

# *Net Positive Energy Homes: Maximizing Performance Using Advanced Software Tools*

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Building Environmental Science and Technology*

## ABSTRACT

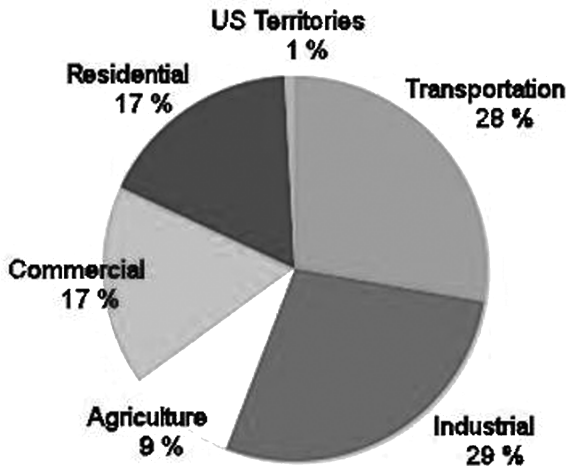
This article explores the art of the possible in advanced high performance homes, reviewing how builders and designers can be guided towards maximum potential using 21st century software tools to prototype net-positive energy home designs. Also reviewed in this article are case studies of home designs analyzed using the advanced computer software, by the authors' consulting practice.

Included is a discussion of features and capabilities of popular software tools: Energy-10™ V1.8 (Author: National Renewable Energy Laboratory); EnergyGauge USA™ (Author: Florida Solar Energy Center); and REM-Design™ (Author: Architectural Energy Corporation).

## INTRODUCTION

As climate change becomes an increasingly important political issue, policymakers and the construction community alike are grappling for solutions. How can we make buildings more efficient in reducing their contribution of atmospheric emissions to our climate-challenged planet?

Residential buildings comprise a significant segment of U.S. atmospheric emissions, particularly of carbon forms of pollutions damaging to our climate. According to the Alliance for Climate Protection (derived from U.S. EPA data, 2005) the residential sector contributes 17% of U.S. greenhouse gas emissions (See Figure 1). Because the USA contributes nearly 21% of total global emissions, this means energy use at our dwellings create over 3.5% of total global emissions of CO<sub>2</sub>.



**Figure 1. U.S. Greenhouse Gas Emissions by Sector; Electric Basis 2005. (Total = 7260 MMT CO<sub>2</sub> Equivalent). (Source: U.S. Environmental Protection Agency 2005.)**

It is shocking to look at these data and find that U.S. residential buildings alone contribute over 1.12 billion metric tons of CO<sub>2</sub> emissions every year. We can do something about this, and must.

Progress towards zero-carbon home building has a strategic way-point, which we have investigated in some detail. The net-positive energy (NPE) home is achievable with current designs and off-the-shelf technology but does entail increased costs of construction, which are being documented.

Our hypothesis was: we can use applied building science and engineering to help designers come up with homes that actually provide more energy (in the form of on-site electric power) back to the grid; hence, on average, becoming net producers of energy rather than consumers. Therefore, at least on the annual operating costs level (and carbon emissions), the NPE redesigned building, in our case a single family home, may be termed “net-positive” for energy.

There is no reason this approach—tweaked for the realities of commercial building design—could not be applicable for offices, schools, and retail. Perhaps the only exception might be hospitals, where electric power demand is comparably high, so that on-site renewable installation sizing to reach the NPE level may be eclipsed by demand.

## WHAT ARE NPE HOMES?

To obtain the level of performance we consider (and can verify through calculations) to be a net-positive energy home, several design avenues need to be pursued simultaneously.

