Optimized Energy Cost Performance at Fossil Ridge High School

Abstract

This paper describes how we optimized energy cost performance under Credit 1 in the Energy and Atmosphere section to earn the full 10 points available towards LEED certification for Fossil Ridge High School. Fossil Ridge is a new 290,000 square foot High School currently under construction, scheduled for completion in 2004 and is designed to house 1500 to 1800 students. EMC performed envelope and HVAC optimization, concept design of HVAC systems, and LEED certification building energy simulation for the project. This paper describes the process by which we identified and addressed design elements related to energy costs in order to minimize annual utility costs.

Design Goals

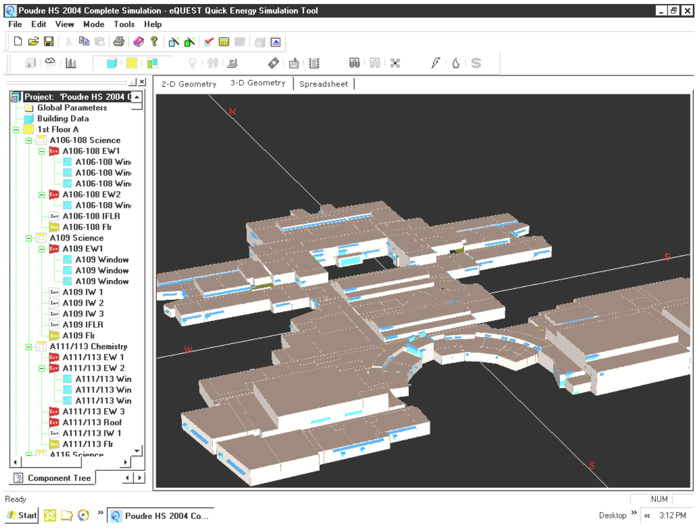
Poudre School District in Fort Collins, Colorado is strongly committed to sustainable design, particularly minimizing energy use in their school buildings. In addition to the requirements and guidelines of the districts Sustainable Design Criteria, energy related goals for Fossil Ridge included:

- Full daylighting in classrooms for improved student performance and energy savings,
- An Energy Star Rating of 90,
- Unit energy cost of $0.042 per square foot of floor area per year, and
- A maximum cooling demand of 1,000 square foot per ton.

LEED certification was not an initial design goal. However, the district decided to seek LEED certification at the end of the design process.

Building Energy Modeling

The key to optimized energy performance is use of an accurate, detailed building energy model. EMC chose the eQUEST (Quick Energy Simulation Tool) program, which is a



eQUEST Graphic of Fossil Ridge High School user interface to the DOE-2.2 building energy model. EQUEST allows quick construction of building energy models with options that allow the level of detail to evolve with the design. Using the Wizard, a simulation for a simple building can be performed in less than an hour. For Fossil Ridge, the model evolved into a detailed room-by-room simulation. The model includes a graphical interface that allows a quick visual check of the building geometry and also HVAC system arrangements.

Daylighting was simulated by taking the average hourly electric lighting requirements for typical daylit spaces for each month predicted by the daylighting consultant and inputting the data into eQUEST as an electric lighting schedule. eQUEST is not capable of accurately simulating the daylighting systems used in the design.

Unit Energy Costs

The focus of Poudre School District was in minimizing annual energy costs for the school as is the Optimized Energy Performance credit of the LEED rating system. Thus the unit energy cost is of critical importance. The City of Fort Collins municipal utility is dedicated to managing the growth of electric demand on their system in order to avoid construction of additional generating capacity. As part of an aggressive demand side management program, including providing design assistance for sustainable design, their utility rate tariff is designed to minimize electric demand on their grid. The electric tariff is divided into three basic charges:

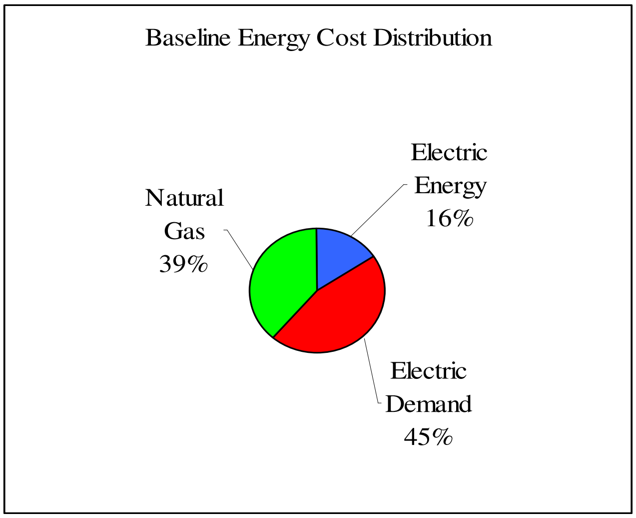
Electric Energy	$0.0164/kWh
Electric Demand	$4.67/kW
Coincident Peak Demand	$11.62/kW

The Electric Demand tariff is applied to the measured 30-minute peak for each month. The Coincident Peak Demand is the time period when the Platte River Power plant experiences its peak demand for the month. Statistically, this has occurred between the hours of 10 a.m. and 9 p.m. Based on statistical data, the coincident peak was assumed to occur from 2 to 3 p.m., April through August and from 5 to 6 p.m., September through March.

