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CONCEPTUAL DESIGN OF NET ZERO ENERGY CAMPUS RESIDENCE

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ABSTRACT

In response to both global and local challenges, the University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. A unique aspect of the Eco-house is the degree of student involvement; in accordance with UD's mission, interdisciplinary student teams from mechanical engineering, civil engineering and the humanities are leading the design effort. This paper discusses the conceptual design of a net-zero energy use campus residence, and the analysis completed thus far. Energy use of current student houses is analyzed to provide a baseline and to identify energy saving opportunities. The use of the whole-system inside-out approach to guide the overall design is described. Using the inside-out method as a guide, the energy impacts of occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment are discussed. The design of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house is described. Eco-house energy use is simulated and compared to the energy use of the existing houses. The analysis shows the total source energy requirements of the Eco-house could be reduced by about 340 mmBtu per year over older baseline houses, resulting in CO_2 emission reductions of about 54,000 lb per year and utility cost savings of about $3,000 per year. Detailed cost analysis and cost optimization have not been performed but are critical aspects of the UD Eco-house project, which will be performed in the future.

INTRODUCTION

Global warming, pollution, and deforestation present major environmental challenges. Non-renewable fossil fuels account for 82% of the world's energy consumption [1]. The use of fossil fuels is the primary contributor to global climate change and the source of the majority of all air pollution [2]. Landfills continue to be repositories for recyclable materials and clean water is difficult to obtain in many regions of world. Many old growth forests are being harvested for lumber production, and toxic materials are prolific in our work and living spaces. These pressing problems demand creative solutions.

Much of the student housing for upperclassmen at the University of Dayton (UD) was built in the early 1900s as housing for factory workers. These houses have minimal insulation and high infiltration rates. Many units are in need of replacement. Currently UD spends over $1 million per year on gas and electricity for the 400 houses in the student neighborhood. A significant portion of this cost is due to irresponsible energy practices. For example, students leave lights and computers on even when no one is home and leave doors and windows open even while heating or air conditioning [3].

In response to these global and local challenges, the University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. Across the United States, different college campuses, businesses, and private citizens have built cutting-edge environmentally-focused buildings. Examples include the College of Law at the University of Denver, The Lewis Center for Environmental Studies at Oberlin College, the Rose House in Portland, Oregon, and the Zero Energy Habitat House in Loudon County, Tennessee. A neighborhood in Vista Montaña, California, developed in conjunction with the US Department of Energy (DOE) Building America research program, is successfully incorporating Zero-Energy Homes into a residential community. DOE's goal is that a large number of new U.S. houses will be true net zero-energy homes by 2020 [4].

A common link between these buildings, besides meeting green or LEED building standards, is that they are principally designed by experienced builders and architects. In contrast, the design of the UD Eco-house is student driven. In accordance with UD's mission, interdisciplinary student teams from mechanical engineering, civil engineering and the humanities are leading the design effort. In addition, the completed Eco-house will be an environment for students to learn and live together in a positive, environmentally and socially conscious community. The Eco-house will also be a bridge between UD and several community partners, serving as a regional showcase of energy efficiency and green building practices for the community. The house will be extensively instrumented and monitored by students, and serve as a living experiment to guide the design of future generations of UD Eco-houses.

To achieve net-zero energy use, the Eco-house will be highly insulated and use high-efficiency appliances. Incorporation of geothermal and solar photovoltaic energy sources will result in zero net off-site energy use. Rain water will be collected and used to reduce municipal water consumption. The Eco-house will be constructed from environmentally-friendly materials.

This paper discusses the conceptual design of a net-zero energy use campus residence, and the analysis completed thus far. Energy use of current student houses is analyzed to provide a baseline and to identify energy saving opportunities. The use of the whole-system inside-out approach to guide the overall design is discussed. Using the inside-out method as a guide, the energy impacts of occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment are designed to be radically smaller than those in a typical house. As a result, renewable energy or lower entropy generating sources can be utilized. The design of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house is described. Eco-house energy use is simulated and compared to the energy use of the existing houses. Finally, conclusions are drawn and future work is noted. Detailed cost analysis and cost optimization have not been performed but are critical aspects of the UD Eco-house project, which will be performed in the future.

Baseline: Current UD Housing

In order to quantify savings from building an Eco-house, the energy use of current student houses must be understood. Most upperclassmen at the University of Dayton live in houses owned by the university. The houses fall into two categories. About 90% of the houses were constructed during the early 1900s. These older homes are wood-framed, with single-pane windows, no perimeter insulation, and little insulation in the walls and ceilings. As the university replaces these older units, new houses are being constructed with wood-frames, double pane windows, and fiberglass insulation in walls and ceilings. Both old and new houses will be used for comparison with the Eco-house.

The building practices described below are for the new houses. Walls consist of wood siding, 0.75-inch OSB sheathing, 2” x 4” wood stud frames built 16 inches on center with 4-inch fiberglass batt insulation, and ½-inch drywall on the interior surface. Assuming, winter convection coefficients, the R-value of the walls is about 13 hr-ft^2-F/Btu. The double-hung windows are double-pane, with vinyl frames. The windows have an R-value of about 2 (hr-ft^2-^{o}F/ Btu) and an average solar heat gain coefficient (SHGC) of about 0.531 [5]. The roof and ceiling consist of asphalt shingles, 0.75-inch OSB sheathing, attic space, 4-inch of fiberglass batt insulation, and drywall on the interior surface. The combined R-value of the roof and ceiling is about 16 hr-ft^2-F/Btu [6]. A blower door test measured the rate of infiltration to be 0.62 air changes per hour [7]. The houses use 80% efficient natural gas furnaces and natural gas hot water heaters with an average efficiency of about 55%. The air conditioners have a SEER of 10 (Btu/Wh).

