WHITMAN-HANSON REGIONAL HIGH SCHOOL
Whitman, MA

Energy Efficiency Report

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and Whitman-Hanson Regional School District

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EXECUTIVE SUMMARY

Architecture Involution, LLC commissioned Andelman and Lelek Engineering, Inc. to perform services related to computer building energy consumption simulation and to evaluate energy efficiency performance of the new Whitman-Hanson Regional High School in Whitman, MA. The scope of the study included three major tasks. They are briefly described below along with the results of the analyses. A more detailed description of each task and the conclusions can be found in the *Analyses Results Description* section of this report on page 8. For information on the facility description and the analysis methodology please refer to the subsequent section of this report.

The first task was to quantify electric energy generated by renewable sources specified for the building which include photovoltaic (PV) array with a peak power rating of 49.5 kW (DC) at Standard Test Conditions (STC) and a 10 kW wind turbine. The estimated annual electric energy output from both systems amounts to approximately 81,360 kWh which is over 6% of the estimated future building electric energy consumption. The contribution of the solar system is approximately 61,930 kWh (or 76% of the total renewable energy generated on site) and 19,430 kWh is attributed to the wind power.

The second task was to create PowerDOE models of the *as designed* building and a *baseline* building and to quantify the difference in annual energy consumption between the two buildings. The base case building elements (building envelop construction, mechanical systems performance, lighting system performance, etc) are assumed to meet requirements of Chapter 13 the Massachusetts State Building Code, Energy Conservation. This task was undertaken to verify that the subject school building meets the Massachusetts Technology Collaborative (MTC) Green School program requirement of exceeding the Massachusetts Energy standard by at least 20%.

The *as designed* building achieves nearly 36% energy savings over a comparable *baseline* building that meets the current energy code requirements. When renewable energy benefits are included, the proposed project offers a 39% energy savings over the baseline. When only the “regulated loads” are compared (excluding plug loads), then the estimated savings amount to almost 40% of the baseline energy consumption.

The third task involved PowerDOE modeling to evaluate energy savings associated with one measure developed for the school building as part of the MTC program. The measure includes an upgrade of the roof EPDM membrane to white color PVC (“Energy Smart”) roof. The analysis was performed to quantify energy cost savings and a simple payback for each measure. This information is used to determine the maximum MTC grant amount for the measure which is the lesser of the amount that produces 5 year payback for the measure or 90% of the incremental first cost for the item. Tables 1 and 2 on the following pages summarize the results related to all three tasks carried out as part of this study.

In addition brief description of other energy conservation measures that were incorporated into the final building design is provided in section titled *Other Energy Efficiency Considerations* starting on page __. These are measures that were partially funded by the electric utility or/and gas utility as part of the utility incentive programs or were determined valuable to the project even without monetary incentive. They are summarized in Table __ at ___ on page ___.

Supplemental information is provided in the *Appendix* section.

Table 1 - Energy Consumption Comparison

Item	Annual Energy Consumption			
	Electricity	Natural Gas	Total - site	Total - source
	kWh	*therm*	*Btu x 10^6*	*Btu x 10^6*
Design case	1,285,966	46,297	9,017	17,489
Renewable energy contribution	(81,357)	-	(278)	(814)
Modified design case	1,204,609	46,297	8,740	16,676
Baseline	2,025,048	69,422	13,851	27,193
Savings	820,439	23,125	5,112	10,517
% Savings	**41%**	**33%**	**37%**	**39%**

Conversion factor for electricity is:	3,412	Btu/kWh	for site MMBtu
	10,000	Btu/kWh	for source MMBtu

for source Btu electricity conversion factor is base on Energy Code requirement

Conversion factor for gas is:	100,000	Btu/therm

Table 2 - MTC Renewable Energy Systems and Energy Efficiency Measures

Measure	Annual Energy Savings			Annual Cost Savings			Measure Implement. Cost	Simple Payback	Max MTC Incentive	
	Electric	Natural Gas	Total	Electric	Natural Gas	Total			90% of incr. cost	5 year payback
	kWh	*therms*	*MMBtu* (1)	*$*	*$*	*$*	*$*	*years*	*$*	*$*
1. PV system	61,925	-	619	$ 7,183	$ -	$ 7,183	(2) $ 519,500	72	$ 467,550	$ 483,584
2. Wind turbine	19,432	-	194	$ 2,254	$ -	$ 2,254	(3) $ 55,700	25	$ 50,130	$ 44,429
3. White roof	7,475	(889)	97	$ 1,294	$ (806)	$ 488	(4) $ 92,948	190	$ 83,653	$ 90,508

Notes:

(1) conversion factor for electricity is 10,000 Btu/kWh to represent source energy
conversion factor for gas is 100,000 Btu/therm

(2) PV cost	$465,000	base price for materials and installation		
	10%	General Contractor coordination and O&P		
	$ 8,000	Independant commissioning		
(3) Wind turbine cost	$ 47,000	base price for materials and installation		
	10%	General Contractor coordination and O&P		
	$ 4,000	Independant commissioning		
(4) White roof premium	$ 0.76	per sq.ft.	122,300	sq.ft.-roof area
virtual electric rate		$ 0.116	/kWh - based on MECo G-3 rate and PowerDOE model of "as designed" building	

FACILITY AND SITE DESCRIPTION

General

The new Whitman-Hanson Regional High School will be located at 600 Franklin Street in Whitman, MA. It will be constructed behind the existing school structure. Once the new school is completed and fully functional the existing school will be demolished. The occupancy pattern for the building is expected to be generally consistent with a typical high school operation. Summer utilization however, is expected to be higher than in a typical high school since most of the building will be air-conditioned and will be used for various summer school and community programs. More information on schedules used in the analysis is provided in the *Appendix* section. The anticipated student population is 1,350. Electric service will be provided by Massachusetts Electric Company (MECo), natural gas will be provided by KeySpan Energy Delivery Company (KeySpan), and the water/sewer services by Whitman Water Department.