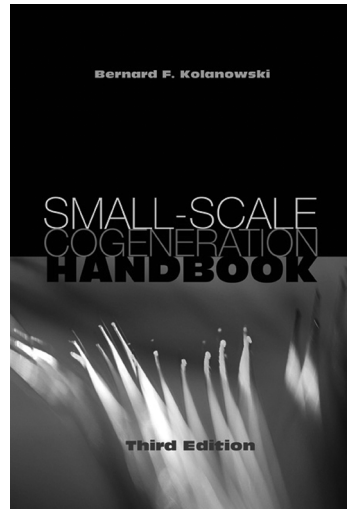
1. Sustainable site considerations must be taken into account, including orientation, local vegetation, proximity to adjacent structures, distances to water bodies and roadways.
2. The thermal envelope must be exceptionally energy efficient, including the insulation system, window and door selections, and extensive measures to control air-leakage. Selection of appropriate foundation design and thermal protection is also vital.
3. The architectural design must be responsive to the local climate to maximize the benefits of passive solar heating, and natural gains-avoidance and cooling strategies.
4. The exterior colors of the buildings surfaces need to be “tuned” to the climate to maximize the potential for reducing solar driven loads where necessary.
5. Water consumption needs to be reduced to the absolute minimum while still maintaining serviceable levels of consumer satisfaction; particularly the hot water service system.
6. Electric demand needs to be reduced to micro-load levels by incorporating super-efficient and right sized appliances, and mechanical systems. Source-energy analysis is used.
7. On-site consumption of fossil fuel resources must similarly be reduced, because the overall energy “budget” of typical North American homes shows heating is a big usage.

In an NPE home, the logical approach is to directly attack the biggest pie segments through super-efficiency and then apply renewable energy solutions to further reduce the demand; then finally implement cost-effective photovoltaic (PV) and small-wind energy solutions to over-

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come the remaining billable energy usage. In our assessment, we shoot for a 10% annual energy “surplus,” which the home provides back to grid, usually via net-metering (in jurisdictions where it’s permitted).

To achieve NPE “status,” the home needs to be net positive on an annual basis. While some months may be above or below the NPE line, the consumer and the environment likely care more about what happens annually and over the long term. This is because when the consumer thinks about investing in a home, their time horizons are usually 7 to 10 years (typical occupancies) and they also look at 30-year and 15-year fixed mortgages.

According to the U.S. DOE, Energy Information Agency, 2004, one may expect the following approximate breakdown of purchased energy costs in a U.S. housing unit, see Figure 2.

Our specific targets have evolved around the heating, air-conditioning, water heating, the refrigerator and appliances loads—such as dishwasher, laundry units, and televisions. In the typical project, we see these usages often account for in excess of 70% of overall purchased energy. Therefore, they become a sizable target of opportunity to engineer-out waste and excess atmospheric pollution emissions.

Fortunately there are super-efficient products on the market today, thanks in large part to the market transformation efforts of EPA/DOE EnergyStar programs. Many new appliances provide exceptional performance while providing consumers with reasonable life-cycle investment

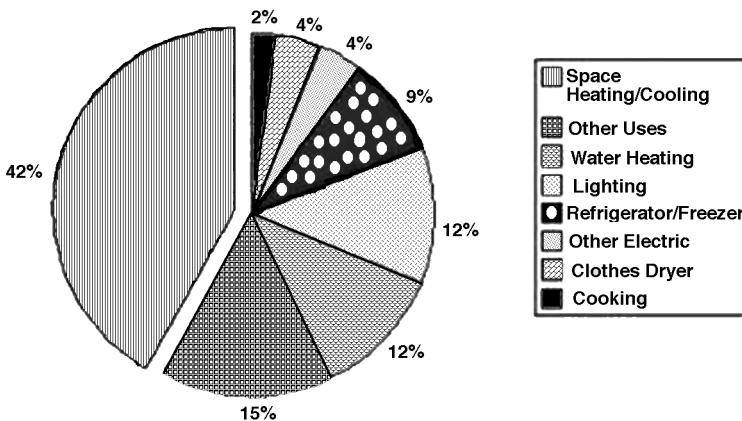


Figure 2. Residential Energy Usage Breakdown. (Source: DOE/EIA 2004)

returns from energy savings. It is important for designers and builders to actively consider installing the most energy-efficient appliances in their products.

