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# COST-BENEFIT ANALYSIS 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 its cost effectiveness. This paper discusses both the design and cost-benefit analysis of a net-zero energy campus residence. Energy use of current student houses is presented to provide a baseline for determining energy savings. The use of the whole-system inside-out approach to guide the overall design is described. Using the inside-out method, the energy impacts of occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment are discussed. The designs of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house are described. Eco-house energy use is compared to the energy use of the existing houses. Cost-benefit analysis is first performed on house components and then on the whole house. At a 5% discount rate, 5% borrowing rate for a 20 year mortgage, a 35 year lifetime, and an annual fuel escalation rate of 4%, the Eco-house can be constructed for no additional lifetime cost.

## INTRODUCTION
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 both minimal insulation and high rates of infiltration. Currently UD spends over $1 million per year on gas and electricity for the student neighborhood. The University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. 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.

The motivation for the Eco-house along with its conceptual design is presented in full detail in the paper "Conceptual Design of a Net Zero Energy Campus Residence". This design followed the inside-out method to analyze the energy impacts of residential occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment. Since publication of "Conceptual Design of a Net Zero Energy Campus Residence", progress has been made on the design of the heating and cooling system, solar thermal system, and solar photovoltaic system. Design occupant behavior, lighting and appliances, walls and windows has remained unchanged.

This paper discusses in detail those house components which have been redesigned. Cost-benefit analysis of selected house components and the whole Eco-house design are presented. Conclusions are drawn from cost-benefit analysis of selected house components and synergistic benefits realized in the whole Eco-house design. Within the primary constraint of net-zero energy, we seek to design the Eco-house to be as economical as possible. In addition, we seek to use this experience to provide guidance for the design of future eco-houses and typical student housing. The cost-benefit analysis is performed using the real discount rate for the University and estimated fuel escalation rates. Lifetime owning and operating costs of current new construction and the Eco-house are brought back to present value and compared.

## Baseline Houses
For our analysis, two types of baseline houses were considered. The older houses on campus were built in the early 1900s as housing for factory workers. These houses have minimal insulation, high infiltration rates, inefficient appliances and lighting, single pane windows (some with storm windows), older furnaces, and older hot water heaters [1].

The University of Dayton is slowly replacing these older houses with newer, to-code houses. The walls have an R-value of 13 hr-ft$^2$-F/Btu, ceilings have an R-value of 16 hr-ft$^2$-F/Btu, and the windows have an R-value of about 2 hr-ft$^2$-$^o$F/ Btu. The rate of infiltration is about 0.62 air changes per hour; 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). A summary of baseline house characteristics may be found in Table 1.

 

Table 1. Summary of Baseline House Characteristics

| House Characteristics | Old House | New House |
|---|---|---|
| Awalls (ft2) | 2,002 | 2,002 |
| Awindows (ft2) | 78 | 78 |
| Aceiling (ft2) | 662 | 662 |
| Number occupants | 5 | 5 |
| Floor area (ft2) | 662 | 662 |
| Perimeter length (ft) | 104 | 104 |
| Rwalls (hr-ft2-F/Btu) | 4 | 13 |
| Rwindows (hr-ft2-F/Btu) | 0.90 | 2 |
| SHGC | 0.85 | 0.531 |
| Rperimeter_insulation (hr-ft2-F/Btu) | 0 | 10 |
| Rceiling_roof (hr-ft2-F/Btu) | 16 | 16 |
| Infiltration (ACH) | 1.21 | 0.62 |
| Internal Loads (kWh/mo) | 1108 | 949 |
| Temperature Setbacks (10pm - 8am) | None | None |
| Winter (F) | 72 | 72 |
| Summer (F) | 72 | 72 |
| Furnace Efficiency | 0.8 | 0.8 |
| COP Air Conditioner | 10 | 10 |
| HSPF Heat Pump | None | None |
| SEER Heat Pump | None | None |

Simulated electricity consumption in the newer baseline house is 13,455 kWh per year and 15,581 kWh per year in the older baseline houses. Simulated natural gas consumption in the newer baseline house is 61.2 mmBtu per year and 163 mmBtu per year in the older baseline houses. The current cost of natural gas in the Dayton area is $12.50 per mmBtu and the cost of electricity is about $0.088 per kWh. Using these unit costs, the total energy costs of the old baseline house and new baseline house are $3,409 and $1,949, respectively.