Architectural

The entire building will have a total area of approximately 234,500 square feet. It will consist of three distinct sections: an academic wing housing classrooms, a library, and administrative offices (Bldg. A and B); common areas including student dining and the kitchen, an auditorium, a band classroom, a choral classroom, coaches' offices, exercise rooms, and lockers (Bldg. C); and a gymnasium wing (Bldg. D). The academic wing will be three-story high and will have a total area of approximately 157,700 square feet. The rest of the building is one story high but the height of the spaces varies.

A courtyard is provided in the academic wing which allows for daylight access to every classroom. In addition skylights are utilized in the cafeteria to further utilize natural light in the occupied school spaces. Skylights were also considered for the gymnasium but concerns with structural integrity of the roof resulted in dismissing that option.

A typical exterior wall in the building consist of either concrete masonry units (CMU) or face brick on the outside followed by an air space, 2" of rigid insulation (extruded polystyrene with total R-value of 10), an air/vapor barrier, a layer of gypsum sheathing, steel studs, and plaster base board on the inside. The roof includes a PVC membrane, a recovery board, a 3½" layer of rigid insulation (polyisocyanurate insulation with total R-value of 20), and a metal roof deck. The membrane is white color and has an initial reflectivity of 0.83 and initial emissivity of 0.92.

Windows are typically energy-efficient 1" insulated, double pane windows with low-e coating. The glass has a winter U-value of 0.31 (0.32-summer), shading coefficient of 0.46 (the solar heat gain coefficient of 0.39), and visible transmittance of 64%.

Mechanical Systems

An entire building with the exception of the gymnasium will be air-conditioned. Most of the building is served by variable air volume systems. The table below provides a summary of major building system types and areas they serve.

System Type	Area Served	Main Features
VAV system	Entire academic wing (Bldg. A and B) including all classrooms, administration offices, library (RTU-1 through RTU-5); also includes the following spaces in Bldg. C - band and choral classrooms (RTU-6), physical education offices, coaches' offices, weight	VFDs for supply and return fans, full air-side economizer capability, DDC controls, occupancy-based control of terminal units, discharge temperature resets, static pressure resets. HW heating coils and CHW cooling coils on each air handler, terminal VAV boxes with HW reheat coils. Typical hours of operation: 6:00AM till

	training/aerobics area, training room (RTU-7).	9:00 PM M-F, 6:00AM till 6:00 PM Saturday, off on Sunday and holidays.
Single zone, VAV system (heating, cooling, and ventilation)	Cafeteria (student dining) – RTU-8	HW heating coil and CHW cooling coil; VFDs for supply and return fans; full air-side economizer capability; variable air volume, fan speed control based on space temperature, discharge temperature resets, demand ventilation controls. typical hours of operation: 6:00AM till 9:00 PM M-F, 6:00AM till 6:00 PM Saturday, off on Sunday and holidays.
Heating and ventilation unit	Gymnasium (RTU-9 and RTU-10)	Constant volume, HW unit, single zone; demand ventilation controls; full economizer available. Typical hours of operation: 7:00 AM till 9:00 PM Monday through Sunday.
Single zone system (heating, cooling, and ventilation)	Auditorium (ERU-1)	HW heating coil and CHW cooling coil; constant volume, single zone; energy recovery; economizer; demand ventilation. Typical hours of operation: 8:00AM till 10:00 PM M-S, off on Sunday and holidays.
Heating and ventilation unit	Lockers (ERU-2)	Constant volume, HW unit, single zone; 100% OA. Typical hours of operation: 7:00 AM till 9:00 PM Monday through Sunday.
Unit heater	Receiving/storage	Constant volume, HW unit, single zone, no outside air.

_____There are seven VAV air handling units in the building. baseline system considered for the building is a four pipe fan coil unit system for most of the spaces. However, the school is considering a variable air volume system as an alternative if the economics proof to be advantageous.

Chilled water for comfort cooling systems will be provided by a central chiller plant consisting of one high efficiency air-cooled chiller with a cooling capacity of 200 tons and a full load efficiency of 1.13 kW/ton (10.6 EER) at ARI standard conditions and one evaporatively-cooled chiller with capacity of 200 tons and a full load efficiency of 0.88 kW/ton (13.6 EER) or better. The chillers are controlled by the building automation system. The evaporatively-cooled chiller will be a lead chiller and will operate whenever the chiller plant is in use. The air-cooled chiller will be turned on only when the chiller plant exceeds the capacity of the lead chiller. Water from the roof storm water collection system will be used for make-up water for the evaporatively-cooled chiller. The chilled water (CHW) supply temperature set point will be reset from 44°F to 48°F based on the building load. CHW will be distributed throughout the building via one primary CHW loop. The flow in the loop will vary as the 2-way control vales on the CHW coils close and open in response to the building load. The chiller plant also includes two 40 hp chilled water pumps each sized at 1000 gpm (one is spare). The pumps will be equipped with variable frequency drives (VFDs) for capacity control and will have premium efficiency motors. There CHW pump speed turn down will be limited so the minimum CHW loop flow will not be less than the manufacturer-recommended CHW flow through the chiller. Pumps and valve controls will all be tied into the building automation system.

Hot water for space heating will be provided by a boiler plant consisting of six Cleaver Brooks condensing boilers model # MCF-1800 with input capacity of 1,800 MBtu/hr. The boilers are a high efficiency type with minimum 86% rating but can reach up to 98% of fuel to water efficiency depending upon operating conditions. The hot water (HW) supply temperature set point will be reset based on the building load from 180ºF to 120ºF. There are two 40 hp hot water pumps (one is spare) in the boiler plant each sized at 700 gpm. The pumps will have premium efficiency electric motors and variable frequency drives for pump capacity control.

