Evaluation of the Smithsonian Environmental Research Center Two-Story Visiting Scientist Housing Designs Using Energy-10

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Abstract

Evaluation of the Smithsonian Environmental Research Center Two-Story Visiting Scientist Housing Designs Using Energy-10. RAINA STRICKLAN (Colorado State University, Fort Collins, CO 80523) Dr. Andy Walker (National Renewable Energy Laboratory, Golden, CO 80401)

The Smithsonian Environmental Research Center (SERC) is located in Edgewater, Maryland. Plans to build visiting scientist housing have been submitted to the Federal Energy Management Program for energy analysis using Energy-10. Energy-10 is a software program that conducts annual hourly evaluations of a building's energy use. It uses thirteen energy efficient strategies to apply to a building to analyze energy efficiency. Modifications had to be made to the program since Energy-10 was designed to be used before the building design process, and the SERC blueprints were already drawn up. Insulation, air leakage control, high efficiency HVAC, and duct leakage strategies were considered for the SERC housing. Additional modifications were made to simulate a ground source heat pump, a waste water heat recovery system, and a solar water heater. Each strategy was analyzed separately, showing insulation and a waste water heat recovery system paired with a solar water heater to offer the greatest energy savings. Strategies were also combined to account for synergistic effects. By implementing a PV system, additional energy would be saved, generating 64% annual energy use savings over the SERC housing as planned. Implementation costs were not estimated as part of this study.

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Introduction

The environment adjacent to the western shore of the Chesapeake Bay in Edgewater, Maryland, is mostly undeveloped, consisting of sparse housing mixed with forest lands, wetlands, and shore habitats. The Smithsonian Environmental Research Center (SERC) owns 2,700 acres of the Chesapeake property and uses it to analyze the complex landscape where land and sea meet. At SERC, scientists access a wide range of habitats, concentrating on the land/sea ecosystem and dedicating themselves to increasing knowledge of biological and physical processes that sustain life on earth (French et al., 1994).

SERC is planning to expand their center to provide better research facilities. The plan includes six housing units, both one- and two-story units, that are energy- and resource-conscious for visiting scientists (Weinstein, 2001). Since SERC is an educational facility, exhibiting energy-efficient housing will allow the public to learn about energy and resources. To ensure the scientist housing follows effective energy use guidelines, SERC contacted the Federal Energy Management Program (FEMP) at the National Renewable Energy Lab to evaluate the building plans.

The purpose of this project was to evaluate the two-story housing unit blueprints submitted to FEMP using Energy-10 software to calculate energy performance. While the architectural company who designed the visiting scientist housing included many energy- and resource-conserving strategies, the goal was to find additional methods or to alter strategies already applied and use Energy-10 to simulate their effects and determine the best energy-efficient strategies for the SERC housing.

Materials and Methods

Energy-10 software assists researchers in designing low-energy buildings less than 10,000 sq. ft. Architects, engineers, builders, and utility representatives developed Energy-10 to allow easy calculation of daylighting, passive solar heating, low-energy cooling, and energy-efficient building envelope design strategies to predict energy performance (Balcomb, 2000). Since Energy-10 was designed to model buildings before the architectural design process, the procedure in this project changed slightly and fine details presented in the blueprints had to be taken into account. Information about SERC's visiting scientist two-story housing units was taken from blueprints (Figure 1) and from a report provided by Architrave P.C. Architects. In addition, a report entitled *Smithsonian Environmental Research Center: Accessible Housing Units* (Walker, 2001) concerning the one-story units was used to compare strategies and results. Energy-10 modeled the building and analyzed its energy use.

The initial input into Energy-10 required location, building use, HVAC system, floor area, number of stories, aspect ratio, and utility service rates (Figure 2). Smithsonian representative Tom Myers (telephone conversation, July 6, 2001) quoted utility service rates. The weather file for Annapolis, Maryland was created using the Energy-10 Weather Maker program (Walker, 2001). The initial inputs allowed Energy-10 to create a hypothetical base case building.

This project concerned three different building cases simulated by Energy-10: the ASHRAE reference case, the SERC housing as planned, and the SERC housing with applied energy efficient strategies (EES). The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) develops standards for energy-efficient design of residential buildings. ASHRAE 90.2 standards from the 1993 version were obtained and entered into the hypothetical base case building properties to create the ASHRAE reference case building. Since the SERC housing had already been designed, wall, window, door, and roof areas had to be measured from the blueprints and entered into the program. In addition, documented alterations in building design that made it more efficient, such as increased insulation and low-e glazing, were added to create a model of the SERC housing as planned. The ASHRAE reference case building and the SERC housing were compared. Using the SERC housing model, different energy efficient and renewable strategies were applied individually and simultaneously. Results were compared to find the best strategies, which were applied to develop the SERC housing with applied EES.

Results

There are thirteen energy efficient strategies to apply to buildings in Energy-10, including daylighting, glazing, shading, energy efficient lighting, insulation, air leakage control, thermal mass, passive solar heating, economizer cycle, high efficiency HVAC, HVAC controls, duct leakage, and PV systems. After modeling the ASHRAE reference case building, Energy-10 ranked air leakage control, duct leakage, a high efficiency HVAC, insulation, and glazing as the top five strategies to reduce energy consumption for a house in Maryland.

Energy-10 calculated the energy use and cost for both the ASHRAE reference case and the SERC housing as planned. Results showed that the SERC housing would use 49,611 kBtus less than the ASHRAE reference case, resulting in $1,091 less in annual energy costs (Table 1).

After considering the thirteen energy efficient strategies in Energy-10, insulation, air leakage control, high efficiency HVAC, duct leakage, and PV systems were chosen to apply to the SERC housing as planned. In addition, waste water heat recovery and solar water heating options were considered. SERC housing plans already included efficient glazing, shading, passive solar heating, lighting, and HVAC controls. The daylighting and economizer options were not designed to be applied to a residence simulation in Energy-10. A thermal mass would not be practical due to the plans for the SERC housing.

The following outline displays the particular details concerning the above mentioned energy efficient strategies applied to the existing SERC housing designs.

