) |

We used Opt-E-Plus, the National Renewable Energy Laboratory's commercial building energy analysis platform, to determine combinations of EDMs that best balance two objective functions: net site energy savings and five-year total life cycle cost (5-TLCC). The output of the optimization is a 5-TLCC versus percent energy savings graph that includes one point for each building, and a curve that connects the minimum cost buildings for a given energy savings, starting at 0% savings (the baseline building) and proceeding to the building with maximum possible percent savings (Long, Macumber, Hirsch & Lobato 2010).

## Characterization of Baseline and Low-Energy Buildings

We applied the following prescriptive requirements from ASHRAE 90.1-2004 (ASHRAE 2004) and ASHRAE 62-1999 (ASHRAE 1999b) to construct the baseline buildings from the prototype models:

- Wall and roof layer thermal properties;
- Fenestration requirements for window U-value, solar heat gain coefficient, and visible light transmittance;
- Lighting power densities (LPDs) (whole-building weighted average LPD of approximately 1.5 W/ft$^2$ for both building types);
- Outdoor air (OA) ventilation rates, prescribed either on a cfm/person or cfm/ft$^2$ basis, depending on space type;
- Minimum energy efficiency ratio of 10.1 for cooling, consistent with ASHRAE code for a 10-ton, 4000-cfm unit;
- Heating efficiency of 80%; and
- Economizer use.

The results suggest that 50% net site energy savings can be achieved cost effectively in general merchandise and grocery stores, in most cases without relying on renewable energy generation. The following EDMs are recommended for all climate zones and store types:

- Reduce LPD by 47%, and install occupancy sensors in the active storage room, Mechanical room, restrooms, and office zones;
- Add a vestibule to the front entrance to reduce infiltration;
- Equip heating, ventilation, and air-conditioning (HVAC) RTUs with high-efficiency fans;
- Install daylighting sensors tuned to a 46.5 fc (500 lux) set point;
- Reduce south façade window-to-wall ratio by 50%; and
- Replace baseline exterior walls with better insulated constructions.

For high plug load general merchandise stores, we also recommend reducing plug loads to 10% of their peak value when the store is closed. The following EDM recommendations are specific to grocery stores:

- Replace baseline frozen food and ice cream refrigerated cases with efficient, vertical models that have doors, LED lighting with occupancy sensors, and hot gas defrost; and
- Replace baseline meat display cases with models that have efficient fans, anti-sweat heater controls, electric defrost, and sliding doors.

Shaded overhangs were not chosen for any building type in any climate zone. Evaporative condensers for grocery store refrigeration systems were also not chosen in any climate zone. Some EDMs followed climate-specific trends:

- Skylights were selected in warm and hot climates where there is ample sunlight for daylighting;
- High coefficient of performance (COP) (a 20% increase over baseline) HVAC RTUs were selected in all but the cold and marine climates, which have low cooling loads;

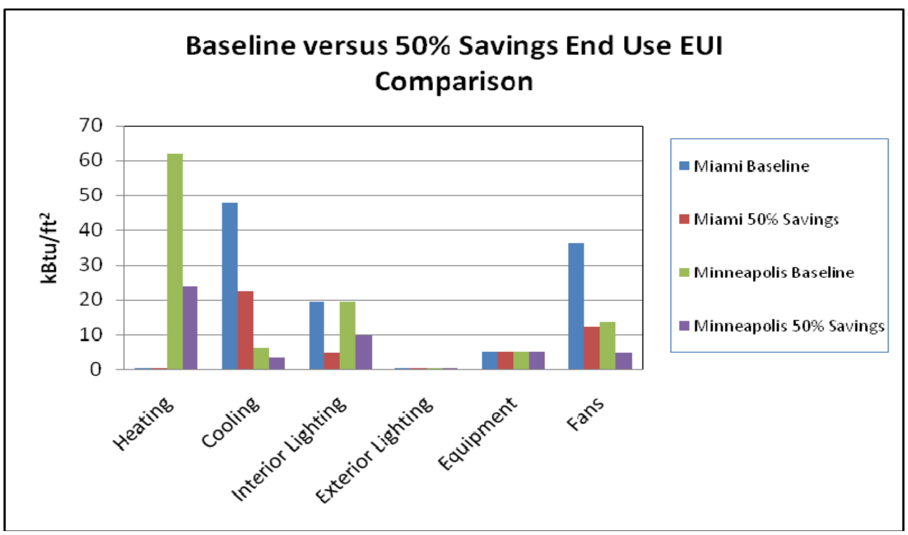
- Infiltration reduction measures (front entrance vestibule and envelope air barrier) were selected often, especially in humid and cold climates;
- Economizers were generally forgone in favor of energy recovery ventilators (ERVs) because of the high availability of exhaust air;
- ERVs played an important role in achieving the energy savings goal, especially in humid and cold climates; and
- For grocery stores, more highly insulated opaque envelope constructions were selected in extreme climates (better insulated walls in hot climates and a better insulated roof in the coldest climate).

