Evaporator Fan Controller for Med. Temp Walk-in

Walk-in cooler evaporator fans typically run all the time; 24 hours per day, 365 days per year. This is because they must run constantly to provide cooling when the compressor is running, and to provide air circulation when the compressor is not running. However, evaporator fans are a very inefficient method of providing air circulation. Each of these fans uses more than 100 watts. Installing an evaporator fan control system will turn off evaporator fans while the compressor is not running, and instead turn on an energy-efficient 35 watt fan to provide air circulation, resulting in significant savings.

Algorithms

Energy Savings (kWh) = ΔkW X 8760 X (1+1F)

Demand Savings (kW) = $((kW_{evap} \times n_{fans} \times DC_{evap}) - kW_{circ}) \times (1 - DC_{comp}) \times (1{=}IF) \times CF$

Definition of Terms

ΔkW= gross customer connected load kW savings for the measure

8760= operating hours over the course of a year

kW_{evap} = connected load kW of each evaporator fan

n_{fans} = number of evaporator fans

kW_{circ}= connected load kW of the circulating fan

DC_{comp} = duty cycle of the compressor

DC_{evap} = duty cycle of the evaporator fan

IF= Interaction factor for reduced cooling load from replacing the evaporator fan with a lower wattage circulating fan when the compressor is not running.

CF= Coincidence Demand Factor, .74

TABLE 141: EVAPORATOR FAN CONTROLLER

Component	Type	Value	Source
kW_{evap}	Fixed	Average = 0.123 kW	1
n_{fans}	Variable	From customer	EDU Data Gathering
kW_{circ}	Fixed	0.035 kW	2

Component	Type	Value	Source
DC_{comp}	Fixed	Assume 50%	3
DC_{evap}	Fixed	100% for cooler, 94% for freezer	4
IF	Fixed.	1.3 for medium temp	5
CF	Fixed	74%	Same as HVAC

Effective Measure Life

16 years

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$90.75/Motor (DEER Database)

Sources:
Algorithm: Efficiency Vermont TRM, December 30, 2008

1. Based on a weighted average of 80% shaded pole motors at 132 watts and 20% PSC motors at 88 watts. This weighted average is based on discussions with refrigeration contractors and is considered conservative (market penetration estimated at approximately 10%).
2. Wattage of fans used by Freeaire and Cooltrol.
3. A 50% duty cycle is assumed based on examination of duty cycle assumptions from Richard Traverse (35%-65%), Cooltrol (35%-65%), Natural Cool (70%), and Pacific Gas & Electric (58%). Also, manufacturers typically size equipment with a built-in 67% duty factor and contractors typically add another 25% safety factor, which results in a 50% overall duty factor.
4. An evaporator fan in a cooler runs all the time, but a freezer only runs 8273 hours per year due to defrost cycles (four 20-minute defrost cycles per day).
5. Interaction Factor (1+IF) assumes 3.5 COP for medium temp, based on the average of standard reciprocating and discus compressor efficiencies with Saturated Suction Temperatures of -20°F, 20°F, and 45°F, respectively, and a condensing temperature of 90°F.

Door Heater Controls for Cooler or Freezer

Door heater controls allow "on-off" control of the operation of the door heaters. Because relative humidity levels differ greatly across the United States, a door heater in Maine needs to operate for a much shorter season than a door heater in Florida. One can realize energy and cost savings by installing a control device to turn off door heaters when there is little or no risk of condensation.

There are two strategies for this control, based on either (1) the relative humidity of the air in the store, or (2) the "conductivity" of the door (which drops when condensation appears). In the first strategy, the system activates the door heaters when the relative humidity in the store rises above a specific setpoint, and turns them off when the relative humidity falls below that setpoint. In the second strategy, the sensor activates the door heaters when the door conductivity falls below a certain setpoint, and turns them off when the conductivity rises above that setpoint.

Algorithms

Energy Savings (kWh) = ΔkW X 8760 X ESF X (1+1F)'

Demand Savings (kW) = kW_{door} x n_{door} X CF

Definition of Terms

ΔkW= gross customer connected load kW savings for the measure

kW_{door}= connected load kW of a typical reach-in cooler or freezer door with a heater

n_{door}= number of doors controlled by sensor

IF= Interaction factor for reduced cooling load from eliminating heat generated by the door heater from entering the cooler or freezer

CF= Coincidence Demand Factor, .74

8760= operating hours over the course of a year

TABLE 142: DOOR HEATER CONTROLS

Component	Type	Value	Source
kW_{door}	Fixed	Cooler 0.075 kW, freezer 0.200 kW	1
n_{door}	Variable	From customer	EDU Data Gathering
IF	Fixed	Interaction factor	2

Component	Type	Value	Source
		1.3 for low temp, 1.2 for medium temp, 1.1 for high temp	
CF	Fixed	74%	Same as HVAC
ESF	Fixed	55% for humidity-based control, 70% for conductivity-based control	3, 4

Effective Measure Life

16 years

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$56/Liner Foot of Refrigeration Case (DEER Database)

Sources:

Efficiency Maine Commercial TRM, March 1, 2007

1. Based on a range of wattages from two manufacturers and metered data (cooler 50-130 W, freezer 200-320 W).
2. Interaction factor assumes 2.0 COP for low temp, 3.5 COP for medium temp, and 5.4 COP for high temp, based on the average of standard reciprocating and discus compressor efficiencies with Saturated Suction Temperatures of -20°F, 20°F, and 45°F, respectively, and a condensing temperature of 90°F, and manufacturer's assumption that 65% of heat generated by door enters the refrigerated case (1+0.65/COP).
3. R.H. Travers' estimate of savings.
4. Door Miser savings claim.

LED Case Lighting

The installation of LED bulbs in commercial display refrigerators, coolers or freezers. The light bulbs in a typical refrigerator, cooler or freezer add to the load on that unit by increasing power consumption of the unit when the light is on, and by adding heat to the inside of the unit that must be overcome through additional cooling. Replacing incandescent and fluorescent lighting with low heat generating LEDs reduces the energy consumption associated with the lighting components and reduces the amount of waste heat generated from the lighting that must be overcome by the unit's compressor cycles.

Algorithms

Energy Savings (kWh) = $(kW_{baseline} - kW_{LED})$ X FLHRs X (1 + IF)

Demand Savings (kW) = $(kW_{baseline} - kW_{LED})$ X CF

Definition of Terms

$kW_{baseline}$= baseline lighting load (kW)

kW_{LED}= LED lighting load (kW)

FLHRs= total lighting run hours per year 24 hours/day, 365 days/year

IF= Interaction factor is based on effective refrigeration compressor EER values of 6.7 and 5.25 Btu/Wh, respectively..

TABLE 143: LED CASE LIGHTING

Component	Type	Value	Source
$kW_{baseline}$	Variable	From customer	EDU Data Gathering
kW_{LED}	Variable	From customer	EDU Data Gathering
FLHRs	Fixed	8,760	
IF	Fixed	0.41 for refrigerators and coolers and 0.52 for freezers	1

Effective Measure Life

16 years

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$TBD (DEER Database)

Sources:

Algorithm: New York Department of Public Service C&I TRM, August 10, 2009

1. Estimated based on energy produced by the lighting systems which must be removed by the refrigeration compressor. This adjustment should be confirmed via metering tests and adjusted when those tests have been concluded.

LED Case Lighting with Motion Sensor

The installation of LED bulbs in commercial display refrigerators, coolers or freezers. The light bulbs in a typical refrigerator, cooler or freezer add to the load on that unit by increasing power consumption of the unit when the light is on, and by adding heat to the inside of the unit that must be overcome through additional cooling. Replacing incandescent and fluorescent lighting with low heat generating LEDs reduces the energy consumption associated with the lighting components and reduces the amount of waste heat generated from the lighting that must be overcome by the unit's compressor cycles. A more advanced system includes motion sensors and dimming power supplies and is designed to save energy by automatically dimming the lights when no one is near the refrigeration cases.

Algorithms

Energy Savings (kWh) = $kW_{baseline}$ x ESF X (1 + IF)

Demand Savings (kW) = ($kW_{baseline}$ – kW_{LED}) X CD

Definition of Terms

$kW_{baseline}$= baseline lighting load (kW)

kW_{LED}= LED lighting load (kW)

ESF= Energy savings factor

CF= Coincidence Demand Factor, .74

EER= values of 6.7 and 5.25 Btu/Wh, respectively for the portion of the saved energy that would have needed to be eliminated via the compressor.

TABLE 144: LED CASE LIGHTING WITH MOTION SENSOR

Component	Type	Value	Source
$k_{baseline}$	Variable	From customer	EDU Data Gathering
kW_{LED}	Variable	From customer	EDU Data Gathering
ESF	Fixed	68%	1
IF	Fixed	Interaction Factor (TBD)	2
CF	Fixed	74%	Same as HVAC

Effective Measure Life

5 years (DEER Database)

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$250/sensor (Engineering Estimate)

Sources:

Algorithm: Adapted from New York Department of Public Service C&I TRM, August 10, 2009

1. Sacramento Municipal Utility District, Customer Advanced Technologies Program Technology Evaluation Report: LED Freezer Case Lighting Systems, July 25, 2008.

2. It is assumed that about 80 percent of the energy produced by the lighting systems must be removed by the refrigeration compressor. This adjustment should be confirmed via metering tests and adjusted when those tests have been concluded.