Monthly electricity use for four new five-person houses is shown in Figure 1. The electricity use patterns are highly variable due to irregular occupancy. After adjusting for occupancy, average annual electricity use in a regularly occupied, un-air conditioned house is about 11,400 kWh.

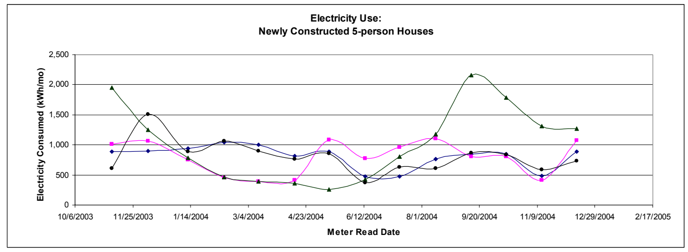


Figure 1. Electricity Use in Newly Constructed 5-person Houses.

Electrical appliances and lighting in the houses were inventoried and approximate operating hours were observed. The power draw of each type of electrical equipment was determined from nameplates and manufacturers data. Using this data, electricity use was broken down by equipment use and calibrated to match the 11,400 kWh measured annual electricity use (Table 1). Summary characteristics of the new baseline houses are shown in Table 2.

Table 1: Equipment Electricity Use in Baseline House

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
Lighting						
60 W Incandescent	60	17	1020	8	365	2,978
34 W T 12 4-foot 2-lamp flourescent	68	1	68	10	365	248
40 W Incandescent	40	5	200	5	365	365
Total Lighting						**3,592**
Appliances						
Electric Range	4100	1	4100	0.25	365	374
Dishwasher	1300	1	1300	0.25	365	119
Refrigerator	160	1	160	16.75	365	978
Washer	500	1	500	0.5	365	91
Dryer	5000	1	5000	0.5	365	913
Microwave	1300	1	1300	0.25	365	119
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
Total Appliances					365	**3,594**
Electronics						
Televisions	110	4	440	5	365	803
Stereos	30	4	120	1.5	365	66
Clocks	5	7	35	24	365	307
Computers	100	5	500	15.75	365	2,874
DVD Player/VCR	40	2	80	1.5	365	44
Gaming System	100	3	300	1	365	110
Total Electronics						**4,203**
Total Electricity Use						**11,389**

Annual and peak building energy use in a typical baseline house were simulated using the ESim building energy simulation software [8]. ESim simulates building energy use on an hour-by-hour basis using typical meteorological data [9]. ESim’s building load calculations consider heat exchange through the building envelope, solar loads, internal sources of heat and humidity, and air exchange. ESim is appropriate for passive-solar, single-zone and large multi-zone buildings with sophisticated HVAC systems and controls. The computational algorithms are based on fundamental thermodynamic, psychrometric and heat-transfer calculations. Solar radiation on each building surface is computed using the HDKR ansiotropic sky model [10]. Energy-storage effects are considered using transfer-function and finite-difference algorithms. Primary equipment efficiencies take into account part loading and ambient conditions. The performance of important HVAC control systems such as night-setback thermostats, economizer cycles, hot-deck reset schedules and VAV controls can be simulated.

Table 2. Summary of Baseline House Characteristics

Awalls (ft2)	2,002
Awindows (ft2)	78
Aceiling (ft2)	938
Number of occupants	5
Conditioned Floor Area (ft2)	1600
Perimeter length (ft)	104
Rwalls (hr-ft2-F/Btu)	13
Rwindows (hr-ft2-F/Btu)	2
SHGC	0.531
Rperimeter_insulation (hr-ft2-F/Btu)	0
Rceiling_roof (hr-ft2-F/Btu)	16
Infiltration (air changes per hour)	0.62
Internal Loads (kWh/mo)	950
Temperature Setbacks	None
Furnace Efficiency	0.8
SEER Air Conditioner (Btu/Wh)	10

Figures 2 and 3 show simulated and actual electricity and natural gas use of a newly constructed five-person university house. The actual electricity use data is from a house without air conditioning; however, the simulation includes air conditioning since many new houses will be occupied during the summer and air conditioning will be used. Except for summer air conditioning, the simulations are well calibrated to the actual energy use data. Simulated electricity consumption is 13,455 kWh per year with air conditioning and simulated natural gas consumption is 61.2 mmBtu per year including heating and hot water.

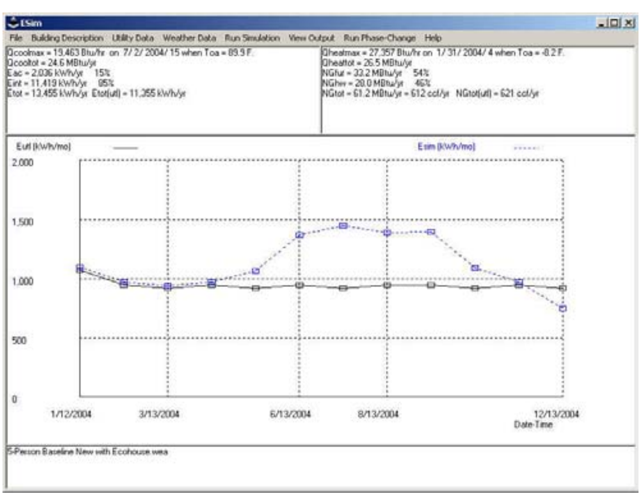


Figure 2. Baseline Electricity Use.