The portfolio of EDMs used in the analysis is mainly limited to a familiar set of technologies. For example, climate-specific HVAC solutions that could yield further savings in certain regions were not considered.

**Energy Savings by End Use**

We illustrate energy savings achieved by 50% energy saving buildings for different end uses using the "low plug load" prototype in two very different cases: Miami, Florida, and Minneapolis, Minnesota. The Miami baseline case consumes 109.3 kBtu/ft$^2$; the Minneapolis baseline case consumes 106.5 kBtu/ft$^2$. Savings in the low-energy prototypes exceed 50% in these two cases; total energy demand in the Miami low-energy case is 45.4 kBtu/ft$^2$ (58.5% savings) and 47.3 kBtu/ft$^2$ in the Minneapolis case (55.6% savings). The EDMs chosen for the two climate types are very similar, except that skylights are not recommended in Minneapolis (4% roof coverage is recommended in Miami), double-pane windows with low-e coating and argon fill are recommended in Minneapolis, and more wall insulation is recommended in Minneapolis than in Miami (R-22.6 versus R-18.1). Seventy percent effective ERV is recommended in both locations, as is 50% reduction in façade glazing, tighter envelope and vestibule, 20% increased RTU COP and efficient fans, and 47% LPD reduction with occupancy sensors and 46.5 fc (500 lux) set point daylighting controls.

**Figure 1. EUI by End Use for Baseline and 50% Savings Cases**



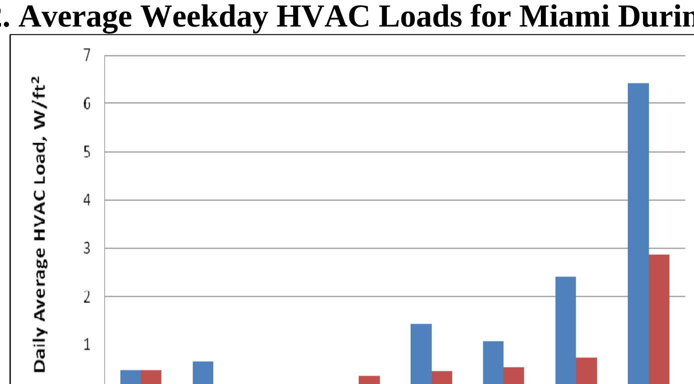
The annual energy use intensity (EUI) by end use is shown in Figure 1 for the baseline and 50% energy savings designs. In Miami, heating energy is negligible. Likewise, exterior lighting is very small in both locations compared to other end uses. Plug load reduction measures were not explored in the low plug load case, so they are identical in the two models.

Two end uses dominate baseline energy use in both climates: HVAC (heating/cooling plus fans) and interior lighting. HVAC energy consumption is 77% of the total in Miami and 75.3% of the total in Minneapolis; interior lighting represents a large fraction of the remainder: 18% of total building energy in both locations.