Strip Curtain for Walk-in Coolers and Freezers

Strip curtains impede heat transfer from adjacent warm and humid spaces into walk-ins when the main door is opened, thereby reducing the cooling load. As a result, compressor run time and energy consumption are reduced. The engineering assumption is that walk-in door is open 2.5 hours per day every day, and the strip curtain covers the entire door frame.

Algorithms

Medium Temperature Walk-in:

Energy Savings (kWh) = LF x 96

Low Temperature Walk-in:

Energy Savings (kWh) = LF x 467

Demand Savings (kW) = 0

Definition of Terms

LF= linear feet of strip curtains installed

96= strip curtain walk-in cooler savings (kWh/ft)

467= strip curtain walk-in freezer savings (kWh/ft)

TABLE 145: STRIP CURTAINS

Component	Type	Value	Source
LF	Variable		EDU Data Gathering

Sources:

1. Regional Technical Forum June 2, 2009. Evaluation of Energy Savings for Strip Curtains. Powerpoint.
http://www.nwcouncil.org/energy/rtf/meetings/2009/06/default.htm

Effective Measure Life

5 years (DEER Database)

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$TBD (DEER Database)

Night Covers for Displays

By covering refrigerated cases, the heat gain due to the spilling of refrigerated air and convective mixing with room air is reduced at the case opening. Night covers are deployed at night and are used for low temperature medium temperature tub style refrigeration cases.

Algorithms

Energy Savings (kWh) = kW x FLHRs x ESF

Demand Savings (kW) = 0 (occurs at night)

Definition of Terms

kW= gross customer connected refrigeration load in kW

FLHR= Hours night covers are installed on refrigeration cases

ESF= the energy savings factor from installing night covers..

TABLE 146: NIGHT COVERS FOR DISPLAYS

Component	Type	Value	Source
kW	Variable	From customer	EDU Data Gathering
FLHRs	Variable	From customer, hours covers used on refrigeration covers.	EDU Data Gathering
ESF	Fixed	TBD from night cover research study	2

Effective Measure Life

5 years (DEER Database)

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$36.54/Linear Foot of Refrigerated Case (DEER Database)

Sources:

Algorithm: Efficiency Vermont TRM, December 30, 2008

1. To be provided at future date.

Vending Machine Occupancy Controls

The VendingMiser is an energy control device for refrigerated vending machines. Using an occupancy sensor, during times of inactivity the VendingMiser turns off the machine's lights and duty cycles the compressor based on the ambient air temperature. The VendingMiser is applicable for conditioned indoor installations.

Algorithms

Energy Savings (kWh) = (V x I x PF x FLHRs) / 1000 X ESF

Demand Savings (kW) = 0

Definition of Terms

V = voltage

I = amperage

PF = Power Factor

FLHRs = annual operating hours

Savings = annual energy savings

1000 = conversion from Watts to kilowatts

TABLE 147: VENDING MACHINE OCCUPANCY CONTROLS

Component	Type	Value	Source
V	Fixed	120 Volts	
I	Fixed	3.56 Amps	1
PF	Fixed	0.85	Engineering Estimate
FLHRs	Fixed	5,840 (based on average of 16 hours/day, 365 days per year	ASHRAE
ESF	Fixed	38%	2

Effective Measure Life

10 years (DEER Database)

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$215.50/machine (DEER Database)

Sources:

Algorithm: Efficiency Vermont TRM, December 30, 2008

1. Average Ampere loading of 44 sampled indoor vending machines, by Bayview Tech.
2. Savings based on average of 26 different independent test sites of VendingMiser.

Vending Machine Central Controls

This measure is essentially an approach for controlling the operations of vending machines so that they only operate when needed. The controls are typically a time-control system that allows the machines to be turned on and reach desired temperatures during the hours of business operations, but turned off during other times.

Because different vending machines have different operational characteristics, consumption of the vending machines will need to be estimated for the pre-installation period for the typical program-covered unit. Where possible, this estimate should be based on a metered sample of units operated with kWh/kW meters to establish the baseline conditions. If metered data is not available, manufacturer's data on unit consumption can be used. The consumption of the units for the baseline condition will be assumed to operate 5,840 hours per year. Savings for the post-installation period will be estimated using the percent of time the units are turned on as a fraction of the total estimated consumption for 5,840 hours per year.

Because the units typically operate during the peak hours in the baseline condition, the peak demand reduction will be set at the average on-time duty cycle adjusted kW draw of the typical unit. The typical kW draw will be estimated using the metered kW draw of the unit (if a metered sample is available) in a non-controlled condition. If meter sample data is not available, manufacturer's data of kW draw and estimated duty cycle can be used.

Algorithms

Energy Savings (kWh) = kW * ESF_s

Demand Savings (kW) = 0

Definition of Terms

kW= the total kW load of refrigeration system being controlled by VendingMiser Central Controls

ESF= Energy savings factor

CD= Coincidence Demand Factor, 74

TABLE 148: VENDING MACHINE CENTRAL CONTROLS

Component	Type	Value	Source
kW	Variable	From customer	EDU Data Gathering or manufacturer data
ESF	Variable	From customer operations and number of machines being controlled	EDU Data Gathering or manufacturer data
CD	Fixed	Coincidence Demand Factor, .74	EDU Data Gathering

Component	Type	Value	Source
			or manufacturer data

Effective Measure Life

10 years (DEER Database)

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$182.88/machine (DEER Database)

Sources:

Algorithm: New York Department of Public Service C&I TRM, August 10, 2009

Auto-Closer for Refrigerated Cases

Walk-in coolers and freezers are designed to be accessed regularly, but leaving the main door open wastes a great amount of cooling energy and money. Auto-closers ensure that the door is fully closed after each access and remove the need to check if door is completely shut.

The reach-in doors or walk-in coolers and freezers are also accessed regularly. Auto-closers can make sure they are closed after each access. A properly installed walk-in door closer should firmly close a main walk-in door that is within one inch of full closure. For a reach-in door, the closer should also firmly close the door.

Algorithms

Energy Savings (kWh) = 560 (low-temperature walk-in)

Energy Savings (kWh) = 373 (medium-temperature walk-in)

Energy Savings (kWh) = 2,806 (low-temperature reach-in)

Energy Savings (kWh) = 241 (medium-temperature reach-in)

Demand Savings (kW) = 0

Effective Measure Life

16 years

Coincidence Factor

.74 (Assumed same as HVAC)

Incremental Capital Cost

$433.22/Door (DEER Database)

Sources:

Bonneville Power Administration and Portland Energy Conservation, Inc.

Residential and Commercial Measures

Solar Photovoltaics

The measure algorithms describe the calculation methodology for realized energy and demand benefit from solar photovoltaic (PV) systems for residential and commercial applications. The energy savings calculations utilize the free online Department of Energy (DOE) PVWATTS (http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/) program to determine the amount of solar radiation, or "insolation" striking a user-defined solar photovoltaic array, where the user enters the system location, type, size, DC to AC conversion efficiency (de-rate factor), tilt, and azimuth. It is assumed that commercial systems have a slightly more efficient inverter, as well as fewer losses associated with wiring, soiling, and overall better maintenance.

Algorithms

Residential Solar Photovoltaics

Electricity Impact (kWh)[18] = KW_R X DF_{RES} X C_F X $HOURS_A$

Demand Impact (kW) = KW_{DC} X DSF

Commercial Solar Photovoltaics

Electricity Impact (kWh) = KW_R X DF_{RES} X C_F X $HOURS_A$

Demand Impact (kW) = KW_{DC} X DSF

Definition of Terms

kW_R = Nameplate rating of photovoltaic array (DC). PV module power ratings are for standard test conditions (STC) of 1,000 W/m^2 solar irradiance and 25°C PV module temperature.

DF_{RES} = Average system DC-AC conversion efficiency, or derate factor for residential systems.

DF_{COM} = Average system DC-AC conversion efficiency, or derate factor for commercial systems.

[18] The user can also directly estimate energy impact using PV watts.

C_F = Capacity factor, proportion of hours per year that total solar radiation will be available to the PV system. Derived utilizing PV Watts simulations.

$HOURS_A$ = Number of hours per year that the PV system is estimated to be available for operation.

DSF = Demand savings factor. Percent of installed capacity that is coincident with peak load. Note that demand savings often are reported as the cumulative sum of the installed systems.

TABLE 149: SOLAR PHOTOVOLTAICS

Component	Type	Value	Sources
KW_R	Variable		-
DF_{RES}	Fixed	77%	2
DF_{COM}	Fixed	82%	2
C_F	Fixed	0.2	1,3
$HOURS_A$	Fixed	7,446 (8760 X 85%)	3
DSF	Fixed	35%	Engineering Estimate

Estimated Useful Life

The estimated useful life for solar photovoltaics is 20 years..

Measure Costs

The incremental capital cost for solar photovoltaics is $8500.00 / kW.

Sources:

1. PV Watts: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/
2. Ibid., p. 3. Cites residential factor of 77% and commercial factor of 82%. More information found at PV Watts: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/
3. NYSERDA, "Final Report on the Initial Three-Year SBC Program-Appendix B", January, 2002, p. 17-18

Other Measures

School Education Programs

No algorithm was developed to measure energy savings for this program. The purpose of the program is to provide information and tools that residential customers can use to make decisions about what actions to take to improve energy efficiency in their homes. Many measure installations that are likely to produce significant energy savings are covered in other programs. These savings are captured in the measured savings for those programs. The savings produced by this program that are not captured in other programs would be difficult to isolate and relatively expensive to measure.