The kitchen will have a commercial kitchen exhaust hood (5,000 cfm) that will include 1.5 hp exhaust fan. In addition there is a 1,000 cfm direct exhaust from the dishwasher area. There kitchen make-up air system consists of one unit with a design air flow of 5,700 cfm and a 5 hp supply fan. The make-up air system includes hot water heating coils. Intelli-Hood control system (Melink system)is provided for the hood and the make-up air unit. The controls include opacity and temperature sensors mounted in the hood to sense smoke (or vapor) and measure temperature at the inlet to the hood and variable speed drives to control the supply and exhaust fans. When possible (non-cooking conditions) the controller slows down the fans thus reducing the amount of exhausted air and heated make-up air leading to a decrease in heating and fan energy.

A comprehensive building automation system (BAS) consisting of direct digital controls (DDC) is designed for the building. Many advanced controls strategies are used for the building to improve energy efficiency including occupancy-based control of terminal units, temperature resets, static pressure resets, and demand control for ventilation.

Lighting Systems and Other Equipment Loads

The lighting system in the building will consist mainly of variety of high efficiency fluorescent fixtures including pendant mounted direct-indirect lighting fixtures. The average lighting power density for the entire building amounts to approximately 1.15 W/ft^2. To further reduce lighting energy occupancy sensors will be provided for most of the spaces and daylight dimming system will be installed in all classrooms and in a perimeter section of the gymnasium track area near south facing windows. In addition, daylight harvesting controls are used in the cafeteria, where four large skylights are provided to allow ample daylight into the space.

The equipment load is assumed at 0.75 W/ft^2 for most of the classrooms and offices, and at 0.25 W/ft^2 for library. Equipment load of 0 W/ft^2 (no plug load) is assumed for all other spaces. Equipment loads comprise all non-HVAC equipment loads plugged into convenience outlets including computers, printers, monitors, kitchen equipment, etc. To reduce electric equipment loads some high efficiency appliances (Energy Star) were also specified for the school.

Domestic Hot Water System and Plumbing

The domestic hot water (DHW) loads include kitchen uses, showers, and lavatory sinks. There are two separate DHW systems in the building. One of the systems provides hot water to the kitchen and to the locker rooms. It consists of a gas fired hot water heater packaged complete with a built in storage tank with capacity of 350 gallons and with minimum efficiency of 82%. The second system will consist of a high efficiency gas-fired hot water heater (min. efficiency of 93%) and a separate storage tank with a capacity of 175 gallons. This system will provide DHW for the academic wing.

Photovoltaic System

There is a photovoltaic (PV) system design for the school building. It consists of 450 Evergreen EC-110-12V modules that will be located on the gymnasium roof. The system is rated at 49.5 kW (DC) at STC. The PV modules will be mounted on the gymnasium roof with a tilt angle of at least 29 degrees from horizontal plane and will be facing directly south (azimuth of 180º from north). The PV modules will feed DC power to a series of inverters that will convert the power to AC power. The inverters will provide AC power directly to the school through the electrical wires and will feed any excess power back to the utility should the system provide more power than the school requires. The modules will be grouped in 6 sub-arrays of 75 modules. The modules of each sub-array will be grouped together on a frame and this frame will be mounted on standoffs that are mounted to or part of the steel frame of the building. The elevated structure allows for better drainage, allowing water and air to circulate freely over the roof surface. It also allows easy access to roof surface for maintenance and repair. In addition it allows natural convection to cool the array, permitting modules to operate more efficiently (PV modules produce more power when cool) and increasing the equipment life. The module specified for the project is manufactured locally in Massachusetts.

A data acquisition and monitoring system will be provided with the solar system. It will include an interactive display provided in a prominent location on the site to increase the promotional and educational benefits of the system. The display will allow students and visitors to monitor system performance in real time, or easily review historical performance. Performance data includes power/cumulative energy production, pollution reduction, and weather conditions. The same information would also be available on the school district’s website on the Internet.

Wind Turbine System

The school is also planning to install a wind turbine system on the school grounds (10 kW GridTek package from Bergey. The system consists of a 10 kW wind turbine, a 100 ft tower, a power processor, and an electric meter. A precise location of the system on the school ground is being determined at this time.

Bergey wind turbines operate at variable speed to optimize performance and reduce structural loads. Power is generated in a direct drive, low speed, and permanent magnet alternator. The output is a 3-phase power that varies in both voltage and frequency with wind speed. This variable power is not compatible with the utility grid. To make it compatible, the wind power is converted into grid-quality 240 VAC, single phase, 60 Hz power in an IGBT-type synchronous inverter (GridTek Power Processor). The output from the GridTek can be directly connected to the building circuit breaker panel. It is also recommended that a utility-type kWh meter be installed between the GridTek and the building’s breaker panel so that the cumulative energy production from the wind turbine can be monitored. That information would be also tied into the interactive data acquisition system provided with the solar system so the students and visitors at the high school can access that information for educational purposes.

The system will be tied to the electric grid so when excess power (more power than the instantaneous site power demand) is generated it will be fed into the grid. The wind turbine is expected to very well complement the PV system as stronger winds typically occur in winter when the solar power generation is limited. The wind turbine will also operate at night when solar power is not available.

ANALYSIS METHODOLOGY AND BASELINE DESIGN DESCRIPTION

Two major tasks were performed as part of the study. These included: estimate of building energy consumption of the *as designed* building and of a comparable *baseline* building, simple payback analysis of one energy efficiency measures that will partially be funded by MTC (MTC measures), and an estimate of electric energy generated by renewable sources specified for the project.

To analyze future energy consumption patterns of the Whitman-Hanson Regional High School and the impact of various energy conservation measures incorporated into the building design, a computer model of the facility was developed and building consumption simulations were performed using the PowerDOE building analysis program. PowerDOE uses the latest DOE-2.2 building energy analysis software as its calculating engine. This very flexible program permits modeling of variety of building types and components including complex building geometry, lighting systems, HVAC systems, central plant equipment, and utility rate structure.

