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Feasibility of Achieving a Zero-Net-Energy, Zero-Net-Cost Homes

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September 2009

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of the Building Technologies Program, U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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ACKNOWLEDGEMENTS

The material presented in this report originates from a wide variety of sources, including energy modeling software, government and other reports, organizations' websites, personal communications, as well as the team members' own knowledge. The report was developed under the guidance of Dr. Iain Walker and was subject to internal review at the Lawrence Berkeley National Laboratory.

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EXECUTIVE SUMMARY

A green building competition, to be known as the Energy Free Home Challenge (EFHC), is scheduled to be opened to teams around the world in 2010. This competition will encourage both design innovation and cost reduction, by requiring design entries to meet "zero net energy" and "zero net cost" criteria. For the purposes of this competition, a "zero net energy" home produces at least as much energy as it purchases over the course of a year, regardless of the time and form of the energy (e.g., electricity, heat, or fuel) consumed or produced. A "zero net cost" home is no more expensive than a traditional home of comparable size and comfort, when evaluated over the course of a 30-year mortgage. In other words, the "green premium" must have a payback period less than 30 years, based on the value of energy saved.

The overarching goal of the competition is to develop affordable, high-performance homes that can be mass-produced at a large scale, and are able to meet occupant needs in harsh climates (as can be found where the competition will be held in Illinois). This report outlines the goals of the competition, and gauges their feasibility using both modeling results and published data. To ensure that the established rules are challenging, yet reasonable, this report seeks to refine the competition goals after exploring their feasibility through case studies, cost projections, and energy modeling.

The authors of this report conducted a survey of the most progressive home energy-efficiency practices expected to appear in competition design submittals. In Appendix A, a summary can be found of recent projects throughout the United States, Canada, Germany, Switzerland, Sweden and Japan, where some of the most progressive technologies have been implemented. As with past energy efficient home projects, EFHC competitors will incorporate a multitude of energy efficiency measures into their home designs. The authors believe that the cost of electricity generated by home generation technologies will continue to exceed the price of US grid electricity in almost all locations. Strategies to minimize whole-house energy demand generally involve some combination of the following measures: optimization of surface (area) to volume ratio; optimization of solar orientation; reduction of envelope loads; systems-based engineering of high efficiency HVAC components, and on-site power generation.

A "Base Case" home energy model was constructed, to enable the team to quantitatively evaluate the merits of various home energy efficiency measures. This Base Case home was designed to have an energy use profile typical of most newly constructed homes in the Champaign-Urbana, Illinois area, where the competition is scheduled to be held. The model was created with the EnergyGauge USA software package, a front-end for the DOE-2 building energy simulation tool; the home is a 2,000 square foot, two-story building with an unconditioned basement, gas heating, a gas hot-water heater, and a family of four. The model specifies the most significant details of a home that can impact its energy use, including location, insulation values, air leakage, heating/cooling systems, lighting, major appliances, hot water use, and other plug loads. EFHC contestants and judges should pay special attention to the Base Case model's defined "service characteristics" of home amenities such as lighting and appliances. For example, a typical home refrigerator is assumed to have a built-in freezer, automatic (not manual) defrost, and an interior volume of 26 cubic feet. The Base Case home model is described in more detail in Section IV and Appendix B.

The authors performed additional model runs to estimate the energy savings from measures that improve the energy performance of several of these home features. To ensure the accuracy of the

model, the authors cross-checked energy use outputs for consistency with other published data on home energy consumption and costs. As expected, the marginal energy savings that result from multiple efficiency measures are often not additive, because the savings resulting from the employment of a particular technology may be negligible if used in a very efficiently designed home. Results of our modeling efforts may be of interest to EFHC contestants exploring different strategies for designing their home.

In order to understand which efficiency measures are most cost effective over the life cycle of the home, the authors estimated the net present value (NPV) of each measure over a 30-year period (incorporating replacement schedules for components expected to last less than 30 years), using an internal rate of return (IRR) of 3.4%. Under the modeled conditions, it was found that air sealing of the home, and the use of a geothermal heat pump, are the only measures expected to be cost effective. It is important to note that the technologies and costs used in our models were calculated using available data; however, cost and performance of innovative home technologies are expected to improve each year, so successful competitors will probably incorporate several of the measures found to be economically unattractive in our evaluation.

In addition to efficiency measures, the authors conducted a review of home-scale energy generation technologies, including both electric-only units (microhydro, small-scale wind, and solar photovoltaic), and combined thermal-electric options (solar-dish stirling engines, fuel cells, and combined heat and power turbine engines). While solar energy, and energy storage, technologies are expected to become less expensive as the industry expands, the installed costs of (renewable) home energy generation technologies are not expected to decrease enough in the short-term to make net zero cost achievable on the time-scale of this competition.

In summary, the authors believe the ambitious zero net cost criteria will present a barrier to entry for many prospective competitors, unless major innovations emerge in the next year. Achieving zero net energy, however, is clearly feasible and should be a requirement for all entrants; however, the relative value of certain aspects of the home energy system can be complicated to evaluate, so the following recommendations should be considered when establishing rules for the competition.

- EFHC rules should require all contestant home designs to meet the specified service characteristics for all amenities, using efficient designs or technologies to meet these requirements with less energy. This will prevent contestants from "saving" energy relative to the Base Case house simply by (for example) installing a smaller refrigerator.
- If the organizers decide to grant credit for net energy production (above the utility rate for electricity sold back to the grid), credit should also be awarded to homes achieving lower than zero net cost; for this reason, a conversion weighting factor must be established to equate monetary and energy savings.
- Entrants wishing to propose the incorporation of new or uncommon components and materials should be required to submit cost reports that justify their estimates of materials and labor costs.
- The EFHC rules should establish "standardized" energy prices which all contestants will use for consistency. Costs to be standardized include electric and non-electric energy consumption, utility-purchasing rates for net metering, inter-tie fees, variable rates for time of use metering (i.e., peak power pricing), and other issues.
- The competition rules should not create incentives for contestants to design all-electric homes, instead of allowing them the flexibility to innovate with the most appropriate fuel types. This

concern stems from the fact that most electricity is produced at thermal power plants, which typically require three units of fuel energy input to create one unit of electric energy output.

The EFHC competition is not expected to stimulate disruptive innovations in solar or other energy generation technologies, for which research efforts are already well funded, but is expected to showcase to the public the enormous capacity for energy efficiency measures to reduce the costs and environmental damage that typically result from the operation of a home. Success requires clear guidelines, a transparent judging process, and reasonable minimum requirements. If these criteria are met, the outcome can make high-performance home design a priority for a wider audience, and reduce the extent to which homes are dependent on fossil fuel intensive technologies.

TABLE OF CONTENTS

I. INTRODUCTION

The green building movement has been steadily gaining momentum since the inception of the Leadership in Energy and Environmental Design (LEED®) rating system in 1998. While strides continue to be made in improving both performance and comfort, green homes have typically been reserved for upper and upper-middle socioeconomic classes because of the high upfront costs. Making these homes more attractive to lower and middle class families will require decreases in upfront costs and improvements in energy efficiency, both of which require significant innovation. A common method of stimulating innovation is the design competition; examples of nation-wide competitions include the USGBC's Natural Talent Design Competition[1], U.S. EPA's Lifecycle Building Challenge[2], and the U.S. DOE's Solar Decathlon[3]. However, performance is generally the primary focus, with limited, if any, attention to costs. Hence, a green building competition has been proposed that encourages both design innovation and cost reduction by requiring "zero net energy" and "zero net cost", referred to as the Energy Free Home Challenge (EFHC), scheduled to be held in 2010. This report outlines the goals of the competition and gauges their feasibility using both modeling results and measured data. Finally, we offer a number of recommendations for the competition organizers based on our findings.

II. GOALS AND SCOPE

The EFHC has two foci: zero net energy and zero net cost. Zero net energy refers to achieving a net zero draw of grid electricity and any non-renewable fuel (such as natural gas or heating oil). The home's primary fuel consumption and grid electricity consumption will be converted to a common unit, summed, and compared to its net renewable energy production; the two must cancel one another out. Net zero cost refers to zero additional cost above a traditional home of comparable size and comfort when evaluated over a 30-year mortgage. In other words, the "green premium" must pay for itself in energy savings within 30 years. The overarching goal of the competition is to develop affordable, high-performance homes that can be mass-produced within communities and are able to perform in harsh climates (the competition is set in Illinois). To ensure that the established rules are challenging, yet reasonable, this report seeks to refine the competition goals, and explore their feasibility through case studies, cost estimation, and energy modeling.

III. EXISTING ZERO AND NEAR-ZERO ENERGY HOMES

In reviewing examples of zero and near-zero energy houses, we examined projects located in the United States, Canada, Germany, Switzerland, Sweden and Japan. A primary source for projects outside the United States is the International Energy Association (IEA) Task 28.[4] Information about Canadian projects was found through the Equilibrium housing initiative sponsored by the Canadian Mortgage and Housing Corporation (CMHC). The Equilibrium housing initiative is similar to the EFHC in that twelve homebuilding teams were selected to build demonstration projects across Canada. In 2008, these projects will be open for public tours; currently, there is no monitored data. In the US, there have been multiple individually initiated projects, as well as many projects that have been conducted as public-private partnerships in different parts of the country. All information and data are assembled from the

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[1] http://www.usgbc.org/DisplayPage.aspx?CMSPageID=257
[2] http://www.lifecyclebuilding.org/index.php
[3] http://www.solardecathlon.org/
[4] http://www.iea-shc.org/task28/publications/index.html

project websites and communication with builders themselves. Detailed descriptions and photos of all case studies examined are included in Appendix A.

Defining a Net-Zero Energy Building

Due to the popularity of reducing residential energy consumption, the term “zero energy building” is widely used. However, a common criterion for defining and evaluating whether a house is a ZEB currently does not exist. The Building America Program defines a net zero energy building (ZEB) generally as, “a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies (Torecellini et al. 2006). However, it is important that designers work with a precise definition because the manner in which energy use is accounted for can have a significant impact on design decisions.

For example, the German EnEV standards for residential energy consumption specify the maximum allowable energy consumption in terms of “primary” energy rather than “site” energy (as will be the criteria in the EFHC) effectively weighting the value of energy drawn from the grid to account for inefficiencies in fuel-to-electricity conversion. Four specific definitions are outlined by (P. Torcellini et al., 2006):

> Net Zero Site Energy Building:
> A site ZEB produces as much energy as it uses, when accounted for at the site.[5] A limitation of a site ZEB definition is that the values of various fuels at the source are not considered.
>
> Net Zero Source Energy Building:
> A source ZEB produces as much energy as it uses as measured at the source. To calculate a building’s total source energy, both imported and exported energy are multiplied by the appropriate site-to-source energy factors.
>
> Net Zero Energy Cost Building:
> A cost ZEB receives as much financial credit for exported energy as it is charged on the utility bills. Net Zero Energy Cost Buildings are the most sensitive to local energy costs and utility rate structures.
>
> Net Zero Energy Emissions Building:
> An emissions-based ZEB produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

In addition to the “net zero” definitions, a range of “low energy” or “near zero” energy definitions exist.

> EnEV Compliant House:

[5] A limitation of a site ZEB definition is that the values of various fuels at the source are not considered. For example, one energy unit of electricity used at the site is equivalent to one energy unit of natural gas at the site, but at the source (power plant) it takes three units of natural gas to produce that one unit of electricity A site ZEB can be easily verified through on-site measurements, whereas source energy or emissions ZEBs cannot be measured directly because site-to-source factors need to be determined.

The German EnEV regulations on energy conservation for new residential construction require that a house's annual primary energy demand for heating/cooling, lighting, ventilation, and domestic hot water not exceed 110 kWh/mper year.

3-Litre House:
The term '3-litre house' applies to low-energy buildings, whose annual primary energy demand for heating figures below 34 kWh/m per year (including the auxiliary energy required for pumps and fans). This corresponds to a primary energy content of 3 liters of fuel oil.[6]

Factor-Four Plus Housing:
"Factor-Four Plus Housing" requires one-fourth or less of the purchased heating energy of houses built to current standards.

Passive House:
Passive houses typically require a maximum of 10 W/m2 of space heating, amounting to an annual energy demand of 15 kWh/m2 in temperate climates (central Europe).[7]

"Whole-House" Energy Use in Zero Energy Buildings

"Whole-house" energy use is the sum of the energy required for the systems of the house such as heating/cooling, ventilation, lighting, and hot water, as well as miscellaneous energy demand (from televisions, computers, fish tanks, swimming pools etc.). As the building envelope, systems, and overall design of a house are optimized, further improvements play less of a role in "whole-house" energy consumption when compared with the percent of total energy use dedicated to energy use that is discretionary. As an example, 38% of the monitored energy use for the Vitali-Velti House (semi-detached low energy house located in Monte Carasso, Switzerland) was discretionary.

In non-Building America projects, annual energy use is presented as a calculated value derived from a code-compliant simulation tool and may not accurately represent the real energy use of the project for any given year. As an example, the German regulations for new residential construction require that a house's annual energy use must not exceed 110 kWh/m^2 and the simulated results of the project's compliance with this standard are typically published. It is important to note that the simulations do not include the discretionary energy use (plug loads) of the occupants (other than domestic hot water) and therefore these numbers represent only the predicted energy required for the house's systems.

"Discretionary" Energy Use in Zero Energy Buildings

Discretionary energy use is omitted from energy standards compliance because it is highly variable from house to house and therefore cannot be accurately predicted or simulated for any given household. However, as the goal of a zero energy house is to reduce "whole-house" energy use to zero, both accounting for the magnitude and variability of discretionary energy use is necessary as well as the development of reduction strategies.

Figure 1 illustrates the high level of variability in energy use between identical houses. It is interesting to note the range between the six Premier Gardens houses on the right, which are meeting and in fact

[6] IEA-SCH Task 28 / ECBCS Annex 38: 3-Litre Twin Houses
[7] IEA Task 28, http://www.iea-shc.org/task28/index.html

exceeding the ZEB definition, and the approximately eight Premier Gardens houses on the opposite tail of the plot that consume energy in excess of the control group average. Because these houses are of the same construction and have the same systems, with comparable solar orientation, the variability in energy consumption can be attributed to the quantity of occupants per house and their behavior.

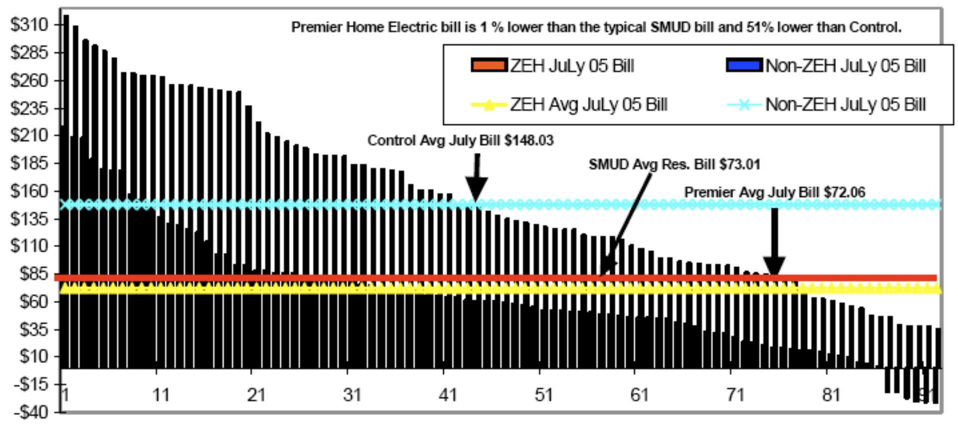

Figure 1: Comparison of July 2005 ZEH vs. non-ZEH (Control) Electricity Bills (from Keesee, 2005)

Net-Zero vs. Net-Zero Peak

In regions where electricity demand may exceed the maximum supply levels that the electrical power industry can generate (often during heat waves when use of air conditioners and powered fans raises the rate of energy consumption significantly), utilities are seeking strategies for load reductions at peak times (usually between 12pm – 7pm). The rate of electricity production from PV's is directly related to the exterior solar conditions, so the relatively small (2 kW) PV systems installed in the Premier Gardens development demonstrate that a house designed as a ZEB can also work to reduce the potential for power outages resulting from excessive peak loads (shown in Figure 2). Although the average peak demand of a Premier Gardens home during the July study was 2.02 kW, it was 55% lower than the 2003 average new home peak demand (4.48 kW) and 73% lower than the peak demand of the adjacent non-ZEB community (Keesee, 2005).

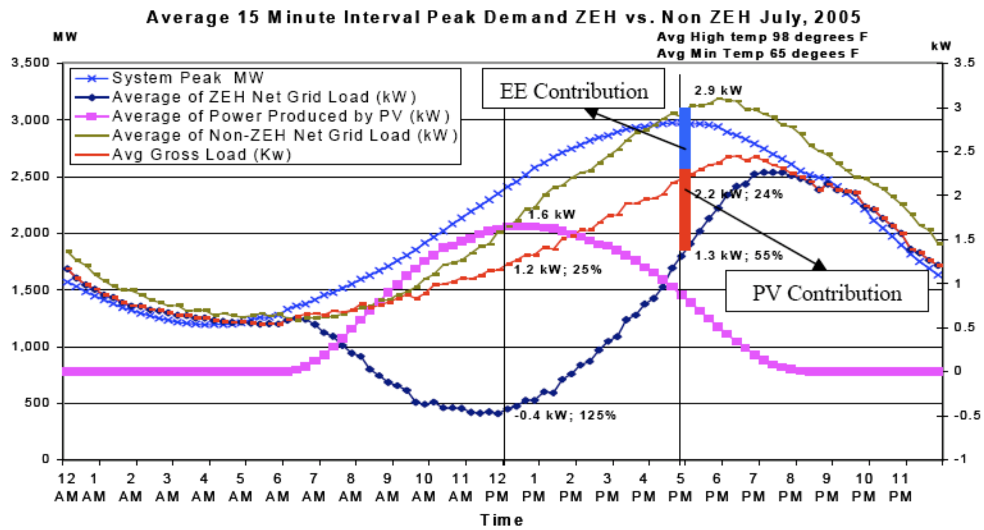

Figure 2: Average peak demand for Premier Gardens ZEB's vs. non-ZEB's, July 2005. (from Keesee, 2005)

Overview of Common Zero-Energy Building Strategies

Strategies to reduce whole-house energy use generally involve a combination of the following measures:

- Optimization of surface-to-volume ratio
- Optimization of solar orientation
- Reduction of envelope loads
- Systems-based engineering of high efficiency HVAC components
- On-site power generation

Choices or trade-offs made in selecting from these strategies are generally based on the ratio of money invested (mortgage payment) to cost of energy saved (price per kWh). As shown in Figure 3, there is generally an optimal point, and as further measures are taken to reduce net energy consumption, the home becomes more expensive. Where this point lies, however, is subject to debate. For a detailed discussion on least-cost energy efficiency strategies the reader is referred to the 2004 Fourth-Quarter Building America Milestone Report: *Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes*, by Anderson et al. (2004).