## Inside-Out Design Approach and Component Economic Analysis

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 [2]. One reason for the success of the inside-out approach is the multiplicative effect of losses as energy is converted, distributed and used. For the design of the Eco House, this means sequentially focusing on occupant behavior, appliances and lighting, building envelope, energy distribution system, primary space conditioning equipment and finally solar heating and electricity systems.

### *Occupant Behavior*

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 electronics when not needed. These students will also keep the house at an efficient temperature and reduce their overall water use. Results indicate that electricity consumption could be reduced by about 32% from 11,399 kWh per year to 7,759 kWh per year [1].

### *Appliances and Lighting*

The Eco-house will incorporate compact fluorescent lights and Energy Star appliances. By improving occupant behavior and using energy efficient appliances and lights, electricity consumption could be reduced to 4,985 kWh per year. This is 36% less than projected electricity consumption from solely reducing operating hours and 56% less than baseline electricity use [1].

The EnergyStar dishwashers currently installed in baseline houses use 328 kWh per year and cost $279. A more energy efficient model uses about 278 kWh per year and costs $780. An even more energy efficient model uses 231 kWh per year costs $1,100. For subsequent cost-benefit analysis on house components will use a real discount rate of 5%, a fuel escalation rate of 4%, and a present natural gas and electricity costs of $12.50 per mmBtu and $0.088 per kWh. The net-present value of owning and operating each system for 13 years is summarized in Table 2. Considering the net present value of owning and operating dishwashers, the energy efficient model was chosen for the Eco-house design.

Table 2. Dishwasher Net-Present Value

| | Baseline | Energy Efficient | Super Efficient |
|---|---|---|---|
| First Cost ($) | $279 | $780 | $1,100 |
| Annual Energy Cost ($/yr) | $29 | $24 | $20 |
| Net Present Value Total Cost ($) | $630 | $1,078 | $1,347 |

The refrigerators currently installed in baseline houses use 479 kWh per year and cost $449. A more energy efficient model uses about 409 kWh per year and costs $679. Despite the apparent cost-ineffectiveness of choosing the energy efficient model, because the current refrigerators are not EnergyStar, the energy efficient model was chosen for the Eco-house design. The net-present value of owning and operating each refrigerator for 13 years is summarized in Table 3.

Table 3. Refrigerator Net-Present Value

| | Baseline | Energy Efficient |
|---|---|---|
| First Cost ($) | $449 | $679 |
| Annual Energy Cost | $42 | $36 |
| Net Present Value Total Cost | $962 | $1,117 |

### *Building Envelope*

Space conditioning 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.

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) from R-Control Systems. SIPs are both tighter and more insulative than framed walls [3]. 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. The R-value of the roof /ceiling is about 51 hr-ft2-F/Btu [4].

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 North, East, and West facing windows will be low-emissivity, triple-pane windows with a center of glass U-value below 0.2 Btu/hr-ft2-F and SHGC below 0.3. On the South side, the windows will be low-emissivity, triple-pane windows with a center of glass U-value below 0.35 Btu/hr-ft2-F and SHGC above 0.4.

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 (ASHRAE, 1989). The Eco-house will have an energy recovery ventilator (ERV) to pre-condition outside air by exchanging energy between the intake and exhaust air streams. To provide 0.35 air changes per hour, the energy recovery ventilator will provide about 75 cfm with an effectiveness of 52% [4].

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 [5].

The current walls in newly constructed 5-person homes at UD have an R-value of about 13 hr-ft$^2$-F/Btu, and a cost of construction of about $25,200. Natural gas and electricity for space conditioning with the current walls is about 33.2 mmBtu and 2,036 kWh per year. Six inch SIP panels could be installed with an R-value of about 26 hr-ft$^2$-F/Btu, and a cost of construction of about $28,300. Natural gas and electricity for space conditioning with 6-inch SIPs would be about 3.5 mmBtu and 2,025 kWh per year. Ten-inch SIP panels could be installed with an R-value of about 41 hr-ft$^2$-F/Btu, and a cost of construction of about $34,300. Natural gas and electricity for space conditioning with 10-inch SIPs would be about 1.4 mmBtu and 2,016 kWh per year. The net-present value of owning and operating each system for 35 years is summarized in Table 4. The 6-inch SIP wall has the lowest present value of owning and operating costs, however the 10-inch SIP wall was chosen for the design of the Eco-house in order to ensure the net-zero energy design requirement with a limited roof space for solar photovoltaic collectors.