The *as designed* and the *baseline* building models were compiled using information obtained from design drawings and anticipated use schedules for the facility provided by the owner. Boston weather data (in TMY2 format) was used in the analysis. Electric utility cost and cost savings were calculated using the Massachusetts Electric's G-3 rate schedule effective January 1, 2003. The thermal energy cost and cost savings were calculated based on the KeySpan's G-43 rate (large, low load) for natural gas.

A *baseline* building model was created to represent a building that is comparable to the *as designed* building and so the major components of the *baseline* building's envelope, lighting, and mechanical systems at least meet the requirements of Chapter 13 of the Massachusetts State Building Code, Energy Conservation. Therefore the shape, size and the building schedules are identical for both the *baseline* and the *as designed* building. The main differences between the two buildings involve insulation levels for walls and roof, windows performance, type and efficiency of mechanical equipment, lighting wattage density, lighting controls, etc. A list of all items that differ in the two building models is provided in Table 3 at the end of this section. The list also provides values used in those varying components in the *as designed* and *baseline* building models.

To analyze the potential of on-site electricity generation from renewable sources various software packages and spreadsheets developed/used by equipment vendors were applied.

To compare the *as designed* building energy performance with the *baseline* building the *as designed* building's estimated annual energy consumption was reduced by the estimated amount of energy that will be generated by the renewable energy sources. The adjusted *as designed* building consumption was then compared to the *baseline* building energy consumption. All forms of energy consumed were converted to source energy in Btu. The conversion factor for electricity was 10,000 Btu/kWh which represents the amount of energy consumed by power plant to generate electricity consumed on site. The conversion factor was selected based on the instructions provided in Chapter 13 of the Massachusetts State Building Code and represents approximately 34% efficient power generation process.

To model and evaluate energy cost savings associated with the MTC Measure the model of *as designed* building was used. The measure was modeled by changing the *as design* model to represent the pre-measure condition. The energy consumption of the building without the measure was then compared to the energy consumption of the *as designed* building. Cost estimates for this measure and for renewable technologies was prepared based on information provided by the product vendors and by Architecture Involution, LLC.

Many of the energy efficiency improvements and measures that are utilized in the *as designed* building were evaluated earlier in the design phase. They were evaluated in detail as part of a comprehensive utility incentive study and earlier (initially) as part of the MTC "Green School" Feasibility Study. In this report they are cumulatively referred to as "Utility Incentive Measures" and are described briefly in *Other Energy Efficiency Considerations* section of the report.

Table 3 - Summary of Major Differences Between *As Designed* and *Baseline* Building

Item	Proposed Case (As Designed)	Base Case
Building shape and orientation	Per design documents (DDs), with self shading	Same as proposed case
Wall insulation	R-10 rigid insulation (continuous)	R-7.5 continuous
Roof insulation	R-20 rigid insulation (continuous)	R-17.7 continuous
Roof color	White color PVC roof membrane with initial absorptance of 0.17; in model an absorptance of 0.3 was assumed to account for long term degradation of this property	Dark color EPDM roof membrane-absorptance 0.7
Glass selection-windows	U-value-0.31/0.32, shading coefficient (SC)-0.46, visible transmittance (VT)-64% In model window glass with following properties was assumed: U-value-0.29, SC-0.48, VT-68%	U-value-0.57, SC-0.88, VT-81%
Glass selection-skylights	Skylights for cafeteria; U-value-0.29/0.31, SC-0.22, VT-35% In model skylight glass with following properties was assumed: U-value-0.29, SC-0.33, VT-41%	No skylights
HVAC system	VAV system for most of spaces. Control sequences include temp. reset, static pressure reset, occupancy based control of VAV boxes in classrooms. Constant volume units for gymnasium and auditorium.	Fan coil system for most of spaces. Constant volume units for gymnasium, cafeteria, and auditorium.
Demand ventilation controls	For cafeteria, gymnasium, and auditorium.	Basic "time of day" scheduling of min. OA
Heat/energy recovery	For auditorium and for locker rooms	None
Boiler plant	6 hot water boilers with minimum efficiency of 86% and up to 95% efficiency in the condensing mode; capacity of 1,548 MBh/each; hot water (HW) supply temperature setpoint reset.	3 hot water boilers with efficiency of 80% and capacity of 3,000 MBh/each; constant HW supply temperature setpoint. HW pumps include single speed motors.

	HW pumps include variable frequency drives (VFDs) for capacity control.	Pumps “ride the curve” as the HW flow varies.
Chiller plant	Two chillers each with 200 tons nominal capacity. Lead chiller-evaporatively cooled chiller with efficiency of 0.88 kW/ton at full load (13.6 EER and IPLV of 18.8); lag chiller - high-efficiency air-cooled chiller with a full load efficiency of 1.13 kW/ton (10.6 EER) at ARI standard conditions. Chilled water (CHW) supply temperature setpoint reset from 44ºF to 48ºF based on building load. CHW loop flow varies (primary loop variable flow). VFDs provided for CHW pumps for capacity control.	One air cooled chiller, 400 tons nominal capacity, efficiency of 1.256 kW/ton at standard ARI rating conditions. Fixed CHW supply temperature setpoint- 44ºF. CHW flow is constant. CHW pumps include single speed motors.
Electric motors for pumps and fans	Premium efficiency	Standard efficiency
Kitchen hoods controls	Intelli-Hood (Melink control) system	Basic on/off switching
Lighting system wattage density	According to design documents-varies by space (on average 1.15 W/ft^2).	According to minimum code requirement (space-by-space method)
Occupancy sensors	Yes – classrooms, offices	None
Daylight controls	Yes - in classrooms, library, offices, cafeteria, and gymnasium.	None
Domestic hot water heater	Per design document – 82% efficiency for gymnasium/kitchen/cafeteria system and 93% efficiency for academic wing system.	Based on minimum requirements (__) – 73% efficient
Renewable systems	PV system-49.5 kW peak power rating; wind turbine-10 kW rating;	None

ANALYSES RESULTS DESCRIPTION

This section contains a more detailed description of the results of three analytical tasks that were performed as part of this study. The tasks included: an estimate of electric energy generated by renewable sources specified for the project, an estimate of building energy consumption of the *as designed* building and of a comparable *baseline* building, and a simple payback analysis of one energy efficiency measure that will partially be funded by MTC (the MTC measure).