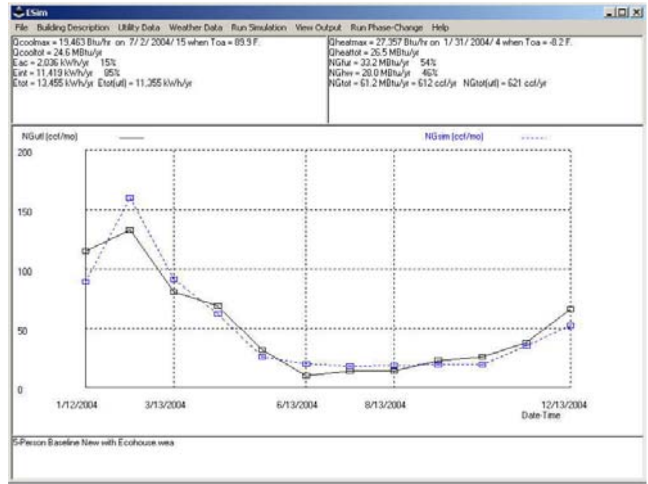


Figure 3. Baseline Natural Gas Use.

Inside-Out Approach

The inside-out approach is a structured method of analyzing opportunities for energy efficiency improvements that begins by focusing on the eventual end use of the energy and proceeds outward to the distribution system and energy conversion equipment. Application of the inside out-approach has been shown to maximize savings while minimizing first cost [11].

One reason for the success of the inside-out approach is the multiplicative effect of losses as energy is converted, distributed and used. For example, consider an electrical appliance that provides 1 kWh of useful work. If the appliance is 50% efficient, the electrical distribution system 93% efficient, and electrical power plant is 33% efficient, then, for every useful kWh provided by an appliance, the quantity of source energy consumed is:

1 kWh / (50% x 93% x 33%) = 6.5 kWh

This means that reducing 1 kWh of energy at the end use (inside) results in 6.5 kWh of energy savings at the source (outside). Thus, minimizing end use energy, then distribution losses and finally improving the efficiency of the primary energy conversion equipment tends to multiply savings.

For the conceptual design of the Eco House, this means sequentially focusing on:

- Occupant behavior
- Appliances and lighting
- Building envelope (walls, ceiling, windows, infiltration)
- Energy distribution system (pumps, fans, radiant panels)
- Primary space conditioning equipment (ground-source heat pump, etc.)
- Solar heating and electricity systems

Eco-house Occupant Behavior

Previous research has documented that occupant behavior significantly affects energy use in campus housing. For example, energy contests sponsored by the UD Sustainability

Club, which focused almost exclusively on occupant behavior, resulted in over $26,000 in energy savings over the course of two years [12].

The Eco-house will be populated by students motivated to practice energy-conscious behavior. Students will reduce electricity consumption by using natural lighting, and turning off lights, computers and televisions when not needed. Table 3 shows estimated electricity use with reduced appliance and lighting operating hours. The results indicate that electricity consumption could be reduced by about 33% from 11,389 kWh per year to 7,654 kWh per year.

Table 3. Equipment Electricity Use in Baseline House with Improved Occupant Behavior

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
Lighting						
60 W Incandescent	60	17	1020	6	365	2,234
34 W T 12 4-foot 2-lamp flourescent	68	1	68	8	365	199
40 W Incandescent	40	5	200	4	365	292
Total Lighting						2,724
Appliances						
Electric Range	4100	1	4100	0.25	365	374
Dishwasher	1300	1	1300	0.2	365	95
Refrigerator	500	1	500	2.5	365	456
Washer	500	1	500	0.5	365	91
Dryer	5000	1	5000	0.5	365	913
Microwave	1300	1	1300	0.2	365	95
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
Total Appliances					365	3,025
Electronics						
Televisions	110	4	440	2	365	321
Stereos	30	4	120	1	365	44
Clocks	5	7	35	24	365	307
Computers	100	5	500	6	365	1,095
DVD Player/VCR	40	2	80	1	365	29
Gaming System	100	3	300	1	365	110
Total Electronics						1,905
Total Electricity Use						7,654

Eco-house Appliances and Lighting

In the United States, residential electricity use makes up 35% of the total electricity use. Appliances account for about 60% of this; thus the use of energy efficient appliances can result in significant energy savings. For example, compact fluorescent lights save up to 73% of the energy consumed by incandescent bulbs. Laptop computers save 70% of the energy consumed by desktop computers [13]. Energy Star refrigerators save 50% of the energy consumed by low-end refrigerators [14]. Table 4 shows projected Eco-house electricity use from both reducing operating hours and using energy efficient appliances and lights. The results show that electricity consumption could be reduced to 4,997 kWh per year. This is 35% less than projected electricity consumption from solely reducing operating hours and 56% less than baseline electricity use.

Eco-house Building Envelope

Following the inside-out method, the next area to consider is the building envelope. Residential natural gas use accounts for 21.1% of the total natural gas use in the US, and space heating accounts for 66% of residential gas use [15]. Thus, space heating is a major target for improvement. To reduce space conditioning energy use, this section focuses on reducing thermal loads. Subsequent sections will focus on improving the energy efficiency of the distribution and primary energy conversion components of the heating and cooling systems.