Table 4. SIP Net-Present Value

| | Baseline | SIP 6" | SIP 10" |
|---|---|---|---|
| First Cost ($) | $25,200 | $28,300 | $34,300 |
| Annual Energy Cost | $594 | $226 | $195 |
| Net Present Value Total Cost | $42,787 | $34,981 | $37,598 |

### *Heating and Cooling System*

Typical UD student houses are heated by furnaces and cooled by air conditioners. In these houses, a constant air volume distribution fan blows air over heating and cooling coils, through ducts to the conditioned space. Simulation results, which assume a pressure drop of 2-inwg, indicate that annual supply fan electricity use is about 1,000 kWh/yr [1]. Eco-house heating, cooling and ventilation will also be supplied through ductwork. The Eco-house will use an air-to-air heat pump with a variable speed fan to distribute heating and cooling. According to ESim, the peak heating and cooling loads for the Eco-house are 9,260 Btu/hr and 9,851 Btu/hr. The heat pump is rated at 2 tons and has the capability to independently control air temperature and humidity. Additionally, the heat pump has internal electric resistance heating elements that supply heat when the outdoor air temperature is too low. Heat pumps are usually more efficient than electric resistance heating. However, when the outdoor air temperature falls below a certain temperature, air-to-air heat pumps become less efficient than electric resistance heating. According to system specifications, the heat pump will operate with an average COP of about 9.4 and an average cooling SEER of about 14.5 (Btu/Wh) [6]. Calculations indicate that the ½ hp variable speed fan on the air-to-air heat pump will use about 188 kWh per year in electrical energy.

The natural gas furnace which is currently installed in newly constructed 5-person homes at UD has an AFUE of 0.94, a lifetime of about 18 years and a cost of $1,978. The air conditioner has a SEER of 10.2, a lifetime of 13 years and a cost of $650 [7]. Natural gas and electricity for space conditioning is about 33.2 mmBtu and 2,036 kWh per year. A more efficient natural gas furnace could be installed with an AFUE of .966, a lifetime of about 18 years and a cost of $2,400. A more efficient air conditioner could be installed with an SEER of 16, a lifetime of about 18 years and a cost of $1,850. Natural gas and electricity for space conditioning would be about 32.4 mmBtu and 1,272 kWh per year. A highly efficient heat pump could be installed with an HSPF of 8.85 and SEER of 14.7, a lifetime of about 18 years and a cost of $2,775. Electricity for space conditioning would be about 5,313 kWh per year. The net-present value of owning and operating each system for 13 years is summarized in Table 5. The highly efficient heat pump was chosen for the Eco-house design. It is also the most cost-effective of the three options.

Table 5. Space Conditioning Net-Present Value

| | Baseline | Energy Efficient | Heat Pump |
|---|---|---|---|
| First Cost ($) | $2,628 | $4,250 | $2,775 |
| Annual Energy Cost ($/yr) | $594 | $517 | $468 |
| Net Present Value Total Cost ($) | $9,856 | $10,539 | $8,463 |

### *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 a traditional high-efficiency, electric hot water heater. A schematic of the hot water system is shown in Figure 1.