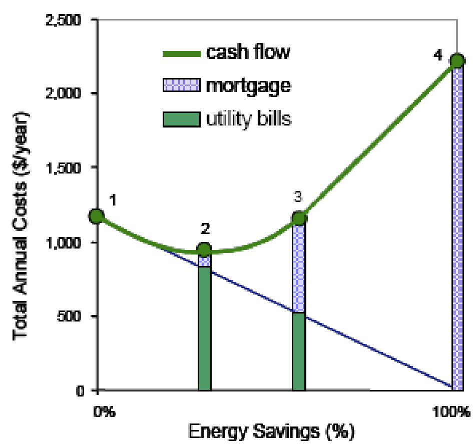

Figure 3: Conceptual plot of a least cost path to a ZEB, (from Anderson et al. 2004)

Zero-Energy Building Comparison Metrics

Parker (2008) prepared the plot in Figure 4 to show how the cost of each project compares with the level of annual site energy used. The baseline building is shown by the red squares, the efficiency measures by the green triangles and the solar PV by the yellow circles.

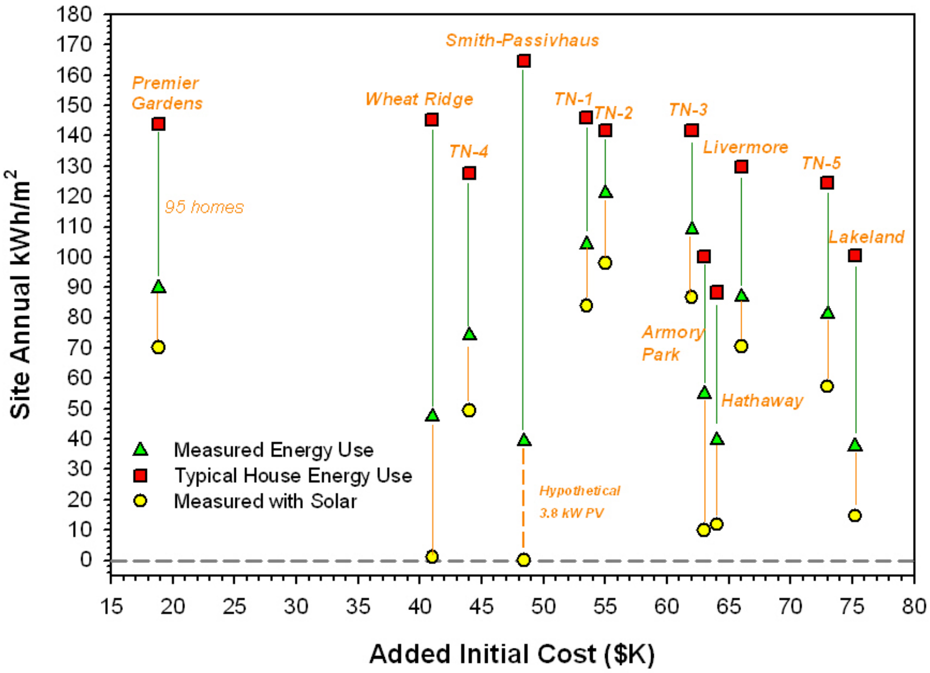

Figure 4: Plot of Cost vs. Measured Total Energy Use of a Compendium of Very Low Energy Homes. (Source: Parker . 2008)

Two conclusions can be drawn from Figure 4:

1. Savings gained from PVs are less in all cases than the savings gained from efficiency measures.
2. "Premier Gardens" project appears to be an outlier in regard to all of the other projects.

Direct comparison between projects is questionable, however, due to differing definitions of zero energy, methods for cost accounting, project location and size, etc.

IV. Energy Performance Modeling

Exploring case studies provides valuable insight into the performance of existing zero and near-zero energy homes, but as highlighted in Section III, a number of questions arise about how zero energy is defined and measured. In order to provide more transparent results, the authors of this report also created their own computer-based home energy model, so that all input assumptions and outputs could be carefully documented. The modeling effort defined a “typical” Base Case, then compared its modeled energy performance with the modeled performance of more efficient home designs.

In this section, the authors briefly discuss how the Base Case home was defined (with more detail available in Appendix B) and then show energy consumption and cost results for various scenarios. The modeling effort used the EnergyGauge, USA software package, which operates as an interface for DOE-2.[8]

Base Case Home

Because energy use is highly dependent on building size, orientation, window area, climate, appliances, occupant behavior, lighting, and many other characteristics, and the “zero cost” criterion is evaluated in relation to a baseline home, establishing a reasonable baseline is extremely important to the success of the EFHC. To determine the characteristics of a "standard" house, we took the following steps:

1. Research Illinois-specific housing characteristics, where available. The authors located a semi-complete DOE-2 model of Illinois new construction, created by another researcher (Lucas 2007). This model provided data on envelope and Heating/Ventilation/Air-Conditioning (HVAC) characteristics, such as wall insulation levels, furnace efficiency, etc.
2. Fill in additional model information via other research. The ENERGY STAR program and other data sources provided information on appliances and other home equipment. This information was not Illinois-specific; it is based on national data.
3. Use EnergyGauge defaults for small details that are not typically published in other data sources. Modeling efforts commonly use these default values, which are typically unimportant to the modeling outcome and/or so standard that they rarely change.
4. Run the model, and cross-check the results to make sure they are consistent with other published data on home energy use and costs. Note that there were multiple iterations to produce the final model discussed herein.

[8] EnergyGauge is available at http://www.energygauge.com/usares/

A summary of the Base Case home is shown in Table 1.

Parameter	Value
Basic house description	2,000 sq ft conditioned floor area, 2 stories, 1,000 sq ft per floor, 25 x 40 ft footprint, 8.5 ft ceilings, unconditioned basement (1,000 sq ft)
Location	Champaign-Urbana, Illinois
Insulation values	
Ceiling	R-30 hr-ft^2-F/Btu insulation
Walls	R-13 hr-ft^2-F/Btu insulation
Floor over unconditioned basement	R-13 hr-ft^2-F/Btu insulation
Construction	Ceiling, walls, floor are all wood-frame construction
Windows	
Geometry	6 windows on north and south walls, 2 on east and west, 360 sq ft of total glazing (equals about 15% of total wall area)
Construction	Wood frame, double paned, clear glass
U-value	U = 0.48 Btu/hr-ft^2-F, not low-E, SHGC = 0.76
Infiltration	0.6 ACH
Heating system	gas furnace, 78% AFUE
Cooling system	air conditioner, SEER 13
Lighting	1242 total watts of bulbs installed; 1.0 kWh/sq ft per year of lighting energy
Hot water heater efficiency	Energy Factor (EF) = 0.72
Appliances and other plug loads	ENERGY STAR – refrigerator/freezer combo; dishwasher; clothes washer non-ENERGY STAR – oven/stove/range; clothes dryer Misc. plug loads – About ~2,700 kWh/year

Table 1: Base Case Inputs

The utility rates used should also be noted. The authors used an electricity rate of $0.075 / kWh (based on research by a group at University of Illinois) and a natural gas price $0.91 / therm (the 'Illinois average' value in EnergyGauge; not the current price, which is higher).

Component-Based Energy Performance Modeling

Figure 5 shows the results of a few modeling runs in which the Base Case house has a single efficiency measure applied to it, and one run (on the far right) with all of the measures added at the same time. The vertical axis of the graph is the annual energy expenditure in dollars. The results demonstrate the different amounts of savings that different measures can achieve. Note that the savings results below are *not additive* (since multiple efficiency measures can interact with each other) and that the plug loads remain unchanged.

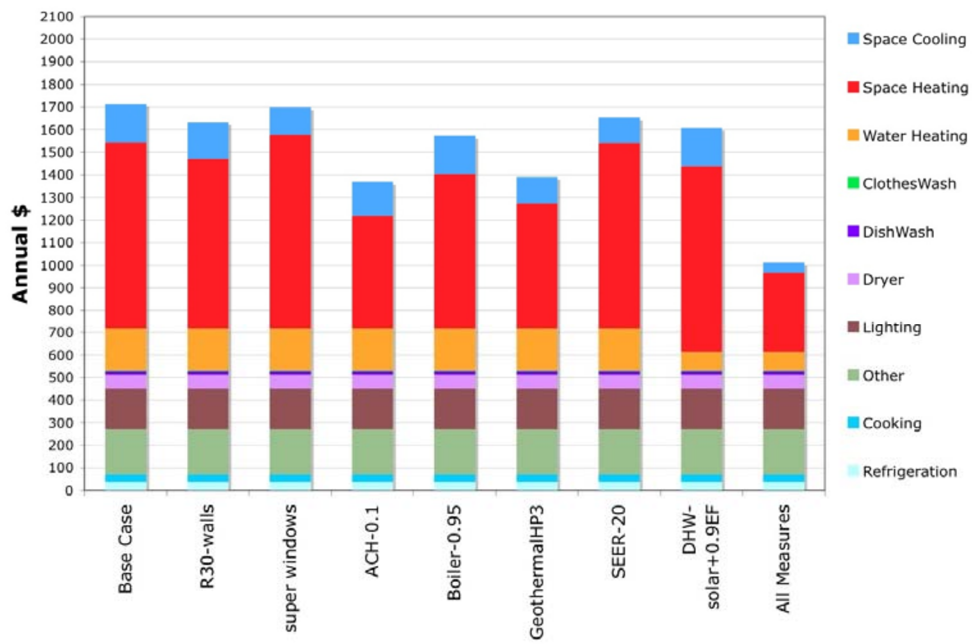

Figure 5: Effects of some simple standard efficiency measures

Overall Home Energy Performance Scenarios

This section considers some simple Zero Energy variants of the Base Case home. Three variants are shown in Figure 6, showing the energy expenditure (in dollars) breakdown in the bar chart, and written above each bar is the required size of the PV array to make that case into a net-zero energy home (based on the default values with Siemens SP75 cells in EnergyGauge's PV calculation tool). The first case, on the far left in the figure, is simply the Base Case model with added PV. Note that the footprint of the building is just 1000 ft^2, so the required amount of PV for the Base Case home would extend well beyond the available roof area. The second case is based on the All Measures case from Figure 5. The third case, on the far right, is a rather extreme case, with as much done to reduce the HVAC and DHW as one could reasonably expect possible, but without doing anything to decrease the other loads (lighting, appliances and plug loads). This highlights the importance that lighting, appliances and plug loads must play in any planning for a net-zero home competition. In existing zero energy homes, occupants are often exercising restraint to conserve lighting, appliance, and plug load energy and stay within their renewable energy budget. However for the competition, no behavior change can be assumed. This third case suggests a near minimum of PV requirements that any entrant should expect to achieve.

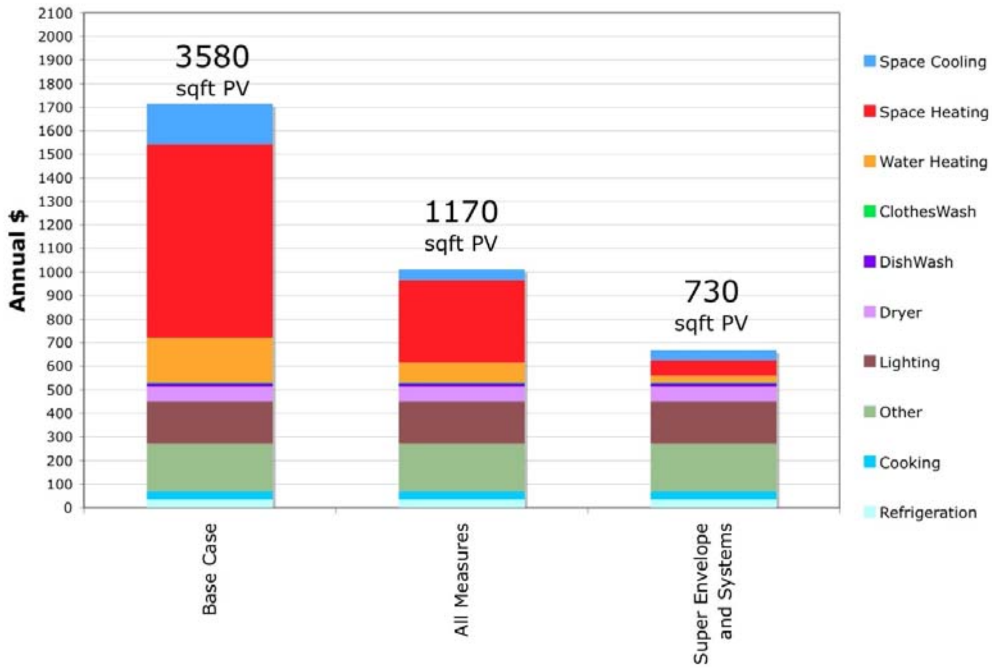

Figure 6: Some simple Zero Energy Variants of the Base Case home.

V. COST ESTIMATES

Section IV provided estimates for how much money energy efficiency measures save annually, but determining the cost-effectiveness of these different scenarios requires upfront cost estimates as well. In this section, we provide estimates for components that improve a home's energy efficiency, as well as energy generation technologies (such as solar panels). Combined with energy performance data, we can begin to reveal whether the zero energy, zero cost requirements are feasible with current technology or reasonably expected advances.

Energy Efficiency

Component Cost Estimates

Insulation

All insulation data was taken from the Oak Ridge National Laboratory's Insulation Fact Sheet, which is current as of January 2008.[9] It contains both cost estimates per square foot of floor area and suggested R-values for various regions defined by the first three zip code digits. "618" was entered because this report is focused on a competition to be held in the Urbana-Champaign area of Illinois. The cost results

[9] Available at http://www.ornl.gov/sci/roofs+walls/insulation/ins_01.html

for different options that are cost-effective in that area are shown in Figure 7. Dollar values are provided in terms of additional expenditures above the baseline scenario outlined in Section IV. The floor insulation baseline is defined as R-13, ceiling is R-30, and walls are R-13. The bar graph shows that the relationship between R-values and cost is not necessarily linear and, in the case of wall and floor insulation, costs can increase dramatically as the R-value increases. However, in a cold climate like Urbana-Champaign, selecting the maximum amount of insulation may still be a wise option.

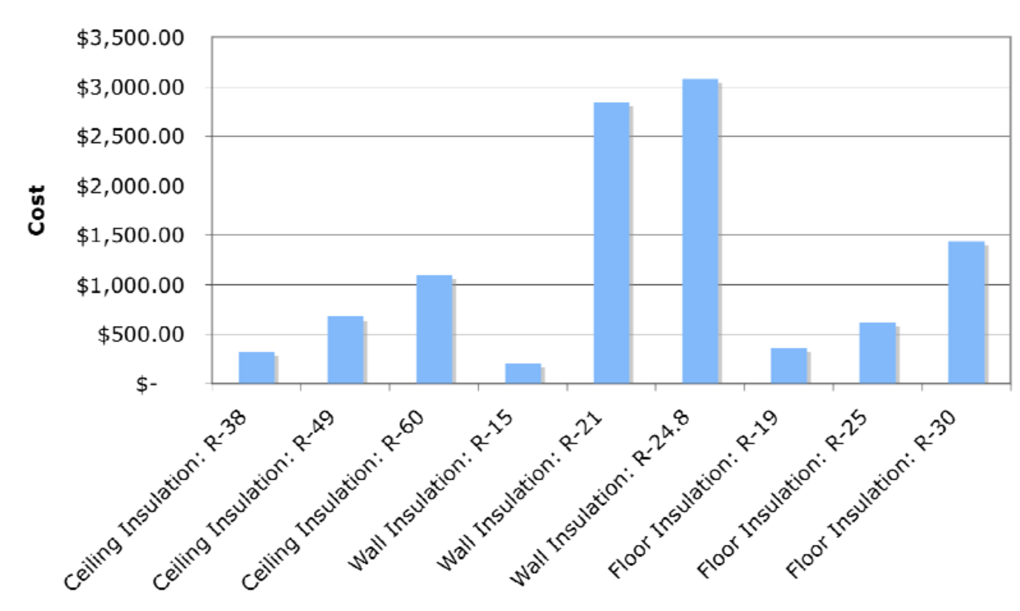

Figure 7: Average Incremental Cost per Home for Insulation

Windows

Window upgrades prove to be on the same order of magnitude as insulation improvements. Cost estimates were taken from a report (Wenzel et al. 1997) and are all representative of a home with 360 sq ft of window area (15.4% of total wall area), with a baseline of wood frame, double paned, clear glass windows (U=0.48 Bu/hr-ft^2-F, SHG=0.76). Because these costs are provided in 1997 dollars, inflation adjustments are made to convert to 2008 dollars using the U.S. Bureau of Labor Statistics online inflation calculator.[10] Common methods for improving the insulating properties of windows can be achieved by applying a low-e (low-emissivity) coating, filling the space between panes with argon or krypton, or applying a coating that filters some radiation based on wavelength. So called "super windows" are triple-paned, argon/krypton-filled, with low-e coatings on one or more of the glass surfaces, and an improvement in terms of visible light transmission while keeping a low solar heat gain coefficient (SHGC). Also a high-performing option is heat mirror windows, which some manufacturers

[10] Available at http://data.bls.gov/cgi-bin/cpicalc.pl

claim to be equivalent to five panes of regular glass. The "heat mirror" is actually a low-e coated film suspended between glass panes that transmit most light, while reflecting a large fraction of infrared and UV radiation. The average costs associated with these technologies are shown in Figure 8. One important assumption made here is that all windows are upgraded, whereas in an actual project, it may be cheaper to use different strategies for different sides of the house depending on the building orientation. Again, as was true for insulation, the cold climate in Illinois means insulating window technologies would be a worthwhile investment in order to reduce heating loads.