Because HVAC energy is the dominant end use in heating (Minneapolis) and cooling (Miami) dominated climates, we focus on how HVAC loads are influenced by the EDM selections that define the low-energy designs in Miami in August and in Minneapolis in January. This comparison is performed using the average weekday HVAC loads for the following categories: people, lights, equipment, windows (heat conduction and transmitted solar), opaque surface conduction, infiltration, and heating/cooling of outside air. Energy expended to treat OA was simulated by running a second set of baseline and low-energy buildings setting OA per person and per square foot of building area to zero. Positive values denote transfer of heat into the building and negative values denote loss of energy from the building. Results are shown in Figures 2 and 3 for Miami and Minneapolis, respectively. In both cases, opaque heat transfer, infiltration, and OA treatment dominate the baseline energy budget. The combination of greater wall insulation (to reduce opaque surface heat conduction), tighter envelope and vestibule (to reduce infiltration), and 70% effective ERVs (to reduce the energy and condition OA) leads to substantial reduction in these three terms. Other features that stand out are the dramatic decrease in energy for lighting in the Miami store by reducing LPD, adding daylighting controls, and 4% skylight coverage. The extra heat transfer through the skylights, a tradeoff with lighting energy savings, is represented by an increase in the "Window" category.

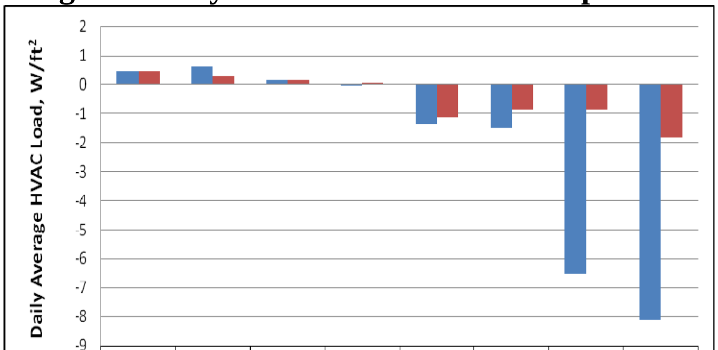
Analyses of diurnal opaque surface heat fluxes for an August day in Miami and a January day in Minneapolis are presented in Figures 4 and 5, respectively, where "Internal" refers to heat transfer between the air and internal mass inside the building and the line labeled "Sum" represents the sum of all the opaque heat transfer terms. The Minneapolis data indicate that energy loss through the roof represents an opportunity for additional energy savings. In Miami, on the other hand, heat transfer through the exterior walls is more significant than that through the roof, supporting the EDM selection of increased exterior wall insulation.

**Figure 2. Average Weekday HVAC Loads for Miami During August**




| | People | Lights | Equipment | Window | Opaque | Infiltration | OA | Net |
|---|---|---|---|---|---|---|---|---|
| Baseline | 0.49 | 0.65 | 0.17 | 0.07 | 1.44 | 1.09 | 2.43 | 6.43 |
| Selected | 0.49 | 0.07 | 0.17 | 0.35 | 0.47 | 0.53 | 0.75 | 2.87 |

Figure 3. Average Weekday HVAC Loads for Minneapolis During January




| | People | Lights | Equipment | Window | Opaque | Infiltration | OA | Net |
|---|---|---|---|---|---|---|---|---|
| Baseline | 0.47 | 0.62 | 0.16 | 0.00 | -1.34 | -1.50 | -6.53 | -8.12 |
| Selected | 0.47 | 0.31 | 0.16 | 0.05 | -1.12 | -0.84 | -0.85 | -1.82 |