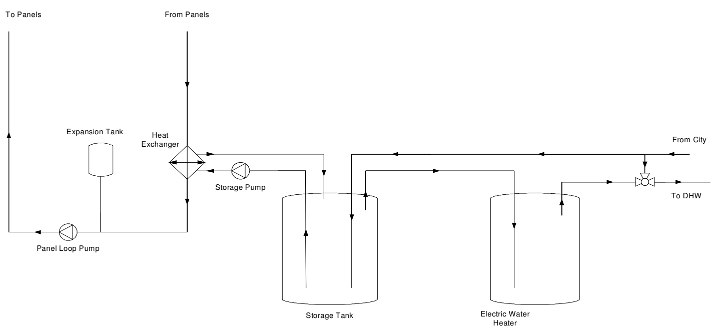


Figure 1: Solar Hot Water System

Energy use for domestic hot water was simulated using SolarSim software [8]. SolarSim uses typical meteorological data [9] to simulate the hourly performance of photovoltaic and solar thermal systems. Using SolarSim, a solar thermal system was designed with two 3.74 $m^2$ solar collectors facing due south at a tilt angle of 44 degrees from the horizon. The FrTa (y-intercept of collector performance curve) is 0.74 and the FrUl (slope of performance curve) is 1.527 [10]. The heat exchanger is 80% effective and the system has 120 gallons of storage. Simulation results indicate that 97% of the solar hot water heating load will be provided by the solar system (Figure 7). The electric hot water heater will provide an additional 122 kWh per year in supplemental hot water heating.

The water heaters which are currently installed in newly constructed 5-person homes at UD have an energy factor of 0.58, an average life expectancy of about 13 years and a cost of $480 [7]. Natural gas for hot water in these homes is about 28.0 mmBtu per year. A more efficient water heater could be installed with an energy factor of 0.63 an average life expectancy of 13 and a cost of $580. Natural gas use for this hot water heater would be about 23.6 mmBtu per year. A solar water heating system including three 1.71 $m^2$ collectors, dedicated PV pump, and hot water tank could be installed for about $3,735. The solar water heating system has an estimated lifetime of 15 years. The net-present value of owning and operating each system for 13 years is summarized in Table 6. The solar water heating system was chosen for the Eco-house design to supporting the design constraint of net-zero energy. It is also the most cost-effective.

Table 6. Hot Water Net-Present Value

| | Baseline | Energy Efficient | Solar Water Heater |
|---|---|---|---|
| First Cost ($) | $480 | $580 | $3,735 |
| Annual Energy Cost ($/yr) | $365 | $307 | $0 |
| Net Present Value Lifetime Cost ($) | $4,918 | $4,315 | $3,735 |

### *Electricity Use*

Annual building electricity use in the Eco-house was simulated using the software ESim [11]. The Eco-house building characteristics used in the simulation are summarized in Table 7. 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 (4,997 kWh/year). Preliminary calculations indicate that 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 16 kWh per month. Thus, the total internal, non-space conditioning electricity use will be about 464 kWh/month.

ESim estimates that total Eco-house electricity use, including space conditioning and hot water heating, will be about 6,500 kWh per year. 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 52% less electricity than the new baseline house, and about 58% less electricity than the old baseline 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. Monthly electricity and natural gas use of all three houses are shown in Figures 9 and 10 in “Conceptual Design of a Net Zero Energy Campus Residence” [1].

Table 7. Summary of Eco-house Characteristics

| House Characteristics | Old House | New House | Eco-House |
|---|---|---|---|
| Awalls (ft2) | 2,002 | 2,002 | 2,170 |
| Awindows (ft2) | 78 | 78 | 150 |
| Aceiling (ft2) | 662 | 662 | 698 |
| Number occupants | 5 | 5 | 5 |
| Floor area (ft2) | 662 | 662 | 698 |
| Perimeter length (ft) | 104 | 104 | 109 |
| Rwalls (hr-ft2-F/Btu) | 4 | 13 | 39 |
| Rwindows (hr-ft2-F/Btu) | 0.90 | 2 | 5 |
| SHGC | 0.85 | 0.531 | 0.3 |
| Rperimeter_insulation (hr-ft2-F/Btu) | 0 | 10 | 23 |
| Rceiling_roof (hr-ft2-F/Btu) | 16 | 16 | 49 |
| Infiltration (ACH) | 1.21 | 0.62 | 0.35 |
| Internal Loads (kWh/mo) | 1108 | 949 | 416 |
| Temperature Setbacks (10pm - 8am) | None | None | Yes |
| Winter (F) | 72 | 72 | 66 |
| Summer (F) | 72 | 72 | 78 |
| Furnace Efficiency | 0.8 | 0.8 | None |
| COP Air Conditioner | 10 | 10 | None |
| HSPF Heat Pump | None | None | 9.4 |
| SEER Heat Pump | None | None | 14.5 |

### *Onsite Electricity Generation*

To achieve net-zero energy use, the Eco-house will employ a photovoltaic solar system (PV) sized to generate the total annual electricity requirements of the house. The PV system was designed using the SolarSim simulation software. Based on these simulations, a system with 32 1.3-$m^2$ collectors, facing due South at a tilt angle of 33 degrees from the horizon was selected. The collectors have a 165 W rating at 47 C normal operating temperature [12]. Based on this simulation, PV system output is estimated to be about 6,577 kWh per year (Figure 12).