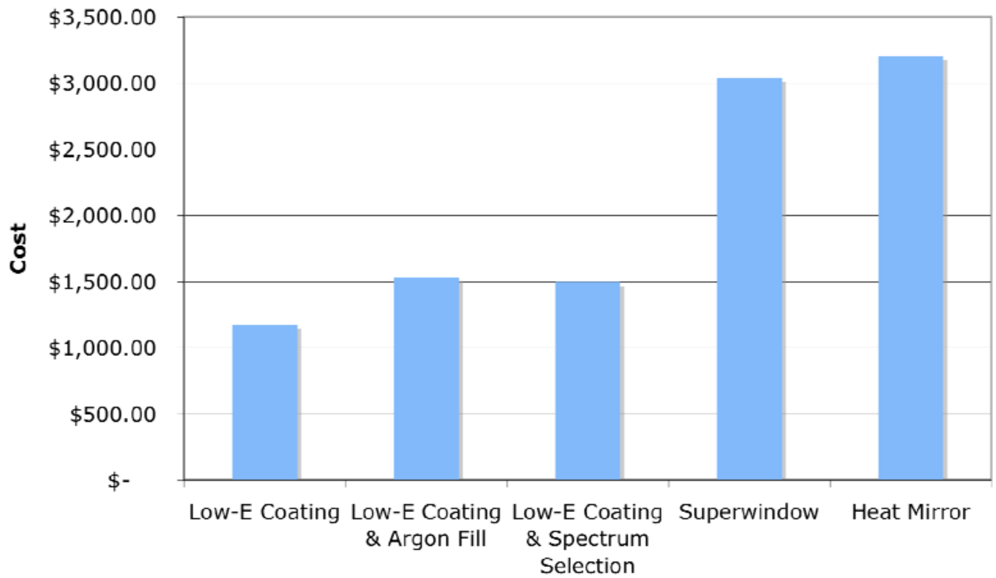

Figure 8: Average Incremental Cost per Home for Windows

HVAC and Water Heating

Another method of reducing the costs associated with heating (and cooling) is to install an alternative to traditional HVAC systems. This can mean simply improving the efficiency of the baseline technology (a gas furnace) or installing a completely different system. Shown in Figure 10 are energy-efficient alternatives to traditional heating, air conditioning, and water heating systems. A hydronic radiant floor heating runs hot water through pipes beneath the floor, allowing the heat to radiate upwards, warming the entire home. Radiant heating (Figure 9) can also be achieved by circulating hot air instead of water, but water is considered to be most cost-effective. In addition to improved energy efficiency, one of the largest selling points for this type of heating comfort, with occupants claiming that it actually provides comfort at an air temperature approximately 4˚ F lower than what is typically required with a gas furnace (Wilson 2002). On the negative side, the system is very expensive, averaging close to $10,000 for a 2,000 sq ft home. Therefore, the efficiency and comfort benefits would need to be closely examined before investing in this technology for a home seeking to achieve zero "green premium" over a 30-year mortgage.

Figure 9: Radiant Heating System (Source Uponor Wirsbo, *Environmental Building News)*

Other options for space heating that are more economical include a geothermal heat pump, as well as a high efficiency gas furnace, shown at 90%, but current technologies can reach upwards of 95%. For cooling, a 19 SEER system can be installed, which is essentially the most efficient traditional air conditioner currently available. Also an option, evaporative cooling systems achieve temperature reductions by humidifying outside air as it is brought into the home, thus causing sensible heat to become latent heat as it evaporates the water and cooling the air.

This is an efficient means of providing cooling, but is only effective in dry climates. Because Illinois summers are generally somewhat humid, evaporative cooling systems are not expected to be used in the competition, but a cost estimate is included in Figure 10 as one of many options.

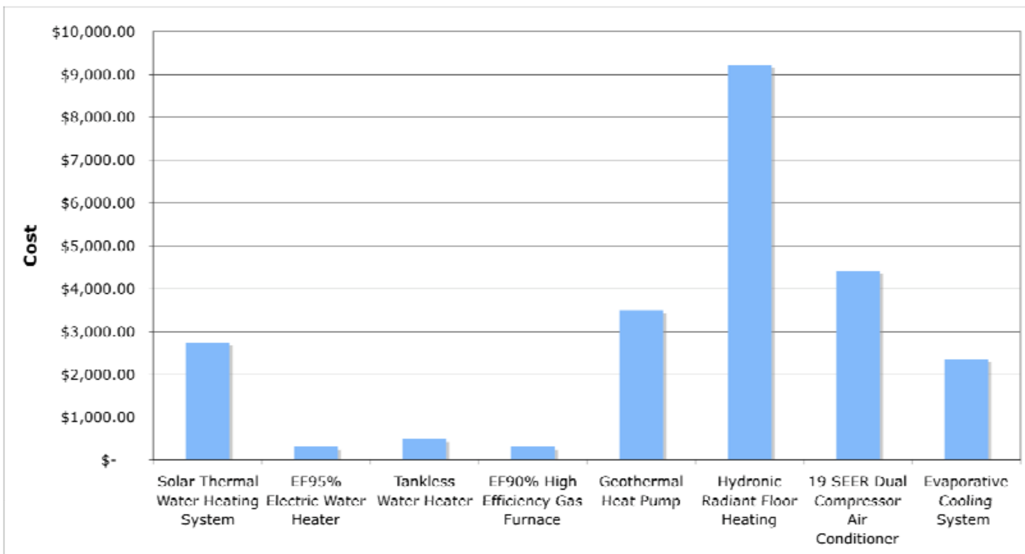

Figure 10: Average Incremental Cost per Home for HVAC & Water Heating

The final step in reducing space heating and cooling, and water heating costs is to ensure than there are no unnecessary losses through pipes, tanks, and ducts. These measures are also some of the most cost effective paths to energy conservation because the upfront costs are very low. As shown in Figure 11, hot water pipe insulation, water heater tank wrap, duct sealing, and air sealing to achieve 0.5 air changes per hour (ACH) were estimated and came to less than $1,000 each.

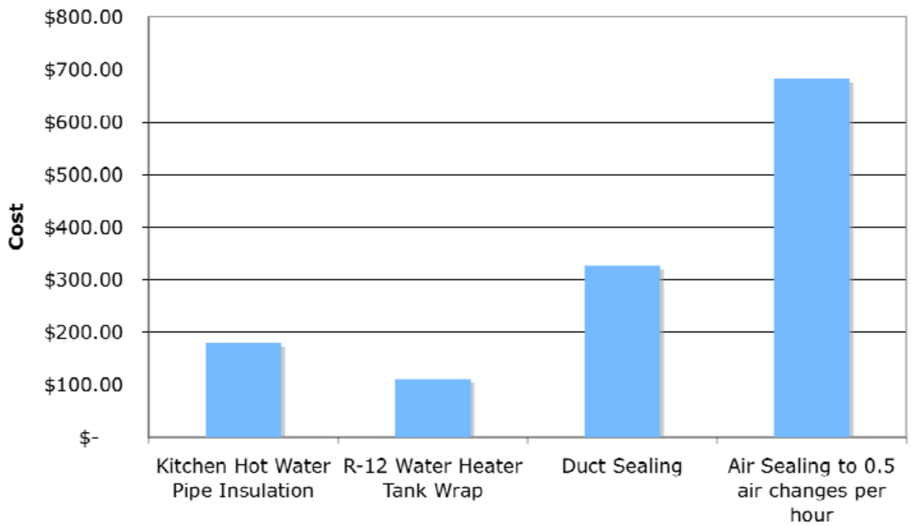

Figure 11: Average Incremental Cost per Home for Duct & Pipe Sealing/Insulation

Scenario Modeling and Life Cycle Costing

While developing a general sense of upfront costs, the numbers have limited meaning without being compared to their resulting energy savings. For this reason, we have developed a scenario based on the best available technology. Of the technologies described in the previous section, seven were chosen and modeled individually within the base case house, and then modeled all together. It is important to note that the energy savings are not additive because each component can have an influence over the energy performance of other components in the system. For example, a more efficient gas furnace lowers total heating requirements, and as a result, lowers the impact that improved insulation or air sealing can have on overall energy consumption. Figure 5 shows the annual energy bills associated with each scenario, combining costs for electricity and natural gas based on an electricity rate o $0.075/kWh and natural gas price of $0.91/therm (representative of current energy costs in Illinois).

To compare energy savings with upfront premiums, the NPV was computed for a 30-year period with an IRR of 3.4%. Figure 12 shows the percentage of upfront costs that are covered by energy savings. It shows that only air sealing and a geothermal heat pump actually pay for the upfront premium in energy savings. However, before concluding that energy efficient technologies will not play as important role in the competition as originally speculated, two points must be made. Firstly, the technologies chosen for these scenarios are the best available, and are disproportionately expensive. They should not be used to demonstrate that energy efficient technologies are not cost effective. In other words, the cost does not vary linearly with performance. Achieving R-30 walls may not be a worthwhile goal, but R-20 may be very cost effective. Super windows are very expensive currently because they are relatively new to the market and are not offered by many manufacturers, so sacrificing some performance in favor of less expensive, double-paned, argon-filled windows with a low-e coating may be worthwhile. The second important point is that, if zero net energy is a requirement, energy efficient technologies must be judged in comparison to the available alternatives. It is expected that solar PV will make up for energy consumed after maximum efficiency is achieved, so as long as the measures shown below are more affordable than solar PV, they are favorable.

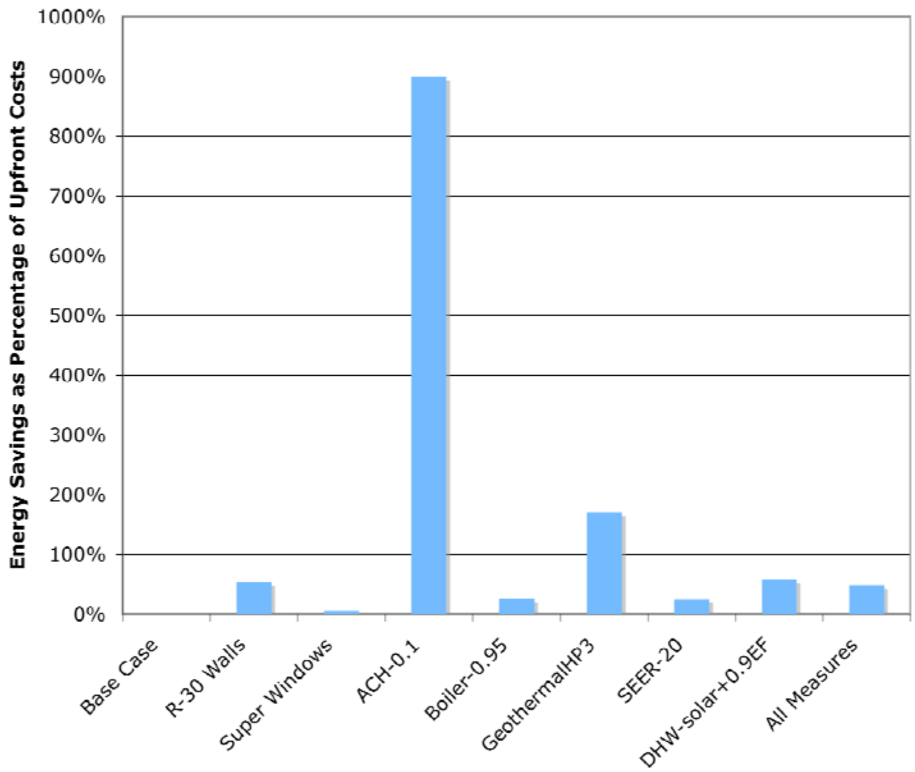

Figure 12: Percent of Initial Investment Recovered in 30 Years

Energy Generation & Storage

Energy Generation Technologies

Out of an extensive list of currently available energy generation options (Figure 13a), only a few technologies appear feasible for residential-scale production (Figure 13b). Technologies that produce only electric power are: microhydro, small-scale wind, and solar photovoltaic. Combined thermal-electric options (in increasing primacy of thermal yield) include: solar-dish Stirling engines, fuel cells, and combined heat and power turbine engines. Biomass sources primarily yield thermal energy, though they can of course be used through various mechanisms to yield electricity, and include wood, biogas (methane), and biofuels. Near term projections (by 2010) for significant and new guaranteed technologies appear unlikely.

The underlying challenge for projecting the feasibility of on-site generation technologies on a residential scale is determining consistent cost projections. A variation in the assumptions for each technology is needed with respect to the lifecycle/replacement rates, operation and maintenance (O&M), installation costs, fuel costs, cost as a function of scale, variability of efficiency with fuel source, variability of efficiency due to building code constraints (wind turbine height, solar panel visibility, etc.). In addition, costs for certain generation technologies are reported in $/kW values while others are in $/kWh. Further assumptions must be made in order to quantify all the results in $/kW or $/kWh due to the differences in fuel sources or heating fluids used. The information compiled thus far is a combination of reported and predicted data due to the variances within the technologies. A comprehensive spreadsheet is provided in Appendix C.

Form	Technology
Electric	**Hydro** Microhydro **Wind** small scale **Solar** Photovoltaic
Electric *(Thermal)*	Dish (Thermal-Electric) **Fuel Cell** generic/unspecified Proton Exchange Membrane (PEMFC) SolidOxide (SOFC)
Electric (Thermal)	**Turbines/Generators** Reciprocating Engines (CHP) Microturbines (CHP) Stirling Engines
Thermal *(Electric)*	**Biomass** Cordwood Pellitized Anaerobic Digestor

Figure 13b: Energy Generation Technologies Likely Feasible at Residential Scale

Form	Technology
Electric	**Hydro** Large Hydro Microhydro Pelton Wheel Banki Turbine UltraMicro in-line
Electric	**Wind** Large scale - vert/horiz. axis Small scale - vert/horiz. axis Micro - Aeroelastic Flutter
Electric / Electric *(Thermal)*	**Solar** Photovoltaic Concentrating - Parabolic Trough Concentrating - Tower + Tracking mirrors Dish - Individual Tracking Mirrors & Heat Engine
Electric *(Thermal)*	**Fuel Cell** Proton Exchange Membrane (PEMFC) Phosphoric Acid (PAFC) Molten Carbonate (MCFC) SolidOxide (SOFC)
Electric (Thermal)	**Turbines/Generators** Reciprocating Engines Microturbines Combustion Turbines Rankine Cycle Stirling Engines Combined Heat & Power (CHP)
Thermal *(Electric)*	**Biomass** Direct Combustion Cordwood Pellitized Waste-to-energy Anaerobic Digestors Animal Fecal Wastes Vegetative Waste Aerobic (Compost) BioDiesel Ethanol
Thermal *(Electric)*	**SolarThermal** Passive Air Hot Water
	GeoThermal *not projected practical within guidelines*
	Animal Bicycle/Generator *not projected practical within guidelines*

Figure 13a: Energy Generation Technologies

In one method of calculating the cost of PV electricity for instance, we used both reported data from others, and our own calculations based on capital costs per kW, divided by 30 years of the mortgage, divided by kWh of production per year at the ideal orientation for the proposed build location in Illinois. The calculated figure of $0.21/kWh is close to other reported values, but adding in a more realistic replacement schedule and O&M would raise the cost significantly. In addition to calculations, we gathered reported cost projections for a range of technologies (Figure 14). Projected costs of solar will be discussed in more detail later in this section.

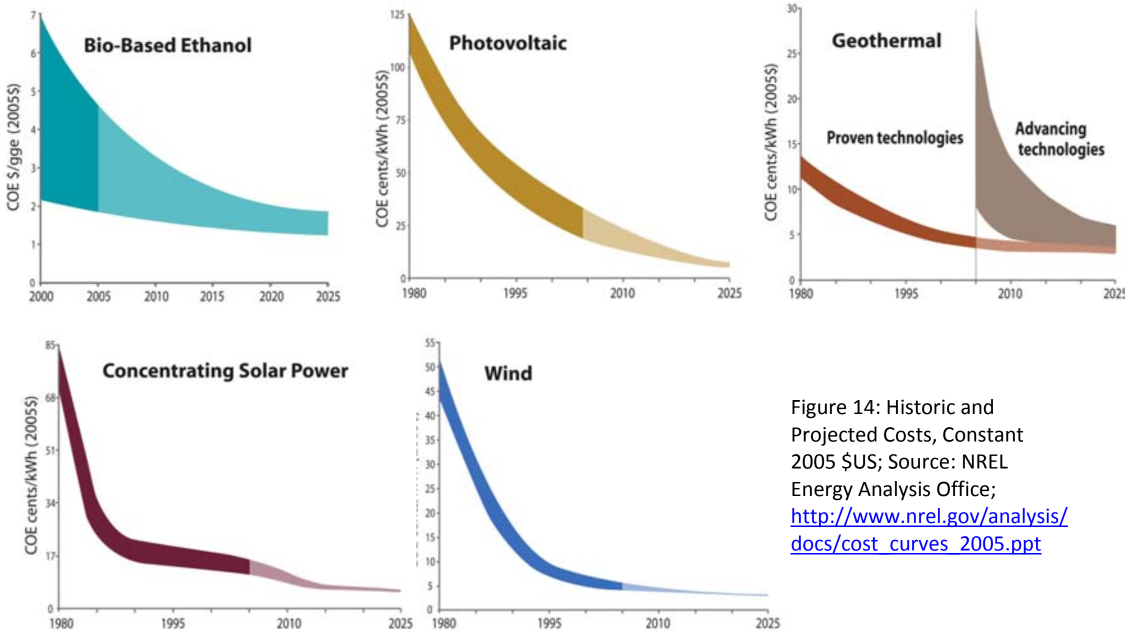

Figure 14: Historic and Projected Costs, Constant 2005 $US; Source: NREL Energy Analysis Office; http://www.nrel.gov/analysis/docs/cost_curves_2005.ppt

Solar Power Cost Outlook

As previously mentioned, the cost of solar electricity over the lifetime of a PV array is significantly greater than average utility prices. Given that most entrants to the EFHC are expected to make up for any net energy consumption with solar panels, the cost may determine whether the "zero cost" requirement is reachable. Therefore, the question is whether prices are expected to drop by 2010 (the start date of EFHC), and by how much? While we are unable to provide a definitive answer, we are able to present a range of reputable predictions and from those, derive a reasonable expected value.