The prevailing natural gas cost at the time of the design and analysis was $0.408/therm.

Baseline Energy Model

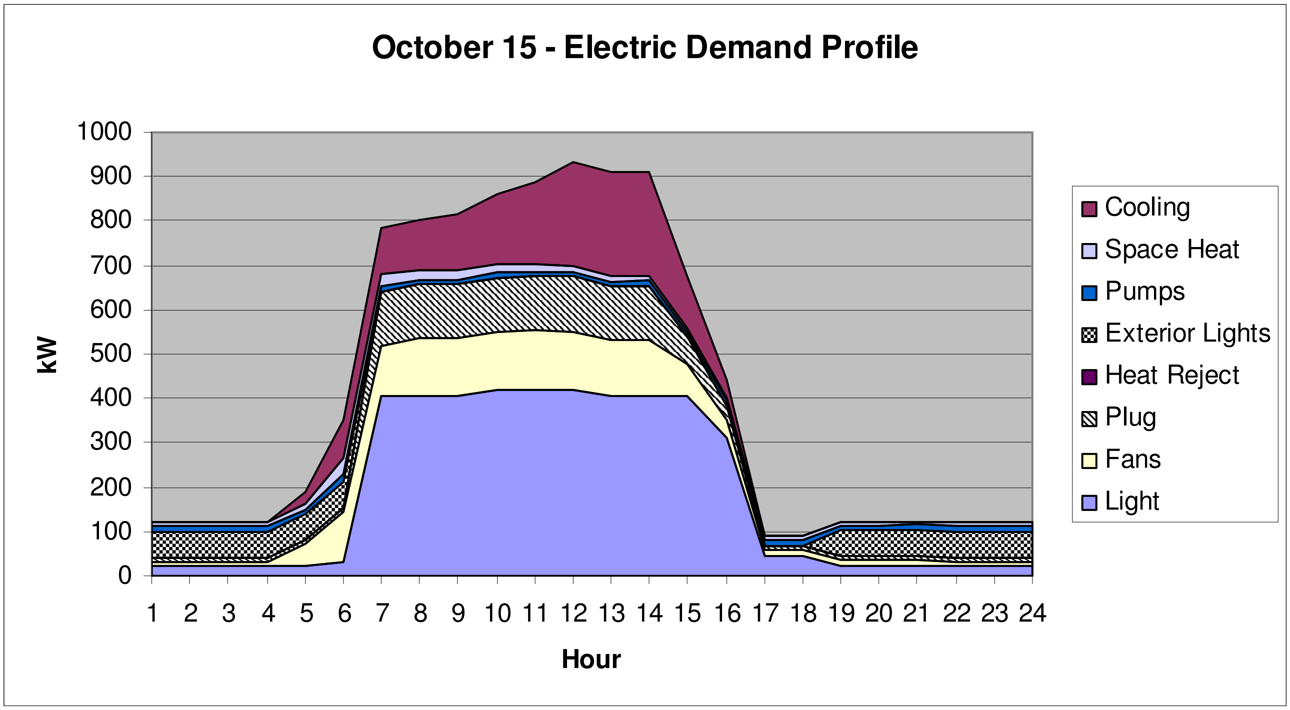
The Baseline Energy Model, based on the requirements for the Energy Cost Budget (ECB) per AHSRAE/IESNA 90.1-1999, was used to simulate the baseline building. For the model, the time of the coincident peak demand was scheduled by month based on statistical data provided by the utility. Figure-3 indicates the relative costs of the three



electric utility charges as well as the natural gas cost. Electric demand charges accounted for 45% of annual electricity costs followed by natural gas at 39%.

Electric Demand Reduction

The electric demand profile for 15 October helps identify the components of the electric demand. Peak demand occurs at noon. Lighting accounts for about 50% of annual electric energy use and is also a major load component on the fan and cooling system. For this project, it was decided early to provide daylighting to most classrooms that would eliminate the need for electric lighting from an hour after sunrise to an hour before sunset. This was accomplished by incorporating clearstories on the north and south sides of each classroom in addition to the vision glass on either the north or south side. South



glazing was provided with external shading to prevent direct solar gain into classrooms. Figure-2 illustrates a typical cross section of a south facing classroom. Glazings with low U-values were selected to prevent excessive heat loss.