Figure 2 shows simulated monthly Eco-house PV production and simulated monthly energy use. One can see that the PV system will produce more electricity than the house needs during most of the year and drop off significantly in the winter.

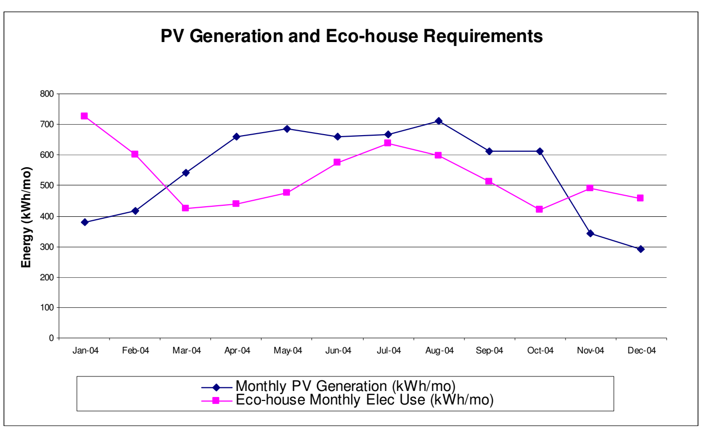


Figure 2: Eco-house PV Generation and Electricity Requirements

## Whole House Cost-benefit Analysis

So far, the design has shown that the Eco-house can be a net-zero energy house. In the following sections, economic analysis is presented to examine the cost-effectiveness of the Eco-house. The following analysis uses real historical fuel escalation rates for Dayton, Ohio and is bracketed by 1% and 4% annual fuel escalation rates as its upper and lower limits. The real interest rate and discount rate for the University of Dayton are used. Estimated additional costs for Eco-house construction are presented. Economic analysis is performed using the estimated first cost for construction and lifetime of the new baseline house and the Eco-house. Cost benefit analysis is performed using all costs as their net present value.

### *Eco-House Annual Electricity Cost*

Although the Eco House is designed to use no energy on a net basis over the year, the cost of energy for the house will not be zero. Current Ohio Law mandates that electric utilities install a single meter to measure the net amount of electricity used (or generated) by the house each month. However, the law permits utilities to sell electricity for the standard residential rate and purchase electricity for their lowest avoided cost. According to DP&L's net-metering regulations, customers may generate excess electricity by solar, wind, biomass burning, hydro power, or fuel cells. The electricity can be fed into the electrical grid and the customer will be compensated according to their shopping credit tariff.

When billing, the utility generally breaks up the electricity tariff into three components, generation, transmission and distribution. The customer is further billed on additional riders, the excise tax surcharge rider, emission fee recovery rider, universal service fund rider, and the energy efficiency surcharge rider. In order to quickly calculate monthly bills, a customer could break these charges into a monthly service charge, which is typically fixed, and a monthly energy charge, based on the number of kWh consumed. According to the Dayton Power and Light Residential Electricity Tariff, the monthly service charge is $4.25 and electrical energy charges are $0.08844 per kWh for the first 750 kWh and $0.07780 per kWh for all kWh over 750 kWh. Since both traditional homes and the Eco-house would be billed the same service charge, it will be ignored in the billing calculation. Homes in the student neighborhood never consume more than 750 kWh per month, so the price of electricity remains in the first block, at $0.088 per kWh. Credits for electricity fed into the grid will be calculated on a net-monthly basis and will appear as credits on the next bill. For residential energy generation, credits will be $0.05338 per kWh for first 750 kWh and $0.04332 per kWh for all kWh over 750 kWh. The Eco-house solar system will never produce more than 750 kWh to sell back to the utility, so the electricity credit will always be $0.05338 per kWh sold. So, using current prices and rates, DP&L will sell electricity for about $0.088 per kWh and purchases it for $0.053 per kWh.

The electricity produced by the photovoltaic system is presented along with the electricity requirements of the Eco-house in Table 8. The monthly electricity charges, credits and annual utility costs are calculated.