Currently, installed costs are approximately $7/Wp (Wp refers to 1 peak Watt of capacity) according to a presentation made for the U.S. Office of Science & Technology Policy[11], which is consistent with estimated U.S. retail panel price of $4.83/Wp[12] when one assumed that 40-50% of the total cost pays for installation. After reviewing the last few decades of performance, most analysts concluded that cumulative installed capacity (not time) is the most accurate predictor of cost decreases, as can be seen in Figure 15. A commonly illustrated rule of thumb states that every doubling of installed capacity resulted in a roughly 20% drop in the cost of installed PV generating capacity (Handleman 2000, Lorenz et al 2008). Handleman explained that the industry's rule of thumb had been that price drops 5% per year, though this was only seen during the industry's slowest growth years from 1985-1995; the growth rate was 15% during these years, but has maintained approximately 30% growth since then.

[11] http://www.ostp.gov/pdf/pearce_miasole_pcast_20sep05.pdf

[12] http://www.solarbuzz.com/ModulePrices.htm

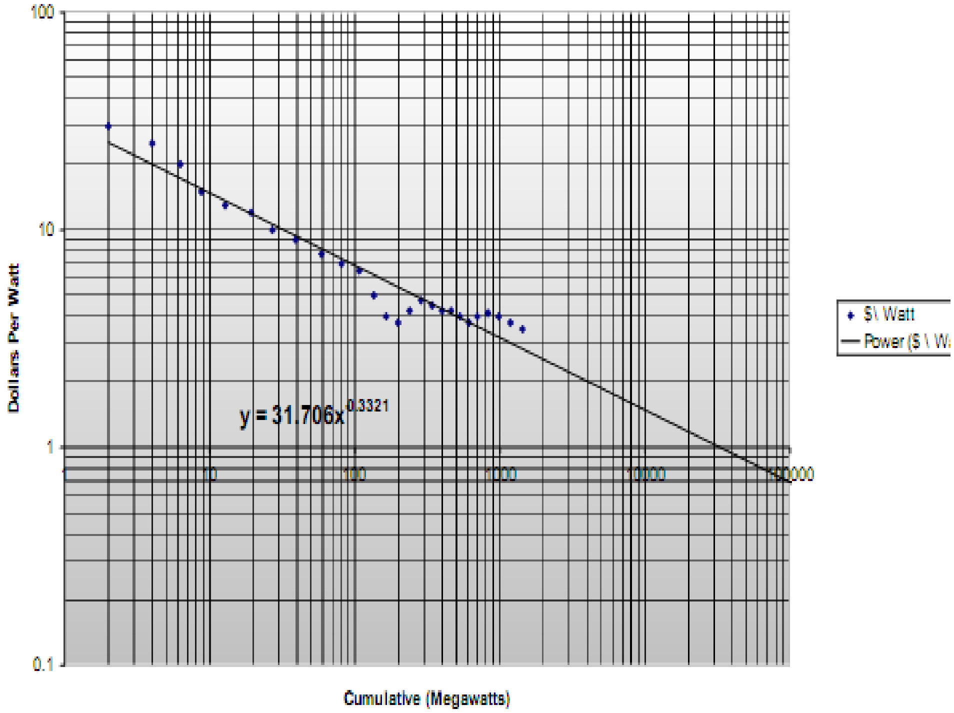

Figure 15: Log-Log Plot of Relationship Between $/Wp & Cumulative Megawatts Installed (1975-2000)
(Source: Handleman 2000)

Of the most optimistic forecasts reviewed was also the most recent publication out of the DOE's Office of Energy Efficiency and Renewable Energy (EERE), which made the following projections (illustrated in Figure 16 and Figure 17):

> *According to the EIA, electricity prices have been increasing 4.7% each year since 2002, which outpaces inflation by about 1.2%. Commercial / utility scale PV systems are currently economically competitive with grid electricity prices in many areas. Both residential and commercial systems will be less expensive than grid electricity by 2010, assuming that the 4.7%*[13] *annual growth rate continues.* (Kimbis 2008).

[13] Note: It is not clear whether the author used net present value to compare grid to PV generation costs.

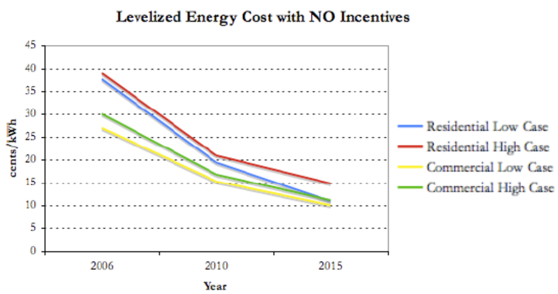

Figure 16: EERE Forecasted Cost of PV Electricity

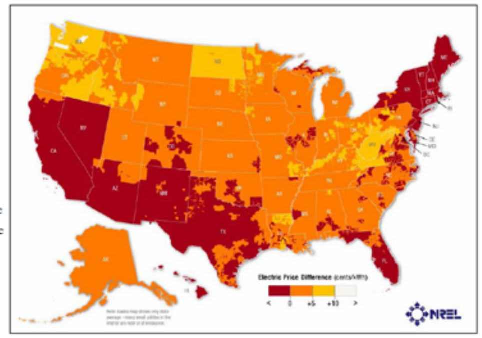

Figure 17: Forecasted Premium Cost of Solar in 2015

These findings largely agree with a projection made in 2000 by the Heliotronics group (Handleman 2000), which modeled the attainment of a $1.00/Wp cost per module (roughly corresponding to a $3 installed system cost for BIPV). Assuming that the industry maintains a 30% growth rate, their model predicts the breakeven point will occur in 2012 (as can be seen in Figure 18).

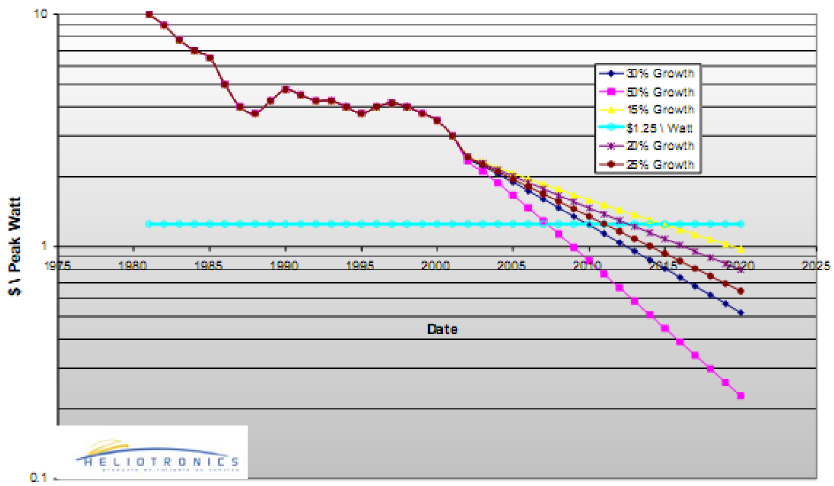

Figure 18: Heliotronics Breakeven Models for PV Modules (Source: Handleman 2000)

According to McKinsey's recent publication, "The Economics of Solar", growth in solar will take place as follows:

> *Even in the most favorable regions, solar power is still a few years away from true "grid parity"—the point when the price of solar electricity is on par with that of conventional sources of electricity on the power grid. Even if all of the forecast growth occurs, solar energy will represent only about 3 to 6 percent of installed electricity generation capacity, or 1.5 to 3 percent of output in 2020.*

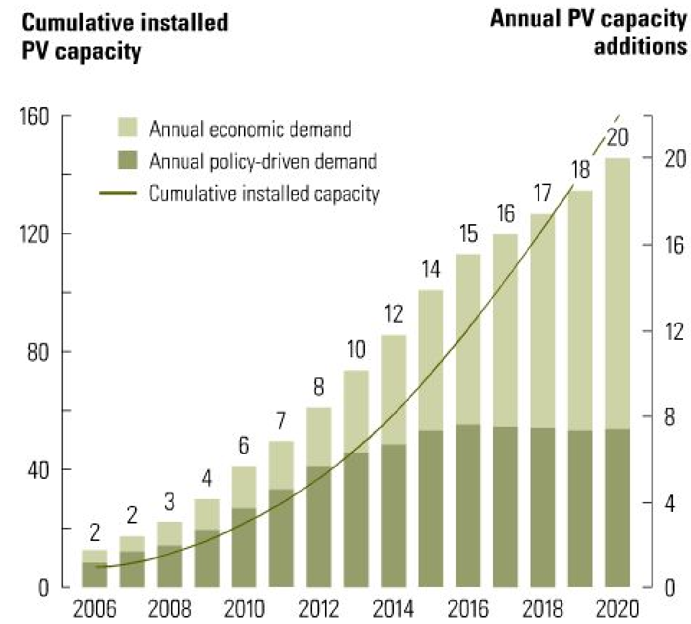

Figure 19: McKinsey's PV Growth Projection,
Source (Lorenz et al. 2008)

Figure 19, provided in the McKinsey report, show the heavy influence of policy on the demand for photovoltaics, and Figure 20 shows that they do not expect the $3-4/W installed cost to be reached for another ten years or so (which is necessary for PV to be cost effective throughout most of the world). A "business as usual" conservative forecast was made assuming a progress rate of 85% (i.e. learning rate of 15%, whereas 1989-2002 saw a progress rate of 80.5%) and growth rate of 25% (less than that from 1993-2001), reaching the target of $3.2/W is expected around 2018. (Poponi 2003).

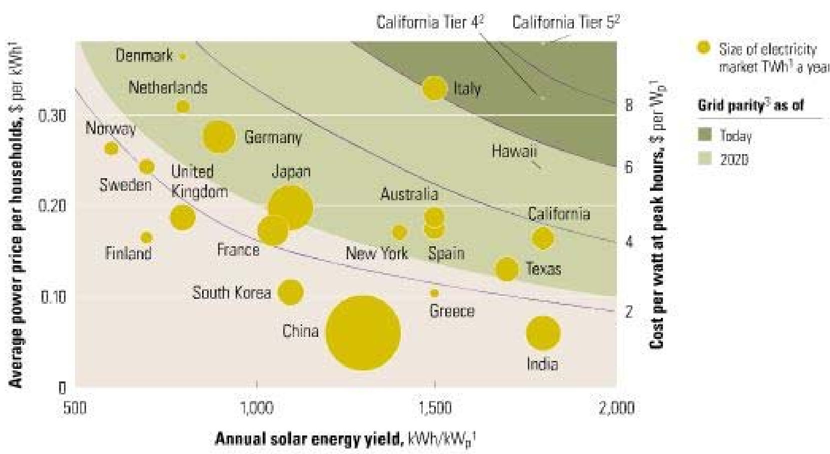

Figure 20: McKinsey's Phase-In Projection for PV Grid Parity,
Source (Lorenz et al. 2008)

In a report presented in 2004, Dutch researchers Schaeffer and de Moor expect southern Italy (where electricity costs £0.20 /kWh) to find PV cost effective at £4/Wp before 2010, and £1/Wp to be achieved between 2020-2030. This projection, though a few years old, agrees well with McKinsey's report, showing that PV is marginally cost effective for residents of Italy where electricity costs are quite high. In order to reach parity with centralized electricity production, corresponding to approximately 0.5 pounds/Wp, an investment of about half a trillion pounds (corresponding to 20% of the world's electricity generating capacity) at a learning rate of 20% would be needed; this is not expected to happen before 2040. (Schaeffer and de Moor 2004).

Energy Storage Technologies

In parallel with on-site energy generation, energy storage options become necessary as well. Costs of storing energy vary widely (Figure 21), and the method chosen is dependent on both scale as well as tradeoffs between energy and power. Batteries are the most likely storage technology at a residential scale, but their costs (Figure 22) illustrate the difficulty of energy storage at a residential scale. Although storage technologies are a clear opportunity for innovation, for the near future, on-site energy storage appears to be the sub-optimal choice when a grid inter-tie is available, as is the case with the EFHC. In future competitions, it is critical that guidelines for a zero energy home challenge clearly specify the rules regarding connection to the grid, including net metering, time of use pricing, buy/sell prices, etc.

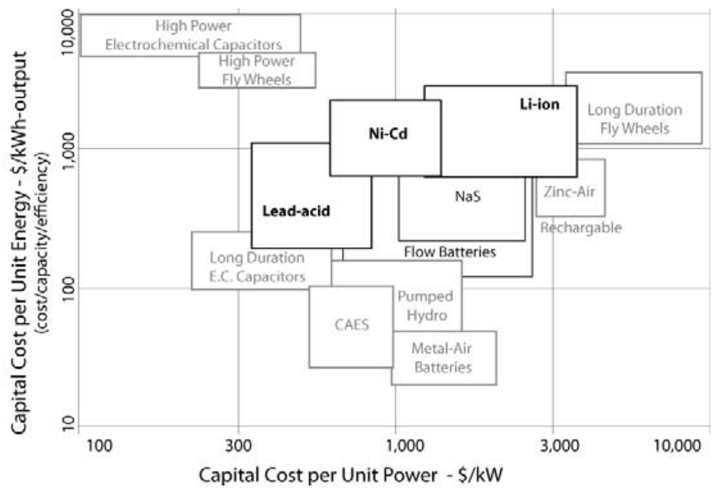

Figure 21: Energy/Power Storage Costs (Source Electricitystorage.org)

Technology	**$ / kW installed** @ 2.5% inflation/year					
Batteries (incl. Flow Batteries	low $256.00	high $2,040.00	average $1,148.00	2010 low $276.00	2010 high $2,203.00	2010 avg $1,240.00
	$ / kWh @ 2.5% inflation/year					
Batteries (incl. Flow Batteries	low $80.00	high $200.00	average $140.00	2010 low $86.00	2010 high $216.00	2010 avg $151.00

Figure 22: Estimated range of energy storage costs

Cost Summary

In summary, the task of getting to zero net energy and zero net cost is indeed a challenge that will require innovations (especially with regard to cost) in both energy savings and generation strategies. This is illustrated in a zero net energy graph from the BEopt software, superimposed with the zero-net-cost bar, and a schematic cash flow path (Figure 23). Another way to visualize the cost bar is to look at the amount of energy that must be generated to balance the energy consumed by the efficient home. As costs decline, the curve becomes less steep, bringing the zero cost bar closer (Figure 24).

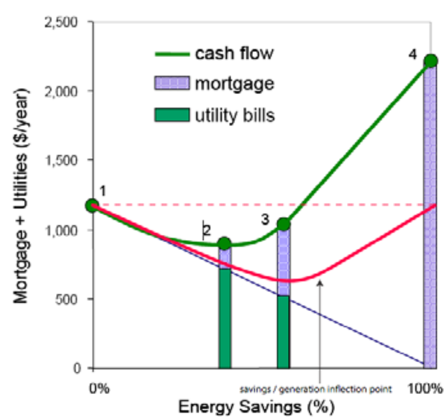

Figure 23: BEopt zero-net-energy chart with zero-net-cost superimposed (red) (NREL BEopt: Software for Identifying Optimal Building Designs on the Path to Zero Net Energy)

Allowance must still be made, however, for the energy savings measures, which initially are cheaper than the energy generation technologies, but become subsequently more expensive as the most cost-efficient measures are exhausted (Figure 25). Two scenarios of how these relate to each other, with one meeting zero net cost as well, are shown in Figure 26. Given that PV is the most likely energy generation technology in the near-term, with total installed costs projected to exceed $5/watt in 2010 (see Itron, 2007), innovations in generation energy alone will not be adequate to reach both the zero net energy and zero net cost targets. With energy efficiency innovations, achieving both zero net energy and zero net cost may be possible, but it is a very ambitious goal.