Insulation: Walls

The SERC housing is designed with 2 x 6 walls (R = 17.7), allowing for a higher R-value than the ASHRAE standard. Two other options were explored. Insulation in the walls was simulated individually for a 6" frame with 1" foam (R = 23) and 6" structurally insulated panels (SIP) with 5.5" foam (R = 24). The analysis results showed that both the 6" frame with foam and the SIP construction decreased energy use for the home. However, while SIP walls saved more energy and money, energy savings differences between the two were slight.

Insulation: Roof

The SERC plans call for both attic (R = 30) and 2 x 10 cathedral ceilings (R = 34.6).

Attic: The attic was simulated with R = 60. The savings were calculated to be $13 annually.

Cathedral: The cathedral ceilings were simulated with SIP construction containing 9.5" foam (R = 44.6). The SIP cathedral ceilings would save $10 annually.

Insulation: Floors

The floors of the SERC housing as planned are 2 x 10 construction with R = 15. An unconditioned crawl space is underneath. As an alternative, the floors were simulated with 2 x 10 construction with a 2" foam layer (R = 35), which showed savings of 3,211 kBtus and $70 annually.

Individual and combined insulation strategy results are displayed in Table 2.

Air Leakage Control

Energy-10 calculated the effective leakage area of the home to be 288.5 in^2, equal to 1.4 air changes per hour (ACH). The ACH value calculated by Energy-10 was high according to several sources. The *1997 ASHRAE Handbook - Fundamentals* states that the average ACH value for housing not incorporating energy-efficient features is 0.50. This value was used for the ASHRAE reference case and the SERC housing as planned. The handbook also states that energy-efficient homes have ACH=0.25. However, without mechanical ventilation, the ACH value should not be below 0.35 for indoor air quality (ASHRAE, 1993). According to ASHRAE IAQ Subcommittee Chair Max Sherman (2001), the required ventilation for a 1,500 sq. ft. house with two bedrooms such as SERC housing is ACH=0.35. To model the air leakage control strategy, Energy-10 simulated the air leakage control option with ACH=0.35. The savings would be 3,645 kBtus and $80 annually (Figure 3).

Duct Leakage

The plan for the duct system in the SERC housing is placement in the unconditioned crawl space to serve the first floor and ducts in the attic to serve the second floor. The fan efficiency is 15%. Energy-10 simulated a duct system placed inside the conditioned spaces with a fan efficiency of 25%, which would save 3,135 kBtus and $68 per year (Figure 4).

High Efficiency HVAC

There are 12 different HVAC systems available for simulation in Energy-10. Since gas is not available at the SERC site, the list was limited to five electric systems that provided heating and cooling. The SERC system is currently planned as an air source heat pump with electric resistance (ER) backup. The remaining four systems were simulated in Energy-10 individually. Out of these choices, Energy-10 found the package terminal air conditioning (PTAC) air-to-air heat pump with ER backup to provide the largest decrease in energy use and cost. Another HVAC option that was considered is a geothermal (ground source) heat pump. This HVAC system is not defined in Energy-10, so alterations to the program had to be made. Kristine Chalifoux, an Energy-10 programmer, advised that the COP be set at 4.7 for both high and low temperatures and the EER = 16 in the HVAC system description box in order to simulate a ground source heat pump (telephone conversation, July 13, 2001). Energy-10 results showed a ground source heat pump would save the most energy and money. Results for all HVAC systems can be found in Table 3.

Waste Water Heat Recovery

A waste water heat recovery system is not available as an energy strategy in Energy-10. Therefore, alternate measurements were taken and input into Energy-10. Several case studies concerning waste water heat recovery systems revealed a savings of 30% of the electricity otherwise used to heat water (Copper Development Association, 1997; Office of Industrial Technologies, 2000; Vasile, 1997). Reducing the hot water load in Energy-10 by 30% would save 4,379 kBtus and $96 per year (Figure 5).

Solar Water Heating

Solar water heating was also considered. For solar systems, the load should be minimized when figuring the size of the system needed. In this case, the waste water heat recovery system was applied first, and then solar water heating was applied to the remainder of the water heating needs. Since Energy-10 is not yet designed to simulate solar water heating, changes to the water heating load were made. A solar water heating screening analysis spread sheet (Brown, 2000) calculated the heating energy load to be 18 kWh/day (Figure 6), based on the ASHRAE figure of 62.5 gallons of water used a day by a family (ASHRAE Handbook, 1997). The estimated solar system size was 8 sq. meters, which would supply 82% of the water heating load not met by the waste water heat recovery system. The default water heating load for Energy-10 is 0.66, and was changed to 0.08 to account for the waste water heat recovery system and the solar system. Together, these systems would save 12,681 kBtus and $278 per year (Figure 7).

Final Results

After each strategy was applied individually, the most efficient option in each category was chosen. These chosen strategies consist of: increased insulation in the attic and floor; SIP construction for walls and cathedral roof; an ACH = 0.35; a ground source heat pump; ducts located inside the conditioned space with a fan efficiency of 25%; a waste water heat recovery system; and solar water heating system. All strategies were simulated together on the SERC housing as planned. Figures 8, 9, and 10 depict Annual Energy Use, Annual Electric Use Breakdown, and Monthly Average Daily Energy Use. The results showed a savings of 30,120 kBtus and $661 annually.

Final Results: PV Systems

PV systems were applied to SERC housing after all energy efficient strategies were applied so that the electric load was at a minimum. SERC housing specifies a metal seam roof. Panels from *Uni-Solar* Roofing Systems were simulated because their dimensions of 16" wide and 9.5' long fit the metal roofing on SERC. Two strings of 16 panels were applied to the south-facing roof. The PV array was simulated in Energy-10 and was shown to output 3,265 kWh. PV simulation results can be seen in Figure 11, and a comparison of annual energy use concerning the ASHRAE reference case, SERC housing as planned, SERC housing with applied EES, and SERC housing with applied EES and PV is in Figure 12.

Discussion and Conclusions

Based on the goals of the Smithsonian and the Energy-10 analysis, the following recommendations are made:

Insulation

SIP construction for the walls and cathedral roof is recommended. SIP construction has many benefits. The panels are very strong, have a high R-value, and allow for quick construction. An important advantage to SIP construction is the reduction of on-site waste and resource consumption, which will benefit the Smithsonian Environmental Research Center by disturbing the surrounding environment less. However, SIP construction is slightly more expensive (Bevier, 2000). For the attic roof, an R-value of 60 is recommended, and for the floors, 2 x 10 construction with R = 35. More insulation will help improve the year-round comfort of the home and reduce energy costs.