A school education program may include the following measures, or other measures: provide energy education curriculum to students, offer students and their families an opportunity to complete a self-audit of their home and learn how to make their home more energy efficient. In addition student families may be provided with energy efficient measures that when installed save energy, such as CFL light bulbs or other energy efficient measures.

TABLE 150: EXAMPLE SAVINGS SCHOOL AUDIT PROGRAMS

Component	Type	Value	Sources
Audit Recommendations w/ Energy Efficiency Kit and CFL bulbs	Fixed	417 kWh	1
Per additional CFL bulb offered	Fixed	68 kWh	2

Sources:

1. K12 audit recommendations savings from "Energy Impact Evaluation of the NEED program in Ohio", prepared by TecMarket Works and Integral Analytics for Duke Energy and "An Evaluation of Energy Star Products: Results of a Process and Impact Evaluation of Duke Energy's CFL Promotion and Lighting Logger Programs", prepared by TecMarket Works for Duke Energy.
2. From "An Evaluation of Energy Star Products: Results of a Process and Impact Evaluation of Duke Energy's CFL Promotion and Lighting Logger Programs", prepared by TecMarket Works for Duke Energy.

Commercial and Industrial Applications

Each custom commercial and industrial application will be treated independently as a custom program. An application must be submitted, containing adequate documentation fully describing the energy efficiency measures installed or proposed. Each program application will be required to include[19]:

1. Program Name
2. Utility Account Number
3. Program Location (s)
4. Type of facilities in which the measures, systems, processes, or strategies will be implemented
5. Customer class and end-use served
6. Estimated demand reduction value (kW) per measure including supporting documentation (i.e. engineering estimates or documentation of verified savings from comparable projects)
7. Estimated energy reduction value (kWh) throughout the year
8. The date by which commercial operation is expected

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[19] Application criteria for submittals is taken from ISO New England's *Measurement and Verification of Demand Reduction Value from Demand Resources*. October 1, 2007.

Residential Applications

The general form of the equation for the residential demand response measure savings algorithms is:

Number of Units X Savings per Unit

To determine resource savings, the per unit estimates in the algorithms will be multiplied by the number of demand response units. The number of units will be determined by the program. Per unit savings estimates will be estimated by each specific measure.

Algorithms

Direct Load Control (Air Conditioning Cycling, Pool Pump, and Water Heater Load Control)

Electricity Impact (kWh) = ESav X Units X Hours

Demand Impact (kW) = ESav X Units

<u>Definition of Terms</u>

ESav = Energy Saved in One Hour in kW
Units = Number of Units in the Program
Hours = Number or hours throughout the year the measure operates

TABLE 151: DIRECT LOAD CONTROL

Component	Type	Value	Sources
ESav	Fixed	Air conditioning Cycling = 1.0 kW Pool Pump Load Control = 0.75 kW Water Heater Load Control = 0.2 kW	1 2 3
Units	Variable		EDU Data Gathering
Hours	Variable		EDU Data Gathering

Sources:

1. Public Service Electric and Gas Company. *Petition for Approval of Demand Response Programs.* August 5, 2008.
2. "2008 OH Power Manager Update Program Summary and Impact Evaluation Results", Prepared by Duke Energy, March 2009.
3. Duke Energy Conserve and Save pilot program (n=30).

Appendix A

Miscellaneous Measures

The measures below were originally included in the utilities' filed list of measures. These measures algorithms, baselines, etc. are "to be determined" and will be updated in future versions of the TRM.

TABLE 152: RESIDENTIAL MEASURES

High Efficiency Electric Clothes Dryer with Moisture Sensor.	
Energy code training	
Energy code enforcement	
Low Flow Faucet Aerators - North (Used normal aerator (4gpm), assumed North)	
Low Flow Faucet Aerators - South	1.5 gal/minute
Bathroom ventilation fan	
Attic fans	
Evaporative cooling	
Duct balancing	
Infiltration reduction - 15%	
Insulated cement forms	
Water bed insulating pad	
Covered Product	CFL Reflector
LED Downlight	LED downlight
Covered Candle (low wattage, CFL or LED)	
Gravity Film Heat Exchanger GFX	40-60 ft GFX unit installed
Low Income Weatherization- Tier 1	low income program
Low Income Weatherization- Tier 2	low income program
Room A/C recycling	

Dehumidifier recycling	
Shower Start - North	Shower start technology with low flow showerhead 1.75 gpm
Shower Start - South	Shower start technology with low flow showerhead 1.75 gpm
Home energy management control systems	
Building energy management controls	
Tankless water heaters (gas and electric)	
Residential Pool Pump Timer	

,TABLE 153: COMMERCIAL MEASURES

Single Line to Multiplex Compressor	
High efficiency, low temperature compressor	High efficiency, low temperature compressor with EER of 5.2
Efficient Refrigeration Condenser	Oversized condensers with low approach temperatures
Efficient Condenser	
Multiplex system with oversized condenser	
Intelligent building controls	
EMS System	Lighting & HVAC
Evaporative assist cooling	
Glass Doors on Low and Med. Temperature Displays	
Demand control ventilation for parking garage	
Demand control ventilation for restaurant hood	
ECM motors in variable air volume HVAC systems	
Plug Load Occupancy Sensors Document Stations	
Additional primary storage required	

Tune-up/Advanced Diagnostics	
Floating Head Pressure Control	
Commercial, Industrial Audit – Sm & Md	
Commercial, Industrial Audit - Large	
Commercial, Industrial Audit - Gov	
Refrigeration Commissioning	
Retrocommissioning	
Flow restrictors, faucet aerators and low flow shower heads	
Thermal Storage	

Appendix C.

Prototypical Building Energy Simulation Model Development

Many of the parameters used in the TRM algorithms are derived from DOE-2.2 simulations of typical residential and commercial buildings. The following sections provide a description of the prototypical buildings and a summary of key modeling assumptions.

Residential Building Prototype Model Development

This analysis is based on DOE-2.2 simulations of a set of prototypical single family residential buildings. The prototypical simulation models were derived from the residential building prototypes used in the California Database for Energy Efficiency Resources (DEER) study, with adjustments make for local building practices and climate. The prototype "model" in fact contains 4 separate residential buildings; 2 one-story and 2 two-story buildings. Each version of the 1 story and 2 story buildings are identical except for the orientation, which is shifted by 90 degrees. The selection of these 4 buildings is designed to give a reasonable average response of buildings of different design and orientation to the impact of energy efficiency measures.

Three separate models were created to represent general vintages of buildings:

1. Old, poorly insulated building constructed in the 1950s or earlier. This vintage is referred to as the "old" vintage
2. Existing, average insulated building conforming to 1980s era building codes. This vintage is referred to as the "average" vintage.
3. New construction conforming to the applicable State Energy Code. This vintage is referred to as the "new" vintage.

A sketch of the residential prototype buildings is shown in Figure 1.