## THE ASSESSMENT PROCESS

Early intervention in a specific project is absolutely vital to success. The further along a project becomes, the more difficult and costly the design changes appear to be. Because elevated investments are considered, and hence higher first costs will derive from the approach, these methods may not be accepted readily by merchant (production) home builders. For now our studies and technical support remain, largely the province of architects and design/build firms.

Our approach is fairly simple, and is relatively similar to that used in the certified Home Energy Ratings System (HERS) today. Currently we conduct our assessments in the pre-design phase of the new home design, specification and construction process. Future work will explore NPE existing homes.

In general, the assessment protocol follows these bullet points:

- Obtain program information, schematic drawings and building site information.
- Compile necessary climate data, utility and fuel schedules, local cost correction factors.
- Develop a "reference home" that complies with local energy codes, or statewide model codes if no local code is in force. This reference home is similar to that used in HERS assessments by the Residential Energy Services Network (RESNET) accredited professional rating providers. ([www.natresnet.org](http://www.natresnet.org))
- Compile alternate super-efficient building shell (envelope) thermal protection package.
- Compile via iteration, the most effective passive solar heated variant of the home.
- Re-run the analysis to minimize collateral excess air-conditioning demand from the selected passive solar heating package; continue to optimize natural heating and cooling.

- Using the “optimal” thermal envelope, passive solar design, and cooling avoidance solutions determined to this point, make preliminary attempt to configure and size a prototype space conditioning solution that is right-sized and reasonable in first cost.
- Implement a mechanical ventilation solution, providing adequate fresh air (re-run).
- Recheck the overall performance of emerging high-performance prototype; tweak (adjust as required).
- Model the home again with a super-efficient appliance and lighting package; tweak (adjust as required).
- Size an appropriate photovoltaic electric system. Consider small-scale wind as needed.
- Prepare report and meet with client team.
- Respond to comments, and re-run if necessary.

By the conclusion of the assessment process generally described, the energy engineer should have a good handle on not only how the home will perform overall, but will have addressed interactions—such as between air-leakage control strategies and sufficiency of fresh air ventilation. So far in every case, we have needed to include an occupant controlled mechanical ventilation system in these NPE home prototypes. Otherwise, the air-tightness levels required to sufficiently reduce heating and cooling costs can not deliver sufficient fresh air via leakage to be considered healthy.

In several cases, the NPE assessment protocol has produced prototype home designs that utilize as little as 20% of the projected energy consumption of their counterpart “reference” homes and would exceed EnergyStar Homes criteria by almost 45% (depending on climate and reference code requirements). This has been encouraging, but getting to a carbon-neutral home design is a more complex and more broadly bounded life-cycle assessment problem.

The end result of deploying super-efficient home thermal designs using passive solar energy strategies has been the reduction in size and cost of the photovoltaic electric power system needed to tip over the line to annual NPE performance capability. This is not a trivial point. It validates a key building energy engineering and passive solar design

axiom around since the early 1980s, that “efficiency first” should be a principal rule of thumb.

## COMPUTER ASSISTED DESIGN BENEFITS

“Follow the money” is a statement true in many forms of human endeavor. There are no more Darwinian economics than those imposed by real-world construction projects. Using computer based design tools definitely helps foster better overall cost-effectiveness of building projects. Imagine trying to make hundreds of different calculations of energy savings value, installation cost differences, thermal loads and weather variations over and over, all at the same time. Nope, can’t do it without computers! Part of the cost-effectiveness equation is improving performance of the green design strategies selected by the designer, by looking at competing options for achieving desired results. There are often competing options with different performance claims, some measured and some estimated by vendors, which need to be considered. Sustainable design strategies also need to be “optimized” in combination with energy-efficiency strategies, that also have cost and savings (value) propositions that exist without solar devices or techniques being applied.