Space cooling accounts for about 30% of peak. Design options that minimize space cooling demand include ice storage, which is recharged at night, evaporative cooling, and ground source heat pumps which are more efficient that air-cooled chillers.

Electric demand reduction doesn't always save energy, but LEED energy optimization credits are concerned with energy costs, not energy. Demand Side Management (DSM) is focused on avoiding construction of new power plants.

High demand costs necessitated daylighting and ice storage.

Natural Gas Consumption

Natural gas at about $0.40 per therm accounted for about 40% of annual energy cost for the baseline building; the fraction would be greater at today's gas prices. The high gas costs for the baseline building were due to mainly to the high ventilation rate which resulted in large heating loads on the pre-heat coil in the AHU and also a fair amount of re-heat load at the VAV boxes. The minimum ventilation rate of 15 cfm per occupant resulted in a minimum ventilation rate of about 0.5 cfm/sf. With micro-loading, the design air flow rate is below 1.0 cfm/sf using 55°F supply air. Thus the minimum VAV airflow fraction is 50% or higher. The limited ability to reduce airflow below 50% with the VAV damper results in additional heating by the reheat coil.

High ventilation loads necessitated air-to-air heat recovery systems.

Optimal HVAC Systems

There were several options for classroom HVAC systems that seemed promising for optimizing the HVAC system. While off-peak ice storage for HVAC cooling seemed like a necessity, there were other HVAC options that seemed appropriate for the climate:

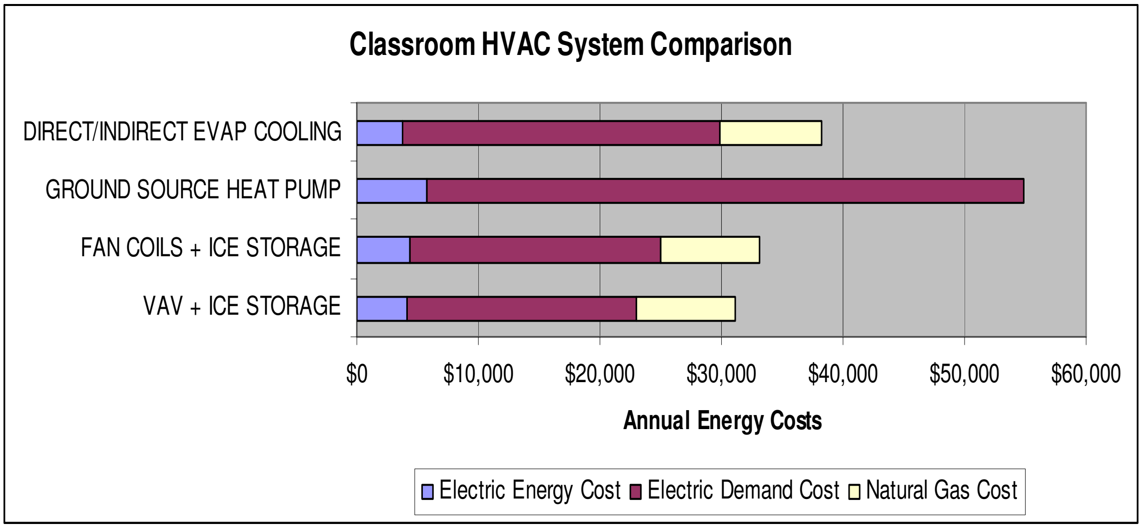
- Ground Source Heat Pumps (GSHPs) use the earth as a heat sink for cooling and are more efficient than air-cooled heat pumps when outside air temperatures are above 70°F. They also provide efficient heating, although they requiring electricity to generate heat. The cost of $0.0155/kWh electricity used in a GSHP with a COP of 3.1 for heating is $1.46/MMBtu. For comparison, burning natural gas at $4.00/MMBtu with an Efficiency of 80% results in a $5.00/MMBtu cost. However, electricity costs are weighted heavily to demand charges at this site, and thermal storage cannot be used with GSHPs.

- The dry Colorado climate favors evaporative cooling which can be designed to provide 55°F at design conditions on peak days by combining direct and indirect evaporative cooling stages. Evaporative cooling uses minimal electricity for cooling, but typically has a higher airflow pressure drop that leads to increased fan energy.

- The VAV systems consist of an air handling unit (AHUs) with a heat wheel on the outside air intake, a chilled water cooling coil served by an ice storage system, supply and return fans with variable speed drives (VSDs), and terminal VAV boxes with hot water reheat coils. Electricity is used at night to make ice, which is used for cooling during the day when peak electric demand occurs.