Air Leakage Control

Reducing the amount of air that flows in and out of the house helps lower energy use and cost. The recommendation is to reduce the number of air changes per hour to 0.35. This is the standard for a satisfactory indoor environment quoted by ASHRAE. If indoor air quality is a concern, the house could be made as tight as possible and paired with a mechanical ventilation system for the desired ACH level, which can provide better air quality and cost less (Bourg et al., 2000).

High Efficiency HVAC

A ground source heat pump (GSHP) is the recommended HVAC for SERC visiting scientist housing. GSHPs are the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available, however, they will cost about $3,500 more than a typical residential system with air-conditioning (National Renewable Energy Lab, 1998).

Duct Leakage

All ducts should be placed within the conditioned space. Ducts in an unconditioned crawl space are more vulnerable to outside air temperature fluctuations, and reduce the effectiveness of the HVAC system. The best recommendation is to place all ducts in a dropped ceiling, which would allow the HVAC system to serve both floors. However, if blueprint plans do not allow for this, another option would be to insulate the crawl space so the ducts are not exposed to outside air temperatures.

Alternative Water Heating

It is recommended that both waste water heat recovery and solar water heating systems be installed on the SERC housing. A waste water heat recovery system will help warm cold water by using hot waste water that flows out of the house through the drain. The solar water heating systems will heat the remaining cold water. In order to apply a solar water heater to SERC housing, the roof over the utility room will have to be redesigned so that it faces south instead of west. The new south-facing roof will not only allow for a solar water heating system, but will also model the regional housing influence requested by SERC. In addition, a solar water heating system will be visible to the public and allow for educational uses and help SERC remain resource conscious. One item to take into account is the foliage surrounding the SERC housing. It is very wooded, and tree branches may be in the path of the sun to the solar water heater. Tree topping is a possibility, but preserving the environment is the number one concern.

Photovoltaics

Once the loads on the SERC housing are minimized by implementing energy efficient strategies, photovoltaics are recommended for application. While providing electric benefits to the house, it also presents an educational opportunity for the public. PV could also be used in other areas of the site to provide lighting in parking lots or for signs.

Acknowledgements

I would like to thank Andy Walker for his assistance, encouragement, and support throughout this project. His endless knowledge of sustainable buildings and energy-efficient strategies allowed me to learn an incredible amount of useful information I would not know otherwise. Also, thanks to Doug Balcomb for his help and direction with the Energy-10 software.

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Figures

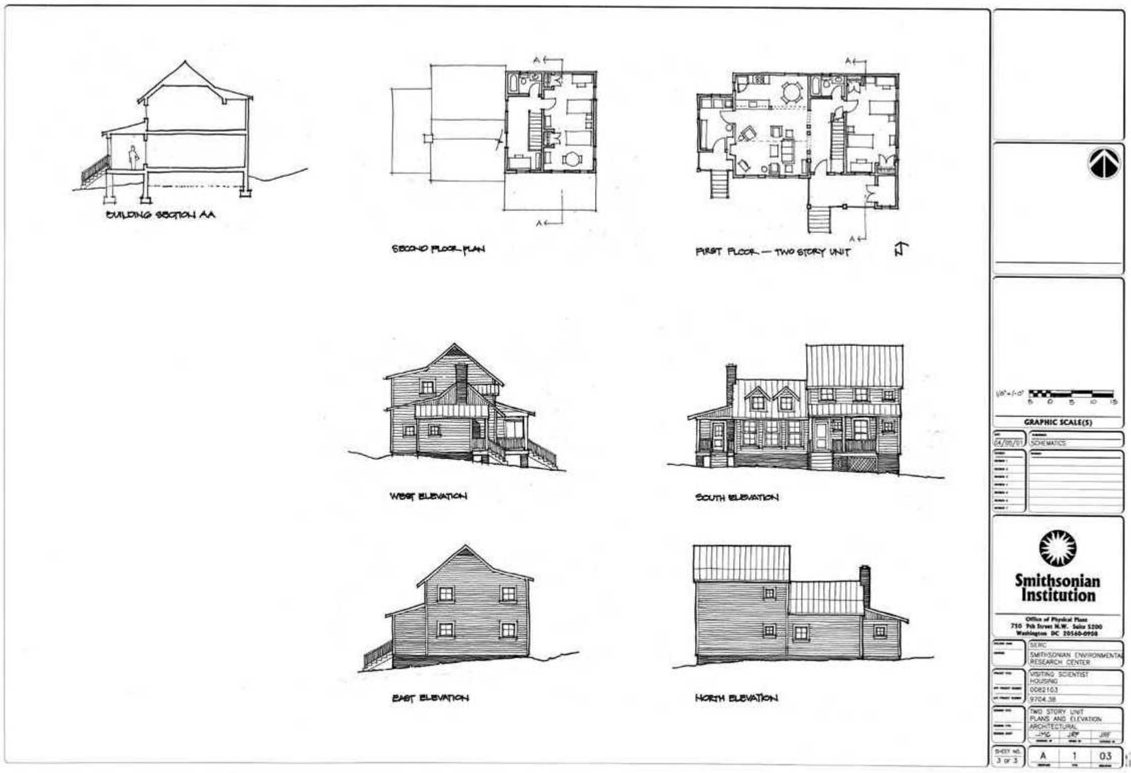

Figure 1. Blueprints of SERC 2-story housing designed by Architrave P.C. Architects.