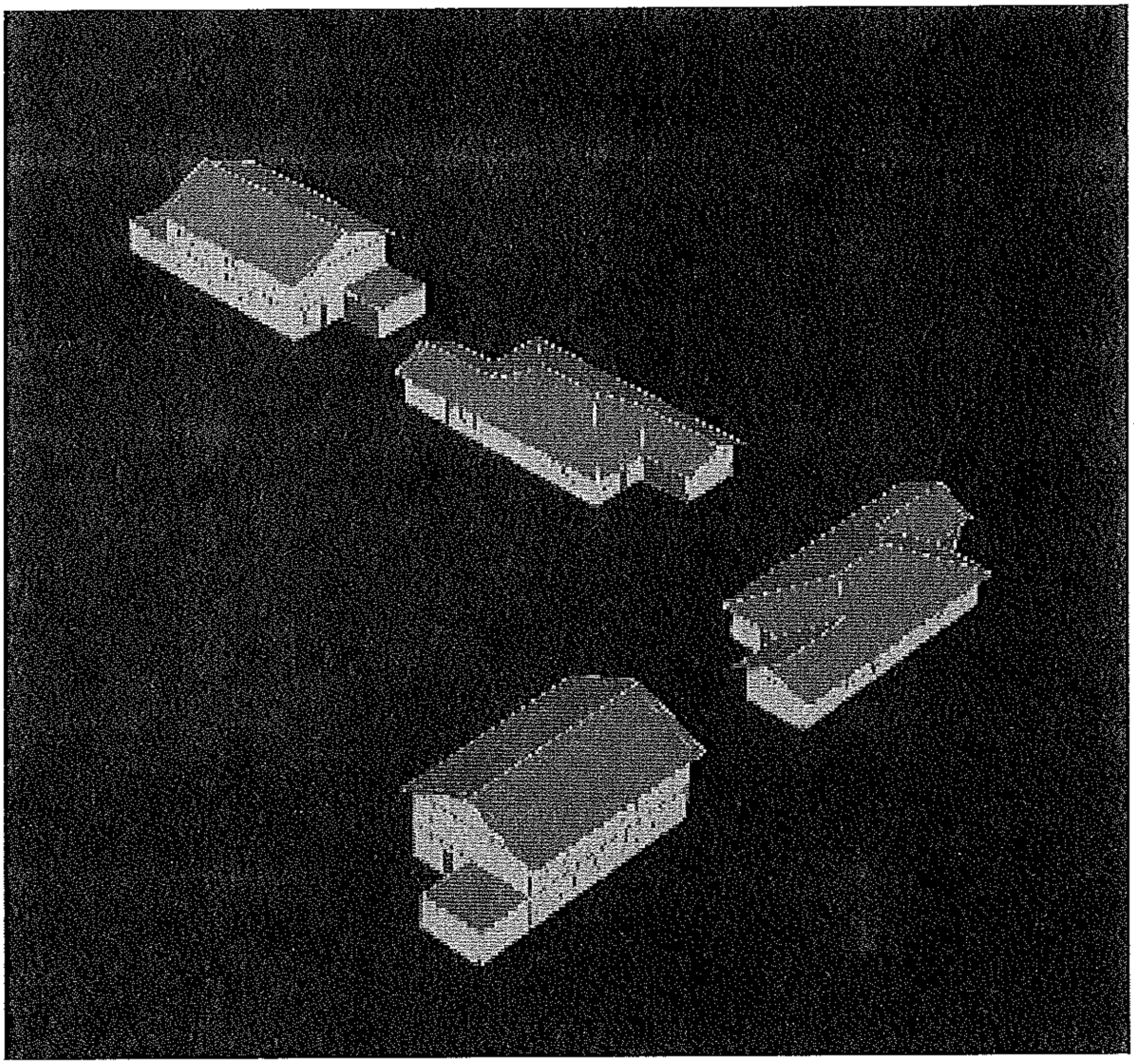

FIGURE 1. COMPUTER RENDERING OF RESIDENTIAL BUILDING PROTOTYPICAL DOE-2 MODEL.

The base prototype includes an unconditioned basement. A separate crawlspace model was developed to analyze floor and crawlspace wall insulation. The general characteristics of the residential building prototype model are summarized in Table 154.

TABLE 154. RESIDENTIAL BUILDING PROTOTYPE DESCRIPTION

Characteristic	Value
Vintage	Three vintages simulated – old poorly insulated buildings, existing average insulated buildings and new buildings
Conditioned floor area	1 story house: 1465 SF (not including basement) 2 story house: 2930 SF (not including basement)
Wall construction and R-value	Wood frame with siding, R-value varies by vintage
Roof construction and R-value	Wood frame with asphalt shingles, R-value varies by vintage

Characteristic	Value
Glazing type	Average of single and double pane; properties vary by vintage
Lighting and appliance power density	0.51 W/SF average
HVAC system type	Central split system AC with gas furnace Central split system heat pump Electric furnace only Gas furnace only
HVAC system size	Based on ASHRAE design day peak load with 20% over sizing.
HVAC system efficiency	Baseline SEER = 13
Thermostat setpoints	Heating: 70°F with setback to 60°F Cooling: 75°F with setup to 80°F
Duct location	Buildings without basement: attic Buildings with basement: basement
Duct surface area	Single story house: 390 SF supply, 72 SF return Two story house: 505 SF supply, 290 SF return
Duct insulation	Uninsulated
Duct leakage	20% of fan flow total leakage, evenly split between supply and return.
Natural ventilation	Allowed during cooling season when cooling setpoint exceeded and outdoor temperature < 65°F. 2 air changes per hour

Wall, Floor and Ceiling Insulation Levels

The assumed insulation R-values for wall, floor and ceiling insulation by vintage are shown in Table 155 through Table 158.

TABLE 155. WALL INSULATION R-VALUE ASSUMPTIONS BY VINTAGE

Vintage	Assumed R-value of insulated wall	Notes
Older, poorly insulated	3.5	Wood frame 2x4 with wood siding, drywall, & composite insulation based on RECS 2001 insulation data + engineering judgment
Existing, average insulation	11	Fiberglass insulation in 2 by 4 wall per MEC 1983; assumes double-pane windows.
New construction	13	State Energy Code 2006 IECC w/ mod.

TABLE 156. CRAWLSPACE AND BASEMENT WALL INSULATION LEVELS BY VINTAGE

Vintage	Assumed R-value of basement or crawlspace wall	Notes
Older, poorly insulated	0	Concrete foundation, no insulation

Vintage	Assumed R-value of basement or crawlspace wall	Notes
Existing, average insulation	0	Floor above unconditioned space must be insulated.
New construction	5 – bsmt 0 – crawl	Unconditioned bsmt walls are assumed insulated & not the floor above; Unconditioned crawl walls assumed uninsulated, but floor above is.

TABLE 157. FLOOR INSULATION LEVELS BY VINTAGE

Vintage	Assumed R-value of floor insulation	Notes
Older, poorly insulated	9.6	3/4" hardwood flooring over joists, & composite insulation based on RECS 2001 insulation data + engineering judgment
Existing, average insulation	13	Fiberglass insulation in floor joists per MEC 1983.
New construction	0 – bsmt 19 – crawl	Unconditioned bsmt walls are assumed insulated & not the floor above; Unconditioned crawl walls assumed uninsulated, but floor above is.

TABLE 158. CEILING INSULATION R-VALUE ASSUMPTIONS BY VINTAGE

Vintage	Assumed R-value of ceiling insulation	Notes
Older, poorly insulated	17.5	Composite R-value of ceiling insulation; based on 2001 RECS data and engineering judgment.
Existing, average insulation	19	Fiberglass insulation per MEC 1983
New construction	30	State Energy Code 2006 IECC w/ mod.

Windows

The glazing U-value and solar heat gain coefficient (SHGC) assumptions for the three vintages are shown in Table 159.

TABLE 159. WINDOW PROPERTY ASSUMPTIONS BY VINTAGE

Vintage	U-value (Btu/hr-F-SF)	SHGC	Notes
Older, poorly insulated	0.90	0.80	Composite of non-upgraded with upgrade windows, adjusted by RECS 2001 data for insulation perceptions.
Existing, average insulation	0.65	0.75	Double pane value from MEC83 Chart 6-B.
New construction	0.35	0.55	State Energy Code 2006 IECC w/ mod.

Infiltration

Infiltration rate assumptions were set by vintage as shown in Table 160.

TABLE 160. INFILTRATION RATE ASSUMPTIONS BY VINTAGE

Vintage	Assumed infiltration rate	Notes
Older, poorly insulated	1 ACH	
Existing, average insulation	0.5 ACH	
New construction	0.35 ACH	Minimum without forced ventilation per ASHRAE Standard 66.

Commercial Building Prototype Model Development

Commercial sector prototype building models were developed for a series of small commercial buildings with packaged rooftop HVAC systems, including assembly, big box retail, fast food restaurant, full service restaurant, grocery, light industrial, primary school, small office and small retail buildings. A large office prototype was also included to analyze measures associated with built-up HVAC systems. The following sections describe the prototypical simulation models used in this analysis.

Assembly

A prototypical building energy simulation model for an assembly building was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 161.

TABLE 161. ASSEMBLY PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	34,000 square feet Auditorium: 33,240 SF Office: 760 SF
Number of floors	1
Wall construction and R-value	Concrete block, R-5

Characteristic	Value
Roof construction and R-value	Wood frame with built-up roof, R-12
Glazing type	Multipane Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Auditorium: 1.9 W/SF Office: 1.55 W/SF
Plug load density	Auditorium: 1.2 W/SF Office: 1.7 W/SF
Operating hours	Mon-Sun: 8am – 9pm
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the prototype is shown in Figure 2.

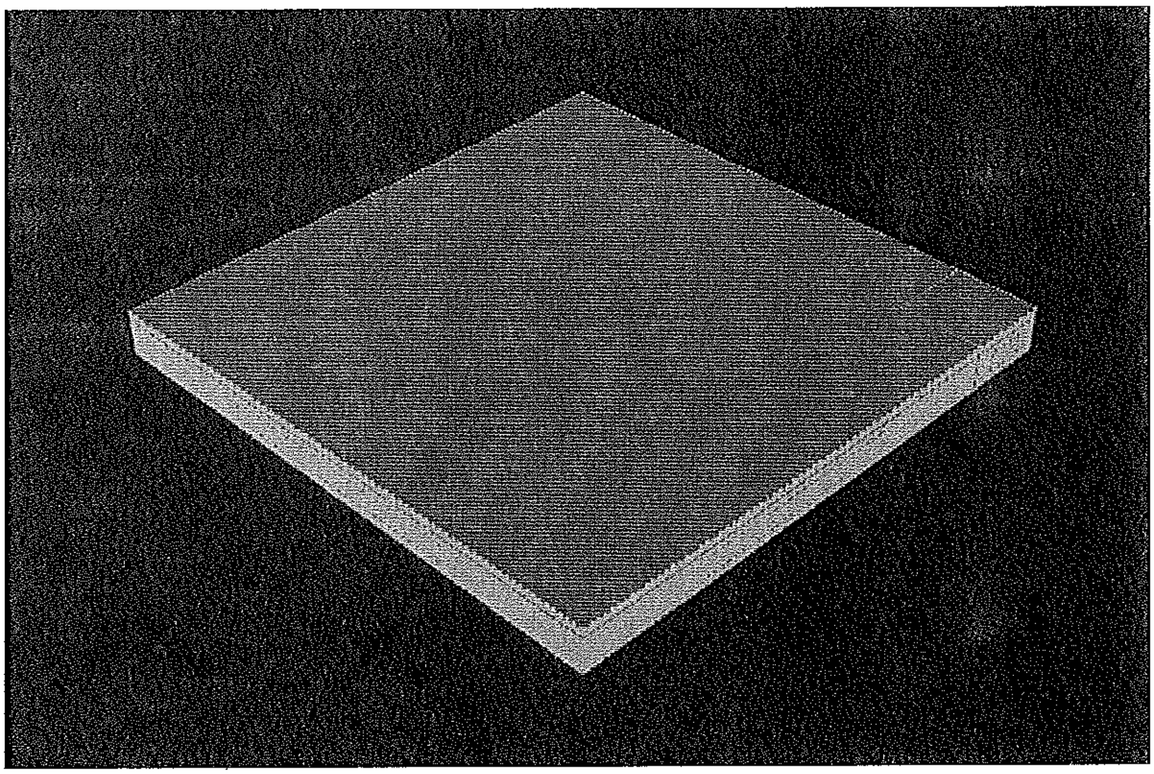

FIGURE 2. ASSEMBLY BUILDING RENDERING

Big Box Retail

A prototypical building energy simulation model for a big box retail building was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 162.

