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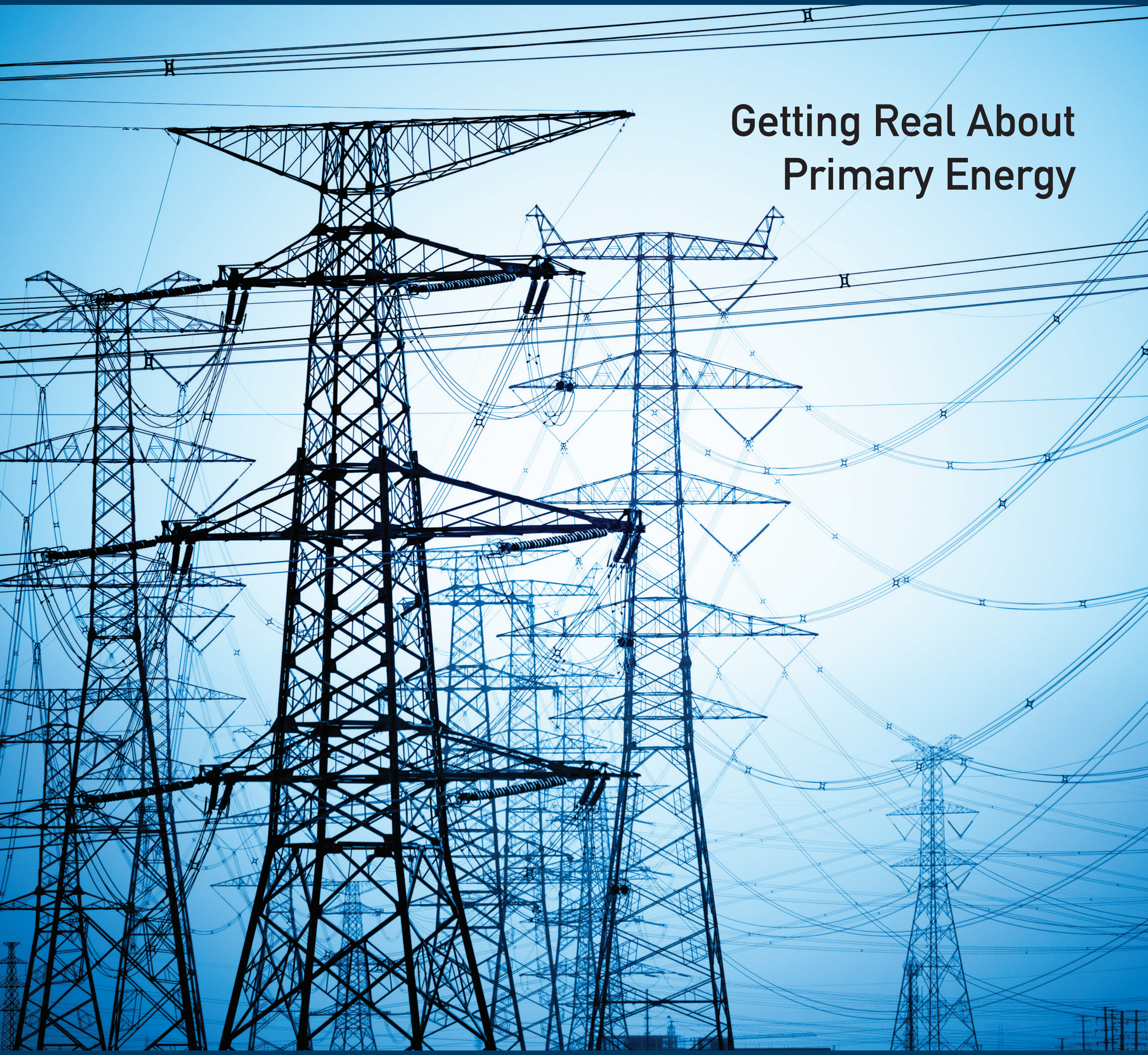
BUILDINGENERGY

THE MAGAZINE OF THE NORTHEAST SUSTAINABLE ENERGY ASSOCIATION



Getting Real About Primary Energy

BuildingEnergy 2013 Conference Program Inside

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BUILDINGENERGY





On the cover

When we measure energy use by what we draw from our outlets—site energy— we're not getting the real picture. Long-distance transmission of electricity over power lines is just one of the inefficiencies accounted for by primary energy. Katrin Klingenberg's story starts on page 8.

About NESEA and *BuildingEnergy Magazine*

The Northeast Sustainable Energy Association (NESEA) is the region's leading organization of professionals working in sustainable energy, whole systems thinking, and clean technology. We advance the adoption of sustainable energy practices in the built environment through this magazine (distributed to NESEA members), our annual BuildingEnergy conference and trade show, professional workshops, our annual Green Buildings Open House, and more. A *Building Energy* subscription is $55/year, which includes NESEA membership.

No More Fires to Fight. Now What?

There are two things I excel at and enjoy more than anything else in my professional life.

The first is using my big-picture vision skills and working with staff and members to solve big problems, to set a strategic course that makes sense.

But for the first time since I joined the NESEA staff three years ago, it seems like there are no fires to fight, no intractable problems to solve. Working collaboratively—members, staff, and board—we have made so much progress. While there are still big operational kinks to work out with respect to all our programs—BuildingEnergy, BuildingEnergy Masters Series, Green Buildings Open House, membership, Zero Net Energy Building Award, chapters—most of these programs are the domain of my super-competent staff. I can assure you that the last thing they want is an overzealous executive director interfering with what she's hired them to do—with what they do best.

So the ship is essentially headed in the right direction, and we have the right people in place to keep it on course. What's an executive director to do?

> While there are still big operational kinks to work out with respect to all our programs, most of these programs are the domain of my super-competent staff.

Fortunately, there's the second thing I excel at and enjoy: connecting people with opportunities that help us meet our mutual goals. So now I'm going to focus on this.

That is, I'm going to lunch.

I plan to invite at least one influential NESEA member to lunch each month to learn more about what they're working on, brief them on what's up at NESEA, and explore possible points of intersection. I'm going to lunch with no real expectations about the outcome, other than that we'll have a good conversation and a good meal. I'm going to lunch knowing that good things happen when we break bread together and truly connect with open hearts and no agenda.

I've started with an invitation to BuildingEnergy10 Conference Chair Betsy Pettit of Building Science Corporation, and another to Nadav Malin of *Building Green*. I'll keep you posted on how this new "program" goes!

As always, I welcome your feedback. Feel free to email me at jmarrapese@nesea.org, friend NESEA on Facebook, connect on LinkedIn, or respond via Twitter @NESEA.org.