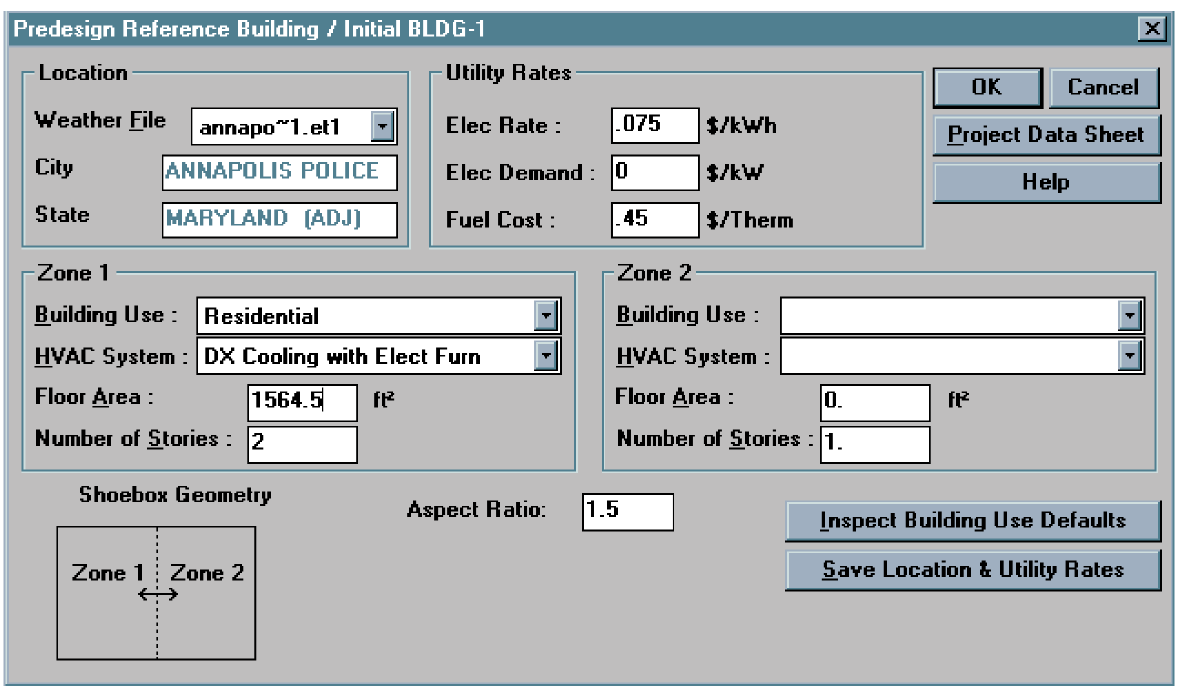

Figure 2. Initial inputs in Energy-10.

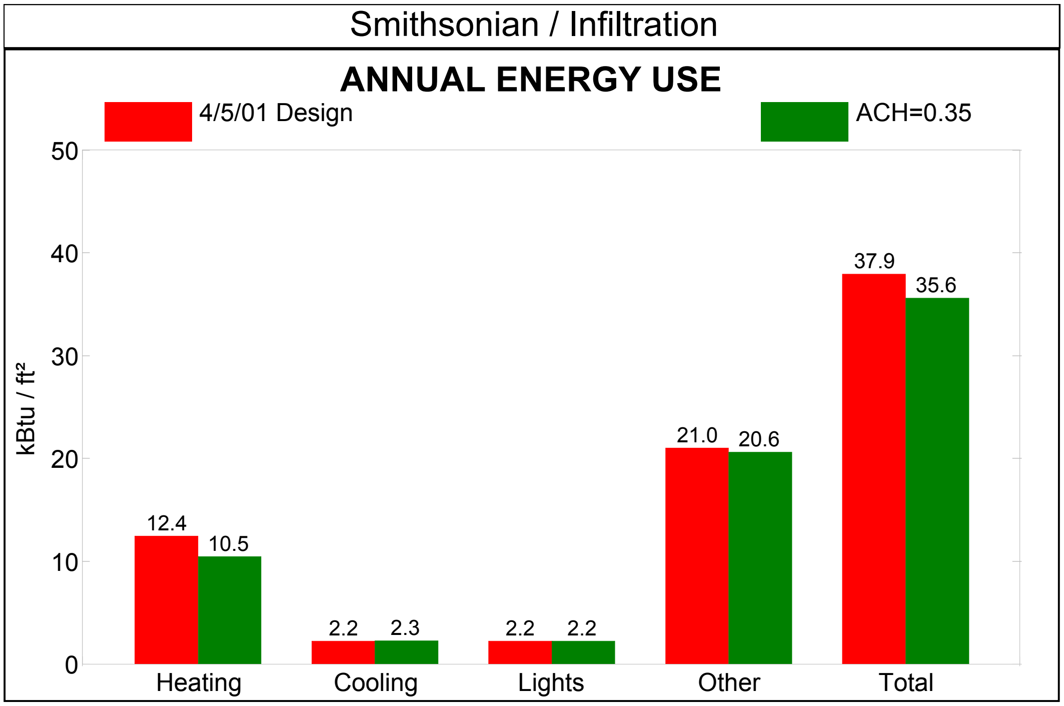

Figure 3. Energy use graph comparing the SERC housing as planned before and after applying air leakage control strategy.