Figure 4. Baseline Opaque Surface Heat Fluxes for an August Weekday in Miami

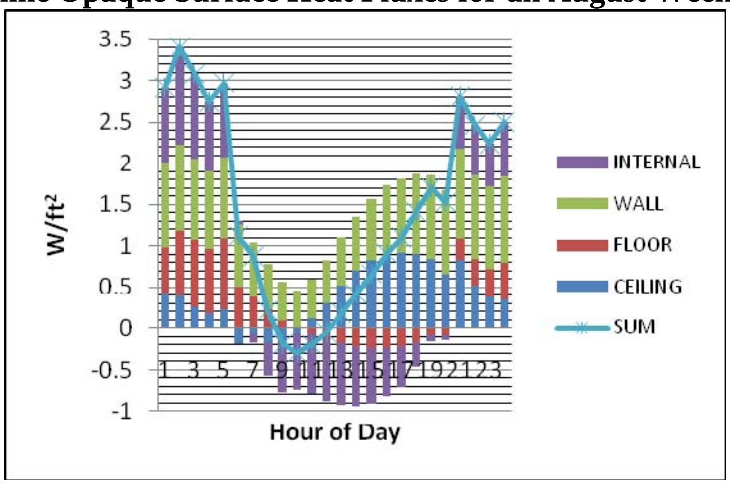
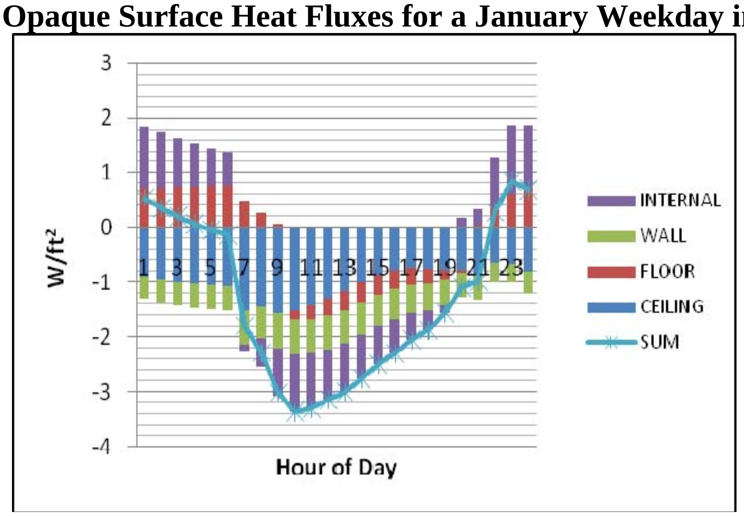



Figure 5. Baseline Opaque Surface Heat Fluxes for a January Weekday in Minneapolis