## CASE STUDIES

(ACTUAL PRE-CONSTRUCTION DESIGNS ANALYZED FOR NPE CAPABILITIES)

### **Home Design A. (Software: Energy-10™)**

In this project, we used the recently updated NREL Energy-10™ model. Energy-10™ Version 1.8 (with PV) is an advanced capability tool to help integrate whole building energy efficiency studies, including photovoltaic (PV) solar electric power simulations, and solar domestic hot water. These solar features were added to Energy-10™ during 2004—2006 development cycle lead by software experts at NREL. Since its inception, Energy-10™ has provided design support information for small commercial and residential projects of 10,000 square feet, or less, conditioned floor area.

Included are many straightforward and user friendly capabilities to analyze: highly insulated building envelopes; passive solar heating and

cooling; natural ventilation; daylighting applications; high-performance windows; efficient electric lighting systems; many types of mechanical equipment options and most recently; solar photovoltaic and hot water energy systems. The best feature of Energy-10™ is its ability to create a base-line (reference) building automatically, and then through a consistent naming process, the user may create a large set of prototype variations to test various design strategies. If carefully done, a useful set of iterative comparisons of different potential strategies on the same building can be created for analysis.

Indeed, with the new capabilities to analyze building-integrated PV systems, Energy-10™ is one step closer to full realization of its potential. The author hopes that development of this tool will continue because it serves a large niche in building construction; the myriad of small-commercial structures that historically tended to “fall through the cracks” when it comes to energy and solar design.

Energy-10™ is cited in the US Green Building Council’s LEED®-NC 2.2 Reference Guide section on effective sustainable low-energy building design. An extensive write-up on this software is available on line, at [www.sbcouncil.org](http://www.sbcouncil.org).

### **Home Design B. (Software: EnergyGauge USA)**

EnergyGauge USA is a sophisticated home energy simulation software tool designed specifically for the easy and accurate evaluation of home energy efficiency. We found that, upon completing use of the built-in help screens, and exploration of the Florida Solar Energy Center (FSEC) support page for the software, that the tool could be put into full use in about three days, by an experienced energy engineer or HERS rater. We learned quickly to frequently save when changing data inputs, because on our PC platform there were occasional lock-ups and crashes (program seems to consume a lot of “resources” on Microsoft Windows® XP Service Pack-2).

This software provides an hourly simulation design tool for the design of high-performance homes and the evaluation of energy use and peak demand impacts of home energy-efficiency improvements. It is capable of evaluating both existing and proposed (new) homes. The software uses the powerful and widely-respected DOE 2.1-E hourly building energy simulation software to simulate energy use and provides for the combined evaluation of both the energy use and the economic and financial impacts of home energy-efficiency decision-making. The

**Table 1. NPE Project House A**

<b>Features</b>	<b>Criteria</b>
Location	Baltimore, MD
Size	1825 sqft (reduced from 2380 sqft)
<b>Energy Efficiency</b>	
Walls, roof/ ceiling, and foundation	R-34 wall (frame) R-49 attic R-19 foundation
Windows and doors	Low-e argon, fiberglass frames, super-spacer R-4.2 doors
Heating, ventilation, air-conditioning approach	Heat pump, SEER 17, HSPF>8.6
Lighting and appliances	"Best in Class," ACEEE Guide 2006
EnergyStar/HERS rating summary (prior to implementing PV system)	HERS ("0") HERS (23)
<b>Renewable Energy</b>	
Passive solar: increased glazing, thermal mass, and attached sunspace. Included significant overhangs omitted in the first cut.	Calculated 62% solar heating fraction (ASHRAE)
Solar hot water	75% solar fraction
Electrical system (PV included)	2.4-kW peak required
<b>Water Efficiency</b>	
Assumed low-flow devices; all hot water taps; relocated wet areas to "stack"	Maximum available efficiency
Home run PEX piping assumed	Estimated 40% water reduced annually
<b>Marginal Cost per Square Foot</b>	
Percentage basis: 16.5% (extra hard construction costs, less land) (MEANS 2006 costs and Green Guide)	Reference home \$175/sqft NPE prototype \$207/sqft
<b>Comments:</b> Not built as of the time of this writing	

EnergyGauge USA complies with all requirements of the International Energy Conservation Code (IECC) for energy code compliance calculations and reporting. It has also been subject to and approved in national accreditation procedures, and meets all technical guidelines, for Home Energy Rating Systems (HERS), including the HERS BESTEST (Building Energy Simulation Tool Test, National Renewable Energy Lab) procedures.