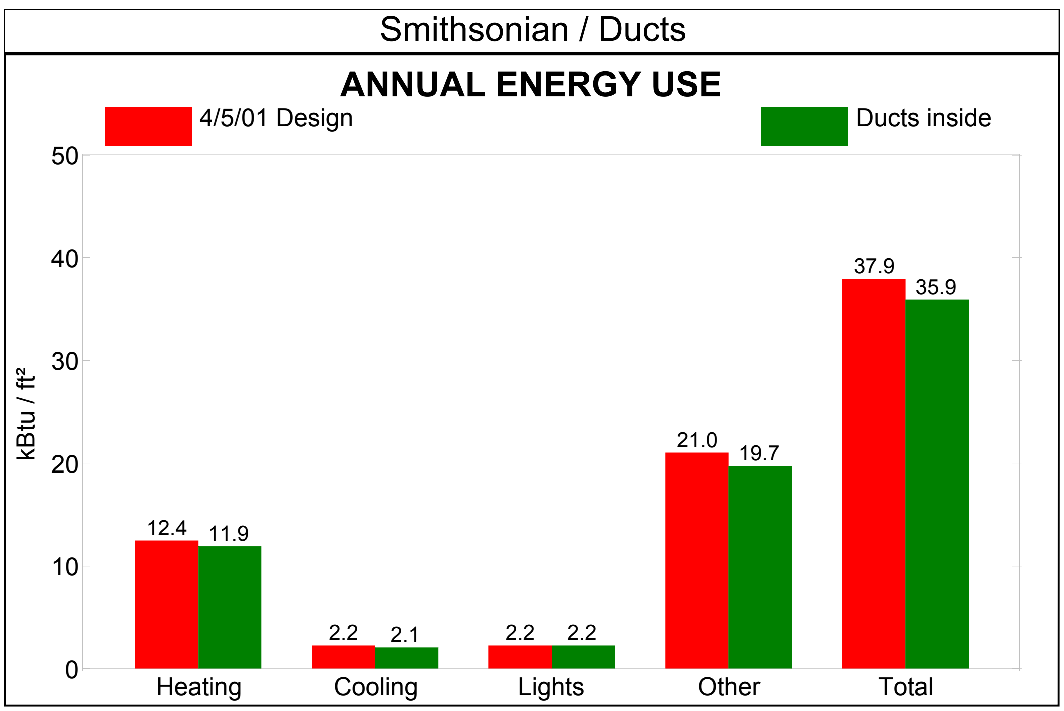

Figure 4. Energy use comparison between SERC housing with ducts as planned and with ducts placed inside conditioned space.

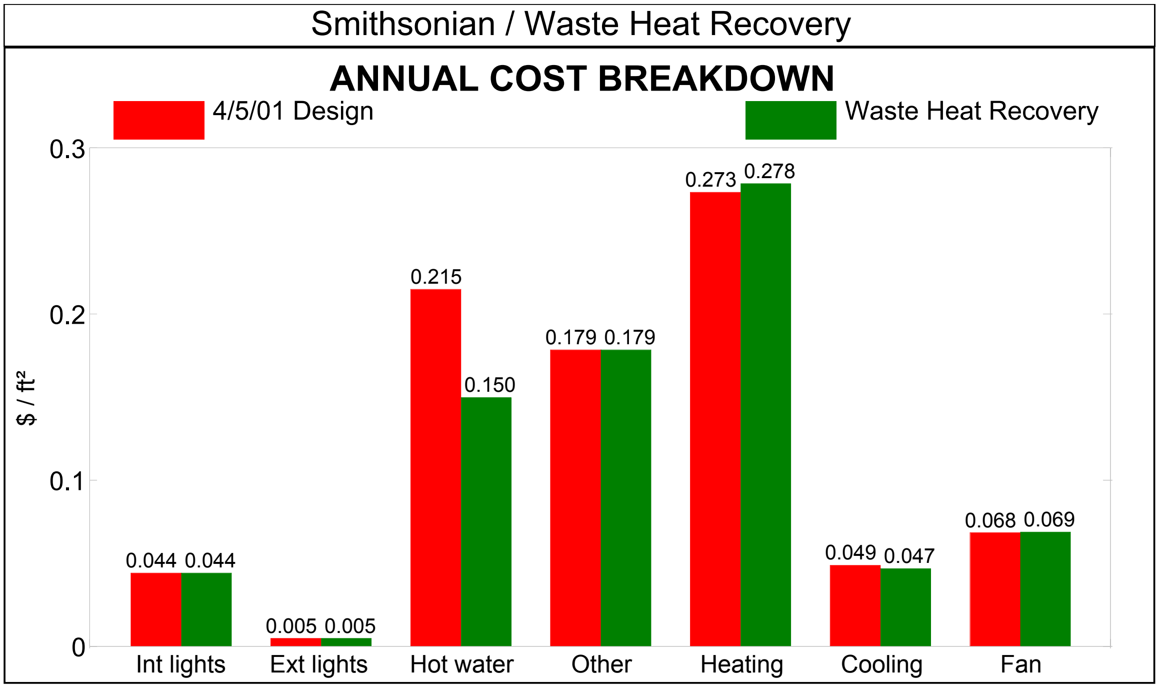

Figure 5. Graph demonstrating cost effectiveness of waste water heat recovery system.

Solar Water Heating Screening Analysis
Smithsonian Institution
Edgewater, MD
Estimate Daily Hot Water Load

Water Use =	62.5 Gallons/day

Calculate daily water heating energy load:

$L = M*C*(T_{cold}-T_{hot})$

M =	62.5 gal/day	237 kg/day	T_{hot} =	140 F	OR	60.0 C
	OR					
C =	0.0012 kWh/kg - C		T_{cold} =	47 F	OR	8.3 C

L = 18.0 kWh/day

Estimate solar system size:

$A_c = L/(R_{solar}*I_{max})$

R_{solar} = 40%
I_{max} = 5.6 kWh/m^2 day

A_c = 8.0 m^2

Figure 6. Example of the Solar Water Heating Screening Analysis spreadsheet.