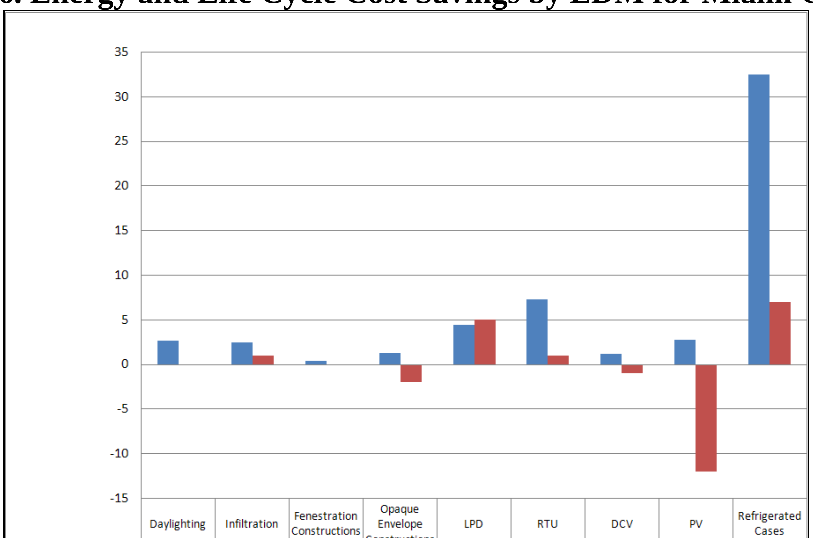


## Cost Effectiveness of Energy Design Measures

EDMs can be grouped into the following types: (1) those that reduce energy costs and whole building capital cost compared to the baseline alternative; (2) those that reduce annual EUI enough to pay back (through energy savings) increased capital cost investment over a particular time horizon; and (3) those that reduce annual EUI but not enough to offset capital cost investment over the life cycle period. In general, EDMs of type 1 are the most desirable, as they represent a good investment regardless of life cycle period. Type 2 EDMs are also desirable, though their desirability depends on the selected life cycle period; shorter life cycle periods result in smaller returns on investment. Type 3 EDMs are desirable from an energy efficiency perspective, but not from a cost perspective for the selected life cycle period, and in most cases would be implemented as needed to meet a particular energy savings goal.

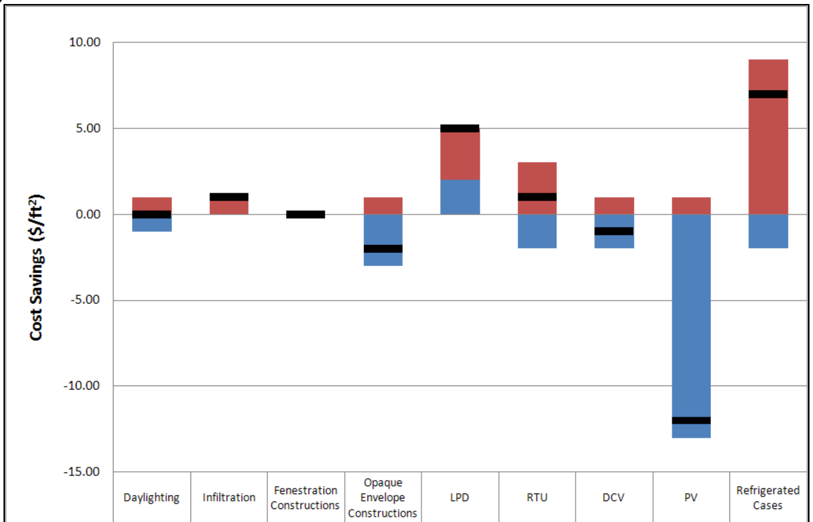
When optimizing energy savings with respect to life cycle cost, Opt-E-Plus selects EDMs in approximate order from type 1 to type 3, such that type 3 EDMs, such as photovoltaics (PV), are selected only if needed to reach the 50% energy savings goal. Figures 6 and 7 present the results of a perturbation analysis for the low-energy grocery model in Miami in which selected EDMs were replaced with their baseline counterparts to ascertain the effects of individual EDMs on energy use and life cycle costs (positive values represent savings resulting from implementation an EDM, negative values indicate that implementation results in higher energy use or cost). Figure 6 presents the overall energy savings and life cycle cost savings associated with a select group of EDMs; Figure 7 breaks the net life cycle cost savings into capital and energy components such that the type can be determined. Electricity costs include a flat monthly fee of $33.10, total demand charge of $6.73/kW, total usage charge of $0.07/kWh, plus taxes of 7.1%. The natural gas price was assumed to vary monthly, with an annual average cost of $11.65/MCF (Hale, Leach, Hirsch & Torcellini 2009).

**Figure 6. Energy and Life Cycle Cost Savings by EDM for Miami Grocery**




| | Daylighting | Infiltration | Fenestration Constructions | Opaque Envelope Constructions | LPD | RTU | DCV | PV | Refrigerated Cases |
|---|---|---|---|---|---|---|---|---|---|
| Energy Savings (%) | 2.7 | 2.5 | 0.4 | 1.3 | 4.4 | 7.3 | 1.2 | 2.8 | 32.5 |
| Cost Savings ($/sq ft) | 0 | 1 | 0 | -2 | 5 | 1 | -1 | -12 | 7 |