- A four-pipe fan coil system incorporates both heating and cooling coils for each zone to provide either heating or cooling. Re-heating of chilled air is eliminated and ice storage can be used with the chilled water system. Fans are typically operated at a constant speed.

All of the above systems were served with air-to-air heat recovery equipment to reduce heating loads. Annual energy use predicted by the building energy model for the 3 classroom modules comprising the school are indicated below. These simulations do not include the gymnasium, auditorium, cafeteria, and similar common areas of the school.



Annual energy costs for the four systems were dominated by electric demand costs which heavily favored systems with off-peak ice storage. The evaporative cooling system was a contender, lacking a cooling compressor, but the high pressure drops across the direct and indirect cooling media resulted in higher electric demand. The VAV system had the lowest cost, but not significantly lower than the fan coil system. VAV systems typically have higher design pressure drops across the terminal unit due to the VAV damper and do suffer some inefficiency in cooling and then heating the same stream of air when re-heating is required.

The school district chose the four-pipe fan coil system for the classrooms. The district maintenance staff didn't like the complexity of VAV systems, feeling that fan coils were easier to maintain and repair. Also, the HVAC design engineer indicated that the cost of a four pipe fan coil system was no more than that of a VAV system. The resulting HVAC system is indicated in the following diagram:

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Other types of HVAC systems were more appropriate for other areas of the school:
- VAV for administration areas,
- Evaporative cooling for the gymnasium,
- Constant volume heating and cooling system for the auditorium.

Design Development

With the concept envelope, daylighting, electric lighting, and HVAC systems defined, the project moved into the design development stage. The following additional energy-related modifications and investigations were addressed in the design development stage:

- **Daylighting Aperture Optimization** investigation focused on using the daylighting model and the eQUEST building energy simulation model in combination to optimize daylighting apertures to minimize the combination of lighting and HVAC energy savings. The process consisted of varying daylighting aperture size and glass properties in a representative group of classrooms to optimize the design. ENSAR, the daylighting consultant, had previously selected glass properties based on commercially available products and had varied glass properties by use (daylighting or view glass) and by orientation. For instance, unshaded south-facing view glass was selected with a very low solar heat gain coefficient of 0.19. All glass was specified with a low U-value of about 0.30. Daylighting apertures were then sized to provide 100% daylighting in most classrooms from an hour after sunrise to an hour before sunset throughout the year using clearstories on both the north and south sides of each classroom. While the daylighting was aggressive, it did not increase the glass area of the final design beyond the Baseline specified by AHSRAE/IESNA 90.1-1999. Optimization studies using the eQUEST to calculate HVAC energy use for possible changes in daylighting aperture areas resulted in no changes in daylighting aperture areas. Slight changes to daylighting aperture areas could have been made, but the original daylighting design was pretty close to optimal for energy optimization. The benefits of reduced electric lighting energy and demand far out weigh the effect on heating and cooling loads, particularly with use of off-peak electricity for cooling.

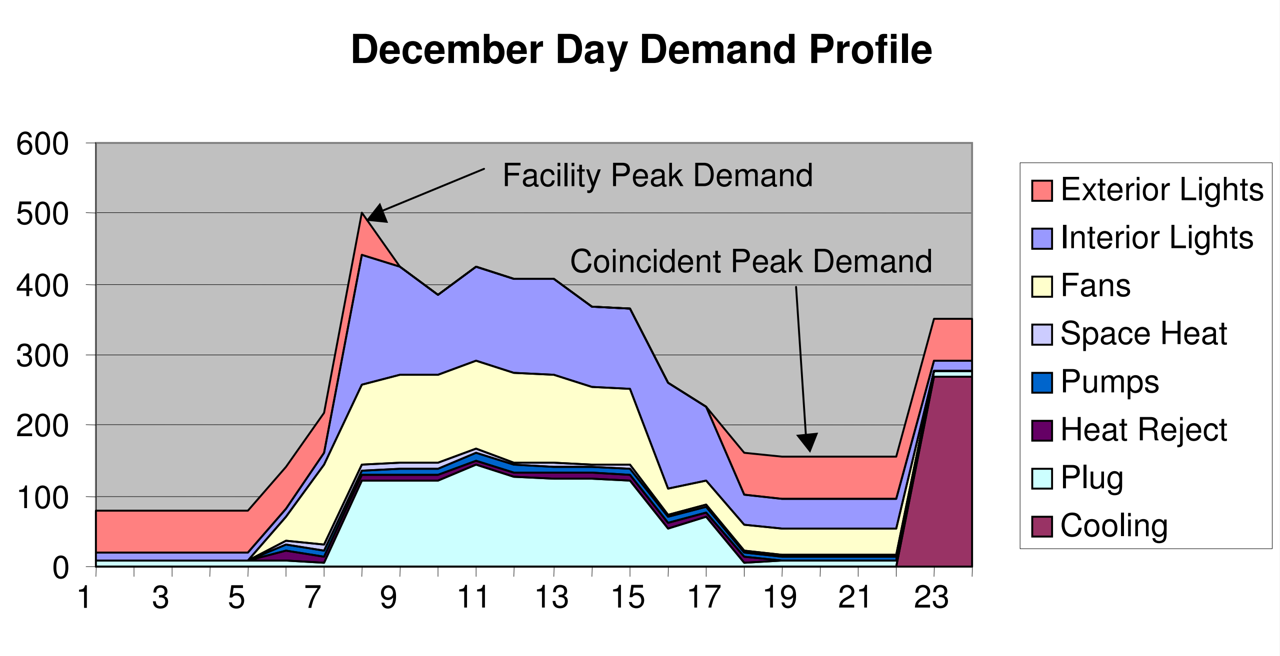
- **Nighttime Setback** was reduced from 60°F at 50°F for heating, which resulted in a significant reduction in natural gas costs based on eQUEST simulations. Nighttime setback was left at 85°F for cooling, which resulted in minimal unoccupied cooling system operation.