TABLE 162. BIG BOX RETAIL PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	130,500 square feet Sales: 107,339 SF Storage: 11,870 SF Office: 4,683 SF Auto repair: 5,151 SF Kitchen: 1,459 SF
Number of floors	1
Wall construction and R-value	Concrete block with insulation, R-7.5
Roof construction and R-value	Metal frame with built-up roof, R-13.5
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Sales: 2.15 W/SF Storage: 0.85 W/SF (Active) 0.45 W/SF (Inactive) Office: 1.55 W/SF Auto repair: 1.7 W/SF Kitchen: 2.2 W/SF
Plug load density	Sales: 1.15 W/SF Storage: 0.23 W/SF Office: 1.73 W/SF Auto repair: 1.15 W/SF Kitchen: 3.23 W/SF
Operating hours	Mon-Sun: 10am -- 9pm
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the prototype is shown in Figure 3.

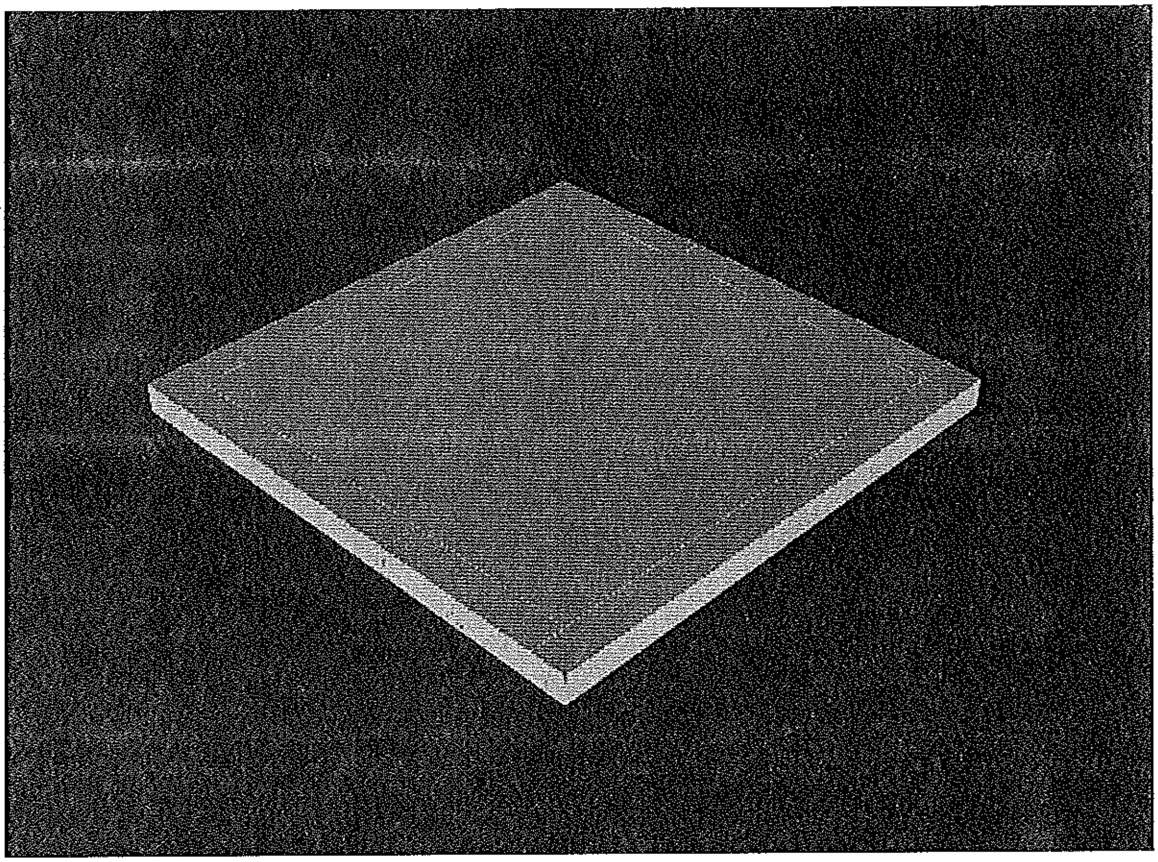

FIGURE 3. BIG BOX RETAIL BUILDING RENDERING

Fast Food Restaurant

A prototypical building energy simulation model for a fast food restaurant was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 163.

TABLE 163. FAST FOOD RESTAURANT PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	2000 square feet 1000 SF dining 600 SF entry/lobby 300 SF kitchen 100 SF restroom
Number of floors	1
Wall construction and R-value	Concrete block with brick veneer, R-7.5
Roof construction and R-value	Concrete deck with built-up roof, R-13.5
Glazing type	Multipane Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Dining: 1.7 W/SF Entry area: 1.7 W/SF Kitchen: 2.2 W/SF Restroom: 0.9 W/SF
Plug load density	0.6 W/SF dining 0.6 W/SF entry/lobby 4.3 W/SF kitchen 0.2 W/SF restroom
Operating hours	Mon-Sun: 6am – 11pm
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the prototype is shown in Figure 4.

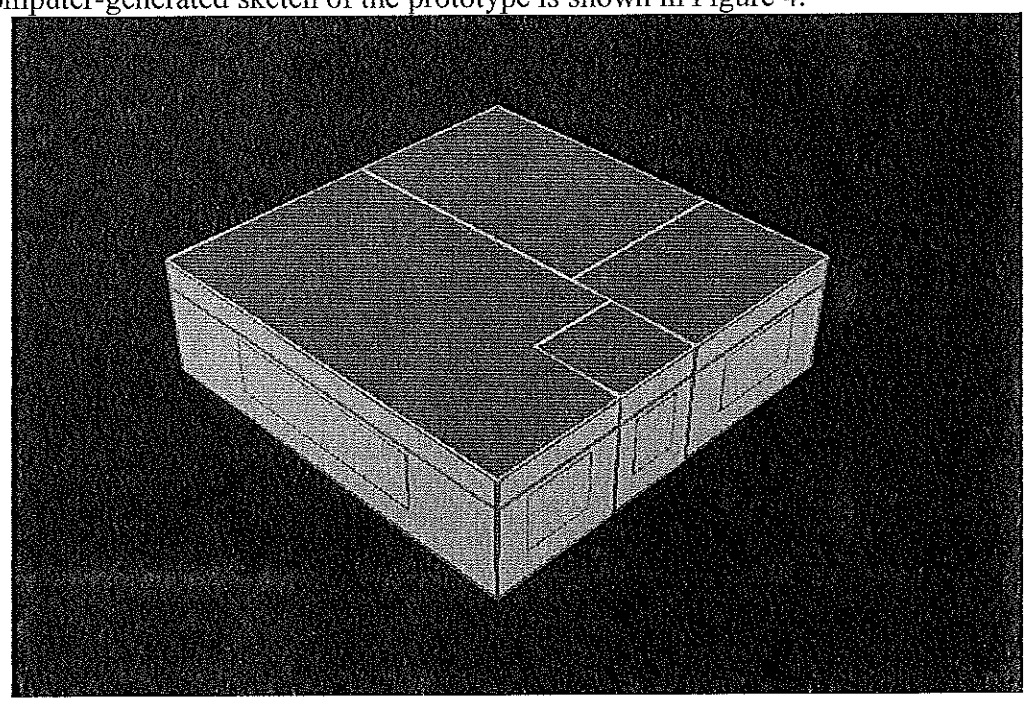

FIGURE 4. FAST FOOD RESTAURANT BUILDING RENDERING

Full-Service Restaurant

A prototypical building energy simulation model for a full-service restaurant was developed using the DOE-2.2 building energy simulation program. The characteristics of the full service restaurant prototype are summarized in Table 164.

TABLE 164. FULL SERVICE RESTAURANT PROTOTYPE DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	2000 square foot dining area 600 square foot entry/reception area 1200 square foot kitchen 200 square foot restrooms
Number of floors	1
Wall construction and R-value	Concrete block with brick veneer, R-7.5
Roof construction and R-value	Wood frame with built-up roof, R-13.5
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Dining area: 1.7 W/SF Entry area: 1.7 W/SF Kitchen: 2.2 W/SF Restrooms: 1.5 W/SF
Plug load density	Dining area: 0.6 W/SF Entry area: 0.6 W/SF Kitchen: 3.1 W/SF Restrooms: 0.2 W/SF
Operating hours	9am – 12am
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the full-service restaurant prototype is shown in Figure 5.