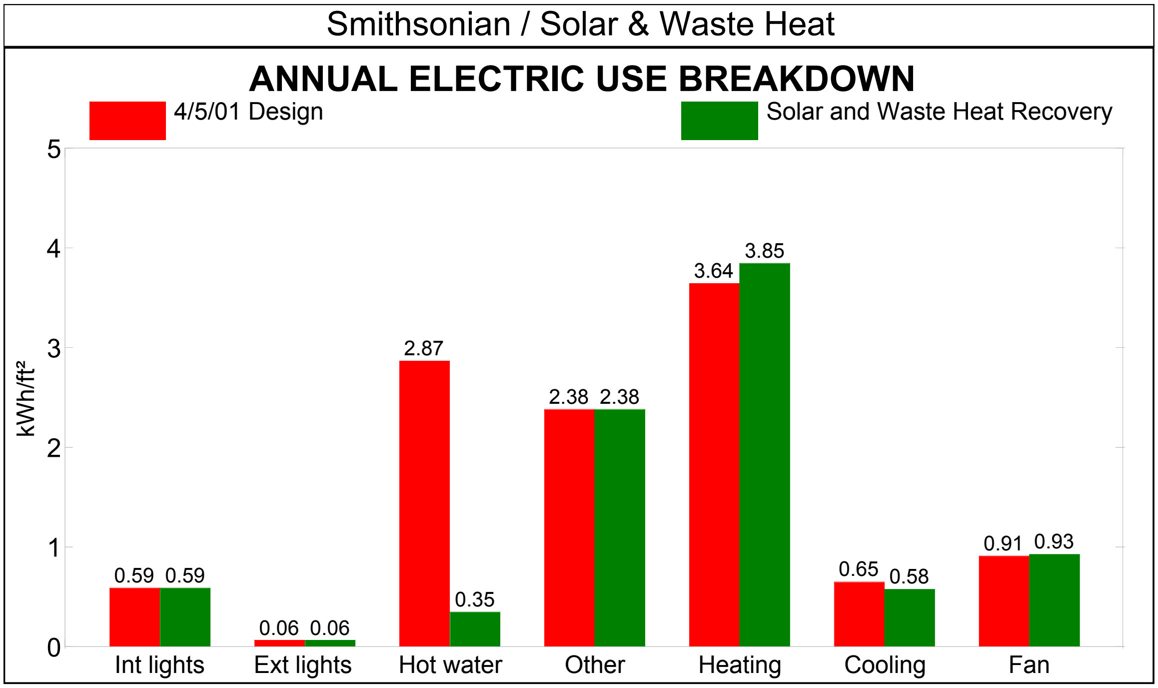

Figure 7. Graph of electric use before and after application of waste water heat recovery system and solar water heating system.

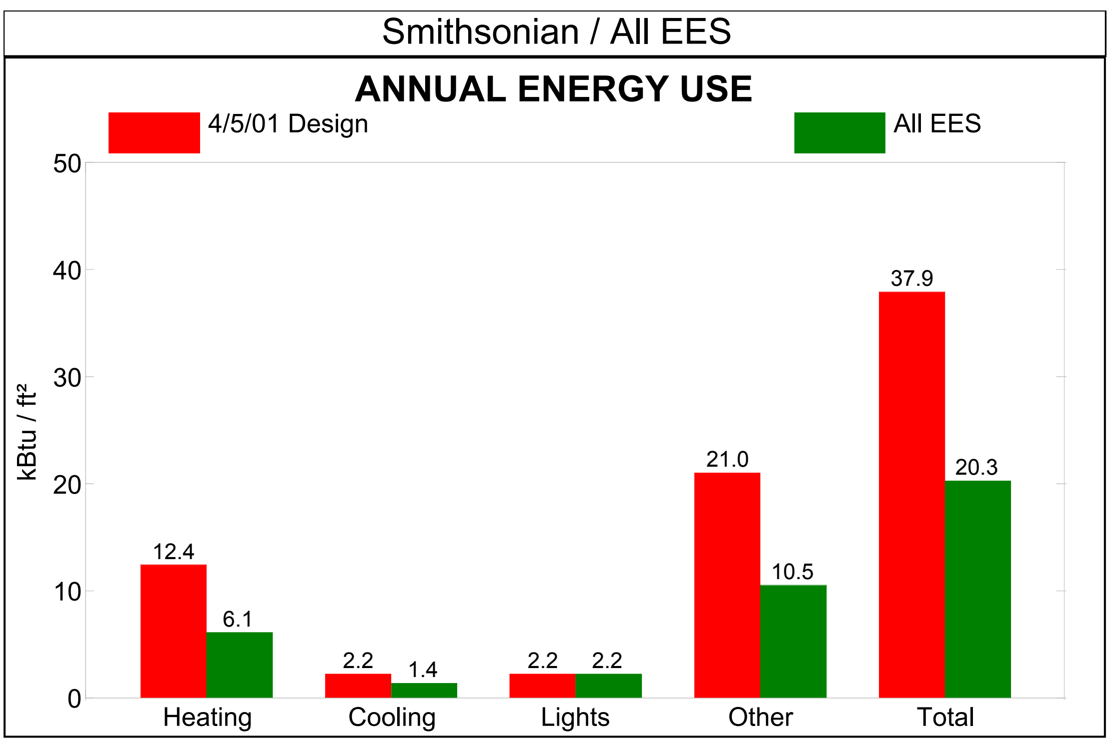

Figure 8. Annual energy use after applying all energy-efficient strategies.

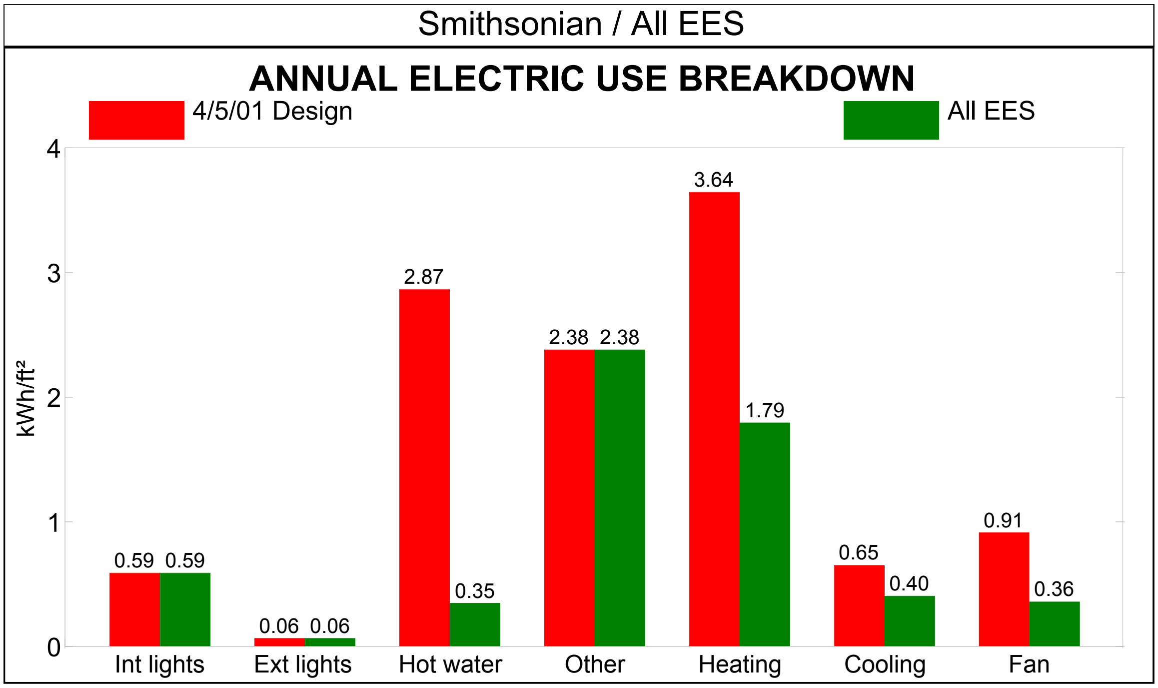

Figure 9. Breakdown of electric use before and after applying all energy-efficient strategies.