- **Two-pipe Fan Coils** were considered as an alternative to the four-pipe fan coils used in the design to reduce construction costs. However, cold sunny winters of Colorado, low winter sun, and the concentration of glass on either the north or south sides of most classrooms, and some interior space like computer labs, resulted in the inability to maintain thermal comfort with a two-pipe system according to eQUEST simulations.

- **Flat-panel Matrix Computer Screens** were considered as an alternative to the Cathode Ray Tubes (CRTs) that currently dominate the personal computer market. However, the cost of the flat-panel screens could not be justified based on savings from reduced cooling and electrical loads. In hind sight, CRTs may be obsolete by the time the school is occupied.

- **Condensing Natural Gas Boilers** with efficiencies ranging from 0.93 to 0.95 were specified for space heating and both domestic hot water and kitchen hot water heating.

- **Exterior Lighting.** After optimization of daylighting, electric lighting, and HVAC systems; it was noted that exterior lighting was a significant component of annual energy costs, most due to electric demand costs in the winter months as the following graphic illustrates:



In December, the peak facility electric demand is set between 7 and 8 a.m. when both interior lighting is at a peak and exterior lights are still on due to darkness. The coincident peak demand is in the early evening when exterior lights must be on. Exterior lighting is most needed during these time periods, so the only way to reduce the demand is to reduce the connected kW of the exterior lights. The original exterior lighting was based on school district design guidelines for exterior lighting systems. Design guidelines required maintaining 1.0 foot-candle of illumination in the parking lot throughout the night. It was proposed to substitute lower-wattage metal halide lamps for the high pressure sodium lamps in the original design and reduce illumination levels to 0.5 foot-candle, which was deemed appropriate for the improved color rendering properties of the metal halide lamps. However, the school district felt metal halide lamps were inappropriate due to the high lumen depreciation of metal halide lamps, but agreed to relax the standards to 0.5 foot-candle with the high pressure sodium lamps. In addition they agreed to turning off parking lot lights from midnight till 5 a.m.

- **HVAC Fan Energy** was a significant contributor to electric energy use and demand as the above figure illustrates. The predominant HVAC fan was the constant speed fractional horsepower fans used in the fan coil units for which high-efficiency PSC (permanent split capacitor) motors were specified. Fan energy can be reduced in several ways. The first thought was to lower the design supply air temperature from 55°F to 45°F; with ice storage we could circulate chilled water at about 35°F. This would allow reduction of fan coil size by about a third. However, there was some concern with low-temperature air distribution. An alternative is to keep the design supply air temperature at 55°F, but to reduce fan speed during light loads. Fan coils typically are supplied with 3 speed motors that can be controlled with a 3 speed switch. In this case, direct digital controls (DDC) could provide the speed changes based on the supply air temperature leaving the fan coil. Thus fan coils can be made to behave much like VAV systems in terms of fan energy and the heating and cooling coils in each fan coil unit prevent simultaneous heating and cooling of the same air stream. Alternatively, energy commutated motors (ECMs) offer the advantage of variable speed control at minimal cost. The variable flow strategy is still under consideration and was not included in the final energy model for LEED certification. The fan coil units will be controlled by the lighting occupancy sensors in each room and will turn off when rooms are unoccupied, unless room temperatures are too far off target.