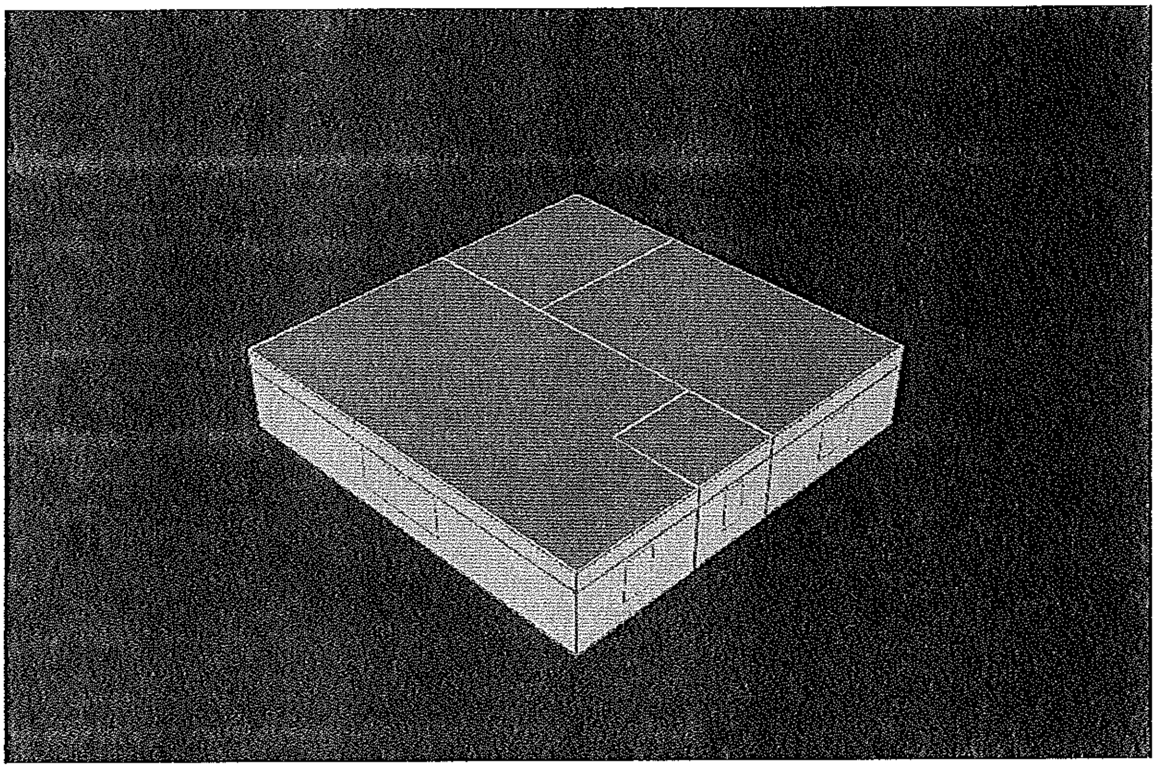

FIGURE 5. FULL SERVICE RESTAURANT PROTOTYPE RENDERING

Grocery

A prototypical building energy simulation model for a grocery building was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 165.

TABLE 165. GROCERY PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	50,000 square feet Sales: 40,000 SF Office and employee lounge: 3,500 SF Dry storage: 2,860 SF 50 °F prep area: 1,268 SF 35 °F walk-in cooler: 1,560 SF - 5 °F walk-in freezer: 812 SF
Number of floors	1
Wall construction and R-value	Concrete block with insulation, R-5
Roof construction and R-value	Metal frame with built-up roof, R-12
Glazing type	Single pane clear
Lighting power density	Sales: 3.36 W/SF Office: 2.2 W/SF Storage: 1.82 W/SF 50°F prep area: 4.3 W/SF

Characteristic	Value
	35°F walk-in cooler: 0.9 W/SF - 5°F walk-in freezer: 0.9 W/SF
Equipment power density	Sales: 1.15 W/SF Office: 1.73 W/SF Storage: 0.23 W/SF 50°F prep area: 0.23 W/SF + 36 kBtu/hr process load 35°F walk-in cooler: 0.23 W/SF + 17 kBtu/hr process load - 5°F walk-in freezer: 0.23 W/SF+ 29 kBtu/hr process load
Operating hours	Mon-Sun: 6am – 10pm
HVAC system type	Packaged single zone, no economizer
Refrigeration system type	Air cooled multiplex
Refrigeration system size	Low temperature (-20°F suction temp): 23 compressor ton Medium temperature (18°F suction temp): 45 compressor ton
Refrigeration condenser size	Low temperature: 535 kBtu/hr THR Medium temperature: 756 kBtu/hr THR
Thermostat setpoints	Occupied hours: 74°F cooling, 70°F heating Unoccupied hours: 79°F cooling, 65°F heating

A computer-generated sketch of the prototype is shown in Figure 6.

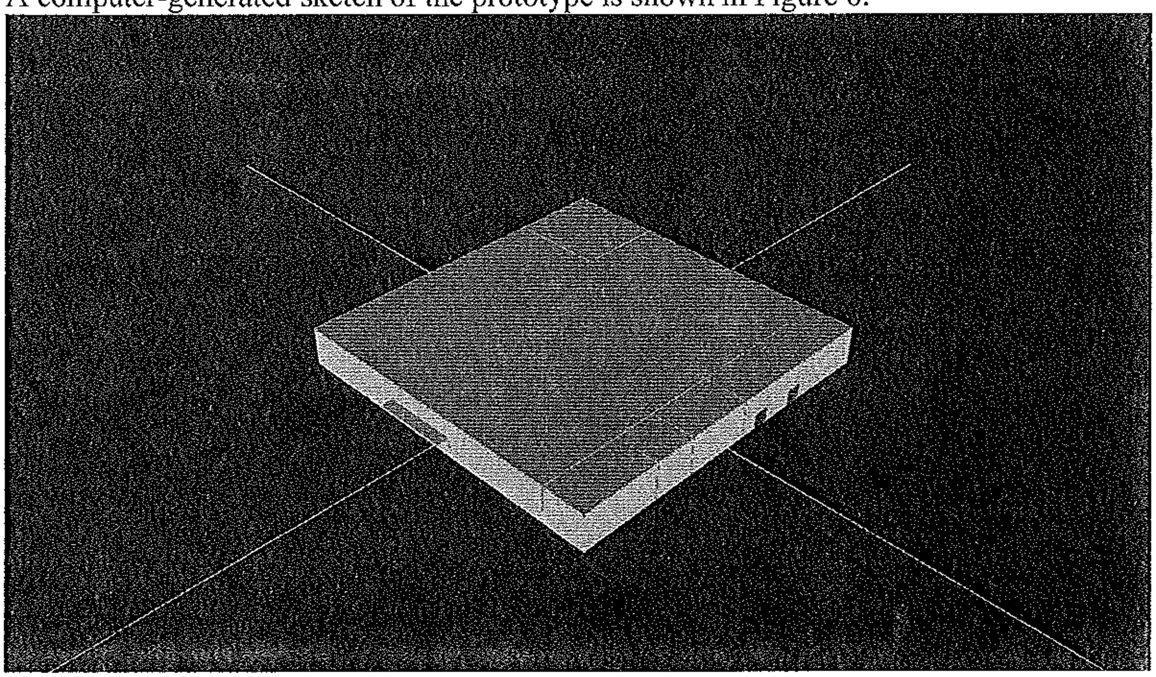

FIGURE 6. GROCERY BUILDING RENDERING

Large Office

A prototypical building energy simulation model for a large office building was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 166.

TABLE 166. LARGE OFFICE PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	350,000 square feet
Number of floors	10
Wall construction and R-value	Glass curtain wall, R-7.5
Roof construction and R-value	Built-up roof, R-13.5
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Perimeter offices: 1.55 W/SF Core offices: 1.45 W/SF
Plug load density	Perimeter offices: 1.6 W/SF Core offices: 0.7 W/SF
Operating hours	Mon-Sat: 9am – 6pm Sun: Unoccupied
HVAC system types	1. Central constant volume system with perimeter hydronic reheat, without economizer; 2. Central constant volume system with perimeter hydronic reheat, with economizer; 3. Central VAV system with perimeter hydronic reheat, with economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Chiller type	Water cooled and air cooled
Chilled water system type	Constant volume with 3 way control valves,
Chilled water system control	Constant CHW Temp, 45 deg F setpoint
Boiler type	Hot water, 80% efficiency
Hot water system type	Constant volume with 3 way control valves,
Hot water system control	Constant HW Temp, 180 deg F setpoint
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

Each set of measures was run using each of three different HVAC system configurations – a constant volume reheat system without economizer, a constant volume reheat system with economizer and a VAV system with economizer. The constant volume reheat system without economizer represents system with the most heating and cooling operating hours, while the VAV system with economizer represents a system with the least heating and cooling hours. This presents a range of system loads and energy savings for each measure analyzed.

A computer-generated sketch of the prototype is shown in Figure 7. Note, the middle floors, since they thermally equivalent, are simulated as a single floor, and the results are multiplied by 8 to represent the energy consumption of the 8 middle floors.