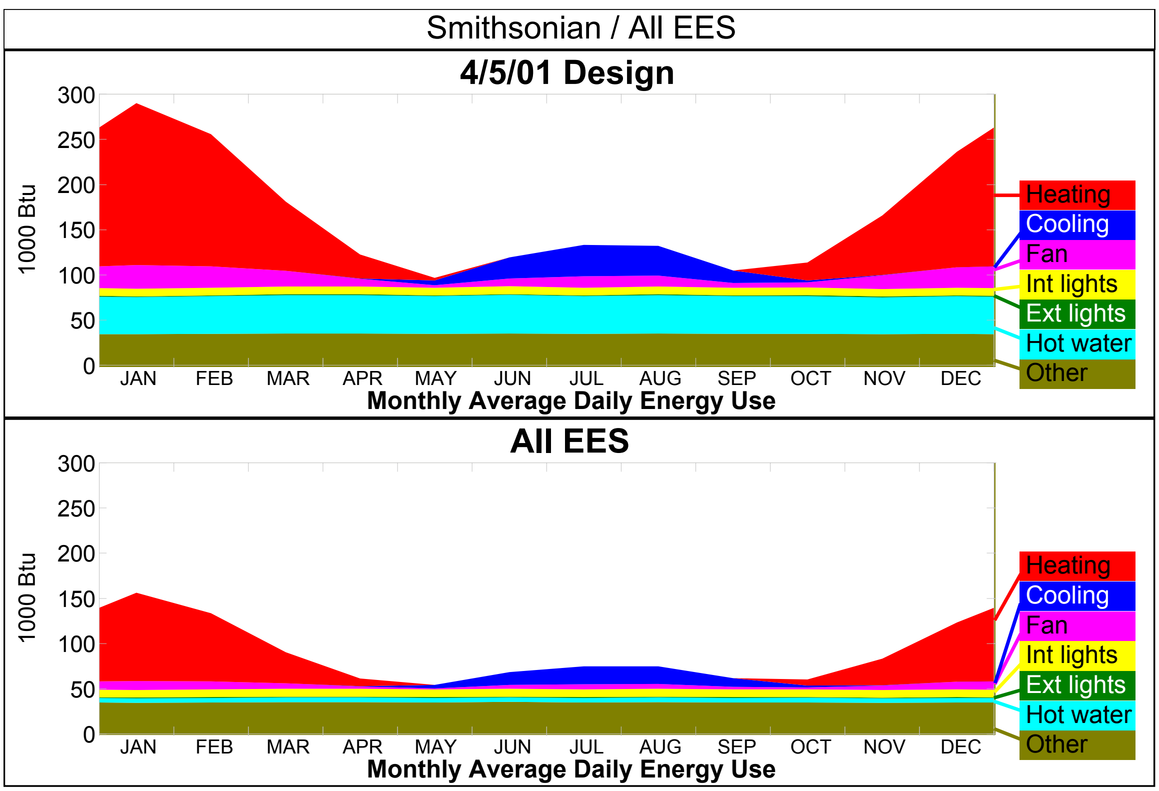

Figure 10. Monthly average daily energy use before and after applying energy-efficient strategies to SERC housing.

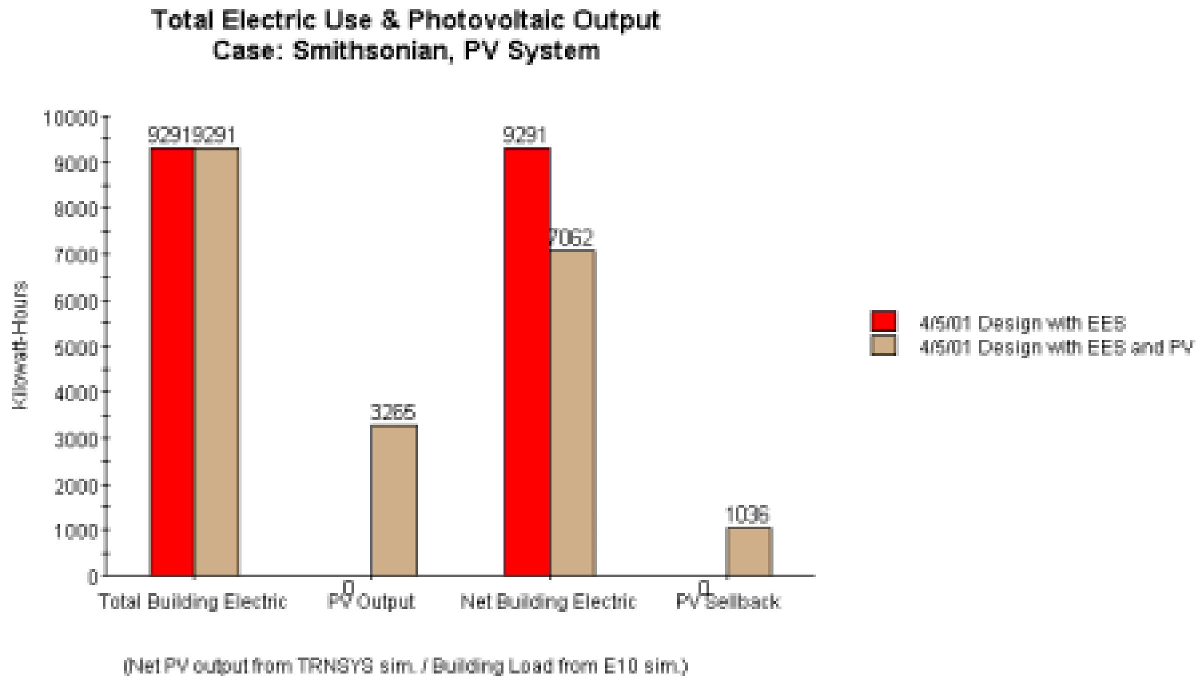

Figure 11. SERC housing with applied EES and PV system.