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Efficiency and Technology Without Resilience Doesn't Cut It Anymore

I recently introduced my wife, Alison, to induction cooking technology. I was excited about saving energy and eliminating gas use in our kitchen. She is very serious when it comes to food, and after she read some articles and looked at some induction range models, she was excited too. Then we lost power, just for a few hours.

On average, we lose power a half dozen times a year for two to six hours. In this case, it was two. Not long, but long enough to dampen our enthusiasm for an electric range, since we can cook with our gas range with or without electricity. So instead we diverted our resources to solar thermal domestic hot-water heating with a new backup oil boiler and double-wall oil tank. I will be sure to set up a means of running the solar pump when there is no power via PV, battery, or one of the kids on a treadmill. As for space heating, our primary system is a woodstove, fueled by whatever falls down in our seven-acre woods: white pine, poplar, black cherry, and when we're lucky, a maple or an oak.

What do *you* lose when the electricity goes out? And how about the buildings where you work or the ones that you design or build? What happens when the electricity goes out?

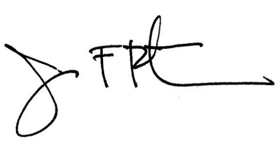
In a recent design meeting for a 55-unit elderly housing apartment building located southwest of Boston, the question of design resilience came up. The owner and the owner's rep, working with a tight budget, settled on a standby natural gas–fired generator to power the sewage ejector pumps, the egress lighting, and the domestic hot-water system. We determined that, except during the heating season, this arrangement would keep the building reasonably habitable for an extended period. We also determined that the building would remain above freezing unless a multiday power outage occurred in tandem with extreme cold temperatures. So for all but the most extreme circumstances, the water-based heating and cooling, potable water, and sprinkler systems would cause no property damage.

I think of sustainability and our designs in terms of failure modes.

But the extreme circumstances seem, to just about everyone, to come more often these days. In the Northeast, 120,000 homes and businesses were still without power two weeks after hurricane Sandy hit in late October. Late-fall, rather than mid-winter, temperatures somewhat tempered the severity of the storm's aftermath. Katrina and Sandy together will likely adjust our common view of sustainability to include resilience.

The public for the most part associates sustainability with windmills, solar panels, and ground-source heat pumps. But I think of sustainability and our designs in terms of failure modes. I ask myself, how would this system or building respond if it were not operating properly due to external forces like weather, or due to operator error? The exercise logically leads me to designs that are less dependent on physical infrastructure—inside or outside the building—and operator acumen. Buildings with high-performance enclosures coupled with hard-to-go-wrong supply-side infrastructure and building systems win out.

With the science of climate change losing out to political allegiances in recent years, we need to recast sustainability as being about methods and technologies that create a resilient built environment. This gives our industry its best shot of providing environmental stewardship, and health and safety, to the public that we serve.



Chair, NESEA Board of Directors
james@petersenengineering.com

P.S. I have really enjoyed being board chair, but by the time you read this, I will have left the reins in the capable hands of Caitriona Cooke of CSG. I look forward to continuing to serve on the board as chair of the development committee.

James Petersen is a mechanical engineer and the founder of Petersen Engineering (www.petersenengineering.com). All of his firm's projects reflect his commitment to integrated design with a goal of significantly elevating building performance. For the past five years, James has also been a BE educational session track chair.

Getting Real About Primary Energy

Understanding primary energy is the key to adapting Passive House standards to North America—and reducing global warming

By Katrin Klingenberg

Passive House is not a brand, but a set of universal principles: building science principles that govern the balancing of losses and internal gains. By applying them to enclosure design, we can create buildings that need little or no active space conditioning yet are comfortable in winter and summer. Conceptually, a house without an active heating or cooling system is the most efficient dwelling: comfort at no cost or energy input. In reality, Passive House principles yield a spectrum of solutions that more or less meet this goal: from no active system in some climates (e.g. San Diego) to small auxiliary systems, or slightly larger ones in extreme climates such as those of Halifax, Nova Scotia, or Lafayette, LA.

Wherever the project, passive principles remain the best starting point and baseline for all high-performance, net zero, or plus-energy buildings in terms of efficiency and cost-effectiveness. Consequently, the primary energy discussion in relationship to Passive House standards is relevant to everyone involved in the high-performance and zero-/plus-energy building sector. Primary energy, because it accounts for environmental impacts, is the most important of the Passive House optimization criteria. But in North America it is poorly understood and often miscalculated—leading to significant underestimation of carbon dioxide emissions.

North America is not Central Europe

Passive House principles actually originated in North America in the 1970s as a response to the 1973 oil embargo. After a long hiatus, during which the Europeans refined and optimized those principles for their continent, Passive House is regaining recognition in the United States. The Passive House Institute US (PHIUS) has been leading the effort to reintroduce Passive House with trainings and rigorous certification programs for people and projects, with an increased focus on climate-appropriate designs. The US Department of Energy recently recognized the PHIUS+ project certification in conjunction with its high-performance Challenge Home Program—a significant development. It acknowledges Passive House as a baseline for achieving zero energy and beyond. Support in the market is strengthening, and Passive House principles are moving into the mainstream.

During the last 10 years, PHIUS and the North American Passive House community have learned a great deal about how well—or poorly—the European standards and tools, developed for a Central European climate (mostly heating dominated), apply in practice in the much more varied climates of North America. It's gradually become clear that the European metrics, methods, and tools need adaptation if Passive House is to be attainable and cost-effective on this side of the ocean.

What is primary energy?

One key to adaptation is primary energy, better known as source energy in North America. Architects, engineers, consultants, and builders need to better understand primary and site energy—and strive to optimize for primary energy consumption, not just site energy.

- *Site energy,* also known as final energy, is the energy that is delivered to the house.
- *Primary energy* accounts for and includes the losses and inefficiencies of the generation and delivery process and is therefore a more accurate representation of total energy use and the impact on the environment.

Each unit of total energy used produces a certain amount of carbon dioxide emissions. To accurately calculate the carbon emissions associated with energy consumption, one has to work from primary energy, not site energy, calculations.

The definition of site energy is rela-

Table of Primary Energy Factors and CO_2 - Equivalent Emissions Factors of Various Carriers

Energy Type		Energy Carrier	PE (non-regenertive) kWh_{Prim}/kWh_{Final}	CO_2 GEMIS 3.0 kg/kWh_{Final}	lb/kWh	lb/kBTU
	1	None				
Fuel Source	2	Oil	1.1	0.31	0.68	0.20
	3	Natural Gas	1.1	0.25	0.55	0.16
	4	LPG	1.1	0.27	0.60	0.17
	5	Hard Coal	1.1	0.44	0.97	0.28
	6	Wood	0.2	0.05	0.11	0.03
Electricity	7	Electricity-Mix	2.7	0.68	1.50	0.44
	8	Electricity from Photovoltaics	0.7	0.25	0.55	0.16

tively straightforward: it is the energy consumption as measured at the meter of the building, typically expressed in kilowatt-hours (kWh) on the utility bill. It is the simplest and most direct

For electricity from the grid, primary energy can be a factor of three or more times the site energy, depending on the dominant fuel source in a given region.

feedback in terms of total energy use. Primary energy requires more detailed analysis: generally, it is defined as the total energy required to generate and deliver energy to the building. For electricity from the grid, primary energy can be a factor of three or more times the site energy, depending on the dominant fuel source in a given region.