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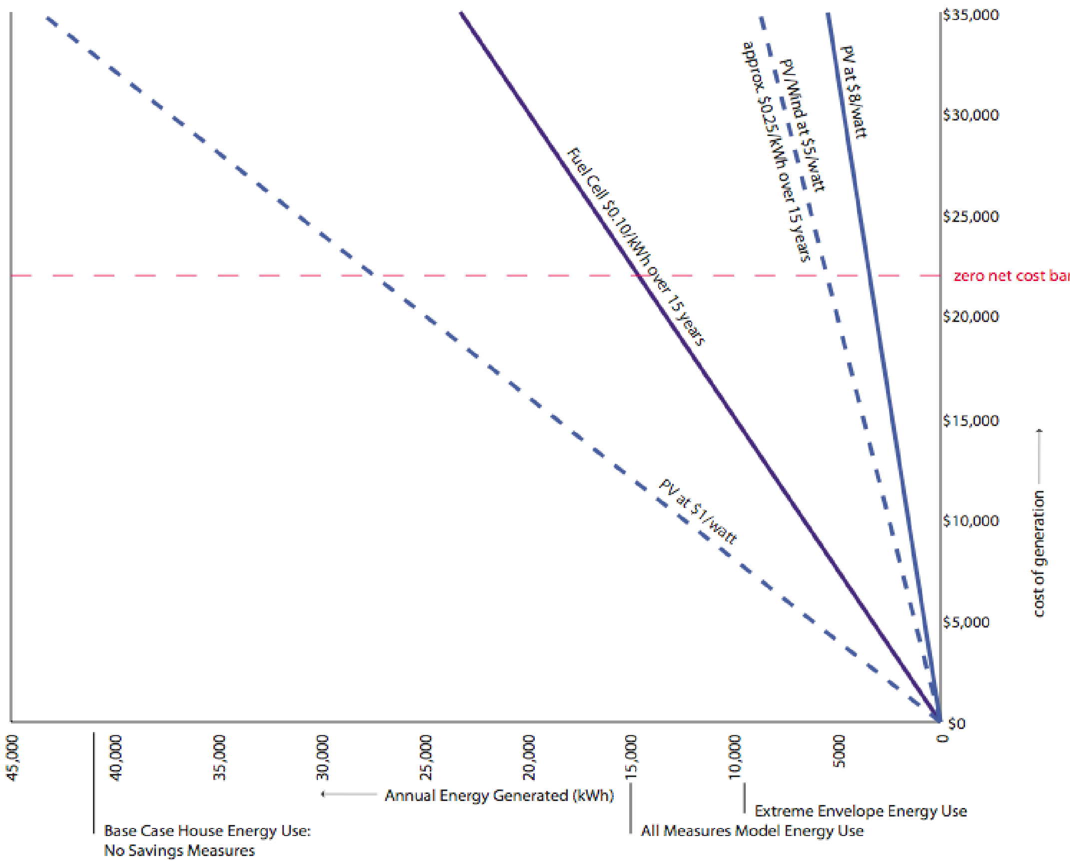

Figure 24: On-site Energy Generation Cost Curves

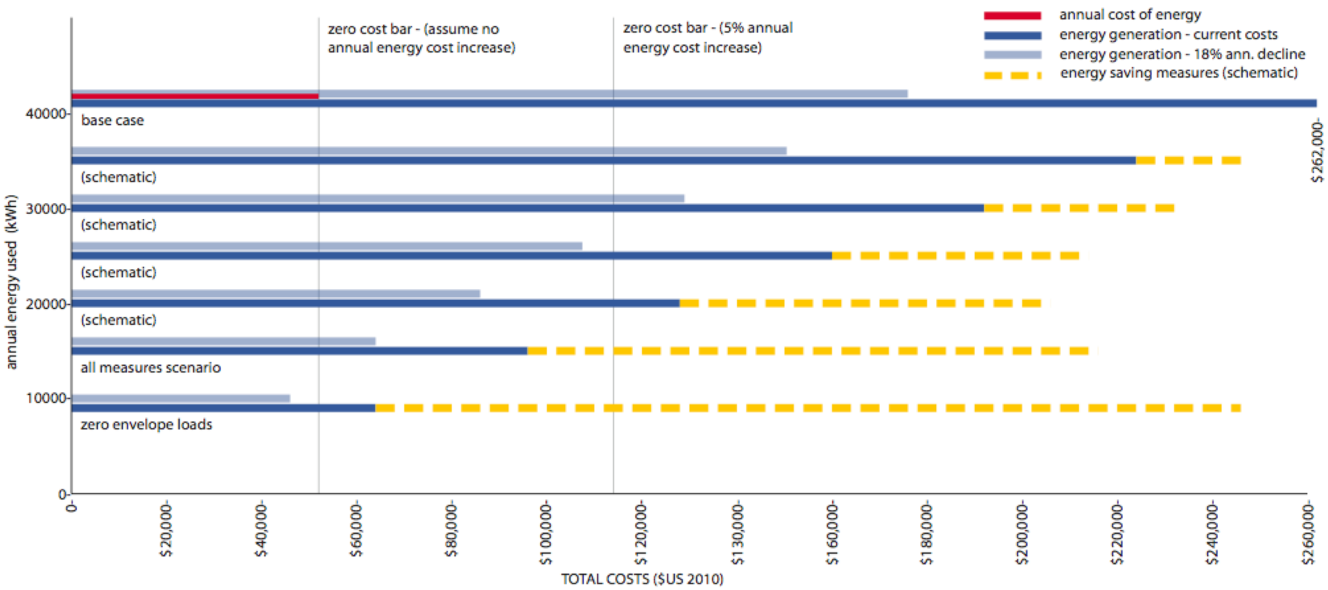

Figure 25: Energy Savings vs. Energy Generation Cost Curves (cost bar based on energy costs, unconverted to annual mortgage payments

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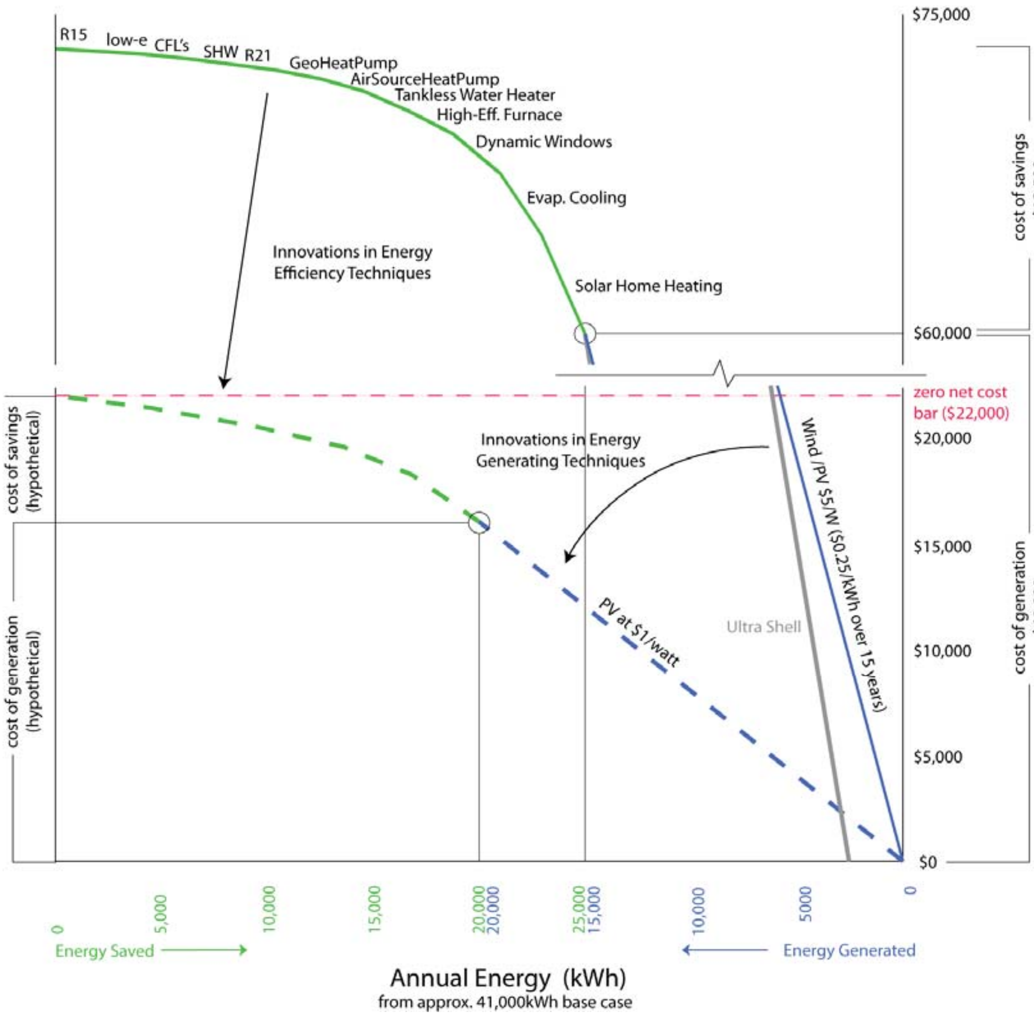

Figure 26: Energy Savings vs. Energy Generation Cost Curves, present technology and hypothetical innovations

VI. Summary and Conclusions

Feasibility of Net Zero Energy

The question of whether net zero energy is technically possible is easily answered: it is certainly possible. Using extensive energy efficiency measures and large solar arrays will reach zero energy, but may not come close to achieving net zero cost.

Feasibility of Net Zero Cost

Given that net zero energy must be achieved, zero net cost remains a significant challenge for entrants. In this report, we have provided cost estimates for various scenarios, trading in various efficiency improvements to determine how much solar (or other electricity generation technology) would be required. We have also explored projections for future cost reductions and have determined that, while solar is expected to become less expensive as the industry expands, the installed costs will not decrease enough in the short-term to make net zero cost easily achievable. Significant innovations in energy efficiency will likely be necessary.

Competition Recommendations and Conclusions

As planning moves ahead for the EFHC, we have a number of recommendations to facilitate the establishment of clear guidelines and make the task of judging less difficult. In terms of the zero net energy bar, it is clearly too fundamental to the competition to sacrifice. Achieving zero net energy should be a requirement for all entrants. Providing credit for net energy production (above the utility rate for electricity sold back to the grid) is up to the organizers, but if credit is also provided for achieving lower than zero net cost, a weighting factor must be used to equate monetary and energy savings. The zero cost bar is ambitious and may present a barrier to entry for many teams. It is, however, difficult to predict what innovations may surface, so we cannot make a definitive judgment about its feasibility. We do strongly recommend that entries exceeding the net zero cost requirement be credited appropriately.

Cost accounting will be an especially difficult task, which may be why most green building competitions choose not to judge based on project costs. In the case of common materials or components, the organizers may choose to establish prices within the rules. This prevents teams from misrepresenting their costs, and protects the entrants from fluctuating prices (steel, for example). For components or materials that are less common, entrants should be required to submit cost reports that cover materials and labor. If the expected lifetime of any equipment is significantly less than 30 years, necessary replacements should also be factored into the costs. In establishing operating costs, the EFHC rules should establish "standardized" energy prices which all contestants will use for consistency. These should cover electric and non-electric energy types, utility-purchasing rates for net metering, intertie fees, peak pricing / variable rate time of use metering, and other issues. Small changes in any of these values will have a large impact, and controlling them for the design phase based on the most realistic prediction possible for the build phase will help contestants to evaluate the myriad tradeoffs embedded in their approaches.

In the area of energy generation there are a number of things that the guidelines can do to make the challenge more predictable, if not less difficult. The rules should clearly outline parameters for using anticipated technologies, and establish a framework for judging new technologies, in terms of local regulations (e.g., wind turbines/tower heights) or code issues. It should be made clear that the judges will be the ultimate arbiters of what is 'reasonably allowable'. In addition, the EFHC rules should avoid creating incentives which drive contestants toward all-electric homes rather than allowing them the flexibility to innovate with fuel types if they so choose. For example, imagine an innovative home heating system that uses one (thermal) energy unit of biomass to eliminate the need for one (electrical) energy unit of electricity which would otherwise be needed to run a space heater. The EFHC rules should *not* consider this a "break-even" one-for-one energy trade, because saving that one unit of electrical energy actually saved *three* units of (thermal) energy from fuels burned at a distant power plant. Thus, the biomass heating solution actually saves two units of energy, on a "source energy" basis.

Most importantly, the organizers of this and any other green building competition are faced with the challenge of deciding what type of impact they hope to make. A balance must always be struck between flexibility and clarity. Ideally, there should be little restriction on entrants so a wide variety of innovations are brought forward, thus maximizing the impact of the competition. Unfortunately, teams will be hesitant to enter if the judging guidelines are unclear and they do not have a finite set of objectives necessary for success. Organizers must therefore make decisions about which areas of innovation their competition is likely to have the greatest impact. For example, bio-based transportation fuels already receive a great deal of research funding from both the public and private sector, so a competition for developing the least expensive cellulosic ethanol production pathway is likely to have little impact. For the EFHC organizers, a good starting point is to examine the distribution of green building research funds in the U.S. 63% of green building research funds in the U.S. are spent in the area of energy, and of that fraction, approximately 54% supports PV research with the rest spent on energy efficiency (Baum 2007). This leads us to believe that, while not impossible, the probability that this competition will spark innovation in PV technology is low. Conversely, the diverse field of energy efficiency may benefit greatly from the incentive that EFHC provides.

The EFHC has potential to stimulate innovation in the green building industry by providing ambitious goals, along with the freedom to meet them in many different ways. However, making it a success requires clear guidelines, a transparent judging process, and reasonable minimum requirements. If these criteria are met, the outcome can make high-performance buildings accessible to a wider audience and reduce our dependence on fossil fuels.

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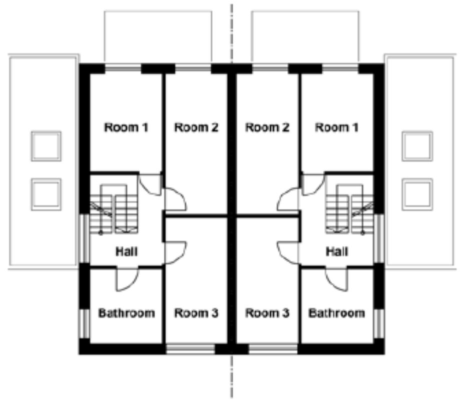
APPENDIX A: Zero and Near-Zero Energy Home Examples



Name: **"3-Litre Houses"**
Location: Ulm, Germany
Conditioned Floor Area: 1916 ft^2 (178 m^2)
Annual Primary Energy Use: ***39 kWh/m²a** (calculated *primary energy, EnEV)
Web: http://www.iea-shc.org/task28/publications/index.html

Description

In collaboration with major manufacturers of building materials, the municipal housing society (NUWOG) of the city of Neu-Ulm, Germany, constructed 3 semi-detached buildings that were designed as "3-litre" houses within a model housing project located in Ulm. The term '3-litre house' applies to low-energy buildings, whose annual primary energy demand for heating does not exceed 34 kWh/m²a (including the auxiliary energy required for pumps and fans). This corresponds to a primary energy content of 3 litres of fuel oil.

Envelope

The external walls are monolithic, 42.5 cm brickwork (U=0.20 W/m²K). The windows are made of triple glazing and wooden frames (Uw=0.80 W/m²K) with high-performance thermal insulation. The horizontal roof is a lightweight construction with high web girders with a mineral wool insulation infill (U=0.08 W/m²K). A 20 cm layer of rigid foam insulation (U=0.11 W/m²K) was applied to the lower surface of the concrete basement ceiling. The n50 – values that were measured in the blower-door test range below 0.6 h-1.

Technical Systems

The buildings are heated by means of a warm air heating system. The entire building services equipment comprising fans, filters, an extract-air heat pump, a cross-flow plate heat exchanger and a hot water tank with an electric heating rod, is integrated in one compact device that was installed in the bathroom.

Building characteristics	
Building volume V_e	599 m³
A/V	0.69 m⁻¹
Usable floor area A_N	191.8 m²

Name: **"3-Litre Urban Villa"**
Location: Celle, Germany
Conditioned Floor Area: 2064 ft^2 (191.8 m^2)
Annual Site Energy Use: **12.7 kWh/m²a** (calculated site energy, 38.2 primary energy)
  Heating and Ventilation: 6.1 kWh/m²a
  Domestic Hot Water: 6.6 kWh/m²a
Web: http://www.iea-shc.org/task28/publications/index.html

Description

The detached, single-family house was built in 2003 with the design goal of being a "3-litre" house. The building was built by a local manufacturer of prefabricated buildings to meet a perceived future demand for low-energy housing.

Envelope

The exterior walls are lightweight timber stud structures. The mineral-fibre insulation layer inserted between the vertical timber studs is 200 mm thick. An additional 60 mm insulating level with a mineral wool infill was applied on the inside. The roof was insulated with a 240 mm mineral-fibre layer between the rafters (U = 0.14 W/m²K); below the rafters, there is a 60 mm layer of mineral wool. The windows were provided with passive house frames and have triple thermal insulation glazing (UW = 0.8 W/m²K). The total energy transmittance of the glazing is equal to 0.55.

Technical Systems

In the 'Urban villa', a compact device with a heat pump is charged with all the tasks of energy supply, i. e. centralized balanced ventilation, DHW and space heating. The essential components of the device include: extract air heat pump, crossflow/counterflow heat exchanger and DHW storage tank. The exhaust air is extracted from the wet rooms to be conveyed through a crossflow/counterflow heat exchanger, which transfers the heat gained in this way to the intake air. A heat pump that was installed in the extract airflow draws more heat from the exhaust air and supplies it to the 200-litre DHW tank and the heating system. As a heat pump is more efficient at lower temperatures, the spaces of the 'Urban villa' were provided with a floor heating system. In case of very high heat demands for space heating or domestic hot water, direct electrical supplementary heating is possible.

Name: **"3-Litre Townhouse"**
Location: Celle, Germany
Conditioned Floor Area: 2249 ft^2 (209 m^2)
Annual Site Energy Use: **52.1 kWh/m²a** (calculated site energy, 66.3 primary)
- Heating: 21.6 kWh/m²a
- Ventilation: 2.2 kWh/m²a
- Domestic Hot Water: 28.3 kWh/m²a

Web: http://www.iea-shc.org/task28/publications/index.html

Description

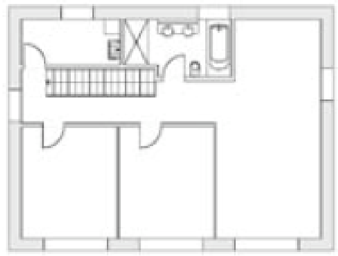
The detached single-family house was built in a newly developed area at the outskirts of Celle, Germany in 2001 with the design goal of using less primary energy annually for heating and ventilation than the equivalent of 3 litres of heating oil (less than 34 kWh/m²a).

Envelope

The exterior walls are lightweight timber stud structures. The mineral-fibre insulation layer inserted between the vertical timber studs is 200 mm thick. An additional 85 mm polystyrene insulating layer was applied to the outside of the wall. The wall has a U value of 0.15 W/m²K. The roof was insulated with a 240 mm mineral-fibre layer between the rafters (U = 0.18 W/m²K). The concrete floor slab of the building was provided with a 120 mm rigid-foam insulation board below the screed (U = 0.31 W/m²K). The wooden windows have a double thermal insulation glazing (UW = 1.6 W/m²K). The total energy transmittance of the glazing is equal to 0.58.