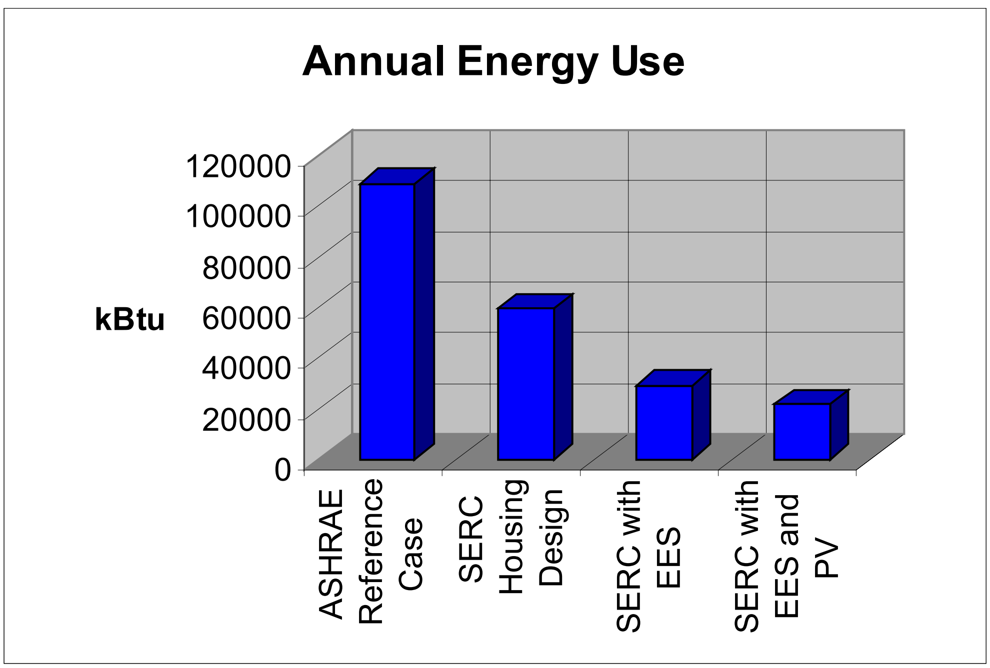

Figure 12. Annual Energy Use of ASHRAE 90.2 reference case, SERC housing design dated 4/5/01, SERC housing with applied EES, and SERC housing with applied EES and PV.

Tables

Table 1. Energy-10 Summary Sheet comparing ASHRAE reference case and SERC planned housing.

Description:	**ASHRAE Reference Case**	**4/5/01 Design**
Floor Area, ft^2	1564.5	1564.5
Surface Area, ft^2	3734.0	4287.6
Volume, ft^3	14862.8	14862.8
Surface Area Ratio	1.03	1.18
Total Conduction UA, Btu/h-F	506.1	262.1
Average U-value, Btu/hr-ft^2-F	0.136	0.061
Wall Construction	2 x 4 frame, R=15.8	2 x 6 frame, R=17.7
Roof Construction	attic, r-30, R=29.4	cathedral, 2x10, R=30.0,etc
Floor type, insulation	Crawl Space, Reff=22.6	Crawl Space, Reff=25.2
Window Construction	4060 double, alum, U=0.67	4070 wood, double, low-e, U=0.30,etc
Window Shading	None	south2 large,etc
Wall total gross area, ft^2	2169	2147
Roof total gross area, ft^2	782	1086
Ground total gross area, ft^2	782	1054
Window total gross area, ft^2	480	180
Windows (N/E/S/W:Roof)	6/4/6/4:0	1/2/4/2:0
Glazing name	double, U=0.49	double low-e, U=0.28
HVAC system	DX Cooling with Elect Furn	Air Source Heat Pump/ER Backup
Rated Output (Heat/SCool/TCool),kBtuh	58/43/58	29/13/18
Rated Air Flow/MOOA,cfm	1974/0	1441/0
Heating thermostat	70.0 °F, no setback	70.0 °F, setback to 65.0 °F
Cooling thermostat	78.0 °F, no setup	78.0 °F, setup to 83.0 °F
Heat/cool performance	eff=100,EER=7.6	COP=2.9,EER=11.5
Duct leaks/conduction losses, total %	11/10	6/2
Peak Gains; IL,EL,HW,OT; W/ft^2	0.20/0.04/0.66/0.36	0.15/0.03/0.66/0.36
Infiltration, in^2	ACH=0.5	ACH=0.5
Energy use, kBtu	108924	59313
Energy cost, $	2394	1303
Total Electric, kWh	31921	17382
Internal/External lights, kWh	1229/134	922/101
Heating/Cooling/Fan, kWh	14573/6311/1462	5702/1019/1427
Elec. Res./Heat Pump, kWh	14573/0	2885/2818
Hot water/Other, kWh	NC	NC
Peak Electric, kW	16.9	10.8
Fuel, hw/heat/total, kBtu	NC/NC/0	NC/NC/0
Emissions, CO_2/SO_2/NO_x, lbs	42902/252/131	23362/137/71

Table 2. Comparison of insulation strategies.

Insulation Strategies	Total Energy Use (kBtu)	Total Electric (kWh)	Total Energy Cost ($)
SERC planned housing	59,313	17,382	1,303
6” SIP (R = 24)	57,195	16,761	1,257
Attic (R = 60)	58,709	17,205	1,290
Cathedral SIP (R = 44.6)	58,835	17,242	1,293
Floor 2 x 10 foam (R = 35)	56,102	16,441	1,233
Combined Strategies	52,891	15,500	1,162

Table 3. HVAC comparisons.

HVAC System	Total Energy Use (kBtu)	Total Electric (kWh)	Total Energy Cost ($)
Air Source Heat Pump with ER Backup	59,313	17,382	1,303
DX Cooling with electric furnace	73,548	21,554	1,616
PTAC with ER Heat	66,226	19,408	1,455
PTAC with ER BB Heat	66,014	19,346	1,451
PTAC AA with ER Backup	57,291	16,790	1,259
Ground Source Heat Pump	49,521	14,514	1,088