LEED Certification Modeling

The following sections are a break down of the different energy saving features modeled in eQUEST for the final design and budget building defined by ASHRAE Standard 90.1-1999.

Upgraded Building Envelope

The following table summarizes the values for the building envelope that were input into eQUEST to both represent the final design building and the budget (ASHRAE 90.1-1999) building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Ext. Wall-U-value	Table B-17	0.084	0.053
Roof-U-value	Table B-17	0.063	0.035
Roof Absorptance		0.3	0.1

The final design building has U-values for the exterior walls and roof that exceed the ASHRAE 90.1 standard by 37% and 43%, respectively. The budget building roof absorptance value of 0.3 is based on the recommended default value in the LEED Reference Guide. Both buildings were simulated with identical floor areas, exterior dimensions, and orientation.

High Efficiency Fenestration

The following table summarizes the values for the fenestration that were input into eQUEST to represent both the final design building and the budget (ASHRAE 90.1-1999) building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Fenestration Area		17.5%	17.5%
Exterior Shading		No	Yes
Shading Coef.-SC		0.45	0.22-0.38*
Fenestration U-value	Table B-17	0.57	0.29-0.31*
Solar Heat Gain Coef.	Table B-17	0.39	0.19-0.33*
Visible Transmittance		0.30	0.18-0.60*
Outside Emissivity		0.84	0.84

*Varied depending on window type or orientation.

In Table B-17 of ASHRAE Standard 90.1-1999, U-values and solar heat gain coefficients (SHGCs) are provided for various ranges of percent glazing relative to total exterior wall area. As the percent glazing increases, ASHRAE recommends a higher U-value and lower SHGC. The average percent glazing for the final design building was 17.5%. Therefore, the recommended U-values and SHGC for the range of 10.1-20.0% were used to model the glazing in the budget building.

Fenestration areas were identical for the two building models. The final design building has exterior shading in the form of overhangs. The overhangs were removed for the budget building analysis.

Efficient Lighting and Daylighting Controls

The following table summarizes the values for the internal gains that were input into eQUEST to represent both the final design building and the budget (ASHRAE 90.1-1999) building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Plug Loads		0.44 W/ft^2	0.44 W/ft^2
Lighting Loads	Table 9.3.3.1	1.5 W/ft^2	Avg-0.86 W/ft^2
Daylighting Controls		No	Yes

The plug loads did not change for the final design and budget building, since ASHRAE does not have a standard for plug loads. ASHRAE recommends a lighting energy density of 1.5 W/ft^2 for a school, which was used to model the average lighting density throughout the budget building.

Exterior Lighting Design

The following table summarizes the values for the exterior lighting that were input into eQUEST to represent both the final design building and the budget building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Ext. Bldg Lights		10.1 kW	9.2 kW
Ext. Bldg Light-Schedule		Dusk to Dawn	Dusk to Dawn
Parking Lot Lights		49.1 kW	38.7 kW
Parking Lot Lights-Schedule		Dusk to Dawn	Dusk to Midnight

It should be noted that ASHRAE has no requirements for exterior lighting. The budget building exterior lighting was based on school district design guidelines for exterior lighting systems.

High Efficiency HVAC

The following table summarizes the values for the fan systems that were input into eQUEST to represent both the final design building and the budget (ASHRAE 90.1-1999) building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Heat Recovery	Table 6.3.6.1	None Required	HR Wheel – Eff=0.77
System Type	Table 11.4.3	Pkgd VAV w/Reheat	CV 4-Pipe Fan Coils
Fan Energy	Table 6.3.3.1	0.001409 kW/CFM	0.000321-0.0007*
Fan Speed Control	Table 11.4.3.A	VFD	CV
Min. VAV Airflow	Table 11.4.3.A	0.4 CFM/ft^2	N/A
Ventilation Rates		15 CFM/person	15 CFM/person
Evaporative Cooling		None Required	None Modeled
Outside Air Economizer	Table 6.3.1.1	Full 100% OA Econ	Some 100% OA Econ
Supply Air Temperature	Table 11.3.4a	55°F	Variable (Design is 55°F)

*Varied depending on HVAC system type.

The VAV system modeled for the Budget Building was not well suited to the micro loading resulting from daylighting, high-performance glass, and exterior glass shading in combination with the high ventilation requirements of the school. Outside air requirements were typically in the range of 0.5 CFM/ft^2 and design cooling airflow in the 0.6 to 0.8 CFM/ft^2 range, leaving a narrow control band in which the VAV damper could operate. This resulted in large amounts of thermal energy use in the reheat coils. The 4-pipe fan coil units used in the final design eliminated cooling and reheating of the same airstream. The heat recovery wheels in the final design also greatly reduced thermal energy use.