Technical Systems

The heat required for townhouse space heating and domestic hot water is generated by a gas-condensing water heater, which can be operated between 3.5 and 11 kW. The heat is distributed to the spaces of the house by means of a single-room controlled, water-bearing floor heating system on the ground floor, and through radiators located on the top floor. There is an individual space heating control in each room with underfloor heating. The spaces are equipped with indoor-air temperature sensors that control the servomotors of the heating circuits, thus influencing the throughput of water. In the other radiator heated spaces, the indoor-air temperature is controlled by means of thermostatic valves. The necessary air change is ensured by means of a balanced ventilation system (with heat recovery). This system is provided with a high-efficiency counterflow heat exchanger. Re-heating of the supply air was therefore considered unnecessary. As a rule, the ventilation system is run at stage 2. Depending on demand, the system can be manually switched to setback operation (stage 1) or to intensive ventilation (stage 3). There is also a time program that allows the fan stages to be timed in advance. The domestic hot water is heated in a 300-litre storage tank by the gas condensing water heater. The entire technical systems were installed in the utility room on the ground floor.



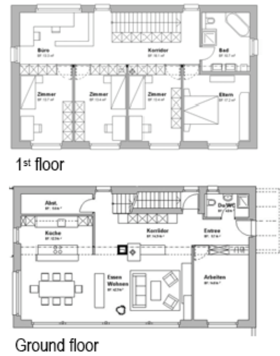
Name: **Dintikon House**
Location: Dintikon, Switzerland
Conditioned Floor Area: 2367 ft^2 (220 m^2)
Annual Site Energy Use: **26.1 kWh/m²a** (26.1 – 17 = **9.1 kWh/m²a** incl. PV)
Space and ventilation heating: 12.5 kWh/m²a (calculated site energy)
Energy source: Electricity
Domestic hot water: 13.6 kWh/m²a (calculated site energy)
Energy source: Solar thermal system 60%, electricity 40%
Electricity for technical systems: 17.0 kWh/m²a
Energy source: Photovoltaics
Web: http://www.iea-shc.org/task28/publications/index.html

Description
The Dintikon House is a privately built single-family house and is listed as the first Minergie-P certified house in Switzerland.

Envelope
The project is constructed with wood frame construction with U-Values [W/m2K] for the following components: walls (0.113), Roof (0.108), Floor (0.083), windows (0.74) (g-value: 52%).

Technical Systems
Supply air is preheated via 2 BP-pipes, 200mm diameter, 40m length. The supply air from the ground pipe is tempered by heat recovered from the exhaust air via a counterflow heat exchanger. Heat is distributed by the fresh air supply, heated with a compact counter flow heat exchanger unit supplied by the exhaust air heat pump. There is an electric powered radiator in the bathroom.

A solar thermal system is used consisting of 4.5 m2 flat plate collectors, a 320 l storage tank, (60% coverage of domestic hot water demand), with heat pump and electric resistance backup. Electricity (and remaining domestic hot water demand) is met via a 49.5 m2, grid connected, photovoltaic array.



Name: **Buttisholz House**
Location: Buttisholz, Switzerland
Conditioned Floor Area: 2765 ft^2 (257 m^2)
Annual Site Energy Use: **27.0 kWh/m²a** (calculated)
Space and ventilation heating 13.3 kWh/m^2a (calculated site energy)
Energy source electricity, wood stove backup
Domestic hot water 13.7 kWh/m^2a (calculated site energy)
Energy source: solar thermal system 71%, electricity 39%
Web: http://www.iea-shc.org/task28/publications/index.html

Description

The Buttisholz House is a privately built single-family house and is listed as the first Minergie-P1 certified house (2003) in the canton of Lucerne (CH).

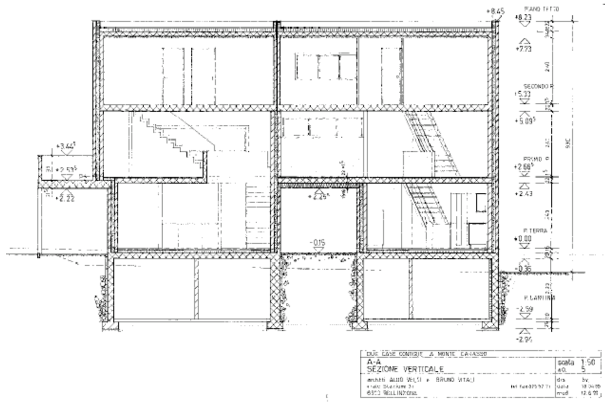
Envelope

Wood frame construction over concrete basement with the following U-values [W/m2K] for components: roof 0.071,walls 0.146,floor 0.124, windows 0.8, glass 0.7 (g-value: 65%).

Technical Systems

Ground pipe preheating of ventilation air 2 PE-pipes 160mm diameter, length: 43m. The supply air from the ground pipe is further tempered by heat recovered from the exhaust air via a counterflow heat exchanger: 260 m3/h (100 Pa), 3-step operation. Heat is distributed by the fresh air supply, heated with the heat exchanger. There is a wood stove backup heating: 80% efficiency, 11 kW, 6-8 hours burn time.

The solar thermal system is estimated to cover 71% of the domestic hot water demand and consists of 4.5 m2 collectors with an efficiency of 80%. The remaining demand is covered by an electrical back-up. The Boiler contains 400 l and has a maximal temperature of 97°C.

Name: **Vitali-Velti House** (semi-detached)
Location: Monte Carasso, Switzerland
Conditioned Floor Area: 2152 ft^2 (200 m^2) fore each unit
Annual site energy consumption 2001-2002: **25.07 kWh/m²a** (measured site energy)
Annual Heating Demand: 13.88 kWh/m²a (monitored site nergy)
Annual ventilation: 0.19 kWh/m²a(monitored site nergy)
Annual domestic hot water: 1.6 kWh/m²a (monitored site nergy)
Annual "domestic use": **9.4** kWh/m²a (monitored site nergy)
Web: http://www.iea-shc.org/task28/publications/index.html

Description

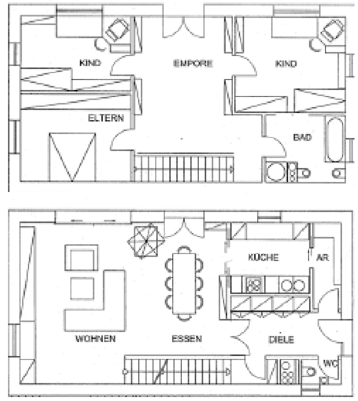
The house is a massive construction, two-family semi-detached house inhabited by the designers in a densely built-up area at the bottom of a south-facing valley.

Envelope

The structure of the house is massive. Each floor is a concrete slab construction. Part of the walls is also made of concrete. In order to reduce the number of thermal bridges, the house bearing structure is built inside the polystirol insulation envelope (13 to 20 cm of insulation thickness). The exterior of the wall is a brick masonry construction. The overall wall construction achieves a calculated U-value of 0.25 W/m2K. Windows have a global Uvalue of 1.1 – 1.3 W/m2K (frame included). The U-value of the roof is approximately 0.15 W/m2K.

Technical Systems

Ventilation air is provided by a constant airflow ventilation system with heat recovery. The southeast facade has a large window area that provides large passive solar gains as well as daylight. The solar heat gains are stored in the extensive building mass. The remaining heating requirement is covered by a wood stove in each house. Hot water is produced with two independent solar hot water systems, one in each house. Each system is sized at one square meter flat plate solar collectors per person (4 people per house). An electric resistance heating element in the hot water tank delivers auxiliary heat as needed.



Name: **Plus Energy House**
Location: Thening, Austria
Conditioned Floor Area: not provided
Annual Site Energy Use: **12.8 kWh/m²** (calculated site energy)

- Heating of space and ventilation air: 750 kWh/a (calculated source energy)
- Domestic hot water: 350 kWh/a (calculated source energy)
- Fans and pumps: 320 kWh/a
- Lighting and appliances: 220 kWh/a

Web: http://www.iea-shc.org/task28/publications/index.html

Description

Described as a “Passive-house type” design, the Plus Energy House strategy is to use an efficient envelope in combination with a solar thermal hot water system and PV array to offset all energy requirements and generate a surplus. The grid connected 10,350 Wp photovoltaic array produces electric energy that is consumed by the house and the surplus is sold to the utility. It is estimated that the house only requires 1/3 of the array capacity. This is the rationale for naming the house the “Plus” Energy House.

Name: **Housing in Goteborg**
Location: Sweden
Conditioned Floor Area: Not provided
Average Annual Site Energy Use: **76.9 kWh/m²** (varies between **45** and **97** kWh/m²a)
Web: http://www.iea-shc.org/task28/publications/index.html

Description

Located at Lindås, 20 km south of Göteborg, the city owned company Egnahemsbolaget has built 20 terrace houses (2004) in which a traditional heating system has been replaced by a heat exchanger in combination with an exceptionally well-insulated construction and a solar thermal hot water system. Building costs were estimated to be normal. The variation in energy use for the house units is large. The total delivered energy demand varies between **45 and 97 kWh/m²a** for different households. Savings compared to houses built according to the Swedish national building code and practice is 50 – 75%.

Envelope

The envelope U-values and construction is as follows: external wall: 0.10, framed construction with 43 cm insulation. Roof: 0.08 masonite beams with 48 cm insulation. Floor: 0.11concrete slab laid on 25 cm insulation. Windows: 0.85, three pane windows with two metallic coats and krypton or argon fill. Energy transmittance is 50% and light transmittance is 64-68%.

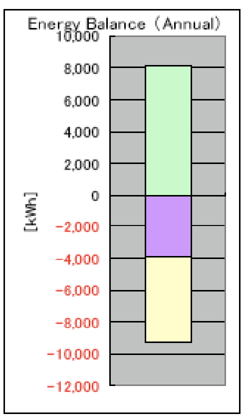
Technical Systems

The exhaust air in a counter flow heat exchanger heats supply air. It provides 80% heat recovery. In the summer the heat exchanger can be turned off (automatic bypass) and the house ventilated without preheating of the supply air and by opening windows. Part of the space heating demand is covered by heat gains from the occupants, ca 1200 kWh/year and energy efficient appliances and lighting, 2900 kWh/year which partly is useful to heat the building. The remaining space heating demand is covered by electric resistance heating, 900 W, in the supply air. Solar collectors of 5 m2 per house provide the energy for half the hot water demand. The 500 l storage tank is equipped with an electric immersion heater to cover the rest of the demand.

Name: **Kanagawa House**
Location: Kanagawa, Japan
Conditioned Floor Area: 2459 ft^2 (228.58 m^2)
Annual Site Energy Use: **39 kWh/m^2** (39 – 35 kWh/m^2 **= 4 kWh/m^2** including PVs)

Description

A detached house built to meet the ZEB goal. The house was monitored over the course of a year its energy consumption compared against the energy generated from its PV array (the Zero Energy Ratio, shown in Figure A1). It is not specified if the house was occupied during testing.



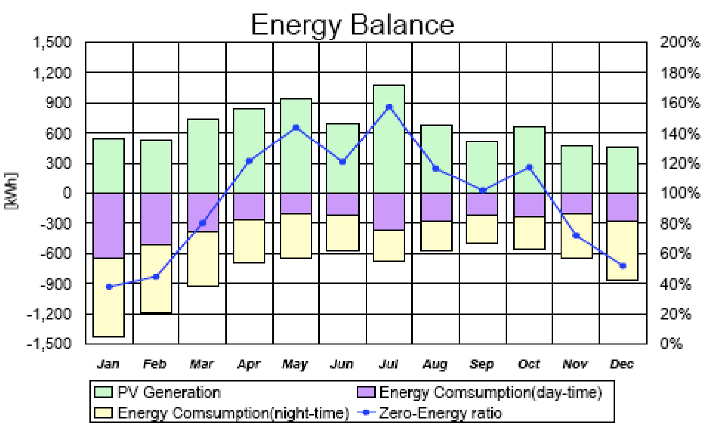


Figure A1 Source: http://www.iea-shc.org/task28/publications/Japan_Kanagawa.pdf

Envelope

U-values of the envelope are as follows values : wall 0.38 W/Km2, roof 0.48 W/Km2, floor1.00W/Km2, window 2.55 W/Km2.

Technical Systems

The PV system on the roof of this house has a 11.3kW value over all (east side:5.2kW, west side :6.1kW). Surplus electricity is automatically sold to power utilities. A heat pump system (COP > 3) is used in addition to high efficiency appliances run on "off-peak" schedules.

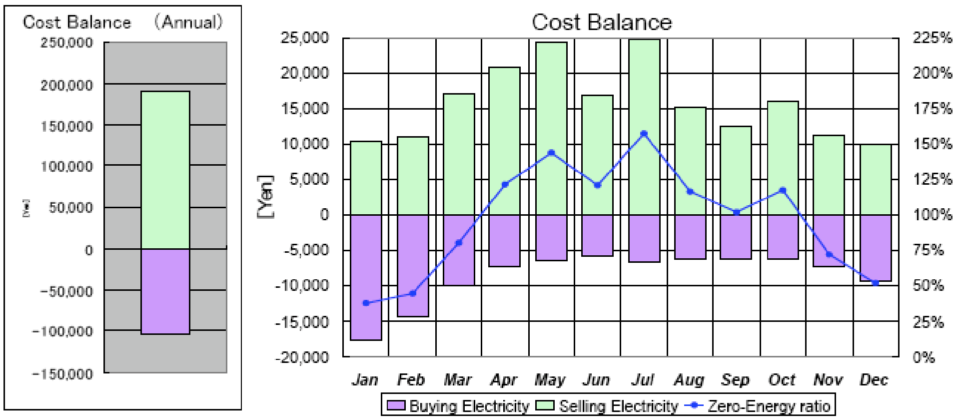
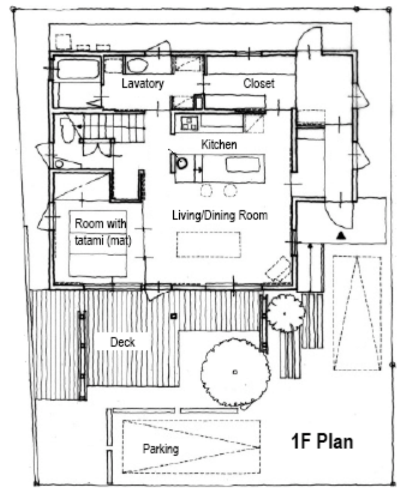


Figure A2 Source: http://www.iea-shc.org/task28/publications/Japan_Kanagawa.pdf

Costs

This house was subsidized from New Energy Foundation in accordance with the subsidy program for residential PV systems. The subsidy ratio of this program is 1/3 of the total installation cost. As a result, the total additional cost compared to a reference standard house is 7 million yen, and the saving running cost is about 300,000yen per year.



Name: **OM Solar House**
Location: Hamamatsu, Japan
Conditioned Floor Area: 1248 sq.ft (116 sq.m)
Annual Site Energy Use: **107 kWh/m²** (includes use of a kerosene space heater)
Web: http://www.iea-shc.org/task28/publications/Japan_OMSolarHouse.pdf

Description

Hamamatsu is located in the central middle part of Japan (N34☐42’, L137☐43 ’), where heating is required from November to April. Based on an assessment of the available solar energy at this location, an innovative solar heating system (“OM”) was tested.

Envelope

The envelope U-values are as follows: values: roof 0.31W/Km2, wall 0.59W/Km2, floor 1.85W/Km2, window 3.49W/Km2

Technical Systems

The OM Solar system operates on the principle of taking solar-heated air collected under the surface of a building's roof and channeling this hot air, via an interior vertical duct, down beneath the ground floor to a heat-storing concrete slab. This concrete slab warms the ground floor and releases hot air through floor vents for distribution throughout the building's interior spaces. Auxiliary devices come into operation for hot water supply and for backup heating on overcast or very cold days. When external air exceeds a certain temperature, hot air collected under the roof's surface is expelled through an exhaust duct located directly under the roof without being circulated through the interior spaces.

Name: **East Star**
Location: Borrego Springs, CA
Conditioned Floor Area: 1,920 ft^2
Annual Energy Use:
Web: http://www.clarumzeroenergy.com/?nav=house&h=4

Description

East Star is one of the four houses developed in Borrego Springs, CA for purposes of the research on Zero Energy Homes. Borrego Springs is located in California Climate Zone 15 and has 1,075 Heating Degree Days and 3,843 Cooling Degree Days. Climate Zone 15 is an extreme hot-dry climate zone that has a period of four to six weeks in late summer with high humidity.

Envelope

Roof: R-38; Walls: (2x6 Frame) 2x6 wood wall system with sprayed-in Icyene® foam insulation R-18; Windows: Dual pane vinyl frame windows with spectrally selective glass.
SL (U=0.35, SHGC = 0.35) FX (U=0.35, SHGC - 0,35) Patio Dr (U = 0.35, SHGC = 0.35); Air infiltration 0.30 ACH; HVAC system: Lennox (21 SEER equivalent); Water and space heating: Tankless w/ Energy Factor = 0.84 & Space Heating; Lights: CFL; Appliances: Energy Star.

Technical Systems

Wall System: The East Star home was built using a 2x6 wood wall system 16 inch on centers. The walls were constructed with sprayed-in Icyene® foam insulation, making the walls equivalent to R-18. The walls were built using standard building practices.
HVAC System: This home uses a two-speed 20.5 SEER Lennox air-conditioning unit.

Costs

East Star House was used in this study as a base house for building costs. It costs $57,242 to build this 2x6 frame, while HVAC Lennox was $15,846.

Name: **Broken Arrow**
Location: Borrego Springs, CA
Conditioned Floor Area: 1,920 ft^2
Annual Energy Use:
Web: http://www.clarumzeroenergy.com/?nav=house&h=3

Description

Broken Arrow is one of four houses within the Borrego Springs, CA ZEH project.