Table 8: Monthly PV Generation, Electricity Use and Utility Charges

| Month | Monthly PV Generation (kWh/mo) | Eco-house Monthly Elec Use (kWh/mo) | Monthly Elec Purchased (kWh/mo) | Electricity Cost |
|---|---|---|---|---|
| 1/12/2004 | 379 | 725 | 373 | $32.87 |
| 2/12/2004 | 415 | 602 | 214 | $18.80 |
| 3/13/2004 | 542 | 425 | -89 | -$4.74 |
| 4/13/2004 | 661 | 439 | -195 | -$10.32 |
| 5/13/2004 | 685 | 477 | -181 | -$9.61 |
| 6/13/2004 | 659 | 574 | -58 | -$3.07 |
| 7/13/2004 | 669 | 638 | -4 | -$0.19 |
| 8/13/2004 | 712 | 598 | -88 | -$4.67 |
| 9/13/2004 | 611 | 512 | -72 | -$3.82 |
| 10/13/2004 | 611 | 420 | -164 | -$8.71 |
| 11/13/2004 | 343 | 490 | 174 | $15.33 |
| 12/13/2004 | 292 | 459 | 194 | $17.04 |
| Total: | | 6,360 | 103 | $38.90 |

## *Fuel Escalation Rate*

DPL reports that at least 95% of its electrical power is produced from coal-fired power plants. We believe that future electricity cost escalation will be caused by increasing concerns about the carbon dioxide emissions from coal fired power plants, and the requirement that DPL and other utilities diversify their generation capacity. Despite aggressive drilling in the Rocky Mountain West, virtually no study projects that domestic gas production will increase substantially in the coming years, even as demand will continue to rise. In the long term, the U.S. will build ports to import LPG from Africa. However, we believe that natural gas prices will continue to increase in the future.

In order to predict the energy cost escalation, we examine local historical energy costs. The costs are adjusted with the implicit price deflator to reflect their real cost in 2000 $US [13]. Historical electricity prices from the Dayton area were obtained from actual bills for a resident of Dayton. Readings were selected from the same time of year to minimize seasonal fluctuations in energy prices. Fuel escalation rate was calculated using the following formula, where F is the future value, P is the present value, n is the number of years in the period, and e is the fuel escalation rate. $F = P \times (1 + e)^n$

Adjusted to 2000 $US, the price of electricity in September, 1995 was $0.101 per kWh. The price of electricity in September, 2005 was $0.093 per kWh. Between 1995 and 2005, local electricity prices have decreased at a rate of 1.16% annually in the Dayton area. Unit costs of natural gas were read for winter months since the majority of natural gas use occurs during these months. Adjusted to 2000 dollars, the price of natural gas in January, 1996 was $0.44 per ccf. The price of natural gas in January, 2005 was $1.03 per ccf. Between 1996 and 2005, natural gas prices have increased at a rate of 7.97% annually in the Dayton area. In 2004, electricity and natural gas were 67% and 33% of all energy costs. Thus, locally, between 1995 and 2005, the weighted fuel escalation rate was 1.85%.

Since deregulation of electrical utility companies beginning in 2001, a fix has been placed on the residential cost of electricity for the next 5 years [14]. Beginning in 2006, it is expected that electricity rates will increase in a similar fashion to natural gas prices. Considering the fact that, locally, energy escalation rates have been about 1.85% between 1995 and 2005, we bracket the study with energy escalation rates between 1% and 4% annually over the 35 year economic lifetime of the Eco-house. The magnitude of annual growth rates can be visualized by applying the rule of seventy, which states that the doubling time is approximately equal to the ratio of 70 and the annual rate of increase. Thus, a 1% annual increase corresponds to a doubling of the real cost of energy every 70 years. A 4% increase corresponds to a doubling every 18 years. In addition, the possibility of increasing energy supply disruptions is very real [15]. Although the economic consequences of supply disruption may be large, they are not considered here.

## *Baseline and Eco-house Energy Costs*

Annual energy costs for the old baseline, new baseline and Eco-house are calculated for the bracketed annual fuel escalation rates of 1% and 4% over the 35 year lifetime that the University allots to a house. As seen in Figure 3, the cost of operating the old baseline and new baseline houses varies significantly more than the cost of operating the Eco-house. This is seen in the flatness of the annual energy costs for the Eco-house and the steepness of the annual energy costs for new construction. Energy costs are subject to a high degree of variability and cannot be determined by the university. An additional benefit of the Eco-house is that it eliminates the risk of energy shortages or sharply increasing prices.