Electricity-Generating Renewable Energy Sources

There are two technologies in this category that are used at the site. One involves installation of the photovoltaic (PV) roofing panels to collect solar energy and convert it to electricity. The second technology involves a wind turbine installed on the site to convert wind power to the electric power.

PV System - The proposed photovoltaic power system for the school consist of 450 frame mounted PV modules (Evergreen EC-110-12V). The system has 49.5 kW (DC) power rating at SRC. The PV modules will be mounted on the gymnasium roof with a tilt angle of at least 29 degrees from horizontal plane and will have an azimuth of 180º from north (will face south). The PV modules will feed DC power to a series of inverters that will convert the power to AC power. The inverters will provide AC power directly to the school through the electrical wires and will feed any excess power back to the utility should the system provide more power than the school requires.

The annual electric energy generation by the arrays was estimated using PVWatts software package. It is Internet-accessible software developed by National Renewable Energy Laboratory for quick performance estimates for grid-connected PV systems. The estimated annual electric energy output from the array amounts to approximately 61,930 kWh. This amounts to almost 5% of the future building electric energy consumption predicted by the PowerDOE computer building energy consumption model. The annual electric cost savings are approximately $7,060. The estimated cost of the PV installation amounts to $519,500. This includes material, installation, and commissioning cost of the PV system.

Wind Turbine System - The wind turbine system considered for the site is based on the 10 kW GridTek package from Bergey Windpower Co. The system consists of a 10 kW wind turbine, a 100 ft tower, a power processor (inverter), and a new electric energy meter. Initial estimates indicate that the annual energy output of the tower would amount to approximately 19,430 kWh. This is over 1% of the future building electric energy consumption as predicted by the PowerDOE building energy consumption model. The annual electric cost savings are approximately $2,215. The cost of the installation is estimated at approximately $55,700. This includes the material and installation cost as well as commissioning fees.

More information on both the solar and the wind turbine system is provided in the Appendix section of this report.

Building Energy Consumption Comparison-*As Designed* vs. *Baseline* Building

This aspect of the analysis was performed to compare predicted *as designed* building energy consumption with a comparable *baseline* building. The *baseline* building is identical in size and shape to the *as designed* building and also has identical schedules for building occupancy, lighting, equipment, etc. The baseline building however is model with wall, roof, window construction performances that meets the minimum requirements of the energy code. Correspondingly, the performance of mechanical and lighting system in the baseline building represent minimum code requirements. A detailed list of all items that differ in each model is provided on page 7. The analysis indicates that the annual energy consumption of the *as designed* school building will amount to approximately 1,285,966 kWh/year and 46,297 therm/year, which translates to $148,630/year and $44,931/year for electricity and natural gas cost respectively. The total baseline utility cost amounts to $193,561/year. When presented on “per square foot” bases the annual values amount to: 5.48

kWh/ft^2, 0.20 therm/ ft^2, \$0.83/ ft^2. Table 4 below provides a detailed comparison of the energy performance of *baseline* and the *as designed* buildings.

Table 4 - Summary of Energy Comparison for As Designed and Baseline Building

Annual Energy Consumption and Cost		***Baseline* Building**	***As Designed* Building**	**Savings**
Electric Energy Consumption	*kWh*	2,025,048	1,285,966	739,082
Electric Energy Consumption	*kWh/ft^2*	8.64	5.48	3.15
Electric Energy Cost	*\$*	\$ 227,703	\$ 148,630	79,073
Electric Energy Cost	*\$/ft^2*	\$ 0.97	\$ 0.63	\$ 0.34
Natural Gas Consumption	*therm*	69,422	46,297	23,125
Natural Gas Consumption	*therm/ft^2*	0.30	0.20	0.10
Natural Gas Cost	*\$*	\$ 66,421	\$ 44,931	21,490
Natural Gas Cost	*\$/ft^2*	\$ 0.28	\$ 0.19	\$ 0.09
Total Site Energy Consumption	*MMBtu* (1)	13,851	9,017	4,834
Total Site Energy Consumption	*MBtu/ft^2*	59.07	38.45	20.61
Total Site Energy Cost	*\$*	\$ 294,124	\$ 193,561	\$ 100,563
Total Site Energy Cost	*\$/ft^2*	\$ 1.25	\$ 0.83	\$ 0.43

Building area	234,500	ft^2
(1) energy conversion factor for electricity is	3,412	Btu/kWh to represent site energy
conversion factor for gas is	100,000	Btu/therm

The energy consumption of the *as designed* building is estimated to be 36% less the energy consumption of a comparable *baseline* building (measured in source energy Btu). This does not include savings associated with "unregulated loads" such as high efficiency appliances.

To account for the savings associated with electricity-generating renewable systems, the modeled energy consumption of the *as designed* building was reduced by the estimated amount of electricity that will be generated by the PV system and the wind turbine. The adjusted consumption was then used for comparison with the baseline building. When renewable energy contribution is taken into account, the proposed design savings increase to 39% over the baseline design as measured in the source energy Btu.

The breakdown of the energy end use, as determined using the *baseline* model, is shown in Figure 1 and Figure 2 below. Figure 3 and 4 on the following pages show *baseline* and *as designed* building energy consumption comparison by end use. Copies of several PowerDOE output reports are included in the Appendix.