Envelope

Values for the envelope are as follows: Roof: R-38 w/ radiant barrier; Walls T-MASS (R-28 equivalent); Windows: Dual pane vinyl frame windows with spectrally selective glass.
SL (U=0.35, SHGC = 0.35) FX (U=0.35, SHGC - 0,35) Patio Dr (U = 0.35, SHGC = 0.35); Air infiltration 0.30 ACH; HVAC system: OASys Evaporative Cooler + Conventional Ducted AC for
periods of high humidity (14 SEER equivalent); Water + Space Heating: Tankless w/ Energy Factor = 0.84 & Space Heating; Lights: CFL; Appliances: Energy Star.

Technical system

Wall System: The Broken Arrow home was built using a Structural Insulated Panels (SIP) wall system. Prefabricated panels consist of six inches of insulation between two, ½ inch layers of wood, equating to an R-27 wall. Prior to construction, the panels were manufactured with window and door openings as well as wiring conduits. At the site, the panels are assembled in the planned order. **HVAC System:** Broken Arrow uses an OASys Evaporative cooling system with an additional conventional ducted AC for periods of high humidity. This is equivalent to a 14 SEER system. The OASys system is a two-stage direct-indirect cooler which utilizes a single down-flow variable speed blower that moves air through the wet side of the indirect cooling module (heat exchanger) and the supply air to the house through the dry side of the heat exchanger as well as through the direct cooling module (cellulose media).

Costs

Compared to East Star, Broken Arrow costs 27% more to build the frame, or $72,674, and 33% more for the HVAC, or $21,009.

Name: **Country Club**
Location: Borrego Springs, CA
Conditioned Floor Area: 1,920 sq.f t.
Annual Energy Use:
Web: http://www.clarumzeroenergy.com/?nav=house&h=2

Description

The Country Club home is of a same size, and in the same location as other houses.

Envelope

Values for the envelope are as follows: Roof: R-38 w/ radiant barrier; Walls T-MASS (R-28 equivalent); Windows: Dual pane vinyl frame windows with spectrally selective glass.
SL (U=0.35, SHGC = 0.35) FX (U=0.35, SHGC - 0,35) Patio Dr (U = 0.35, SHGC = 0.35); Air infiltration 0.30 ACH; HVAC system: OASys Evaporative Cooler + Radiant Floor Heating and Cooling; Water + Space Heating: Tankless w/ Energy Factor = 0.84 & Space Heating; Lights: CFL; Appliances: Energy Star.

Technical System

Wall System: The Country Club home is one of the two homes built using T-MASS®™. These high thermal mass walls consist of four inches of extruded polystyrene between a two inch layer and a four inch layer of concrete; the four inch layer makes up the inside wall. This wall system equates to an R-28 wall. Prior to construction, these walls were manufactured with window and door openings, as well as wiring conduits and trucked to the site. At the site, the walls were erected with the use of a crane and set into place on a buried welded base. **HVAC System** The Country Club home also uses an OASys Evaporative cooling system, just like Broken Arrow with an additional conventional ducted AC for periods of high humidity. The use of the OASys system in this home differs from the Broken Arrow home with its use to cool the slab, providing radiant flooring. This is equivalent to a 14 SEER system.

Costs

The Country Club costs 75% more to build the frame or $100,301; and 29% more for the HVAC, or $12,923 in total.

Name: **Di Giorgio**
Location: Borrego Springs, CA
Conditioned Floor Area: 1,920 ft^2
Annual Energy Use:
Web: http://www.clarumzeroenergy.com/?nav=house&h=1

Description

Di Giorgio is one of the four ZEH at the Borrego Springs site.

Envelope

Values for the envelope are as follows: Roof: R-38 w/ radiant barrier; Walls T-MASS (R-28 equivalent); Windows: Dual pane vinyl frame windows with spectrally selective glass.
SL (U=0.35, SHGC = 0.35) FX (U=0.35, SHGC - 0,35) Patio Dr (U = 0.35, SHGC = 0.35); Air infiltration 0.30 ACH; HVAC system: Freus w/ Ducts and Floor Pre-cooling + Night Breeze; Water + Space Heating: Tankless w/ Energy Factor = 0.84 & Space Heating; Lights: CFL; Appliances: Energy Star.

Technical system

Di Giorgio was built with 10" T-MASS®™ wall systems. It uses a Freus Cooling system, an evaporative condenser connected to a variable speed air handler. This condensing unit can be operated at night to cool water that is circulated through radiant flooring tubes in the slab. Di Giorgio also uses a NightBreeze® residential economizer that has a variable speed air handler, operating at very low speeds, and outside air damper for fresh air ventilation for cool spring and fall nights.

Costs

Di Giorgio house costs 74% more to build the frame or $99,762; and 13% more for the HVAC, or $20,440 in total.

Name: **Premier Gardens**
Location: Rancho Cordova, CA
Conditioned Floor Area: 1,285, 1,503, 1,26, 1,846, and 2,248 ft^2
Annual Energy Use:
Web:http://www.eere.energy.gov/buildings/building_america/cfm/project.cfm/project=Premier%20Gardens/state=CA/FULL=California/city=Rancho%20Cordova

Description

In 2004, SMUD led a collaborative effort between Premier Homes, the US DOE, the National Renewable Energy Laboratory (NREL), ConSol (BIRA team lead) and GE Energy to build the first all-ZEH community in Sacramento . The Premier Gardens ZEH project provides us with an excellent opportunity to compare the impact that ZEH features have on customer's energy use and bills. This is because adjacent to the Premier Gardens project, a competing homebuilder built 95 similarly sized homes marketed to the same demographic. As a result, the Premier Gardens ZEH energy use, utility bills, and electric peak demand can be compared to the energy use, utility bills, and electric peak demand of SMUD customers living in the adjoining non-ZEH homes.

Envelope

- Low Infiltration
- Vinyl, low-e, spectrally selective windows;
- 92 percent efficient furnace (AFUE .92);
- SEER 14 with TXV air conditioner;
- Engineered heating and cooling duct runs ; • Tankless water heater with a .82 Energy Factor;
- Insulated hot water pipes;
- Fluorescent lighting for all permanent light fixtures;
- Third-Party inspection and testing of the home's energy efficiency features, such as the quality of the insulation installation, (qualifying the home as an Energy Star Home).

Name: **Solar Harvest**
Year: 2005
Location: Boulder, CO
Conditioned floor area: 4585 ft^2 finished (heated) and 400 ft^2 unfinished (heated sports garage) & 600 ft^2 unfinished (unheated) carport, including 275 ft^2 of sunspace for passive gain with active distribution
Annual Energy Use: 10,000 kWh/year thru 2007;
9,500 KWh/year 2008+ (estimated)
Energy savings compared to other homes in the area: 324kWh
Web-site: http://www.ecofuturesbuilding.com/pdfs/printbooklet.pdf

Description: (from the builder)
Solar Harvest was designed and built with the overriding intentions of not only creating a safe and comfortable living space, but also of becoming a model in sustainable home construction –in this case, a Net-Zero Energy Home. Our guiding design principle was to incorporate appliances, systems and controls into a home so that throughout the course of a year the home will ultimately supply more energy to the utility than it consumes. By meeting this net zero energy goal, we are striving to build a house that will be affordable and viable 100 years from now, when who knows how much natural gas – and electricity –will cost. This is a showcase project but also to be our family home. We have two children, 6 and 8, and plan on adopting another child several years from now. We have also designed for the contingency of elderly parents staying with us, as well as foreign exchange students, traveling activists, and visiting relatives and friends. The home will have adequate space for meetings of all kinds – political, parenting, personal growth, or neighborhood groups. We look forward to being a community resource in this sense, in our time here. And with the home built to last several hundred years, the spaces and layout are adaptable to a wide variety of needs of future residents

Envelope:
Maximum allowed fly ash content in all concrete for foundations, slabs
House & garage rest on 54 drilled piers, with basement on a suspended structural slab: expansive soils will not affect the longevity of home Incorporates Optimal Value Engineering framing techniques (see www.eeba.org for more information) Forest Stewardship Council (FSC) certified 2x6 & 2x4 wall studs
Recycled content in steel beams and columns .

Technical System

Insulation and Shell
2 x 6 stud wall with 1½"resilient channels at 24"on center. Icynene insulation 7"thick in walls and 12"in ceiling. Above ground walls rate R-34 and ceiling R-45 with Icynene •Basement walls rate R-30 with GreenBlock ICFs (see Foundations). Fiberglass windows w/ Heat Mirror glass; e.g., North glass rate sat R-15. 3011. Wall profile:1"rigid foam (XPS) encased with 1/8"GrailCoat waterproofing. 1½"resilient channels at 24"on center across all wall framing members, creating 7"deep cavity for insulation; encased by double 5/8"sheetrock for added thermal mass.

Windows and doors
Fibertec fiberglass windows with Alpen glazing provide overall U-values of 0.20 on the west and east, and 0.12 on the north in addition to extremely low air leakage ratings. Solar Heat Gain Coefficients calibrated for each exposure to reduce or increase solar energy intake as derived: South Glazing is 10.6% of upper level floor area. 0.27 on East & West🕙0.50 on North 0.67 on sunspace (east half) & 0.62 (west half) 0.54 on upper level south windows

Heating
Passive heat gain accomplished by 275 ft2of sunspace vertical glazing with active distribution ducts and Panasonic ECM motor fans, controlled by thermostats in rooms with no direct gain•Double 5/8"sheetrock on all walls and ceilings except stairs and hallways for distributed, indirect thermal mass•100% of expected building heat needs achieved through passive solar gain, thermal mass, solar collectors and the solar storage tank, with staple-up tubing in upper 2 levels and in-slab basement tubes for radiant floor heat. Design heat load of about 29,000 BTUs/hr for 3 levels totaling 4585 ft2plus 400 ft2 garage, plus 360-gal. spa

Ventilating and Air Conditioning
No air conditioning unit -natural cooling provided by super insulation, nighttime intake of cool air assisted by whole house fan as necessary, shade trees on east and west, and south roof shaded by solar panels. Summer cooling by natural "chimney" effect of airflow through operable skylight in hall of top floor and whole-house fan, with improved air flow through windows above bedroom doors, & Return Air Pathways above N BR door (baffled transfer grilles that let air through but block¾of sound; made by Tamarack . Air destratification achieved by ERV and sunspace systems. Natural ACH expected to be 0.1 or lower. Ground-cooled air brought into home through buried pipes –air expected to be about 55 deg F, year
Energy Recovery Ventilation (ERV) supplies fresh air to bedrooms and living spaces •Bathrooms exhaust through ERV; Kitchen vents directly to outside. 93%-96% apparent sensible recovery; 81%-83% sensible recovery efficiency; 88% latent efficiency. Power consumption: 48 watts @ 70 cfm; 260 @ 205 cfm. •Air to ERV supplied through 260 ft of 6"PVC pipe buried 8 feet below grade for pre-warming (winter) and –cooling (summer). *Cooling* Colorado R600 High Efficiency Air Conditioner installed. Max. 750 watts @ 1200cfm air•Produces 64ºF air with 120ºF+ outdoor temps•Low water consumption•EER 40+Whole-house fan byTamarack Technologies, Inc. purchased fromPositive Energy Conservation Products, Boulder 303-444-4340 *HV1600-GDR* -Tamarack 1600 Gold with R-38 Doors, 1600 cfm on high speed and 800 cfm on low

PVs
6.84 kW grid-tied PV power mounted in two arrays. Half of the panels flush-mounted on 20-degree roof and half on 40-degree roof; these different tilt angles affect electricity production only by a few percent . When the panels produce more electricity than the home is consuming, electricity flows back out to the utility grid through a "net meter" that counts the outgoing power as a credit; when it is too cloudy

or nighttime, electricity flows back through the meter and billable power is recorded by Xcel. With this size system, and low electrical demands, the home is designed to be a net power provider –as can be any home with such perfect solar access. Net meter reading was minus 1000 kWh as of October 3, 2006.

Energy Efficiency
Low electrical demand achieved through use of compact fluorescent bulbs with occupancy sensors (manual on/timed off) . “Phantom loads” reduced through use of power strips on switched outlets. Energy-Star rated major appliances including fridge, dishwasher and washer/dryer. Annual net energy bill is expected to be zero, or less

Name: **zeroHouse**
Year: 2005
Location: anywhere (prefabricated structure)
Conditioned floor area: 650 ft^2 250 ft^2 covered exterior decks
Annual Energy Use: not measured yet (presumably 0 – off-grid house)
Energy savings compared to other homes in the area:
Web-site: http://www.zerohouse.net/

Description:
zeroHouse is a prefabricated structure that can be put up to any surface, including a slope of 35 degrees, and water up to 10 feet deep. It differs from other prefabricated structures because it requires no external utility or waste disposal connections.

Envelope:
The envelope is composed of steel-reinforced polyurethane-filled SIPS panels that achieve an R-value of 58. Exterior cladding is a custom-colored aluminum/polyurethane sandwich panel installed with a pressure-equalized rainscreen attachment system.
Four stainless-steel helical micropiles fitted with field-adjustable leveling jacks.
A multi-part turbular-steel structural system supports the living and service modules, as well as the large photovoltaic/rainwater collection panel. All parts are independently anchored to this frame, allowing flexibility in high wind conditions.

Technical system:
PV: 40 high efficiency BP_41/5 solar panels, generating up to 7000 watts.
Power Storage: 36 interlinked Concorde Sun-Xtender sealed lead-acid batteries.
Operational Voltage: 48v battery bank and standards 115v operational voltage. Utilizes Systems FX 2524T sealed inverters. Climate control: 9000 BTU Daiking Micro-Split Heat pump system with two independently controlled zones. SEER: 18 Water Supply: Four 550-gallon primary storage tanks elevated for passive pressurization. UV and reverse-osmosis processing. Waste Processor: Centrex 3000 auto-composter with negatively-pressurized vent system. Odor-free high grade compost needs to be removed every 6 months.

Foundation Anchors: Four Chance Pulldown helical micropile anchors, stainless steel with leveling plates. Structural System: Turbular cold-rolled steel frame sections with bonded powder-coat finish. Body Shell: Structural insulated panel system (SIPS), with integrally colored Alycobond exterior cladding. Insulation: Closed-cell polyethylene foam panel cores. Metalliezd Tyvek panel wrap. Assemblyrated R-58. Window Assembly; Triple-pane insulating units with SentryGlas laminated exposure fil, low e-coating, and argon-filled cavities. Exterior Doors: Kevlar reinforced door shell with vacuum-sealed aerogel insulated core.

APPENDIX B – Base Case House Model

This section contains all the technical details specified in the model of the Base Case house, as well as the relevant references.

B.1. Table of envelope, HVAC, site, and climate characteristics

The table below lists the EnergyGauge/DOE-2 model inputs for the Base Case house, including site, climate, envelope, and HVAC characteristics. The table does *not* include inputs for lighting, appliances, other plug loads, or hot water use, which are discussed in subsequent sections.

Category	Parameter	Base Case value	Notes
Site / climate	Location	Champaign-Urbana, Illinois	
(Notes 1-4)	IECC climate zone	IECC Zone 5	1,2
	DOE-2 weather file	Springfield, IL	3
	Site shading (trees + buildings)	none	4
House geometry	House type	Single family, 3 bedroom / 2 bath	
(Notes 5-7)	Configuration	2 stories, no garage, unconditioned basement	
	Area	2000 sq ft conditioned floor area, additional area in unconditioned basement	
	Dimensions and orientation	25 x 40 ft, long sides face north/south	5
	Ceiling height	8.5 ft	6,7
Occupants	Number of occupants	4 occupants	
Roof / ceiling	Roof type	Gable or shed	8
(Notes 8-12)	Roof construction / materials	composition shingles, wood frame construction	8,9
	Attic	Full attic, unconditioned	10
	Ceiling construction / materials	wood frame construction	8
	Ceiling insulation R-value	R-30 hr-ft^2-F/Btu	11,12

Walls / doors	Wall construction / materials	wood frame construction	13
(Notes 13-17)	Wall insulation R-value (not including windows or doors)	R-13 hr-ft^2-F/Btu	14,15
	Door placement	two doors, 21 sq ft each, one each on north and south sides	16
	Door U-value	U-0.33 Btu/hr-ft^2-F	
Basement / floor	Floor / basement arrangement	Floor over unconditioned basement	18
(Notes 18-21)	Basement area	1000 sq ft	18
	Floor construction / materials	wood frame construction	19
	Floor insulation	R-13	20,21
Windows	Window arrangement	* North and south walls - Six 4.5 ft wide by 5.0 ft tall windows (three per floor) * East and west walls – Two 4.5 ft wide by 5.0 ft tall windows (one per floor)	22
(Notes 22-29)	Total window area	360 sq ft (15.4% of wall area)	23
	Window construction / materials	wood frame, double paned, clear glass	24,25
	Window U-value and coating	U = 0.48 Btu/hr-ft^2-F, not low-E	26,27
	Window SHGC	SHGC = 0.76	28, 29
Shading devices	Overhangs	none	30
(Notes 30-31)	Blinds	yes	31
Infiltration	Infiltration (ACH)	0.6 ACH	32,33
(Notes 32-33)			

Heating / cooling systems	Heating system type	gas furnace	34
(Notes 34-39)	Heating system efficiency	78% AFUE	35, 36
	Heating system size	60.0 kBtu/hr (auto-sized by DOE-2)	
	Cooling system type	air conditioner	
	Cooling system efficiency	SEER 13	36, 37, 38
	Cooling system size	30.1 kBtu/hr (auto-sized by DOE-2)	
	Heating and cooling set points	Heating set point = 68 F Cooling set point = 78 F	39
Ducts and fans	Duct location	Ducts in unconditioned attic	40
(Notes 40-43)	Supply duct insulation	R-8 insulation	41,42
	Duct leakage	5.64%	43
Lighting	See lighting section		
Appliances	See appliances section		
Hot water use	See hot water section		
Misc. plug loads	See section on miscellaneous plug loads		
Notes	[1] DOE "Residential Requirements", slide 12		
	[2] This is the available weather file closest to Champaign-Urbana		
	[3] Illinois spans Zone 4 and Zone 5. Use Zone 5 since it has slightly more stringent efficiency requirements. This part of US is in IECC's "humid" classification.		
	[4] Varies too much by site, and landscaping for energy performance is outside of competition rules anyway		
	[5] LBNL assumption		
	[6] Lucas 2007, p.3.1		
	[7] Note that wall height is 9.0 ft per story		
	[8] Authors' assumption, since this is the DOE-2 default		

[9] Materials choice also implies DOE-2 default values for roof absorptivity, emissivity, etc.