EnergyGauge USA capabilities (Edited from source: FSEC Web site) include:

- Detailed, hourly simulation modeling and reporting using an FSEC-enhanced version of the widely-respected DOE 2.1-E building energy simulation program.

Analysis modules include:

- Computation of heating and cooling system part load performance
- Prediction of indoor air relative humidity
- Coil air flow and system sizing impact on heat pump and air conditioner performance
- Accurate ground contact modeling
- Attic modeling (including attic ventilation/reflective roofing and radiant barriers)
- Detailed hourly modeling of duct heat transfer and air leakage
- Whole building heating and cooling system sizing
- Energy code compliance in accordance with the IECC
- IECC 1998 and IECC 2000 whole-building performance method.
- Ideal for evaluation of low energy and zero energy building designs
- Hourly prediction of solar electric PV system performance
- Hourly prediction of solar hot water heating systems
- Hourly prediction of end-use electrical and gas energy consumption for evaluation of peak impacts.

For more information on EnergyGauge USA, go to [www.energauge.com/usares/](http://www.energauge.com/usares/).

### **Home Design C. (Software: REM/Design V12.2 and REM Rate)**

We have been using the Architectural Energy Corporation (AEC) REM series programs for efficiency policy research, building design assessment,

**Table 2. NPE Project House B**

<b>Features</b>	<b>Criteria</b>
Location	Atlanta Metro area
Size	2650 sqft (reduced from 3280 sqft)
<b>Energy Efficiency</b>	
Walls, roof/ ceiling, and foundation	R-28 wall (frame), note: SIPs alternate R-42 roof/ ceiling (SIPs) R-10 slab perimeter R-5 under slab
Windows and doors spacer	Low-e argon, fiberglass frames, super- spacer  R-3.2 doors
Heating, ventilation, air-conditioning approach	Heat pump, SEER 16, HSPF>8.3
Lighting and appliances	"Best in Class," ACEEE Guide 2006
EnergyStar/HERS rating summary (prior to implementing PV system)	HERS ("0") HERS (21)
<b>Renewable Energy</b>	
Passive solar: increased glazing, thermal mass, and attached sunspace. Included significant overhangs omitted in the first cut.	Calculated 78% solar heating fraction (ASHRAE)
Solar hot water	86% solar fraction
Electrical system (PV included)	2.7-kW peak required
<b>Water Efficiency</b>	
Assumed low-flow devices; all hot water taps; relocated wet areas to "stack"	Maximum available efficiency
Home run PEX piping assumed	Estimated 35% water reduced annually
<b>Marginal Cost per Square Foot</b>	
Percentage basis: 18.3% (extra hard construction costs, less land) (MEANS 2006 costs and Green Guide)	Reference home \$162/sqft NPE prototype \$192/sqft
<b>Comments:</b> Out for bid as of the time of this writing (Nov 2007)	

and HERS ratings since initial release. Now in its 12th generation, the EEBA Excellence 2000 award-winning REM software provides a very useful tool for residential designers, remodelers, project managers, weatherization program managers, and energy professionals. REM/Design calculates heating, cooling, hot water, lights and appliance loads, consumption and costs. Climate files are included for about 250 North American cities. It is compatible with Microsoft Windows® PC platforms.