Figure 1 - WHITMAN-HANSON RHS - BASE CASE ELECTRIC USAGE (kWh)

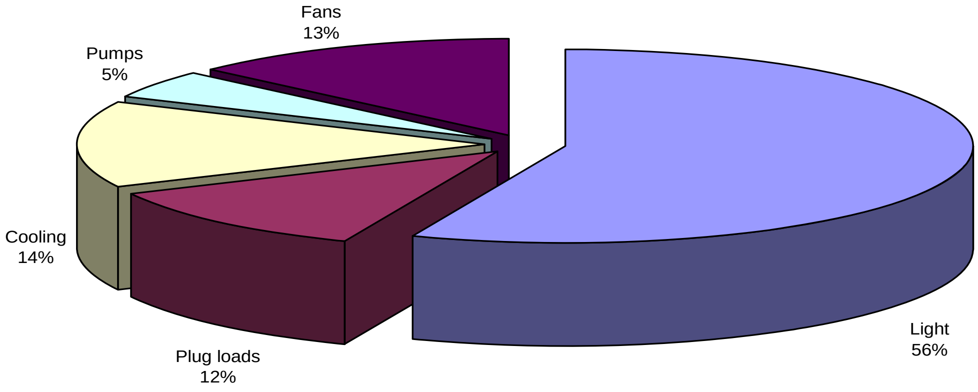


Figure 2 - WHITMAN-HANSON RHS - BASE CASE TOTAL ENERGY USAGE (SOURCE Btu)

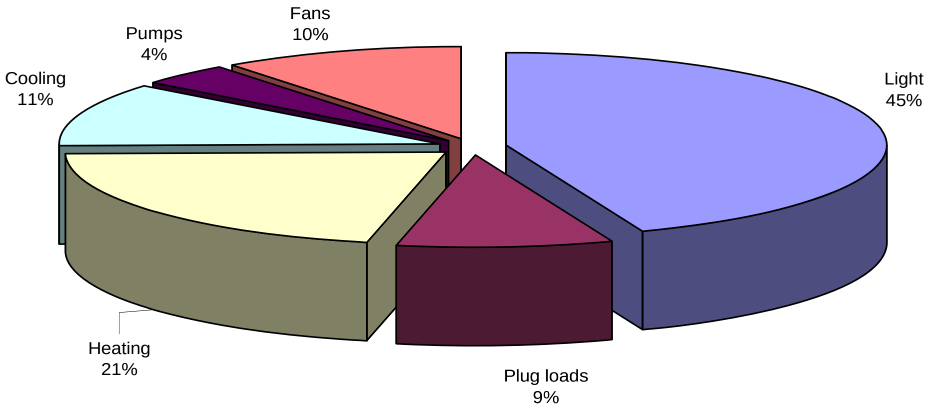


Figure 3 - WHITMAN HANSON RHS - ELECTRIC END USE COMPARISON

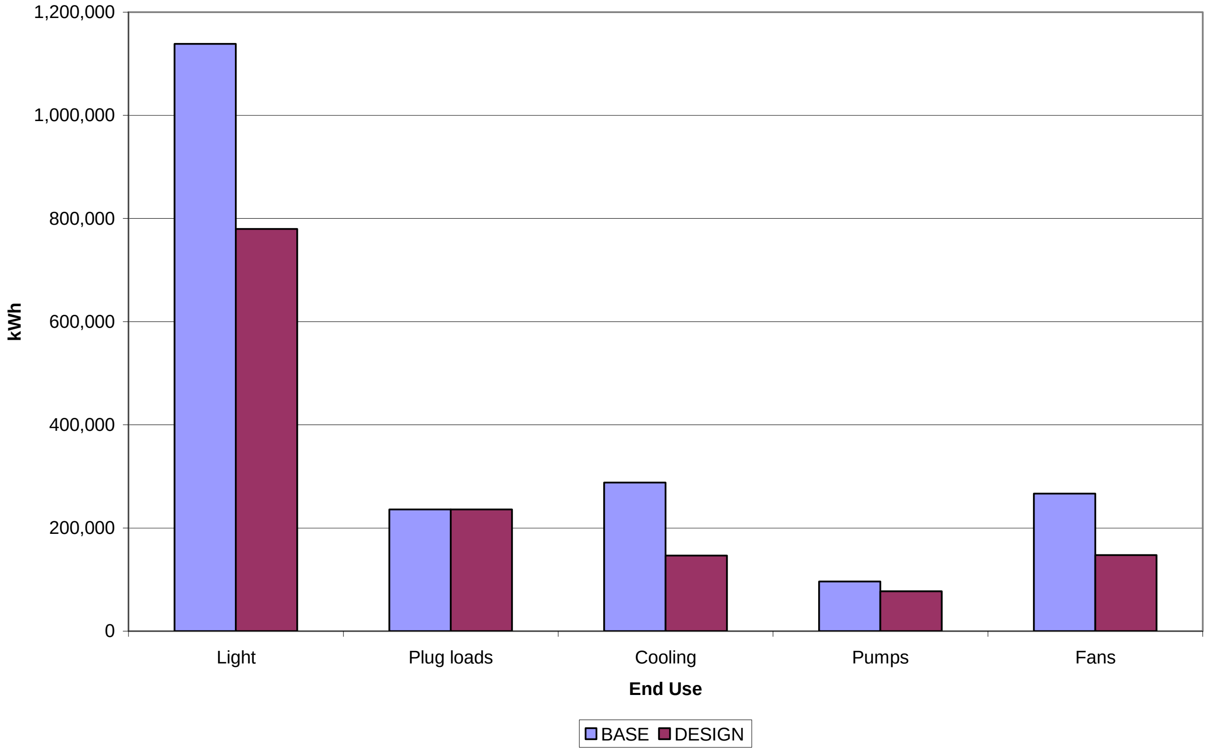
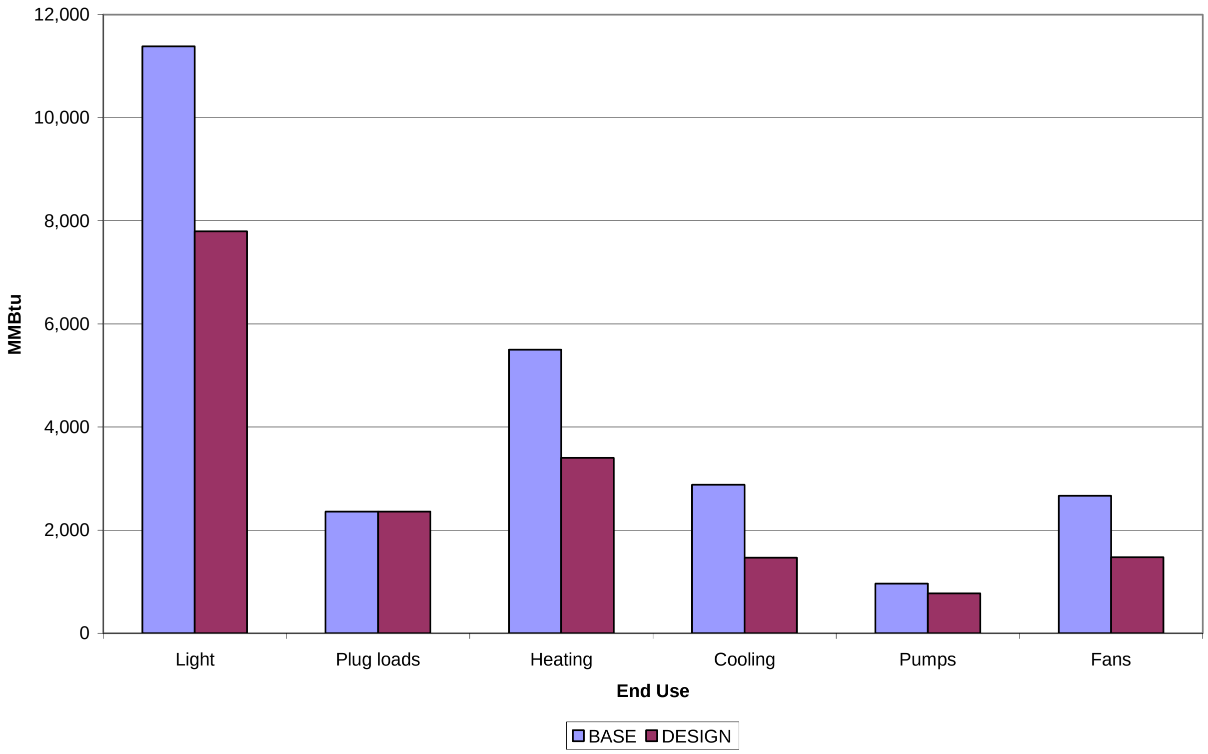