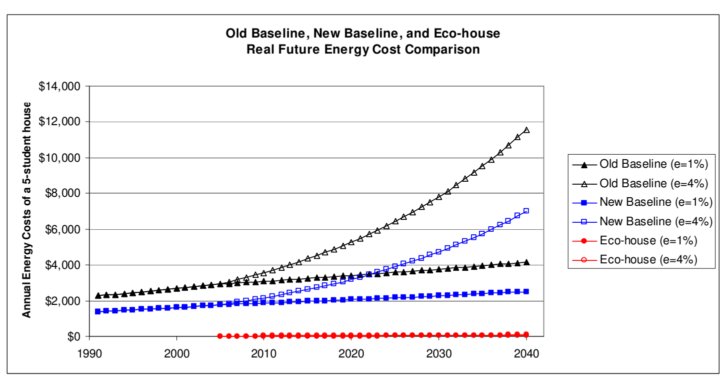


Figure 3: Old Baseline, New Baseline, and Eco-house Real Future Energy Cost Comparison

### *Baseline and Eco-house Owning and Energy Costs*

In order to compare owning and operating costs of the new baseline and Eco-house, present values of owning and energy costs are calculated. A schematic of the owning and energy costs for a residence over the lifetime of the residence is shown in Figure 4.

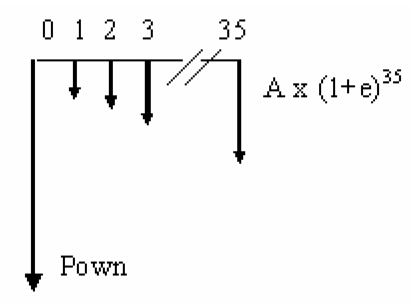


Figure 4: Owning and Energy Cost Schematic.

The present value of the owning and energy costs, Pown,engy is the sum of the present values of the owning, Pown, and energy, Pengy, costs.

$$\text{Pengy} = A \times \text{ESPWF}(i,e,n)$$

$$= A \frac{1}{(i-e)}\left[1-\left(\frac{1+e}{1+i}\right)^{n}\right]$$

$$\text{Pown,engy} = \text{Pown} + \text{Pengy}$$

where ESPWF(i,e,n) is the escalating series present worth factor.

## Owning and Energy costs for New Baseline

In 2005, a typical new 5-student house costs $225,000 fully-furnished with appliances, painting and carpeting. To finance the house, the University of Dayton typically borrows $225,000 at a 5% interest rate over a 20 year period. The economic lifetime of the house is 35 years. The largest single operating cost associated with student housing is the cost of energy. The annual energy cost for new baseline houses is $1,940.

## Owning and Energy Costs for Eco-house

The Eco-house design is similar in size and layout to the new baseline houses currently constructed at UD. Thus, the cost of construction of the Eco-house is the added cost of Eco-house components and cost of construction of the baseline house. The additional costs of constructing the UD Eco-house are summarized in Table 9. Significant additional costs are solar PV, solar hot water systems, and data monitoring. The predicted net additional cost is $46,657. Not every change in the design of the new baseline house is more expensive. Some changes eliminate traditional systems and save on the construction cost. For example, in the replacement of a traditional furnace and air conditioner, with an air to air heat pump, the costs of the furnace and air conditioner are eliminated. Also, the sole use of electricity eliminates the need for a natural gas hookup.

Table 9: Summary of Eco-House Net Additional Costs

| Components | Baseline | Eco-house | Net Addition |
|---|---|---|---|
| Walls / Roof | $25,200 | $31,300 | $6,100 |
| Windows | $3,684 | $4,254 | $570 |
| Furnace | $1,978 | $0 | -$1,978 |
| Air Conditioner | $650 | $0 | -$650 |
| Heat Pump | $0 | $2,775 | $2,775 |
| Heat Exchanger | $0 | $561 | $561 |
| Hot Water | $480 | $3,735 | $3,255 |
| Clothes Washer/Dryer | $648 | $988 | $340 |
| Refrigerator | $449 | $679 | $230 |
| Dish Washer | $279 | $780 | $501 |
| Solar PV | $0 | $34,953 | $34,953 |
| Data monitoring | $0 | $3,000 | $3,000 |
| Natural Gas hookup | $3,000 | $0 | -$3,000 |
| | | | |
| Total | $33,368 | $83,025 | $46,657 |

The present value of owning costs of the Eco-house would be about $271,657. Current annual energy costs of the UD Eco-house will be $29 per year. The present value of the owning and energy costs is shown in the Table 10.