Table 4. Electricity Use with Energy Efficient Appliances and Improved Occupant Behavior

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
Lighting						
18 W CF bulbs	18	17	306	6	365	670
34 W T 8 4-foot 2-lamp flourescent	58	1	58	8	365	169
13 W CF bulbs	13	5	65	4	365	95
Total Lighting						934
Appliances						
Electric Range	3750	1	3750	0.25	365	342
Dishwasher		1				181
Refrigerator		1				392
Washer		1				278
Dryer	1800	1	1800	1	365	710
Microwave	700	1	700	0.25	365	64
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
Total Appliances						2,968
Electronics						
Televisions	110	4	440	1.5	365	241
Stereos	30	4	120	1.5	365	66
Clocks	5	7	35	24	365	307
Computers	30	5	150	6	365	329
DVD Player/VCR	40	2	80	1.5	365	44
Gaming System	100	3	300	1	365	110
Total Electronics						1,095
Total Electricity Use						4,997

In order to reduce heating and cooling loads, Eco-house walls, ceiling, windows and perimeter insulation will have high thermal resistances. The walls and ceiling will be constructed with Structurally Insulated Panels (SIPs). SIPs are both tighter and more insulative than framed walls [16]. The proposed SIP wall structure, from exterior to interior, consists of exterior wood siding, ½-inch OSB, 8.5-inch polystyrene foam, ½-inch OSB and ½-inch drywall on the inside. Assuming winter wind conditions, the R-value for the proposed SIP walls is about 39 hr-ft2-F/Btu. The cathedral style roof/ceiling will be constructed of thicker SIPs. From outside to inside, the construction is light-colored asphalt shingles, felt paper backing, ½-inch OSB, 11.25-inch polystyrene foam, ½-inch OSB, ½-inch drywall. Assuming winter wind conditions, the R-value of the roof /ceiling is about 51 hr-ft2-F/Btu [6].

Significant winter heat loss and summer heat gain occurs through windows. In addition, poorly installed windows also increase air leakage into and from the house. The Eco-house will use low-emissivity, argon-filled Tripane SuperSpacer windows, which have a center-of-glass R-value of 4.76 and a solar heat gain coefficient of 0.65 [17].

Houses constructed with SIPs are far more airtight than typical frame houses, and require mechanical ventilation to maintain fresh indoor air. ASHRAE recommends a minimum ventilation rate of about 0.35 air changes per hour to prevent the build up of indoor air pollutants [18]. The Eco-house will have an air-to-air heat exchanger to pre-condition outside air by exchanging energy between the intake and exhaust air streams. To provide 0.35 air changes per hour, the heat exchanger will provide about 75 cfm with a heat exchanger effectiveness of 81% [6].

Perimeter insulation reduces heat transfer from the basement to the ground. The Eco-house will have insulated, pre-cast basement walls with an overall R-value of 23 hr-ft2-F/Btu [19].

Eco-house Heating and Cooling Distribution System
Typical UD student houses are heated by furnaces and cooled by air conditioners. In these houses, an air distribution fan blows air over heating and cooling coils, through ducts to the conditioned space. This method of distributing heat requires large volumes of air since air has a relatively low density and specific heat. The air distribution fan motors in UD houses are typically about 0.3 hp. Assuming a 0.3 hp motor is 75% loaded and 80% efficient, the motor draws about 210 W. Total fan motor electricity consumption depends on how often the fan runs. Simulation results, which assume a pressure drop of 2-inwg, indicate that annual supply fan electricity use is about 1,000 kWh/yr, which amounts to about 10% of all household electricity use.

To reduce distribution energy use, heating and cooling in the Eco-house will be delivered by hot and cold water streams that flow through microtubing mats in the ceiling. To minimize friction losses, panels will be arranged in parallel whenever possible. The piping configuration will use indirect return to assure equal flow through each panel. A separate thermostat will control each zone. Preliminary calculations indicate that the house will require 75 panels, and pump energy requirements, assuming continuous flow, will be about 120 kWh per year. An example of installed microtubing is shown in Figure 4.

Figure 4. Microtubing mats during and after construction [20].

In addition to the pump, the air-to-air heat exchanger employs two 75 cfm fans. Assuming the fan motors are 80% efficient, the fans are 70% efficient and the pressure drop is 1 inwg, the motors will consume about 380 kWh per year in continuous operation. Thus, total distribution electricity use will be about 500 kWh per year, which is about half of the distribution energy use in a typical UD residence.

Eco-house Primary Heating and Cooling
The next step in the inside-out design approach is to consider the primary heating and cooling equipment. The Eco-house will use a geothermal, water-to-water heat pump to provide warm and cool water for the microtube panels. The heat pump will transfer heat to and from water circulated through a ground loop, which acts as a heat source during winter and a heat sink during summer. A schematic of the proposed design is shown in Figure 5.

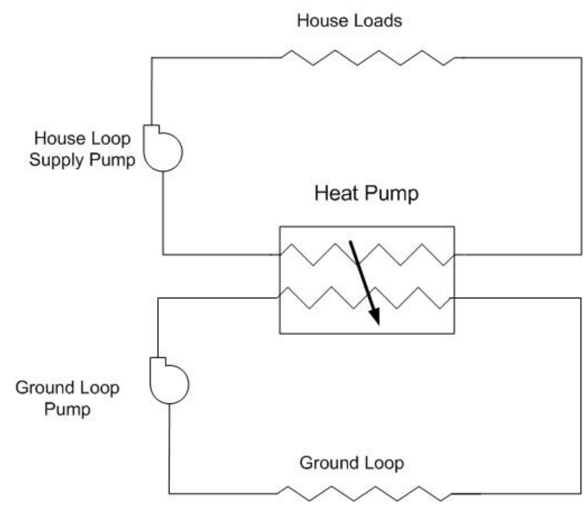


Figure 5. Geothermal heat pump schematic.