**Figure 7. EDM Cost Effectiveness Breakdown for Miami Grocery**




| | Daylighting | Infiltration | Fenestration Constructions | Opaque Envelope Constructions | LPD | RTU | DCV | PV | Refrigerated Cases |
|---|---|---|---|---|---|---|---|---|---|
| Energy Costs | 1.00 | 1.00 | 0.00 | 1.00 | 3.00 | 3.00 | 1.00 | 1.00 | 9.00 |
| Capital Costs | -1.00 | 0.00 | 0.00 | -3.00 | 2.00 | -2.00 | -2.00 | -13.00 | -2.00 |
| Life Cycle Costs | 0.00 | 1.00 | 0.00 | -2.00 | 5.00 | 1.00 | -1.00 | -12.00 | 7.00 |

LPD reduction represents an important example of a type 1 EDM. Although the associated high-efficiency lighting equipment requires an increased capital investment over the baseline lighting equipment, it reduces the heating load enough that the HVAC system can be sized nearly 20% smaller than the baseline system. This reduces LPD in the overall capital investment with respect to the baseline building configuration. Improving the efficiency of the refrigerated cases is an important type 2 EDM. By making a capital investment in higher efficiency case models, substantial annual energy savings (at 32.5%, by far the most significant contribution of a single measure to the energy savings goal) can be realized, resulting in considerable overall life cycle cost savings. As mentioned previously, installing PV panels on the roof is a type 3 EDM. In this case, PV was necessary to meet the 50% energy savings target, but its high cost of implementation resulted in a significant increase in overall life cycle cost for a relatively modest energy saving (2.8%).

## Diverse Paths to 50% Energy Savings

The 50% energy savings general merchandise and grocery store designs discussed thus far are informative, and can serve as a starting point for individual projects. However, there are limitations to providing just one design per location. Our cost and long-term performance data are uncertain enough that the designs we found to be optimal may not remain so given project-specific data. Also building design has enough qualitative aspects that a "one size fits all" solution for any building type and location is unlikely.

For these reasons, our technical reports introduce a new type of analysis for enumerating a diverse set of alternative designs. We run multiple optimization searches, each with a slightly perturbed search space. At a minimum, some EDM categories are removed from consideration so we can answer questions such as: "Is daylighting required to meet the 50% energy savings goal?" and "If I choose not to install more efficient ice cream cases, what can I do elsewhere in the store to meet my energy efficiency goal?" The algorithm is described in detail in an upcoming paper by Hale and Long (2010).

The algorithm in the full-length reports was abbreviated, in that we looked only for designs that forced a single design strategy to the baseline level, and did not find designs that excluded two or more strategies from consideration. We focus here on a rerunning of the algorithm for the San Francisco, California, grocery store model.

If the algorithm were run to completion, the result would be a list of all possible ways to reach the 50% net site energy savings goal, where different designs would be distinguished by the combination of design strategies set to the baseline level. Unfortunately, the significant computational demands (memory requirements, in particular) that would be required precluded an exhaustive list. The goal of design enumeration was largely accomplished, however, as 69 feasible designs were generated. A selected number are summarized in Table 2. The strategies that were chosen for at least one design can be found in Table 1.

Table 2 illustrates that in this case, there are a number of ways to reach the energy efficiency goal. Design 0 indicates that the most cost-effective design uses vestibules and air barriers to reduce infiltration, more efficient electric lights, and daylighting controls to dim the lights near the windows at the front of the store; however, design 73 demonstrates that, as a package, those changes are not required. Table 3 shows that metrics directly examined by the search algorithm (net site energy use and lifetime cost) vary little over the set of feasible designs. However, other metrics such as PV energy and peak electricity demand do vary significantly and can be used to inform the decision about which design best matches the goals and philosophy of a given project.

In addition to generating alternative designs that reach the energy efficiency goal, unsuccessful searches show that a strategy is needed. For the grocery store design and the San Francisco run, we found that 50% net site energy savings cannot be reached with the baseline dairy/deli refrigerated cases. Even though PV panels cover 60% of the roof, the San Francisco store reached only 45.2% net site energy savings with baseline dairy/deli refrigerated cases.