Each region relies on its own mix of fuel types for electricity generation. To convert site energy to primary energy (PE), a PE factor—essentially the source-to-site ratio—is calculated for each region by dividing total energy delivered (PE) for each fuel component by total energy used (site, or final), and then summing the results. Each primary fuel source, such as coal, oil, gas, or wood, has a different PE factor. Some are better than others (see the table at left). Oil, gas, or wood are considered forms of primary energy. Gas or propane are delivered to the site and then burned there to provide heat and/or electricity. The PE factor for gas reflects only distribution and line losses, yielding a much better value than grid electricity. Coal and oil are also considered primary fuels that can be burned on-site. Here too there are only inefficiencies in storage, distribution, and line losses, which explains the initial low values for fossil fuels.

Wood is considered a renewable on-site fuel source and also results in a very low PE factor. Hydro, wind, and solar are assumed to have a PE factor of 1.0 (energy used = energy delivered). It is assumed that there is no combustion or conversion loss in the process of generating these forms of electricity. There is a difference between European and US conventions in terms of PE values assigned to renewables like PV and wood. In the United States, they are considered neutral (PE value = 1), but in Europe they are assigned a value below 1. PV is counted at PE = 0.7, and wood at PE = 0.2, which means that the primary energy must be smaller than the final energy.

The Table of Primary Energy Factors on the facing page shows the primary energy and related CO_2 emissions used for modeling in the Passive House methodology. Note that the table is still showing the old PE value of 2.7 for electricity mix in Germany, and that GEMIS (Global Emissions Model for Integrated Systems) is a European software help tool and database. There are PE factors for each distinct grid region. Following the same method, a national PE factor is calculated as well.

In the passive building design methodology, only the "nonrenewable" portion of the total PE factor is used for energy balancing to convert specific site energy into total primary energy and its equivalent carbon dioxide emissions. The renewable energy component of the entire grid mix is already considered climate neutral (hydro, wind, solar, biomass) and, to account for the remaining emissions accurately, is actually removed from the total PE factor in order to arrive at this nonrenewable portion of PE. For example, in Germany, the total PE factor is 3.0, but the nonrenewable portion is 2.6 (the grid has approximately 15 percent renewables to date, which corresponds roughly to the reduction of the overall PE factor from 3 to 2.6). For all of Europe, the total PE is 3.31, and the nonrenewable portion is 3.14. For Austria, the total PE is 1.91, and the nonrenewable portion is 1.3! Nationwide in the United States, the total PE is 3.315, but the nonrenewable portion is 3.138, according to a National Renewable Energy Laboratory report using 2004 data.

CO_2 emissions are underestimated

Outside Germany, the Passive House designer should ideally use the locally accurate PE factor to achieve accurate modeling results in terms of total primary energy and emissions. However, certifying to the current Euro standard requires use of the German PE factor of 2.6. And this presents a problem: the German PE factor of 2.6 reflects the considerably higher mix of renewables in Germany's electricity generation. Therefore, using that German figure significantly underestimates the correct primary energy balance and related carbon dioxide emissions specific to North America! And that defeats part of the fundamental purpose of building to Passive House standards.

This presents a difficult set of decisions for the North American market. For example, should there be a nationwide PE factor adjustment for the United States and Canada, or a regional factor for individual energy grids to calculate primary energy for a specific building? In the United States, this might make sense, as there are five distinct regional grid interconnections. According to the National Renewable Energy Lab (NREL), they have less than 1 percent interconnection. Either way, a higher national PE value would make it more difficult for all projects in the United States and Canada to meet the current European Passive House standards. The regional solution would

At BE13 *"Getting Real About Primary Energy: What It Means for Passive House," a half-day workshop with Katrin Klingenberg. Go to www.nesea.org/buildingenergy for details.*

make it easier for some (mostly in the Pacific Northwest, due to lots of hydro), but even more difficult for much of the nation. The primary criterion for small homes is already difficult to meet, a situation now well known as the "small homes penalty."

The best solution at this point seems to be a national nonrenewable PE factor by country. After a quick review of the certified passive homes in the PHIUS database, it appears that this is a reasonable approach. Only about 20 percent of those projects would no longer meet the criteria if the PE factor were adjusted according to a national (US) nonrenewable PE factor of 3.14.

The Passive House optimization strategy

To fully understand where primary energy fits into the Passive House approach, it's important to first understand how the Passive House optimization strategy differs from traditional methods. The process starts with two of three main quantitative Passive House criteria: the specific space conditioning demands annually of 4.75 kBtu/ft^2/yr heating and cooling. (Alternatively, one could shoot for meeting the peak load limits of 1 W/ft^2, which can also qualify a project even if the annual quantitative criteria are not met.) Those criteria are energy metrics specific to conditioned square footage per year or hour and aim at guiding the optimization of the envelope in conjunction with minimization of the mechanical system (by passive means) first! Primary energy is the third criterion annually relative to the conditioned floor area (38 kBtu/ft^2/yr). It comes into play after envelope optimization and mechanical minimization, to assure that the equipment choices are the most efficient in terms of primary energy and carbon emissions.

Passive House methodology should result in significantly better primary energy balances than traditional design methodologies, before counting renewable energy. The traditional engineering approach for high-performance or zero-energy homes seeks to optimize the level of insulation relative to a cost break-even point, in combination with efficient (perhaps renewable) technologies. Experience tells us that this approach yields a building that consumes approximately three times more specific energy for space conditioning, compared to Passive House goals. That's because it signals to the designer that it is not cost-effective to insulate beyond a certain cost break-even point. This can lead to projects that have three times more primary energy consumption and carbon-equivalent emissions for space conditioning.

The reason for this lesser level of efficiency is that the classic engineering approach is to use efficient systems to lower and optimize site energy. This process, in effect, favors optimizing for site energy! The economic argument tells the designer to relax the insulation level of the envelope, leading to (for the sake of the argument) three times the loss of specific energy through the envelope (escaping Btu's) compared to a comparable Passive House. From a site-energy perspective, it might appear that the classic engineering and Passive House approaches yield similar efficiencies, the difference being that the coefficient of performance of the system in the Passive House—which might bring actual energy down by a factor of four—has not been factored in. The Passive House achieved the same result through the envelope measures alone.