HVAC systems in the budget building utilize an outside air economizer control strategy. The final design uses a heat recovery unit to feed outside air to the fan coil units in the classrooms. These systems do not employ the outside air economizer control strategy. However, conventional rooftop units serving areas such as administration and the auditorium do use economizer control.

High Efficiency Cooling Equipment and Ice Storage

The following table summarizes the values for the cooling systems that were input into eQUEST to represent both the final design building and the budget (ASHRAE 90.1-1999) building.

Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Cooling Coil	Table 11.4.3A	DX	Chilled Water
Chiller Efficiency	Table 6.2.1A	9.7 EER	9.4 EER
Chiller EIR (BTU/ BTU)		0.352	0.363
Condenser Type	Table 11.4.3	Air-Cooled	Air-Cooled
Condenser Fan Power		Included in EER	0.0195 BTU/BTU
Ice Storage		No	Yes

The packaged VAV system is DX cooled and the efficiency of the cooling components in the budget building were based on the ASHRAE Standard. The efficiency of the cooling equipment in the final design was based on actual chiller performance data.

Efficient Heating Equipment

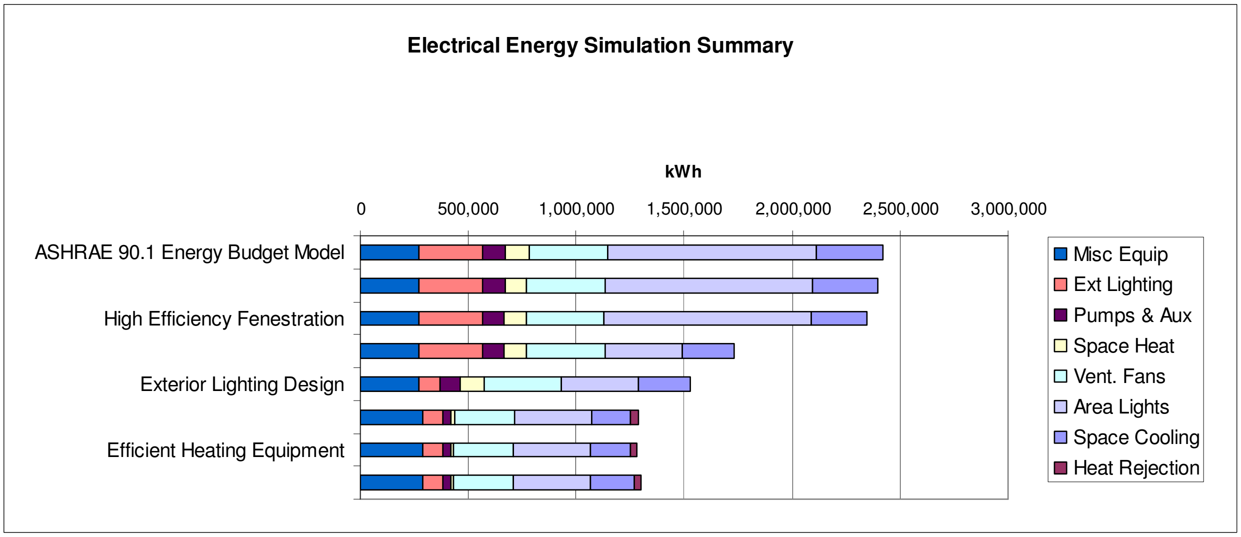
The following table summarizes the values for the heating systems that were input into eQUEST to represent both the final design building and the budget (ASHRAE 90.1-1999) building.