[10] LBNL assumption

[11] DOE "Residential Requirements", slide 14,16; Lucas 2007, p.3.1

[12] R-30 is standard practice for Chicago; IECC requirement is R-38 insulation or U-0.030

[13] Authors' assumption, since this is the DOE-2 default

[14] DOE "Residential requirements, slide 14,16; Lucas 2007, p.3.1

[15] R-13 is standard practice for Chicago; IECC requirement is R-19 insulation or U-0.060

[16] Number and area of doors from Lucas 2007, p.3.2; placement is LBNL assumption

[17] Derived from single family residence DOE-2 modeling effort in RMI 2007.

[18] LBNL assumption

[19] Authors' assumption, since this is the DOE-2 default

[20] DOE "Residential Requirements", slide 14,16; Lucas 2007, p.3.1

[21] R-13 is standard practice for Chicago; IECC requirement for floor above unheated basement is R-30 insulation or U-0.033

[22] assumed window dimensions; assumption is consistent with the 357 sq ft total glazing area reported in Lucas 2007

[23] calculated from window specs above

[24] LBNL analysis; DOE 2007 table 5.5.8

[25] Assumed construction; this window construction corresponds approximately to U=0.48 and SHGC=0.76

[26] Lucas 2007, p.3.1, 3.2

[27] standard practice is U-0.48, not low-E; 2006 IECC Zone 5 requirement is U=0.35, low-E

[28] MEEA 2003, p.37; DOE "Residential Requirements", slide 14

[29] no IECC requirement for Zones 4 or 5

[30] Lucas 2007 DOE-2 model

[31] LBNL assumption

[32] MEEA 2003, p.29; Lucas 2007 DOE-2 model; engineering judgment

[33] DOE-2 model used in Lucas 2007 lists 0.486 ACH. The model appears to be of the IECC-compliant house. Since infiltration isn't mentioned in his report as a variable, though, assume that this is the value for both Lucas's "base case" and IECC houses.

[34] LBNL assumption

[35] DOE Bldg E Data Bk, Table 5.6.3; Lucas 2007, p.3.1

[36] set by Federal law, not IECC

[37] Lucas 2007, p.3.1

[38] SEER 13 seems reasonable. DOE Bldg E Data Bk table 5.6.5 says that the average SEER in 2004 was 11.2 and best in show was 18.9. See <http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12300> for additional information

[39] These set points come from the draft of the EFHC rules in effect at the time the model was run

[40] LBNL assumption

[41] Lucas 2007, p.3.1

[42] this is IECC 2006 required value for ducts outside conditioned envelope; "standard" practice is no insulation

[43] LBNL assumption. Roughly consistent with the 6.7% leakage assumed in modeling effort for California homes in RMI 2007. The 6.7% is the supply duct leakage for a 2-story home in AC, from the DEER database

B.2. Lighting

The authors derived the lighting characteristics for the Base Case house model from the DOE-2 model used in Lucas 2007 and from the DOE *Building Energy Data Book*. The authors' goal was to create inputs that would both (a) yield modeling results consistent with the annual lighting energy use reported in these sources, and (b) be consistent with common-sense assumptions about number and type of fixtures (which determine the peak installed wattage) and the usage schedule.

Modeling inputs

- 1242 Watts of peak installed lighting capacity, counting basement lights. This wattage corresponds to a mixture of incandescent bulbs and CFLs.
- A lighting schedule [1]
  - Main floor lights on 3.75 hours per day
  - Second floor lights on 6 hours per day
  - Basement lights on 0.75 hours per day

These inputs yield a modeled annual lighting energy use of 2026 kWh/yr, consistent with the 2000-2400 kWh/yr estimates derived from the sources mentioned above [2][3].

These lighting inputs should also be consistent with the following lighting service characteristics. The authors did *not* check that the assumed fixtures could indeed produce the listed illumination levels at night, and they assumed that daylighting would help provide adequate illumination during daylight hours when few or no lights are on.

Service characteristics

- Interior lights
    - Between 30-50 fc of illumination in all spaces [4]
    - This level of illumination should be available to occupants at any time, via daylighting and/or artificial light, if they wish to illuminate spaces.
- Exterior lights
    - No requirement

Sources / notes

- [1] Based on Swinton et. al. 2001, p.19
- [2] The estimated range of lighting energy use is 2000-2400 kWh per year. This estimate is based on calculations from three sources: the DOE-2 model used by Lucas 2007; DOE 2007 Building Energy Data Book, Tables 5.9.1 and 2.1.1; and DOE 2007 Building Energy Data Book Table 5.9.3.
- [3] As a cross-check, dividing 1471 Watts by the non-basement floor area of 2000 sq ft yields a power density of 0.7355, which seems reasonable.
- [4] LBNL estimate of reasonable lighting levels for residential space. As a cross check, UC Berkeley's lighting standards are 45 fc for classrooms, <http://www.cp.berkeley.edu/CDS_ucb/Div-16-4.html>

B.3. Appliances

This section describes the appliance characteristics (not counting miscellaneous plug loads, which are discussed later) in the Base Case house model.

This section also describes the assumed usage and "quality of service" characteristics for each piece of equipment. For example, a refrigerator should be able to hold a certain volume of items. Contestants designing for the Energy Free Home Challenge are encouraged to innovate in order to meet these service requirements using as little energy as possible, but they cannot change the requirements themselves.

Technical note:

- Some data on appliance characteristics is taken from RECS 2005. Where possible, the authors have used RECS data specific to the region in which Illinois is located, which is the "East North Central" division of "Midwest" census region. (See region descriptions at <http://www.eia.doe.gov/emeu/recs/glossary.html>.)

B.3.1. Refrigerator

Modeling inputs

- Total annual energy use of 492 kWh/yr [1][3]
- Peak power draw of 56 Watts
- Constant operation [4]

This energy usage corresponds to a refrigerator with the service characteristics described below.

Service characteristics

- Volume: Refrigerator fresh volume is 18 ft^3, freezer fresh volume is 5 ft^3; adjusted volume is 26 ft^3 [1]
- Other characteristics [2]
    - Freezer built in
    - bottom mounted freezer (not fridge and freezer side by side)
    - frost free (not manual defrost)
    - does not have through the door ice and water
    - ENERGY STAR certified
- Service life: 13 years [1]

Sources / notes

- [1] EPA 2008 refrigerator savings calculator
- [2] RECS 2005, Table HC 12.9, Table HC12.10
- [3] The IECC 2006 reference case DOE-2 model reports a higher annual energy usage, presumably because they assume a less efficient model
- [4] IECC 2006 reference case DOE-2 model says fridge usage is fairly flat (typically ~75% or more of peak wattage
- [5] For reference, the EPA 2008 refrigerator savings calculator lists the cost of an ENERGY STAR refrigerator as $1,100

B.3.2. Stove / Range / Oven

The authors considered "the stove" to combine stove, range, and/or oven functionality into a single appliance.

Modeling inputs

- Annual energy use is 447 kWh/yr [2] [4]
- Appliance is electric, not natural gas [1]
- Peak power draw is ~1 kW [3]
- Operating schedule
    - Used 1 hour total per day [3][4]

Service characteristics

- Range / stove / oven are considered to be a single appliance
- Used for 1 hour total per day [3][4]

Sources / notes

- [1] RECS 2005, Table HC 12.9
- [2] This is roughly consistent with the 365 kWh/yr implied by Mills 2007, p.41-42
- [3] Mills 2007, p.41-42

- [4]Energy use from IECC 2006 reference case DOE-2 model. The model has more spread out usage, but still has biggest usage peak in the evening

B.3.3. Dishwasher

Modeling inputs

- Energy use (not counting hot water) is 187 kWh/year [3] [4]
- Hot water consumption = 4 gallons/load [3] [5]
- Operating schedule
    - 4 loads per week [3][6] is the usage as reported in the source data, but DOE-2 cannot accommodate such a schedule. Instead, the modeled usage is 5 operations per week, with the energy use pro-rated to yield the proper total annual energy usage.

The hot water used by the dishwasher is fed into the hot water portion of the DOE-2 model, and its energy use is accounted for in the water heating calculations.

Service characteristics

- Standard size: A capacity greater than or equal to eight place settings and six serving pieces. The majority of models with 18-inch cavities can fit this amount. [1]
- Runs 4 loads per week [3][6]
- ENERGY STAR certified [2]
- Service life: 11 years [3]

Sources / notes

- [1] See ENERGY STAR FAQ at <http://energystar.custhelp.com/cgi-bin/energystar.cfg/php/enduser/std_adp.php?p_faqid=2537>
- [2] RECS 2005, Table HC12.10
- [3] EPA 2008 dishwasher savings calculator.
- [4] This is roughly consistent with Mills et. al. 2007, p.41, assuming 4 loads per week
- [5] Mills et al. assume 11 gallons per load, and the EPA dishwasher savings calculator assumes 6 gal/load for non-ENERGY STAR models. These higher usages are ignored.
- [6] IECC 2006 reference case DOE-2 model has one daily usage peak, which would mean more than 4 loads per week. According to RECS, most households do either 2-5 or 6-9 loads per week (RECS 2005, Table HC12.10); so, 4 loads per week is on the lower end of the usage range. However, it seems unlikely that a family of four would need to fully load a dishwasher (given the capacity above) every single night.
- [7] For reference the EPA 2008 dishwasher savings calculator lists the cost for an ENERGY STAR unit as $545

B.3.4. Clothes Washer

Modeling inputs

- 56 kWh/yr electricity use, not counting hot water energy [4] [5]

- Water consumption is 15 gallons/load [4] [6]
- Operating schedule
    - 1 load per day [2][4]

The hot water used by the clothes washer is fed into the hot water portion of the DOE-2 model, and its energy use is accounted for in the water heating calculations.

Service characteristics

- ENERGY STAR certified [1]
- Runs 1 load per day [2][4]
- Service life: 11 years [4]

Sources / notes

- [1] RECS 2005, Table HC12.10
- [2] Mills et. al. 2007, p.37-38
- [3] IECC 2006 reference case DOE-2 model has only one daily peak
- [4] EPA 2008 clothes washer savings calculator
- [5] EPA reports about double this usage for a non-ENERGY STAR unit, yielding annual kWh use roughly consistent with the IECC 2006 reference DOE-2 model and Mills et. al.
- [6] Estimates of per load hot water usage in Mills et. Al .2007 differ
- [7] For reference, the EPA 2008 clothes washer savings calculator lists the cost of an ENERGY STAR unit as $500

B.3.5. Clothes Dryer

Modeling inputs

- Dryer is electric, not natural gas
- Total annual energy use: 835 kWh/yr [3] [4]
- Operating schedule
    - Runs 1 load per day, just like the clothes washer [1][4]

Service characteristics [2]

- Runs 1 load per day
- Should be able to accommodate at least the same size load as the clothes washer [5]

Sources / notes

- [1] Mills et. al. 2007, p.39
- [2] Note that ENERGY STAR doesn't label clothes dryers
- [3] DOE 2007 Building Energy Data Book, Table 5.10.3
- [4] This is consistent with the IECC 2006 reference case DOE-2 model
- [5] LBNL assumption, since other "typical" service characteristics could not be found

B.3.6. Pool Pumps

No pool-related loads were included in the Base Case house model.

B.4. Hot Water Use

To determine the total hot water use for the Base Case house, the authors used an estimated schedule for occupant hot water use, as well as data about the water usage for showers and other activities. Then, the authors added appliance hot water use to determine the daily total gallons of hot water consumed.

Operating schedule for non-appliance hot water use :

- Each day [1]
  - 2 showers (each 10 min, 20 gallons) [2]
  - 6 faucet uses (each 3 min, 4 gallons) [3]
  - Total = 64 gallons
- Energy Free Home Challenge contestants may meet these requirements using less water via efficient fixtures or other measures.

Total daily hot water consumption , counting appliance hot water use:

- 64 gallons – non-appliance use
- 2.3 gallons – dishwasher use [4]
- 15 gallons – clothes washer use
- Total = 81.3 gallons per day [5]

Once the aggregate hot water usage was determined, the authors added other data to complete the hot water modeling inputs:

Modeling inputs

- Water heater uses natural gas (not electricity)
- Daily hot water usage: 81.3 gallons
- Temperature set point: 120 degrees F [6]
- Tank capacity: 100 gallons
- Energy Factor (EF) = 0.72 [7]

Service characteristics

- Hot water heater must provide sufficient hot water each day for occupants to use:
  - 2 showers (each 10 min)
  - 6 faucet uses (each 3 min)
- Hot water heater must also provide sufficient hot water for appliances
- EFHC contestants are encouraged to select appliances and fixtures that provide these services to occupants with less hot water than listed in the Base Case model discussion above. There are

non-trivial amounts of hot water that cool in the pipes between small uses. These have not been explicitly modeled, but contestants are encouraged to seek strategies that reduce these losses as well.

- Hot water heater set point is at least 120 F [6]
- The service characteristics should also specify a first hour rating (i.e., How much hot water can the heater supply in one hour, starting with a tank full of hot water?), but the authors found no data on "typical" ratings for hot water heaters

Sources / notes

- [1] Per activity water consumption values from DOE 2005 "EERE Consumer's Guide." This source assumes no water conservation measures. Numbers of each use per day are LBNL assumptions.
- [2] Total hot water usage was lower than expected for a family of four, according to DOE 2005 "EERE Consumer's Guide"; Pigg 2003; and Lutz 1996. Reviewing these sources, the likely reason is that they assume small children, who do not take showers every day.
- [3] In reality, the house would probably have shorter, more frequent faucet uses for the same total water consumption
- [4] Daily average of 4 gallons per load, four dishwasher loads per week
- [5] This is roughly consistent with the ~56-64 gallons/day total hot water usage for a family of four reported in Lutz 1996, Pigg 2003, and by EERE at <http://www1.eere.energy.gov/femp/procurement/eep_waterheaters_calc.html>.
- [6] Dishwashers require the hottest water (135 to 140 F) but also typically come with booster heaters. So, users can set the hot water tank set point to 120 or 125 F. See <http://www1.eere.energy.gov/femp/procurement/eep_gas_waterheaters.html>. Also, Lucas 2007 DOE-2 model uses 120 F set point.
- [7] See <http://www.consumerenergycenter.org/home/appliances/waterheaters.html>

B.5. Other Plug Loads

The Base Case model also included miscellaneous plug loads for devices such as televisions, cordless phones, entertainment systems, and other small appliances. The authors used the total annual kWh use listed in the IECC 2006 reference case DOE-2 model as the target value. The authors then assumed an operating schedule and peak wattages (based on their own judgment) which would yield the correct energy use.

Modeling inputs

- 100 watts of continuous miscellaneous load [1]
- 615 watts of miscellaneous load operating 8 hours/day [1]

These inputs yield a total annual energy use of 2,672 kWh per year, consistent with the IECC 2006 reference case DOE-2 model. [2][3]

Service characteristics

- The house should be able to provide sufficient energy for miscellaneous plug loads

Sources / notes

- [1] LBNL assumptions designed to generate the appropriate amount of end-use electricity
- [2] From IECC 2006 reference case DOE-2 model
- [3] For popular press discussions of typical home device wattage, see for example <http://reviews.cnet.com/4520-6475_7-6400401-2.html> and <http://www.donrowe.com/inverters/usage_chart.html>

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APPENDIX C: Capital Costs for Electricity Generation Technologies

E_Form	Generation Technology	$/kW installed			@ 2.5% inflation/year			$/kWh			@ 2.5% inflation/year		
		low	high	average	2010low	2010high	2010avg	low	high	avg	2010low	2010high	2010avg
Electric	**Hydro**												
	Microhydro	$3,000	$4,000	$3,500	*$3,240*	*$4,320*	*$3,780*	$0.03	$0.03	$0.03	*$0.03*	*$0.03*	*$0.03*
	Wind							$0.05					
	small scale	2000	4000	$3,000	*$2,160*	*$4,320*	*$3,240*	$0.14	$0.35	$0.24	*$0.15*	*$0.38*	*$0.26*
	SolarElectric												
	Photovoltaic	$6,000	$10,000	$8,000	$4,650	$4,870	$4,760	$0.20	$0.25	$0.23	$0.07	$0.13	$0.10
	Dish - Tracking	$2.83	$2.83	$2.83	$1.37	$1.37	$1.37						
Electric	**FuelCell**												
(Thermal)	generic/unspecified							$0.13	$0.13	$0.13	$0.07	$0.13	$0.10
	Proton Exchange Membrane (PEMFC)	limited commericializiation			$1,000	$5,000	$3,000						
	SolidOxide (SOFC)	limited commericializiation			$1,000	$1,500	$1,250						
Electric	**Turbines/Generators**												
(Thermal)	Reciprocating Engines (CHP)	$700	$1,200	$950	*$756*	*$1,296*	*$1,026*						
	Microturbines (CHP)	$700	$1.300	$1.000	*$756*	*$1.404*	*$1.080*	$0.005	$0.016	$0.011	*$0.005*	*$0.017*	*$0.011*
	Stirling Engines	$2,000	$50,000	$26,000	*$2,160*	*$54,000*	*$28,080*						
	Biomass												
	Cordwood	$425	$425	$425	*$459*	*$459*	*$459*	$0.06	$0.07	$0.07	*$0.07*	*$0.08*	*$0.07*
	Pellitized	$275	$275	$275	*$297*	*$297*	*$297*	$0.06	$0.06	$0.06	*$0.08*	*$0.06*	*$0.06*
Thermal	Anaerobic Digestor							$0.22	$1.66	$0.94	*$0.07*	*$0.13*	*$0.10*