The tool uses a specially configured seasonal adaptation of full-annual simulation methods, based on work done by the National Renewable Energy Laboratory (NREL). This reduces run-times on PC platforms, while maintaining good levels of accuracy. Users can provide specific inputs or use a "Simplified" initial approach to start developing a building model. The user may then move all the previous work into a detailed model, as more information becomes available. This is particularly useful to designers that want to incorporate energy efficiency into the project early in the schematic phase, and then improve the details as the project evolves.

REM/Design tool also provides automatic (and editable) sizing of heating and air-conditioning equipment, and can help determine whether a project complies with numerous standards and model codes for both the prescriptive and performance compliance paths. Solar energy systems can be modeled in conjunction with efficiency improvements, including: sunspaces, photovoltaic solar electric systems, and solar water heating.

Passive solar design analysis is somewhat limited, and users will need to be creative to include high-thermal mass applications. All the utility rates, component costs, and default building characteristics inputs may be customized by expert users, while the novice or intermediate user may remain assured the default data is very representative. We like REM/Design because it is flexible, powerful, and easy to use for iterative comparison of different combinations.

For more information, visit the REM/Design Web site at [www.archenergy.com/products/rem/](http://www.archenergy.com/products/rem/).

## ADDITIONAL SOFTWARE PACKAGES

### **Home Energy Efficient Design (Formerly SOLAR-5)**

SOLAR-5 was incorporated into Home Energy Efficient Design (HEED), a more user-friendly version, in mid-2000. HEED is quite user friendly at all levels of energy-modeling and solar design expertise. It is

**Table 3. NPE Project House C**

<b>Features</b>	<b>Criteria</b>
Location	Grand Junction, CO
Size	2125 sqft (spec plan book house)
<b>Energy Efficiency</b>	
Walls, roof/ceiling, and foundation	R-36 wall (panels) R-60 attic Note: SIPs alternative bid R-30 shallow cellar (was crawl space)
Windows and doors	Low-e argon, fiberglass frames, super-spacer R-4.2 doors
Heating, ventilation, air-conditioning approach	LPG tankless boiler N=91, No air conditioning, possible use of mini-split systems later
Lighting and appliances	"Best in Class," ACEEE Guide 2006
EnergyStar/HERS rating summary (prior to implementing PV system)	HERS ("0") HERS (18)
<b>Renewable Energy</b>	
Passive solar: increased glazing, high thermal mass, and attached sunspace. Significant use of shading and wing walls. Night flush ventilation (high elevation)	Calculated 86% solar heating fraction (ASHRAE)
Solar hot water (Aux = combination system)	100% solar fraction
Electrical system (PV included)	1.8-kW peak required
<b>Water Efficiency</b>	
Assumed low-flow devices; all hot water taps micro-flow restrictors; relocated wet areas to "stack." Rainwater catchment system bid	Maximum available efficiency
Home run PEX piping assumed	Estimated 50% water reduced annually
<b>Marginal Cost per Square Foot</b>	
Percentage basis: 16.5% (extra hard construction costs, less land) (MEANS 2006 costs and Green Guide)	Reference home \$178/sqft NPE prototype \$207/sqft
<b>Comments:</b>	
Going out for bid as of the time of this writing	

so simple to start off, that some homeowners have employed the tool to make retrofit decisions on their dwellings. Other users include architects, builders, students, energy program managers, weatherization pros, and green building consultants.

It employs a graphic interface to draw a floor plan, and then users click and drag various elements like windows to selected locations. Default lists of standard wall and roof construction are available and may be edited. A simple base-case building can be generated, then is subject to further analysis. Advanced users may employ detailed design input options and display output graphics similar to the original SOLAR-5 tool. HEED expands on SOLAR-5 features including: editable utility rates, new fuel rates for oil and propane, editable air pollution data, attic radiant barriers, operable shading, enhanced thermal mass algorithms and dealing with previous minor software bugs.