Preliminary calculations indicate that house-loop supply temperatures required for meeting peak heating and cooling loads are 84 F and 67 F, respectively [6]. The design volume flow rates through both the house and ground loops are 7 gpm. The average annual ground temperature for Dayton, Ohio is about 50 F. Assuming the ground loop supplies 42 F fluid to the heat pump during winter and 58 F fluid during summer, the heat pump will operate with an average heating COP of about 4.8 and an average cooling EER of about 24 (Btu/Wh) [21].

Eco-house Solar Water Heating
The inside-out approach was also applied to the hot water system. On the inside, energy and water-efficient dishwashers and clothes washers are assumed to reduce overall hot water use by 20%. In the distribution system, hot water supply temperature has been reduced from 60 C (140 F) in typical UD residences to 48.9 C (120 F). Finally, a solar thermal hot water system will be the primary source of heat for hot water. Supplemental heat will be provided by electric resistance heaters.

Energy use for domestic hot water was simulated using SolarSim software [22]. SolarSim uses typical meteorological data [9] to simulate the hourly performance of photovoltaic and solar thermal systems. SolarSim uses the Hay, Davies, Klucher, Reindl (HDKR) model for calculating incident solar energy on a surface [10]. The computational algorithms are based on fundamental thermodynamic, psychrometric and heat-transfer calculations. Using SolarSim, a solar thermal system was designed with three 2-m^2 solar collectors facing due south at a tilt angle of 52 degrees from the horizon. Collector [23] and system specifications for the system are shown in Figure 6.

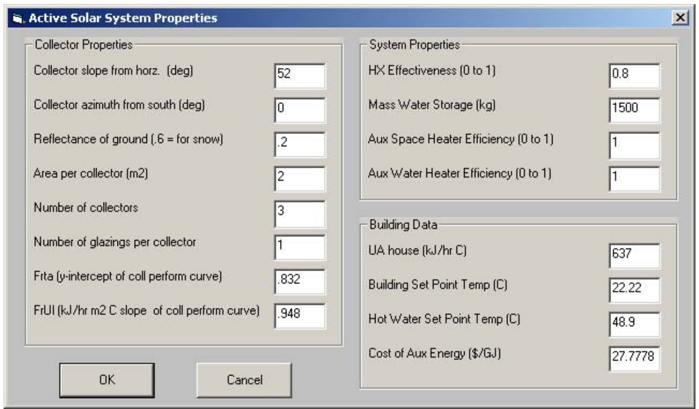
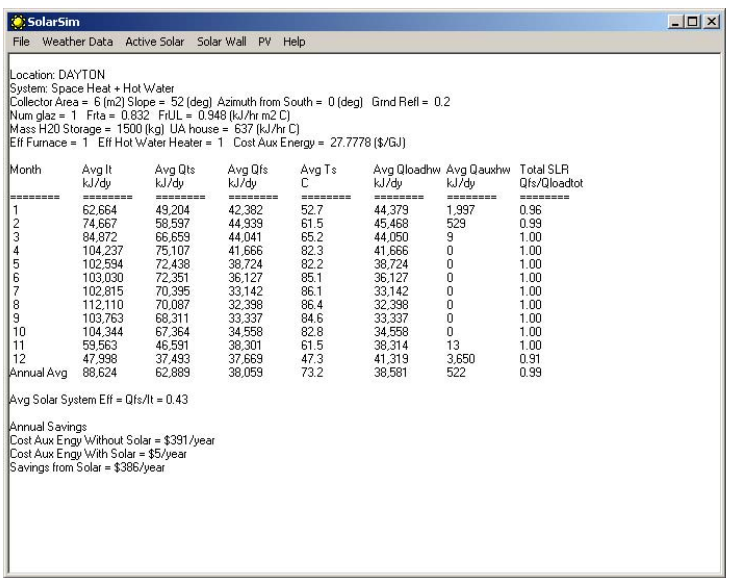


Figure 6. SolarSim input screen for modeling space and water heating.

Simulation results indicate that 3,858 kWh per year of the 3,911 kWh per year of electricity necessary for water heating will be provided by the solar system (Figure 7). The overall Solar Load Ratio will be 99%. Electric resistance heaters will provide an additional 53 kWh per year in supplemental hot water heating.


SolarSim
File Weather Data Active Solar Solar Wall PV Help

Location: DAYTON
System: Space Heat + Hot Water
Collector Area = 6 (m2) Slope = 52 (deg) Azimuth from South = 0 (deg) Grnd Refl = 0.2
Num glaz = 1 Frta = 0.832 FrUL = 0.948 (kJ/hr m2 C)
Mass H20 Storage = 1500 (kg) UA house = 637 (kJ/hr C)
Eff Furnace = 1 Eff Hot Water Heater = 1 Cost Aux Energy = 27.7778 ($/GJ)

Month	Avg It kJ/dy	Avg Qts kJ/dy	Avg Qfs kJ/dy	Avg Ts C	Avg Qloadhw kJ/dy	Avg Qauxhw kJ/dy	Total SLR Qfs/Qloadtot
1	62,664	49,204	42,382	52.7	44,379	1,997	0.96
2	74,667	58,597	44,939	61.5	45,468	529	0.99
3	84,872	66,659	44,041	65.2	44,050	9	1.00
4	104,237	75,107	41,666	82.3	41,666	0	1.00
5	102,594	72,438	38,724	82.2	38,724	0	1.00
6	103,030	72,351	36,127	85.1	36,127	0	1.00
7	102,815	70,395	33,142	86.1	33,142	0	1.00
8	112,110	70,087	32,398	86.4	32,398	0	1.00
9	103,763	68,311	33,337	84.6	33,337	0	1.00
10	104,344	67,364	34,558	82.8	34,558	0	1.00
11	59,563	46,591	38,301	61.5	38,314	13	1.00
12	47,998	37,493	37,669	47.3	41,319	3,650	0.91
Annual Avg	88,624	62,889	38,059	73.2	38,581	522	0.99

Avg Solar System Eff = Qfs/It = 0.43

Annual Savings
Cost Aux Engy Without Solar = $391/year
Cost Aux Engy With Solar = $5/year
Savings from Solar = $386/year

Figure 7. ESim Domestic Hot Water Results.