The argument that the two approaches are equally efficient would be true if, say, the Passive House were to be heated with direct electric baseboard heat (a bad choice for a Passive

A Passive House To-do List

- From the climate perspective, primary energy should become the Passive House standard's most important qualifying criterion
- The required criterion should possibly be tightened to match worldwide carbon reduction goals
- Passive House should be amended with a per-person guideline aimed at inspiring more equitable energy use
- Regional PE factors need to be used to certify Passive House baseline status accurately and to reflect per-project primary-energy and emissions impacts correctly
- Designers should practice the specific Passive House optimization and design measures that lead to the lowest possible primary-energy and carbon dioxide emissions at a reasonable cost to society

House; it means giving up the advantage in efficiency through additional envelope measures). But if the Passive House then also employs a heat pump with a coefficient of performance of 4, its site and resulting primary energy for space conditioning is then also four times more efficient than that of the classic engineering optimization case. Excluding efficient equipment from the optimization process initially is key to optimizing for primary energy.

Passive House also has a fixed optimization goal, but this goal is an optimal heat balance point rather than a cost break-even point first. The reasoning: costs for materials and energy constantly fluctuate and are therefore unreliable for true optimization. It's a moving target, an important secondary optimization criterion. Passive House optimizes based on building science and comfort principles. It then applies efficient technology (no on-site renewables yet)—for example, heat-pump technology with a COP of 4—further reducing the specific energy needed for space conditioning. Only at this point is renewable energy added and considered in the balance as a saving, as an offset, rather than a credit toward a goal like zero energy or plus energy.

Envelope, envelope, envelope

All this puts conservation first, and the focus is on the performance of the envelope in terms of absolute kWh/Btu's used for space conditioning. It promotes optimization of the mechanical system through the choice of the most efficient solutions after the envelope has been optimized to provide those absolute kWh using the least amount of on-site energy through efficiency and with it optimized primary energy and carbon.

Within the Passive House methodology, renewable on-site system generation is added to the overall balance only after envelope and systems optimization. Nor is it counted to help meet the primary energy criterion.

After the Passive House conservation criteria have been met, onsite PV or wind can be used to reach renewable production goals: It can be used to produce just enough to offset total site energy use of the home and take the home to site zero. Typically, for a well optimized 1,000-square-foot Passive House, this means a system of 2.5 kWh to 3 kWh! Or the system can be sized to overproduce, to outweigh the higher primary energy balance, which would make it a plus-energy home by site-energy measurements. But best of all, this methodology allows sizing to the next critical level: going beyond site or primary zero, the designer can now realistically target the emissions-equivalent amount of carbon that needs to get zeroed out, aiming for carbon neutrality.

In practice, not all Passive Houses are achieving excellent primary-energy results. As a design and professional community, we need to get better at optimizing for it. This relies on specific design choices and the designer's effort to optimize toward primary energy (and eventually for carbon) rather than site energy or monthly utility bills or overall initial cost increase compared to standard construction. There are Passive Houses that, due to the cost-related design choices (direct electric-resistance heat instead of a more efficient heat pump), barely make the Passive House primary energy criteria. In terms of primary energy, they perform similarly to homes using classic engineering optimization (a point that John Straube from Building Science Corporation made in his 2009 paper on Passive Houses in cold climates).

It's about the environment

In conclusion, I suggest that primary energy is the most important of all of the Passive House optimization criteria because it is the measure of impact on the environment. Not optimizing for primary energy after superinsulating wastes resources. There is only one thing as bad as a poorly optimized building shell with a giant renewable system to get to site zero: an over- or underinsulated Passive House that misses the opportunity to optimize for primary energy.

Current European standards, which are not optimized by climate, lead people on a wild goose chase in extreme climates to meet an envelope criteria (4.75) that does not apply there. In climates different from Central Europe's, this can lead to either extreme overinsulation or significant underinsulation. To succeed in reducing CO_2 emissions and thereby global warming, the building sector must fine-tune the current optimization guidelines. (Some argue that the current European primary-energy targets are too lenient and do not match the reduction we need worldwide in regards to carbon.)

We should also investigate one more change. Primary-energy targets set per ft²/yr have a problematic unintended consequence: they favor large homes with few people in them and penalize smaller, more efficient homes for the same number of people. They favor larger homes with relatively higher energy consumption. The criteria need a per-person amendment to adjust for and to curb this effect.

Katrin Klingenberg, a licensed architect in Germany, is cofounder and executive director of the Passive House Institute US (PHIUS). She is the lead instructor for PHIUS Certified Passive House Consultant (CPHC) training. She also directs the technical and research programs of PHIUS. In 2003, she designed and built the very first US home constructed using the European Passive House standard and design specifications. She has since designed and consulted on numerous passive projects across North America's varied climate zones.

Peer reviewer *Marc Rosenbaum, PE, is director of engineering at the South Mountain Company, based in Martha's Vineyard, MA. Much of his recent work has consisted of deep energy retrofits, Passive Houses, and zero net energy buildings. His work has been recognized nationally by ASHRAE, AIA, EEBA, and NESEA.*