HEED's primary analysis component, SOLAR-5, is a full-annual hourly simulation program, and was mostly recently updated in June 2000. It has been validated to DOE-2 and BLAST using the NREL BESTEST procedure. HEED self-installs on stand-alone non-networked Microsoft Windows® 95/98 and XP operating systems. An Apple Macintosh® OS X version is also available. Climate data is available for over 500 locations. HEED has also been translated into the Spanish language.

This handy software is available at no cost from the UCLA Department of Architecture and Urban Design, either on line by free download, or by contacting Research Professor Murray Milne [Email: Milne@ucla.edu]. Note: HEED is represented as a BETA release because it is undergoing continuing development.

For more information on, visit the Home Energy Efficient Design Web site at <http://mackintosh.aud.ucla.edu/heed/>.

### **PV-DesignPro (Solar Design Studio)**

Previously available as a stand-alone application, PV-DesignPro by Maui Solar Energy Software Corporation is now part of a design tool suite called Solar Design Studio delivered via CD-ROM. Compatible with recent versions of Microsoft Windows® including XP, this tool requires considerable expertise in solar energy systems design and analysis to obtain maximum results, but can be used by a novice since it has embedded help functions.

Inputs include default values and database entries that can be

edited and customized. Numerous configurations of panels, connections and wiring strings may be entered, along with performance parameters for AC inverters, power conditioning, battery charging, and grid interfaces. Numerous climate files are included, along with a weather file generator to customize for site micro-climates.

Results available include, for example, solar-fraction charts; annual and monthly performance details; battery charge status; and economics estimates based on energy sold; life-cycle system costs; and rates of return over the life of the project based on user editable prices per kWh.

Additional features of the Solar Design Studio include: a solar hot water design tool, a climate generator tool, global insolation database, video tutorial on CD-rom, and graphing tools for 3-D (three dimensional) and I-V-P (amps-volts-power) plotting of results. Special order variants include larger scale PV systems, water pumping, and time-of-use rates, along with a Spanish version.

For more information, visit the Maui Solar Energy Software Web site at [www.mausolarsoftware.com](http://www.mausolarsoftware.com).

## SUMMARY AND CONCLUSIONS

Our research shows that NPE designed homes are technically possible, but prior to more interest by builders and consumers, it is apparent that more cost information is needed

Project "green teams" thrive on good input for decision-making. It is remarkable that engineers and architects produced so many buildings before today's vast computation power came onto the scene. Design tool software help designers pick through potential mine-fields of completing claims, and the results provide improved information for project teams.

One of the most important breakthroughs in the evolution of sustainable design, whether it is for buildings, sites, or other infrastructure, has been the improved interdisciplinary communication and evolution of effective project teams. For these teams to function effectively, they thrive on good information with prompt turn-around times when questions arise.

Computer tools also provide data sources for program compliance verification, such as in LEED® for Homes, NAHB Green (National

Association of Home Builders-National Green Building Program), and EnergyStar™. Without such information, provided in a manner consistent with sound engineering judgment and environmental principles, it would be virtually impossible to tell a “green building” from one slathered with “green-wash.”

The next logical step is to include this type of analysis in broader design assessment research on how to create truly carbon-neutral home designs, and to look at the associated economics.

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### **About the Author**

**Bion Howard** via his consulting practice, Building Environmental Science and Technology (B.E.S.T.), provides technical assistance and training on green building including energy efficiency, indoor environmental quality, and renewable energy system implementation in buildings. Bion Howard’s prior service includes the U.S. Environmental Protection Agency (helped design EnergyStar Homes program); Alliance to Save Energy (Senior Program Manager—Buildings), and the National Association of Home Builders Research Center (Senior Energy Analyst). Mr. Howard is a member of ASHRAE, American Solar Energy Society (life member), and Residential Energy Services Network (serves on Standing Technical Committee for HERS ratings). In the U.S. Green Building Council, he serves on the Energy and Atmosphere Technical Advisory Group (EA TAG). Mr. Howard holds a BA and Masters from the University of Wisconsin at Green Bay in environmental studies.