Eco-house Simulated Electricity Use

Annual building electricity use in the Eco-house was simulated using the software ESim [8]. The Eco-house building characteristics used in the simulation are summarized in Table 5. In the Eco-house Appliances and Lighting section of the report, it is estimated that annual appliance and lighting electricity use will be about 416 kWh/month. Preliminary calculations indicate that the house pump will consume about 10 kWh per month and the air-to-air heat exchanger fans will consume about 32 kWh per month. Based on the SolarSim simulation, auxiliary electricity use for hot water will be about 4 kWh per month. Thus, the total internal, non-space conditioning electricity use will be about 462 kWh/month.

Table 5. Summary of Eco-house Characteristics

Awalls (ft2)	2,002
Awindows (ft2)	78
Aceiling (ft2)	938
Number occupants	5
Conditioned floor area (ft2)	1,600
Basement perimeter (ft)	104
Rwalls (hr-ft2-F/Btu)	39
Rwindows (hr-ft2-F/Btu)	4.76
Window SHGC	0.65
Rbasement walls (hr-ft2-F/Btu)	23
Rceiling_roof (hr-ft2-F/Btu)	49
Ventilation (air changes per hour)	0.35
Air-to-air heat exchanger effectiveness	0.81
Internal electricity use (kWh/mo)	462
Occupied temperature set point (F)	72
Temperature setbacks (10pm – 8am)	
Winter (F)	68
Summer (F)	76
Heat Pump Coefficient of Performance	4.8
Heat Pump EER (Btu/Wh)	24
Ground loop pressure drop (ft H20)	5.5
Ground loop flow rate (gpm)	7

Using these input data and TMY2 weather data for Dayton, Ohio, simulated Eco-house electricity use is shown in Figure 8. ESim estimates that total Eco-house electricity use, including space conditioning and hot water heating, will be about 6,520 kWh per year.

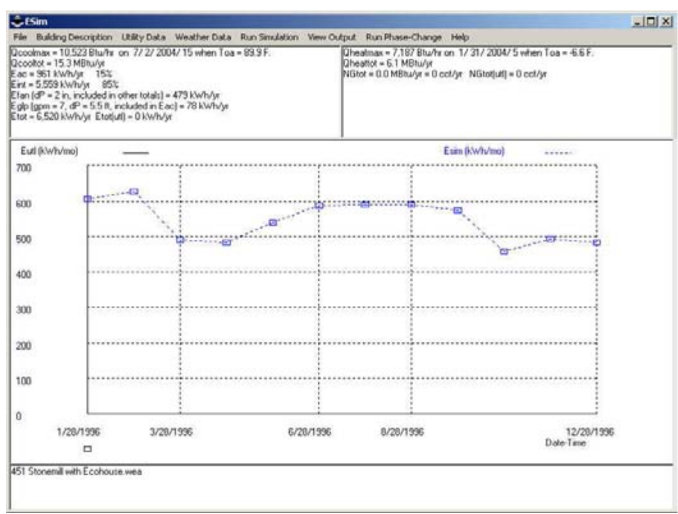


Figure 8. Simulated electricity use for the Eco-house.

The simulated electricity use of the Eco-house is compared to electricity use in older and newer baseline houses in Figure 9.

Annual electricity use in the newer baseline house is 13,455 kWh per year, and annual electricity use in the older baseline house is 15,581 kWh per year. Thus, the Eco-house will use about 51% less electricity than the new baseline house, and about 58% less electricity than the old baseline house.

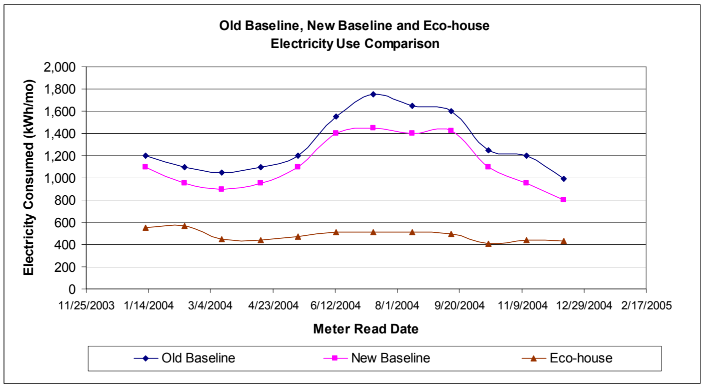


Figure 9. Comparison of electricity requirements for new baseline house and Eco-house.

Natural gas use in the older and newer baseline houses and the Eco-house are shown in Figure 10. The Eco-house will use no natural gas, compared to 61 mmBtu per year for the newer baseline house and 163 mmBtu per year for the older baseline house.