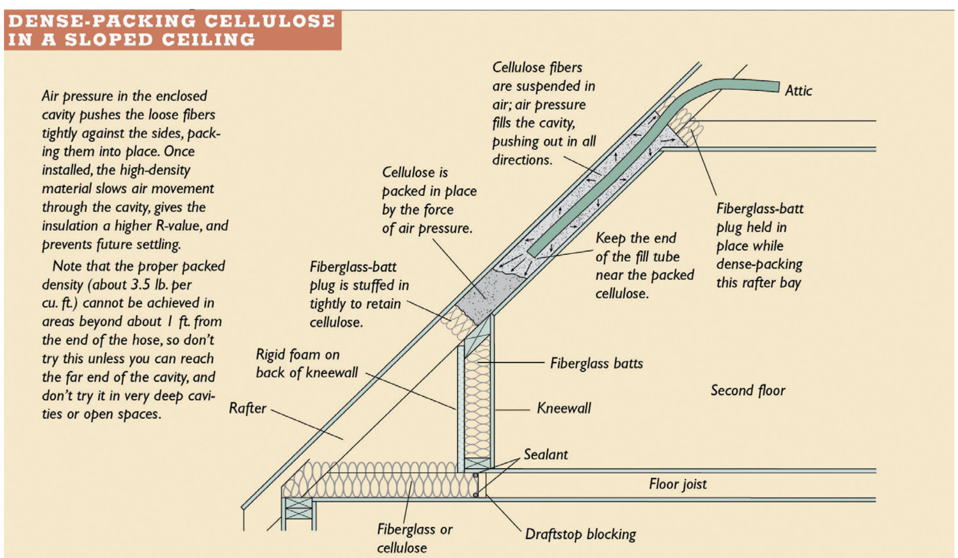
Insulation Challenge: Sloped Ceilings

Expert advice on tackling this tricky but common heat-loss area

By Bruce Harley

Many homes have sloped ceiling areas: places where plaster or drywall is applied directly to the underside of the roof rafters. Cape-style houses, for example, usually have sloped ceilings between the knee wall and the flat ceiling above (see the drawing at right) or rooms with partial or full cathedral ceilings. Some homes just have a narrow sloped area for a few feet near the eaves. These enclosed cavities are more challenging than an open attic. Some have fairly easy access from an attic space; this is typical of a Cape. A full cathedral ceiling or a flat roof is more difficult. And moisture control is a big concern. The risk of condensation and moisture damage is much greater in closed cavities, where venting can be difficult or impossible. Moisture can go unnoticed until serious damage has occurred. Some folks say that dense-packing cellulose into unvented cavities is an easy fix, but I'm not convinced.

Venting is easy in an open attic, but there are serious concerns relating to venting a cathedral- or flat-roof ceiling space. Good air sealing (to which dense-packing can contribute) and indoor humidity control via mechanical ventilation help reduce condensation and moisture buildup. But cellulose is not an air barrier; even an excellent dense-pack job can allow some air movement. In an unvented cathedral ceiling or flat roof, significant moisture may be deposited at the roof deck, especially in a home with high humidity or an isolated leakage path that is packed improperly. There are two basic strategies to avoiding increased risk of condensation and potential damage to the roof deck: either use foam insulation to control condensing temperatures or ensure an opening from the unvented cavities into a larger, vented space.



Enclosed cavities are more challenging than an open attic.

Continuous foam insulation

The first approach—using continuous foam insulation—is the only proven, code-approved method for an unvented roof. It can take two basic forms: rigid foam insulation added above and in contact with the roof deck, or sprayed foam added directly to the underside of the roof deck. Rigid foam is typically added during a re-roof, but usually a new sheathing surface (with a furred, vented space in heavy snow areas) is needed on top of the foam. This approach is expensive, but it's a practical way to address a house with full cathedral ceilings if the roof is close to needing replacement.

Consider interior sprayed-foam insulation if you are planning more extensive interior renovations (see facing page). In this case, in climate zones 5 and higher, you must either use closed-cell foam (which is itself a vapor retarder) or include a vapor retarder (such as sprayed vapor retarder primer) in direct contact with the interior surface of the foam. With either foam method, once the roof deck is protected from condensation by a high enough R-value of foam, the remainder of the cavity may be insulated with blown insulation or batts, with no additional vapor control layer. The R-value of foam insulation needed depends on climate (see table and map on facing page). Both of these methods are explicitly allowed by code. And both are energy efficient and present a code-compliant assembly with low risk in any climate.

A partial venting path

The second approach is to provide a partial venting path for the closed dense-pack area. This can be achieved

If you don't need much R-value, you can use a two-part DIY spray-foam kit for the foam layer. Be sure to get consistent coverage; this application will need a second layer to fill the cracks.

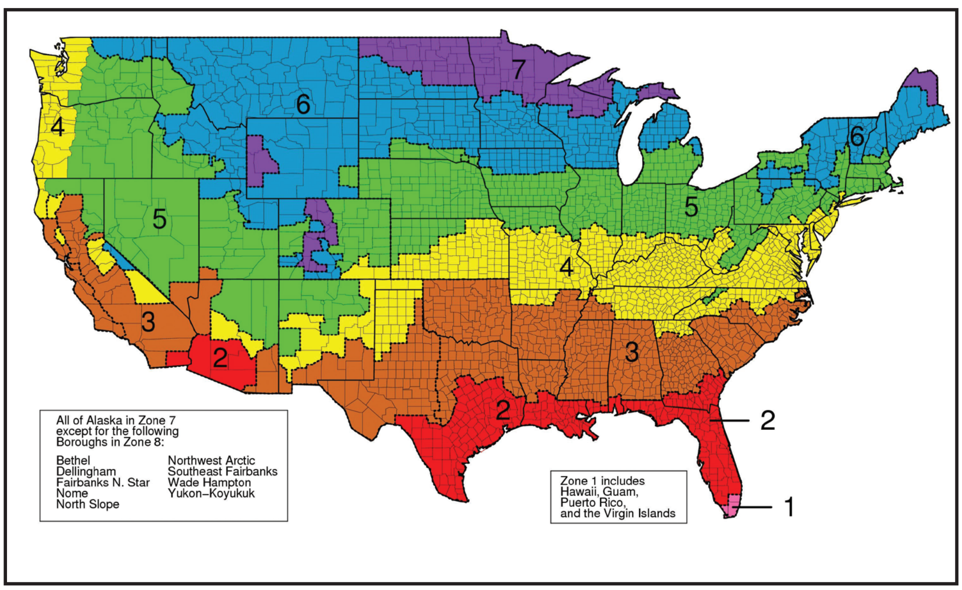
in homes (such as Cape-style homes) that have sections of sloped ceiling that may be difficult or impossible to vent properly. If one end of the dense-packed area is open to a vented attic space (preferably the top), any wetting effects appear to be balanced by drying toward the vented space. This approach can also be used under low-slope roofs (for example, that of a row house, or a shed dormer), where access near the low side is impossible. Experience has shown that up to one-third of the total attic area can be dense-packed without venting, provided that the remaining attic space is vented normally.

Note that this second method does not conform to standard code requirements, but it has been accepted by some local building officials. I would consider this approach much more risky in climate zones 6 to 8, where winters are colder and condensation potential increases. Of course, just as with an open attic floor, you have to be careful to avoid chimneys and non-IC-rated recessed lights. If you have a chimney in a key leak area, you will need to seal around it with noncombustible materials and ensure that no cellulose or foam is within 2 inches of the chimney. If you have non-IC-rated recessed lights, you'll need to replace them with IC-rated fixtures.

Focus on sealing

If you don't have the plans or budget for sprayed foam and partial venting is not an option, you can focus on sealing the tops of wall cavities (and their leaks) where the walls and roof connect. You can use this approach on all interior walls that intersect with the roof. To seal the wall tops, you can drill a series of holes in each wall cavity just below the ceiling and inject two-part foam from a kit, or you can dense-pack insulation at the top of the cavity (see illustration on page 16). This approach stays within code, but it falls short of the continuous foam method because it doesn't increase the roof insulation or venting. However, it can be effective in houses with air-leakage-dominated problems such as ice dams or roof-cavity condensation.