Table 10. Present Value of Owning and Energy Costs for New Baseline and Eco-house

| | New Construction | | Eco-house | |
|---|---|---|---|---|
| Fuel Escalation Rate 2005 to Future | 0.01 | 0.04 | 0.01 | 0.04 |
| Real Discount Rate | 0.05 | 0.05 | 0.05 | 0.05 |
| Annual Energy Cost ($/yr) | $1,949 | $1,949 | $29 | $29 |
| Lifetime (yrs) | 35 | 35 | 35 | 35 |
| Escalating Series Present Worth Factor | 18.6 | 28.5 | 18.6 | 28.5 |
| Lifetime Owning Cost ($) | $225,000 | $225,000 | $271,657 | $271,657 |
| Lifetime Energy Cost ($) | $36,212 | $55,471 | $539 | $825 |
| Lifetime Owning and Operating Cost ($) | $261,212 | $280,471 | $272,196 | $272,482 |

At an annual fuel escalation rate of 1%, the present values of owning and energy costs are $261,212 and $272,196 for the new baseline and Eco-house, respectively. At an annual fuel escalation rate of 4%, the present values of owning and energy costs are $280,471 and $272,482 for the new baseline and Eco-house, respectively. At an annual fuel escalation rate of 1%, the Eco-house is less cost-effective than the new baseline. However, at an annual fuel escalation rate of 4%, the Eco-house is more cost-effective than the new baseline.

In addition to supporting the university's commitment to sustainability and environmental stewardship, the Eco-house would be cost-effective to build and operate over a life-cycle of 35 years. If the Eco-house is operated for more than 35 years, additional energy savings will be accrued. Additional externalities such as publicity for the University and attraction of new students could easily add to the cost effectiveness of the Eco-house. Further, the Eco-house will provide a living-learning community where students will be encouraged to study the effect of technological improvements and occupant behavior on energy consumption. The Eco-house will begin construction in March, 2006. It will be finished by August, 2006, when students will move in. Occupants will monitor building performance through instantaneous monitoring equipment. Thermocouples, humidity sensors and power meters will be installed to enable monitoring.

## Summary

At an annual fuel escalation rate of 4%, the present values of owning and energy costs are $280,471 and $272,482 for the new baseline and Eco-house, respectively. The current cost of natural gas in the Dayton area is $12.50 per mmBtu and the cost of electricity is about $0.088 per kWh. Using these unit costs, the energy cost savings from the Eco-house compared to the old baseline house and new baseline house will be $3,340 and $1,910 in the first year, respectively. 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. Assuming 2.3 lbs $CO_2$ per kWh of electricity (NRDC, 1998) and 113 lbs $CO_2$ per mmBtu of natural gas, total $CO_2$ emissions for the old and new baseline houses are about 53,713 lbs per year and 37,964 lbs $CO_2$ per year, respectively. The Eco-house will generate no net $CO_2$ emissions.

## Conclusions and Project Future

Net zero energy houses have significant environmental benefits. This paper shows that a net-zero energy residence can also be the least-cost investment for new university housing. As the university continues to replace old houses in the student neighborhood, the Eco-house design offers an energy-efficient, cost-effective, environmentally-superior alternative design.

If the economic effectiveness of individual energy efficiency improvements (wall insulation, windows, appliances, lighting, HVAC equipment, et cetera) are analyzed separately, their overall cost effectiveness is typically less than when they are combined. This analysis demonstrates the synergistic benefits of combining energy efficiency improvements.

The Eco-house will be built in the spring of 2006, and students will begin to live in it in August 2006. The design team will monitor energy and environmental points throughout the house and track the system's performance. This information will be used to improve the design process and to inform the design of additional university eco-houses.

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