Figure 4 - WHITMAN-HANSON RHS - TOTAL ENERGY END USE COMPARISON



MTC Measures Analysis

There are two energy efficiency measures that are expected to be partially funded by the MTC Green School construction grant. In this report they are referred to as the MTC Measures. The analysis of these measures focused on energy savings and a simple payback associated with each measure. A description of each of the evaluated measures is provided below.

White Roof – This measure involves providing a white color roof membrane in lieu of _____

Skylights for Cafeteria – This measure _____.

This measure would involve providing an energy efficient lighting system for entire building. This may include high efficiency indirect lighting for classrooms, administration, library and other areas and high bay fluorescent lighting for the gymnasium. Occupancy sensors would also be provided as part of the measure in most of the spaces in the school. It was assumed in the analysis that the average lighting power density would be reduced from approximately 1.5 W/ft^2 in the baseline case (throughout the building) to approximately this following values in the proposed design: 1.05 W/ft^2 in corridors, 1.2 W/ft^2 in dining room and kitchen, and 1.15 W/ft^2 in

OTHER ENERGY EFFICIENCY CONSIDERATIONS

Utility Incentive Measures

There are several energy efficiency measures and technologies that were incorporated into the final building design. They are all included in the "as design" building model. Many of these measures were evaluated in detail as part of a comprehensive incentive study that was performed for MECo. These measures were evaluated for cost-effectiveness and for their incentive potential and the results of the evaluation were presented in a separate report submitted to the school district, MECo, and Keyspan. A summary of these measures is provided in Table 5 on page __. A brief description of each measure is provided below. All these measures are eligible for monetary incentive from MECo or/and Keyspan.

High Efficiency Lighting - This measure involves providing an energy efficient lighting system for an entire building including indirect lighting fixtures for classrooms. The average lighting power density is for the building is approximately 1.15 W/ft^2 as compared to the code mandated maximum of 1.5 W/ft^2. This measure offers electric energy savings by reducing the lighting system energy consumption. It also provides for reduction in cooling energy by reducing cooling load in air-conditioned spaces. During heating season however, it results in slight increase in natural gas consumption as the reduction in heat from lighting system has to be made up by the boiler plant.

Daylight Harvesting Controls for Classrooms and Gymnasium - Daylight harvesting controls enable integration between natural daylight available in the space and the electric lighting serving the space. Appropriate daylighting controls provide for dimming of the electric lighting fixtures when sufficient daylight is available in the space. This measure results in an installation of light sensors/controllers in every classroom and in the perimeter sections of the gymnasium track area near south facing windows. The controller in each classroom will control selected lighting fixtures output based on illumination level in the space. Fluorescent lighting fixtures include dimmable ballasts for continuous light output adjustment.

The measure offers electric energy savings by reducing the lighting system energy consumption when daylight is available. Since the electric lighting also generates heat in the space, the amount of heat generated by lighting system is also reduced when the output of electric light is reduced due to daylight dimming. This is an additional benefit of the measure during cooling season as the cooling load in the space is reduced resulting in improved comfort in non-air conditioned spaces and in cooling energy savings for air-conditioned spaces. However, this also causes heating energy penalty during heating season as any reduction in the heat from lighting system has to be made up by the boiler plant resulting in a slight increase in the natural consumption as compared to the baseline system.