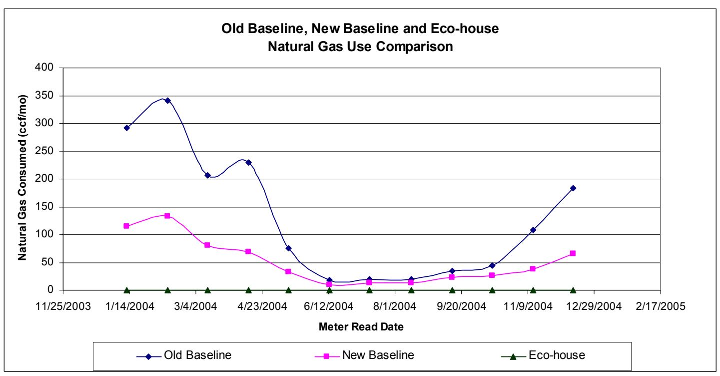


Figure 10. Comparison of older baseline, newer baseline and Eco-house natural gas use.

Eco-house Solar Electricity

To achieve net-zero energy use, the Eco-house will employ a photovoltaic solar system (PV) sized to generate the total electricity requirements of the house. When the PV system output exceeds house electricity requirements, excess electricity will be put into the utility grid and the house electricity meter will run backward. When the PV system does not provide enough electricity for the house, the Eco-house will purchase the required electricity from the utility.

The PV system was designed using the SolarSim simulation software. Based on these simulations, a system with 29 1.26-m^2 collectors, facing due South at a tilt angle of 33 degrees from the horizon was selected. The properties of the PV collector [24] and system, as entered in SolarSim, are shown in Figure 11.

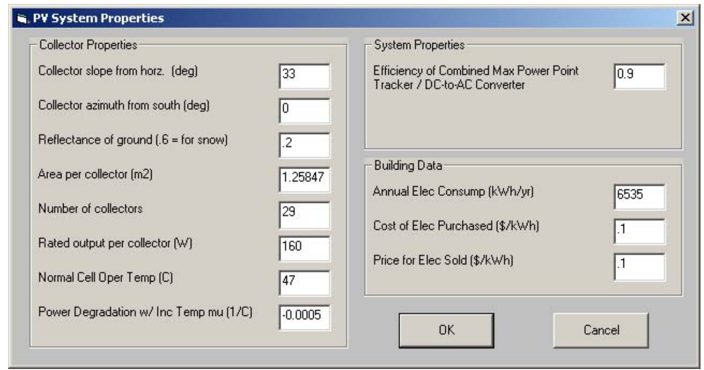


Figure 11. PV system inputs for SolarSim.

Based on this simulation, PV system output is estimated to be about 6,756 kWh per year (Figure 12). This will result in a net-positive cash flow of about $22 from the electrical utility to the Eco-house.

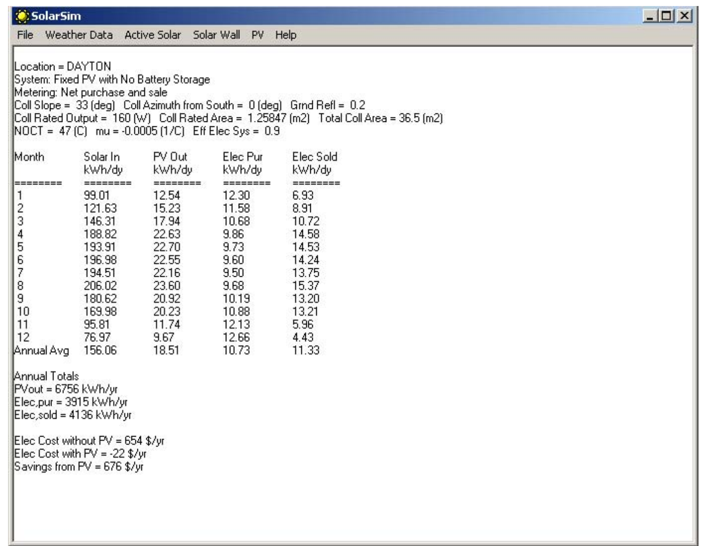


Figure 12. SolarSim Output.

Annual Savings Summary

According to these simulations, the Eco-house will save about 163 mmBtu per year in natural gas use and 15,581 kWh per year in electricity over the old baseline house, and 61.2 mmBtu per year in natural gas use and 13,455 kWh per year in electricity over the new baseline house. Assuming the total efficiency of the electrical generation and distribution is 30%, the total source energy savings from the Eco-house compared to the old baseline house and new baseline house will be about 340 mmBtu per year, and 214 mmBtu per year, respectively (Figure 13).

It is also appropriate to compare reductions in CO_2 emissions. The local utility generates about 2.3 lbs CO_2 for each kWh of electricity generated [25]. Assuming 10% excess air, about 113 lbs CO_2 are generated for each mmBtu of natural gas combusted. Using these numbers, the total CO_2 emission savings from the Eco-house compared to the old baseline house and new baseline house will be about 53,713 lbs per year and 37,964 lbs CO_2 per year, respectively (Figure 14).