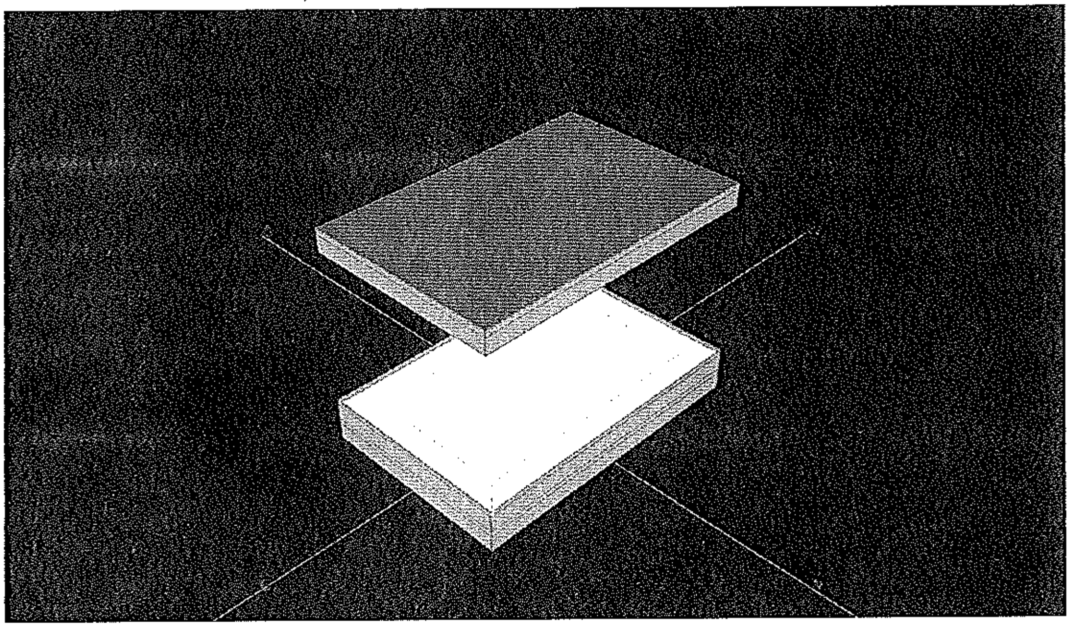

FIGURE 7. LARGE OFFICE BUILDING RENDERING

Light Industrial

A prototypical building energy simulation model for a light industrial building was developed using the DOE-2.2 building energy simulation program. The characteristics of the prototype are summarized in Table 167.

TABLE 167. LIGHT INDUSTRIAL PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	100,000 square feet total 80,000 SF factory 20,000 SF warehouse
Number of floors	1
Wall construction and R-value	Concrete block with Brick, no insulation, R-5
Roof construction and R-value	Concrete deck with built-up roof, R-12
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Factory – 2.25 W/SF Warehouse – 0.7 W/SF
Plug load density	Factory – 1.2 W/SF Warehouse – 0.2 W/SF
Operating hours	Mon-Fri: 6am – 6pm Sat Sun: Unoccupied
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the prototype is shown in Figure 8.

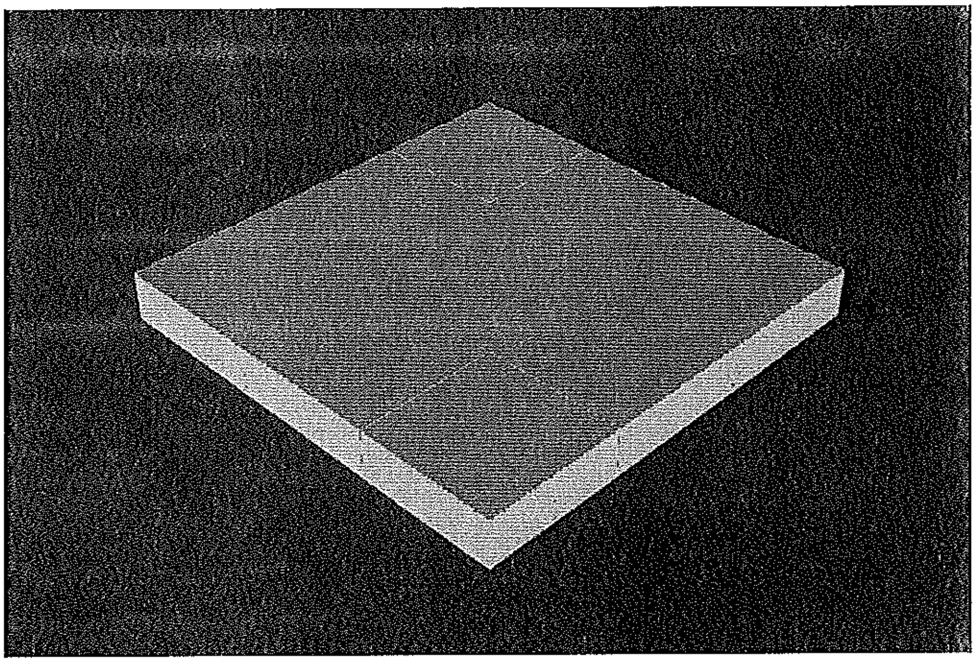

FIGURE 8. LIGHT INDUSTRIAL BUILDING RENDERING

Primary School

A prototypical building energy simulation model for an elementary school was developed using the DOE-2.2 building energy simulation program. The model is really of two identical buildings oriented in two different directions. The characteristics of the prototype are summarized in Table 168.

TABLE 168. ELEMENTARY SCHOOL PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	2 buildings, 25,000 square feet each; oriented 90° from each other Classroom: 15,750 SF Cafeteria: 3,750 SF Gymnasium: 3,750 SF Kitchen: 1,750 SF
Number of floors	1
Wall construction and R-value	Concrete with brick veneer, R-7.5
Roof construction and R-value	Wood frame with built-up roof, R-13.5
Glazing type	Multipane Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Classroom: 1.8 W/SF Cafeteria: 1.3 W/SF Gymnasium: 1.7 W/SF Kitchen: 2.2 W/SF

Characteristic	Value
Plug load density	Classroom: 1.2 W/SF Cafeteria: 0.6 W/SF Gymnasium: 0.6 W/SF Kitchen: 4.2 W/SF
Operating hours	Mon-Fri: 8am – 6pm Sun: 8am – 4pm
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the prototype is shown in Figure 9.

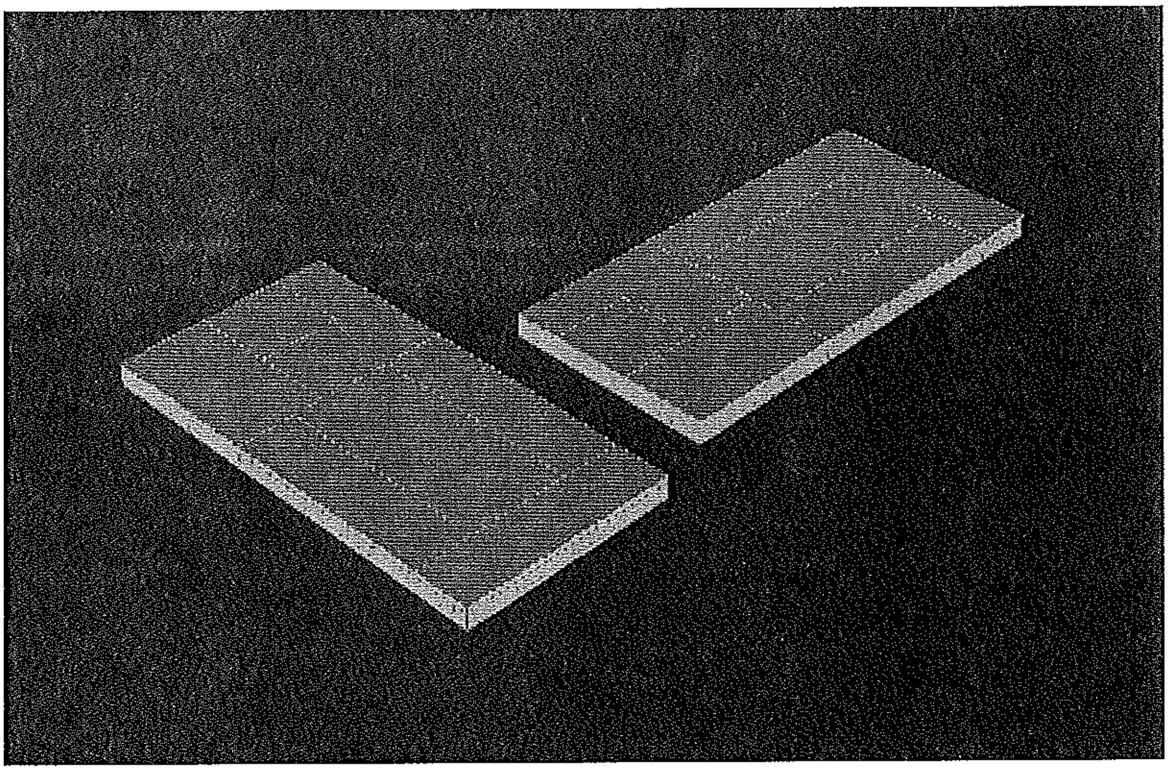

FIGURE 9. SCHOOL BUILDING RENDERING

Small Office

A prototypical building energy simulation model for a small office was developed using the DOE-2.2 building energy simulation program. The characteristics of the small office prototype are summarized in Table 169.