Daylight Harvesting Controls for Cafeteria - This measure would provide 12 skylights in the cafeteria to allow ample daylight into the entire space. It will also include light sensors and dimming ballasts for the lighting fixtures. Light sensors would be tied into the lighting controller and would control lighting fixtures output based on illumination level in the space.

The potential energy cost savings associated with this measure are estimated at $1,054 per year. The estimated measure incremental cost amounts to $19,500. The payback for this measure is too long to qualify for custom utility incentive but prescriptive incentive could be available for dimmable ballasts and for light sensors that could partially offset the incremental measure cost. In addition MTC grant money could be also allocated to this measure to further reduce the net measure cost to the school.

Optimized Window Glazing - The improved windows have low-e coating and enhanced insulating properties for superior thermal performance. The measure offers electricity and natural gas savings by reducing cooling load due to solar radiation and heating energy losses due to heat conduction through the glass.

VAV HVAC System with Optimized Controls - This measure provides a variable air volume system for classrooms, library, and the administrative offices in lieu of the baseline fan coil system. The advantages of VAV system include the ability to reduce air flow during hours of reduced cooling load and to allow better utilization of outside air for cooling purposes when the conditions permit. The proposed system also includes advanced control sequences such as discharge air temperature reset and static pressure reset. In addition occupancy sensors in each classroom will be used to control the VAV box. When the space is unoccupied the box will be allowed to shut down entirely if there is no cooling or heating load in the space. This will allow for additional reduction in the supply and outside air flow when spaces are unoccupied. Variable frequency drives (VFDs) will be provided for capacity control of the supply and return fans. All fan motors would be premium efficiency. VFDs will also be provided for the cafeteria system. The fan speed will be controlled based on the space temperature. The supply and return fans for the cafeteria will be allowed to slow down during periods of reduced or non-existent cooling load.

Variable Flow Pumping - This measure provides variable frequency drives (VFDs) for the capacity control of the hot water and chilled water pump and high efficiency electric motors for the pumps. The VFDs will adjust the speed of a circulation pump based on a differential pressure in the hot water or chilled water loops. The chilled water flow turn down will be limited so the minimum CHW loop flow will not be less than the minimum manufacturer-recommended CHW flow through the chiller. Pump and valve controls will be all tied into the building automation system. This measure offers energy savings by better matching pump capacity (and power demand) with the required water flow at part load.

Enhanced Kitchen Hood Controls - This measure provides kitchen hood controls to reduce hood exhaust and fresh air make-up when cooking equipment served by the hood is not in use. The recommended controls include opacity and temperature sensors mounted in the hood to sense smoke (or vapor) and measure temperature at the inlet to the hood and variable speed drives to control the supply and exhaust fans. By slowing down the fans and reducing the amount of exhausted air (and heated make-up air) when possible, a decrease in heating and fan energy can be attained.

Optimized Chiller and CHW Controls - This measure provides an optimized chiller plant consisting of one 200 ton evaporatively-cooled chiller and one 200 ton high efficiency air cooled chiller. The proposed evaporatively-cooled chilled will have performance of 0.88 kW/ton or better at full load (min 13.6 EER) and IPLV of at least 18.8. The evaporatively-cooled chiller will be a lead chiller and will operate whenever the chiller plant is in use. The air-cooled chiller (with min 10.6 EER at ARI Standard Condition) will be a lag chiller and will be turned on only when the chiller plan load exceeds the capacity of the lead chiller. The measure also offers improved controls for the CHW system including CHW supply temperature set point reset based on the building load. The measure offers energy savings by reducing electric energy consumption of the chiller plant.

Demand Ventilation for Selected Spaces - Demand ventilation is a method of controlling amount of the ventilation air delivered to the spaces based on the number of people in the space (based on the demand for outside air). A CO_2 sensor is installed in the space that functions as an indicator of the number of peopled in the space. The amount of outside air that is delivered to the space is adjusted continuously based on the CO_2 level. This control method saves heating and cooling energy by reducing the amount of outside air that needs to be conditioned (heated or cooled) before it can be delivered to the space. This control method is particularly applicable to common spaces such as gymnasium, cafeteria and auditorium that can have high design ventilation air volumes but for most of the time are not fully occupied.

This measure provides CO_2 sensors for the cafeteria, gymnasium, and the auditorium. Appropriate controls tied into the building automation systems will control outside air dampers based on the CO_2 level when the unit is not in the economizer mode.

Optimized Boiler Plant - This measure provides high efficiency gas-fired condensing boilers for the building. The boilers have a minimum combustion efficiency of 86% but can have 95% (or higher) efficiency in the condensing mode. The hot water supply temperature is reset based on building load from 180ºF to 120ºF. This measure offers natural gas savings by using more efficient boiler plant system as compared to a baseline system consisting of non-condensing boilers with efficiency of 80% (code minimum).

Heat Recovery for Selected Units – This measure ____

High Efficiency Domestic Hot Water Heater – This measures ___

Other Energy Efficiency Measures

There are other items that were incorporated into the final building design that where not part of the utility or MTC incentive programs but still contribute to improved building energy performance. These measures include: occupancy sensors for lighting control in classrooms and offices, roof and wall insulation levels exceeding the minimum code requirements. In addition some of the kitchen/cafeteria appliances were specified to meet the Energy Star rating standard. Any savings that can be associated with such appliances are not accounted for in this report.

Insert Table 5 – summary of Utility Measures

APPENDIX

- Renewable Energy Related Analysis
- PowerDOE® Output Reports
- Miscellaneous Supporting Information
    - Schedules
    - Graphs

- **Renewable Energy Related Analysis**

- **PowerDOE® Output Reports**