## Conclusions

Our analysis emphasizes the importance of reducing envelope heat transfer, infiltration, and energy used to condition OA to reach 50% energy savings in extreme climates and the critical role refrigerated cases play in grocery store energy use. We also provide a framework for comparing the performance and cost effectiveness of different EDMs chosen as part of a 50% energy savings design package. This framework facilitates better understanding of whole-building interactions, such as how substantial energy savings through an EDM such as LPD reduction can lead to capital cost savings and overall life cycle cost savings through its impact on HVAC sizing. It also highlights where investments should be made to lower the cost of technologies that save substantial energy but are not currently cost effective and to develop reliable application packages for technologies that have the potential to save significant amounts of energy such as daylight harvesting. Lastly, we present an optimization framework that allows users to identify multiple design packages that can achieve 50% energy savings and to compare them using performance, life cycle cost, capital cost, and peak demand metrics. We recognize that using site energy rather than source energy or other energy metrics will influence the choice of low energy design and plan to include other metrics in future research. The results presented here should be used as a starting point to inform building design rather than as prescriptive recommendations, as the details of actual projects will differ from the idealized cost and performance assumptions used here.

**Table 2. Selected Alternative Designs for Grocery Stores in San Francisco, California***

| | Included Strategies** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Design No.** | **IN** | **LPD** | **DL** | **WI** | **RI** | **FT** | **HVC** | **DCV** | **ERV** | **FFC** | **MC** | **Notable Attributes** |
| 0 | x | x | x | x | | | x | | x | x | x | Optimal design; lowest life cycle cost ($144/ft$^2$) |
| 1 | | x | x | x | | | x | | x | x | x | Lowest capital cost ($127/ft$^2$); removes vestibule and air barrier |
| 7 | x | x | x | x | | x | x | x | | x | x | DCV and double paned skylights make up for removing ERV |
| 8 | x | x | x | x | x | x | x | | x | | x | Roof insulation, double paned skylights, and PV make up for using baseline frozen food cases |
| 13 | | x | | x | | | x | | x | x | x | Same as design 1 except no daylighting controls, slightly less energy savings. |
| 59 | x | x | x | x | x | x | x | x | | x | | Lowest electric demand: 180 kW versus 226 kW for design 0; significant PV (8.0 kBtu/ft$^2$yr) |
| 73 | | | | x | | | x | | x | x | x | Highest electric demand: 263 kW; no PV, baseline infiltration and lights |

*All listed designs include reduced window area, and non-baseline HVAC systems, ice cream cases, and dairy/deli refrigerated cases.

** IN - infiltration; LPD - lighting power density; DL - daylighting; WI - wall insulation; RI - roof insulation; FT - fenestration type; HVC – HVAC; DCV – demand control ventilation; ERV – energy recovery ventilator; FFC – frozen food cases; MC – meat cases

**Table 3. Summary Statistics for 69 Grocery Store Designs With at Least 50% Energy Savings Over Baseline**

| | **Net Site Energy** | **PV Energy** | **Lifetime Cost** | **Capital Cost** | **Peak Demand** | **Energy Savings** |
|---|---|---|---|---|---|---|
| **Statistic** | **kBtu/(ft$^2$yr)** | **kBtu/(ft$^2$yr)** | **\$/ft$^2$** | **\$/ft$^2$** | **kW** | **%** |
| Min | 107.7 | 0.0 | 144 | 127 | 180 | 50.0 |
| Max | 115.7 | 8.0 | 162 | 146 | 263 | 53.4 |
| Mean | 113.8 | 0.5 | 147 | 130 | 215 | 50.8 |
| $\sigma$ | 2.4 | 1.6 | 3.5 | 3.5 | 21 | 1.0 |
| 100$\sigma$/mean | 0.2 | 27.3 | 0.2 | 0.3 | 9.6 | 2.0 |

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[ASHRAE] American Society of Heating, Refrigerating and Air Conditioning Engineers. 1989. **ANSI/ASHRAE/IESNA Standard 90.1-1989, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings**. Atlanta, Georgia.

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