I've insulated a number of unvented roofs (including my own, which is partially vented), and I know a number of contractors who regularly insulate closed roof cavities with cellulose. But there have been cases of significant roof-sheathing moisture damage in homes that have been treated this way—usually in homes with high humidity levels—so the decision is yours. Your choice will depend on the climate, the building inspector, the shingle warranty, and the condition of the roof, as well as your confidence in the reliability of a given



In the Northeast, both insulation and moisture-control requirements are high.

Minimum R-values of Foam Insulation by Climate Zone

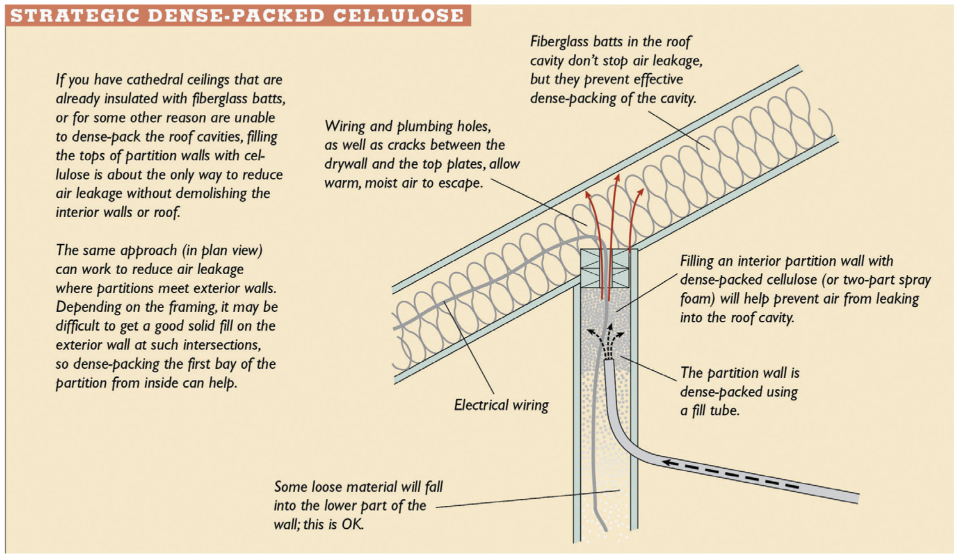
IECC Climate Zone	Minimum Foam R-value*
2B, 3B (tile roof only)	none required
1, 2, 3	5
4C	10
4 A,B	15
5	20
6	25
7	30
8	35

*Foam must be supplemented by other cavity insulation to meet the total R-value required by code or design.

At BE13 *"Energy Calculations for Everyone," a session with Bruce Harley. Go to www.nesea.org/buildingenergy for details.*

project's mechanical ventilation and indoor humidity control.

Roof-shingle warranties are another concern. Unvented cathedral ceilings experience hotter roof temperatures (typically by 2 to 4 percent) than vented roofs. Because those higher temperatures may accelerate degradation (venting is assumed to reduce roof temperatures), some roofing manufacturers won't honor warranty claims on unvented, or hot, roofs. But research has shown that shingle color actually has a much larger impact on roof temperature than venting does—about 10 percent—and several manufacturers do provide warranty service for unvented roofs. Choose one of those, or vent the roof first if shingle-warranty service is important to you.



Filling the tops of partition walls with cellulose is sometimes the only way to reduce air leakage.

An insulated, unvented attic

In some cases, you may even want to convert an existing vented attic into an insulated unvented attic. There's a trade-off, though. If an attic area is free of mechanical equipment and you can reach the air leaks at the attic floor, sealing the leaks and then insulating the attic floor with blown cellulose is a great approach. It's inexpensive, and you can do much or all of the work yourself. But what if you have a complex space with floored areas that obscure big leaks, or lots of mechanical equipment and ductwork in the attic space? Or what if you plan to renovate and finish the attic space at some point in the future? You may not want to spend the time treating the attic floor, only to have the extra insulation in the way later on.

In these cases, consider insulating

and sealing the roof and gable walls with sprayed polyurethane foam, creating what is often referred to as a "cathedralized attic." This is not a do-it-yourself job: spray rigs are expensive and require specialized training. But compared to the time and effort it would take to air-seal and insulate the attic floor and thoroughly seal and insulate the ducts, it may be well worth the extra investment. It may also be easier to find a competent spray-foam contractor than to get someone who is willing and able to do those other jobs right. Spraying foam on the roof and walls to create a complete, airtight thermal enclosure reduces air leakage and adds an insulation layer in one step.

> Moisture control is a big concern. The risk of condensation and moisture damage is much greater in closed cavities, where venting can be difficult or impossible.

I have created new, finished top-floor space by insulating with sprayed foam before hanging drywall. These houses have lower total energy cost, even with significantly increased living area. If a cathedralized attic is left unfinished, ductwork may be left as is—losses from the ducts are retained inside the new, enlarged thermal boundary. Although it's a good idea to connect any disconnected ducts, you won't benefit substantially from any duct insulation or sealing.

No matter how you choose to address your sloped-ceiling insulation job, by taking care of this difficult heat-loss area of a home, you or your clients should end up ahead. You'll save on the home's heating and cooling costs, make it more comfortable, and increase its durability while reducing greenhouse gas emissions.

Bruce Harley, technical director of Conservation Services Group (csgrp.com), is a 22-year veteran of residential energy efficiency programs, building science, and energy modeling. This article is excerpted from Bruce's book Insulate and Weatherize, *originally published in 2002 and now completely revised and expanded. The new Taunton Press edition focuses on energy-efficiency fixes to existing homes as well as energy-efficient renovations. You can find it at www .tauntonstore.com.*

Systems Literacy: What You Didn't Know You Knew

It's time to help each other learn the language of systems thinking

By Jamie Wolf

It's been said that science equips you with the tools to interpret what happens in front of you. So does language. Or drawing. Giving what you observe a measure, a name, or an image helps you to own what you know and, from that, to see and solve problems. You may even discover what you didn't know you knew.

Your professional development depends on gaining fluency with the language required to describe the work you do to both your peers and those you serve.