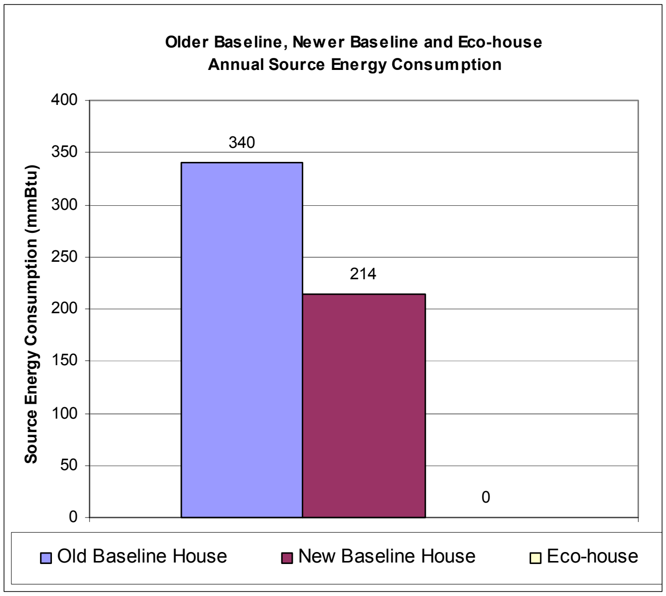


Figure 13. Source energy use of older baseline, newer baseline and Eco-house.

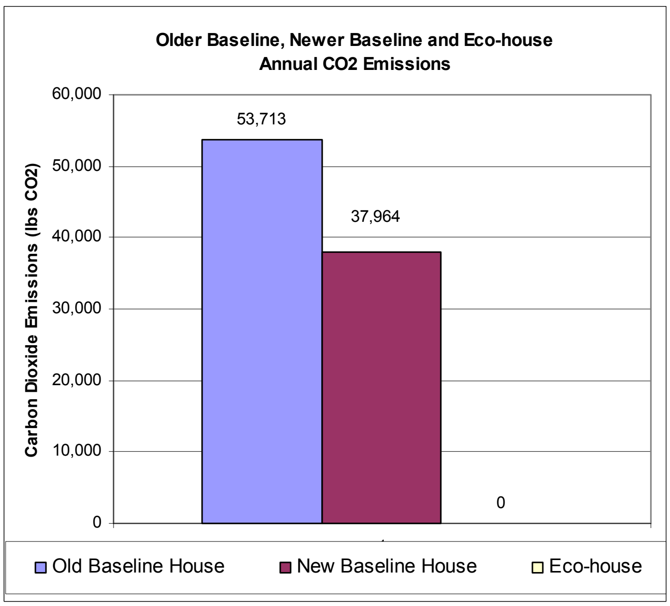


Figure 14. CO_2 emissions for older baseline, newer baseline and Eco-house.

The current cost of natural gas in the Dayton area is $9.40 per mmBtu and the cost of electricity is about $0.098 per kWh. Using these unit costs, the total energy cost savings from the Eco-house compared to the old baseline house and new baseline house will be $3,009 per year and $1,902 per year, respectively (Figure 15).

Summary and Future Directions

In response to both global and local challenges, the University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. This paper describes the conceptual design approach and early results. The University of Dayton Eco-house will be constructed the summer of 2006. A unique aspect of the Eco-house is the degree of student involvement; in accordance with UD's mission, interdisciplinary student teams from mechanical engineering, civil engineering and the humanities are leading the design efforts. Students living in the Eco-house will monitor the performance of the Eco-house systems, including solar thermal hot water system, solar photovoltaic system, energy efficient appliances and lighting, and heating and cooling systems. The design process follows an inside-out approach.

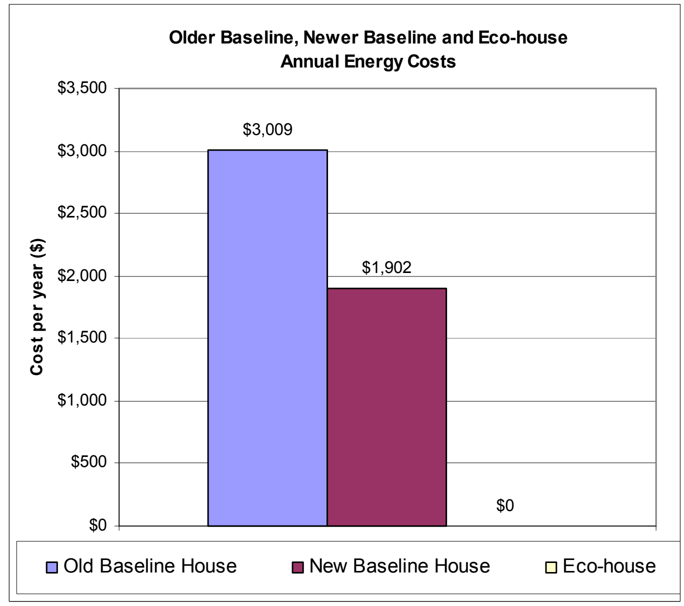


Figure 15. Energy costs of older baseline, newer baseline and Eco-house.

To achieve energy efficiency, the occupants will practice environmentally conscious behavior. To further reduce electricity use, energy efficient appliances and lighting will be used. Space conditioning loads are reduced by a highly-insulated building envelope with an air-to-air heat exchanger. To minimize distribution energy requirements, space conditioning energy will be delivered by a hydronic system and microtubing mesh. The primary heating and cooling equipment will be a high-efficiency ground-loop heat pump. Finally, the house will be powered by a grid-connected PV system. This design results in substantial source energy, CO_2 emission and annual cost savings.

This paper describes the conceptual approach used for designing a net-zero energy student residence and preliminary design calculations. Future work includes more detailed design and cost analysis. To support these efforts, better models of heat transfer through the hydronic microtubing mesh and ground loop will be developed. The issue of indoor air humidity will be further investigated. Use of thermal mass and night ventilation to reduce building cooling loads will be explored. Finally, a life-cycle cost analysis will be conducted to select and size components of the building structure, equipment, and energy supply systems [26].

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