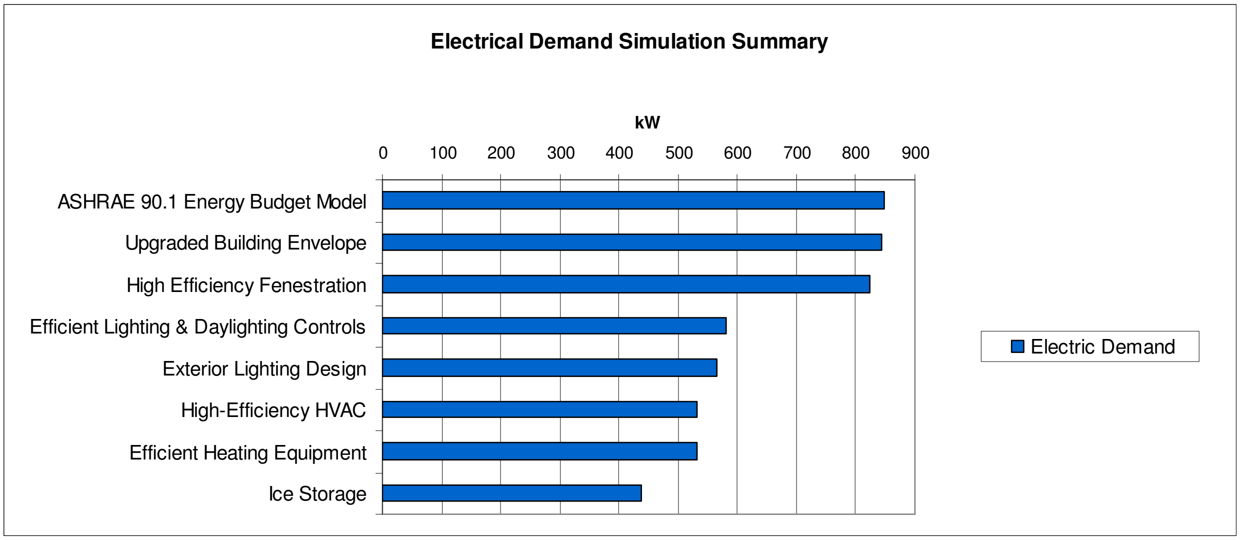
Description	ASHRAE 90.1 Ref.	Budget Building	Final Design Building
Heating Type	Table 11.4.3A	Natural Gas Boiler	Aerco Condensing Boiler
Boiler Efficiency	Table 6.2.1F	0.8	0.95
SHW Heater Efficiency	Table 7.2.2	0.8	0.925

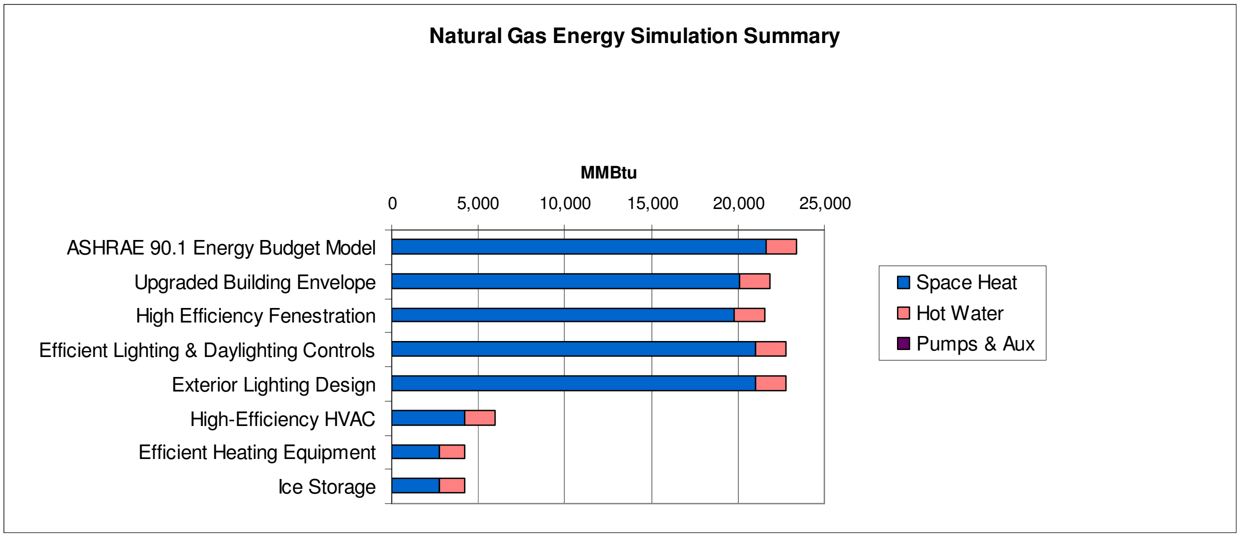
A standard hot water boiler curve in eQUEST was used to model the part-load budget building boiler. The part-load curve for the Aerco boiler was based on performance data from Aerco.

Final Simulaiton Results

The following charts show the electrical energy use, electrical demand, and natural gas use broken down by category and energy savings measure.







The following table shows the energy comparison of the final design building and the budget building energy use.

	ASHRAE 90.1 Energy Model-Budget Building	**Final Design – Final Design Building**
Annual Electric Energy (kWh)	2,420,800	1,301,854
Average Electric Demand (kW)	848	437
Annual Natural Gas (MM Btu)	23,370	4,250
Energy Use Index (kBtu/ft^2)	107.8	29.6
Electric Energy Cost	$39,702	$21,350
Electric Demand Cost	$113,584	$58,869
Natural Gas Cost	$97,794	$17,785
Total Annual Energy Cost	**$251,080**	**$98,004**
Fraction of Energy Budget	**100%**	**39%**