TABLE 169. SMALL OFFICE PROTOTYPE BUILDING DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	10,000 square feet
Number of floors	2
Wall construction and R-value	Wood frame with brick veneer, R-7.5
Roof construction and R-value	Wood frame with built-up roof, R-13.5
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Perimeter offices: 1.55 W/SF Core offices: 1.45 W/SF
Plug load density	Perimeter offices: 1.6 W/SF Core offices: 0.7 W/SF
Operating hours	Mon-Sat: 9am – 6pm Sun: Unoccupied
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the small office prototype is shown in Figure 10.

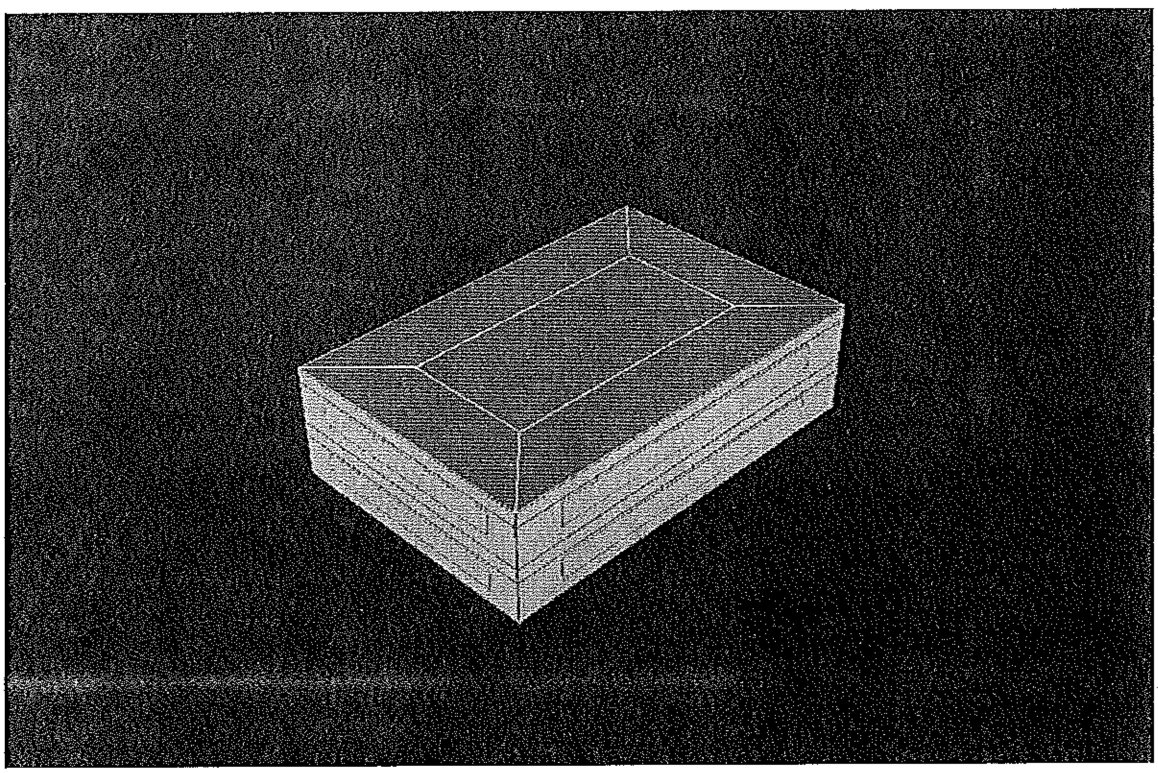

FIGURE 10. SMALL OFFICE PROTOTYPE BUILDING RENDERING

Small Retail

A prototypical building energy simulation model for a small retail building was developed using the DOE-2.2 building energy simulation program. The characteristics of the small retail building prototype are summarized in Table 170.

TABLE 170. SMALL RETAIL PROTOTYPE DESCRIPTION

Characteristic	Value
Vintage	Existing (1970s) vintage
Size	6400 square foot sales area 1600 square foot storage area 8000 square feet total
Number of floors	1
Wall construction and R-value	Concrete block with brick veneer, R-7.5
Roof construction and R-value	Wood frame with built-up roof, R-13.5
Glazing type	Multipane; Shading-coefficient = 0.84 U-value = 0.72
Lighting power density	Sales area: 2.15 W/SF Storage area: 0.85 W/SF (Active) 0.45 W/SF (Inactive)
Plug load density	Sales area: 1.2 W/SF Storage area: 0.2 W/SF
Operating hours	10 – 10 Monday-Saturday 10 – 8 Sunday
HVAC system type	Packaged single zone, no economizer
HVAC system size	Based on ASHRAE design day conditions, 10% over sizing assumed.
Thermostat setpoints	Occupied hours: 75 cooling, 70 heating Unoccupied hours: 80 cooling, 65 heating

A computer-generated sketch of the small retail building prototype is shown in Figure 11.

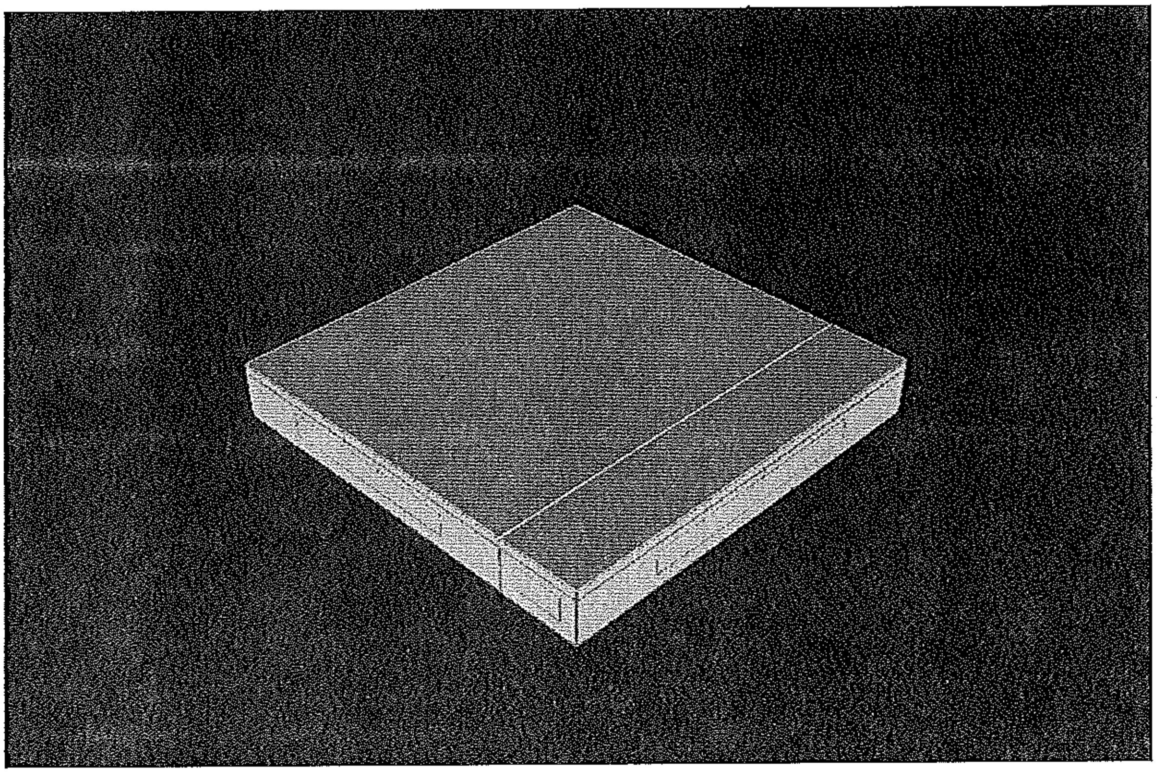

FIGURE 11. SMALL RETAIL PROTOTYPE BUILDING RENDERING

Weighting of Results

The simulation models provide results at a level of detail that generally surpasses the normal data collection procedures from customer incentive applications and other EDC data collection. Thus, weights were assigned to individual simulation results, and the weighted averages were reported in the TRM sections. The weights used for the residential and commercial analysis were derived from Duke Energy data.

For the residential analysis, the buildings were assumed to be weighted 50/50 by building type (basement and no basement). The weights assigned to HVAC system type by building vintage are shown below:

TABLE 171. RESIDENTIAL HVAC SYSTEM TYPE WEIGHTS BY VINTAGE

System Type	Vintage		
	Old	Exist	New
Central AC with elec furnace	0.050	0.031	0.013
Central AC with gas furnace	0.492	0.189	0.045
Central air source heat pump	0.058	0.053	0.009
Central dual fuel heat pump	0.009	0.009	0.004
Elec heat no AC	0.005	0.000	0.002
Gas furnace no AC	0.029	0.000	0.001

For the commercial building analysis, the weights assigned to each of the building types are shown below:

TABLE 172. COMMERCIAL BUILDING TYPE WEIGHTS

Building Type	Weight
Assembly	0.118
Big Box	0.017
Fast food	0.017
Full Service	0.042
Light industrial	0.008
Primary school	0.059
Small office	0.176
Small retail	0.563

Note, the large office and grocery store models were used to analyze specific measures unique to the HVAC system and equipment types used in these buildings. Results relevant to these building types were reported separately and not included in the weighted averages.