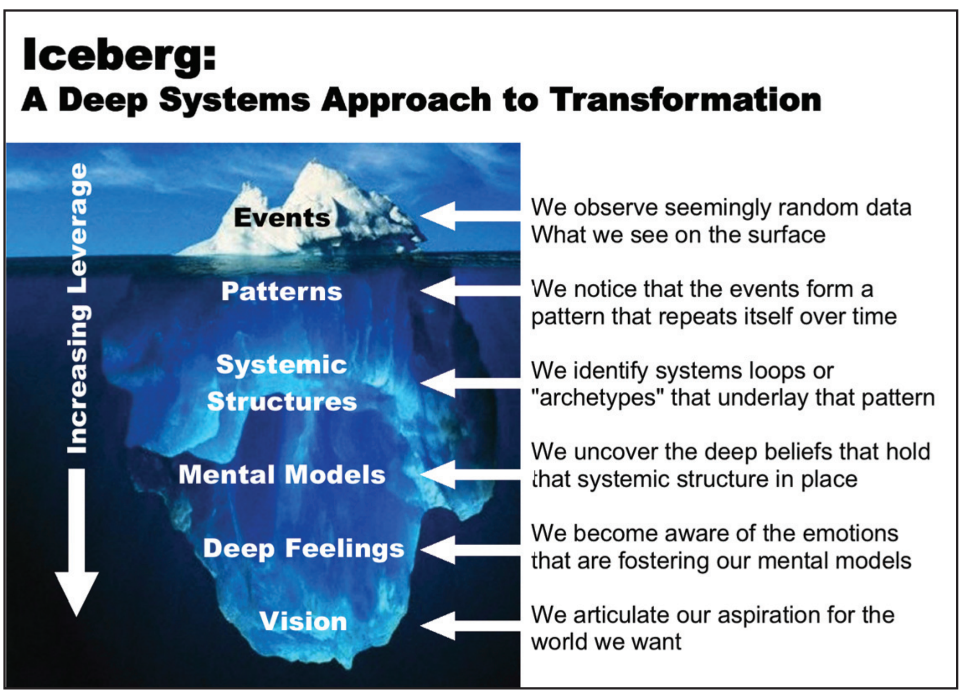
Every professional discipline uses precise language to communicate its principles and practices. Your professional development depends on gaining fluency with the language required to describe the work you do to both your peers and those you serve. As our understanding of sustainable practice develops, we confront the need to develop literacy in diverse, and often initially unfamiliar, fields. Over decades, we at NESEA have helped each other to learn and use the languages of these fields. It is time to help each other learn the language of systems thinking.

Those who study systems see certain patterns emerge over and over. These recognizable **systems archetypes** have been given names that help us think about and change systems. **Shifting the burden** is one. You may be familiar with others, like **tragedy of the commons** and **success to the successful.** Developing the capacity to recognize these patterns—and, further, the capacity to act with that awareness—takes time and application. We need to use the language. We need to name names.

Case in point: building science

Back in 1986, at what was then NESEA's Advanced Residential Construction Conference (now BuildingEnergy), Liz Fox quoted some Canadian building scientist by the name of Joe who claimed that roof venting was unnecessary in cold climates if there was adequate insulation (R-40) and something called an air/vapor barrier. Heated discussion ensued. A few months later she brought the guy, Joe Lstiburek, on the road for a series of two-day workshops. He introduced us to this thing called building science, and with it, to a whole lexicon for talking about how buildings actually perform. We also got to drink with Joe and hear tales of the wondrous north!

Year after year at NESEA conferences, in trade journals, and over beers, those of us working to design and build responsibly tried to understand and apply this new language to what we were building. Each term described a fundamental piece of a



Courtesy of Seed Systems

dynamic and intricately linked system. Words like *dew point, permeance*, and *diffusion*, and the ways in which those things were measured and what those measures meant, were presented, applied, observed, and discussed for what didn't just feel like, but actually were, decades. The better we got at using this language, the more sophisticated those conversations became.

At first—at least for those of us without science backgrounds—it was a struggle to successfully apply what we were learning. Just when you thought you were getting a grip, someone would present a new idea that seemed to contradict what you thought you knew. Or Joe would change his mind! Images of jaw-dropping building failures were evidence of the risk of failing to understand these fundamental principles. ("What fool did that?" you would think . . . then quickly wonder if maybe you had done it too.) Along the way we began to develop some fluency in this language. The words became tools. The principles they described helped us think critically about what we were doing. This literacy, practically applied, gradually made us better designers and builders.

The discipline of systems thinking empowers us to observe, understand, and act to change seemingly intractable problems. It is essential to sustainable practice. NESEA's mission statement embraces it.

We can say the same about energy literacy. To talk about watts, Btu's, energy factors, and COPs, you need a nimble understanding of each measure and its application to the others. The more comfortable and fluent we become with these words, and the more actively we work at using them appropriately, the better equipped we are to apply NESEA member Marc Rosenbaum's simple dictum: Think clearly. Then act!

Systems Thinking at a Glance

- Consider a problem that is resistant to change
- Start by observing the behavior of the system to discover what is happening beneath the surface
- Look for patterns, systemic structures, mental models, deep feelings, and the vision that supports them all
- Use verbal, visual, and mathematical language to create a model of what you see
- From what you observe, seek insight into the leverage points in the system
- With that focus, make changes to the structure of the system to achieve enduring improvements

For useful links, books, and other "systems" resources, visit wholesystemsinaction.wordpress.com

A language for sustainable practice

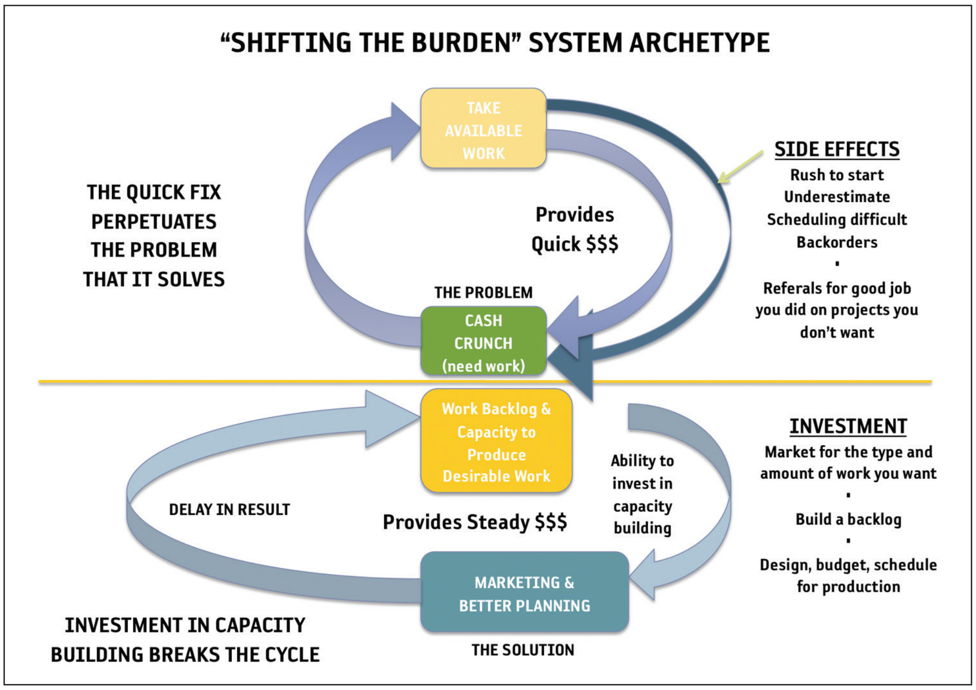
So we come to the discipline of systems thinking. It empowers us to observe, understand, and act to change seemingly intractable problems. It is essential to sustainable practice. NESEA's mission statement embraces it: "We as a community of professionals recognize and respond to the crucial connections between the generation and use of energy and the whole systems that sustain planetary health."

Like building science, systems thinking is a discipline that employs verbal, visual, and mathematical language to describe and help us understand the dynamics of a system. But this language is unfamiliar to many of us, just as the language of building science once was. With exposure and practice, that can change. This is an invitation to observe systems at work in our lives and begin using systems language with each other to gain and describe insights we might otherwise miss. The language matters.

Insight in systems thinking comes from the principle of **leverage**, which says that we should determine which actions and changes in system structures are most important to creating enduring improvement. To discover these often small, easily overlooked leverage points, we begin by looking **beneath the surface** events that so often have our attention—and thus invite us to respond in ways that may only perpetuate a problem. By **observing the behavior of the system** over time, we recognize deeper structural patterns. These patterns, or **system archetypes**, reveal predictable behaviors that, as we gain familiarity with them, help us determine how and where to effectively intervene.

As we observe and come to understand the behavior of the system, we wonder about the **mental models** that may be holding it in place. These models (or belief systems, aka **bounded rationality** in systems-speak) are embedded in the system and can be dramatic points of leverage. The more deeply embedded they are, the more

At BE13 *"Systems Literacy: What You Didn't Know You Knew," a Whole Systems in Action track session with Jamie Wolf and others. For details, go to www.nesea.org/buildingenergy or wholesystemsinaction.wordpress.com.*



Systems thinking sheds light on a common busness dilemma. Embracing the value of delay is key.

powerful the leverage. The very deepest are rooted at the level of our vision of the world we want to live in. To effect change at this level, we must understand the deep feelings and aspirations that hold mental models in place. Change here comes the hardest but means the most.

For example, we know that occupant behavior can affect home energy use by a factor of 50 percent. We acknowledge this when we call the best homes we are building "net zero livable." Awareness and intention are as important as remarkable thermal performance and equipment efficiency. Mental models matter. And vision matters most.

It's all about patterns

Verbal, visual, and mathematical language let us create models that help us see, share, talk about, and hopefully discover the leverage points that can resolve systemic problems. We often turn to the study of systems when a problem keeps reemerging despite our best effort to resolve it at the surface level. We look for patterns. Take the situation illustrated above. Your business needs cash, so you take work you shouldn't (the best choice at the moment of urgency), without the preparation necessary. So the project suffers, you barely break even, and the business needs cash—again! See the loop? See the pattern over time?

System behavior reveals itself as a series of events over time. The causal connections we observe produce balancing or reinforcing **feedback loops** (this event causes that event, etc.).

> We often turn to the study of systems when a problem keeps reemerging despite our best effort to resolve it at the surface level. We look for patterns. System behavior reveals itself as a series of events over time

We describe them, draw them, and measure their **stocks** and **flows** (what enters and leaves) in order to "see" what's at work, always with an eye toward opportunities for **leverage**. We can draw the cycle, but we should also look for measures of these events with an X-factor over a period of time (picture the cash coming and going over the course of that project). If we intervene effectively, these patterns reveal a positive change.

Since ultimately **everything is connected**, we run the risk of drowning ourselves in endless causal connections. Observation needs boundaries. Being clear about the problem that interests us helps us think about where the important edges are. So first we observe and map the essential cycle and its measures. From there we look for additional influences that may have important effects on that cycle. As the pattern takes shape, we draw boundaries on our observation, at what matters.

Take our business example and some likely side effects that compound the problem. Chronic cash shortages deprive the business of the ability to invest in marketing and in systems that could break the cycle. Doing work that is not aligned with your strengths may attract more such work. The threat of bounced checks keeps you frozen in the moment. These **side effects** create a vicious circle (a **destructive reinforcing feedback loop**) that inhibits your ability to thrive by doing what you are actually best at. How could we intervene to achieve a different outcome from this system?

Delay is part of the system

The answer introduces another factor that is important to understanding systems and their outcomes: **delay**. You know that if you were to invest in marketing, organization, scheduling, and planning, you might have a backlog of the work you actually want to be doing and the capacity to do it profitably. But that would require two resources you are probably short on: money and time. In addition, you are not likely to see the results of those investments immediately. Unless you can embrace the value of this delay—namely, the resulting backlog of work—you'll remain trapped by the urgencies that are driving the cycle. In turn, a backlog of desirable work would **serve as stock**, providing a **buffer** that removes the condition—cash crunch—that kept the vicious circle in motion.

Introducing a delay in the system gives you time to focus on organization and sales. That focus produces the resources that allow you to invest in the time the delay requires. By embracing the delay you shift the burden from the negative outcome of the short cycle to the enduring and positive outcome made possible by the longer cycle.

There is one other critical delay, one to be avoided: once you recognize the potential for change, the longer you wait to act, the more difficult that change becomes!

The systems lab is always open

Again, it takes time to develop literacy in any field. One of the surest ways to develop yours is to attempt to understand and use the language of systems to describe problems you encounter in your work, in your personal and civic life, or in the world. The systems lab is always open, because systems are at work everywhere and at every scale. Endeavor to learn and use the language that systems thinkers employ. Encourage others to share in the conversation. In a few decades, we'll be speaking like natives.

Jamie Wolf works to foster engagement and participation in the NESEA community while operating Wolfworks, a design/build enterprise in Avon, CT, that strives for "beautility" in low-energy homes. You can see his work at www.homesthatfit.com.

A Building That Teaches

Year-one results for the country's first Passive House K-12 public school demonstrate the power of methodology

By Adam Cohen

Seven years in the making, the Center for Energy Efficient Design (CEED) in Rocky Mount, VA, is more than a K-12 school. From its conception, it was envisioned as a classroom for advanced-placement environmental studies students, a practical demonstration of sustainable building practices, and a problem-based learning model for environmental science, advanced learning technologies, architecture, and building systems. And it is succeeding.

The Center for Energy Efficient Design, a K-12 school in Rocky Mount, VA, was conceived as a demonstration of sustainable building practices. It's being used to support the curriculum of the whole county and has sparked the interest of the entire region.

> It was a year of discovery and growth, but in short, the building performed every bit as well as expected, thus demonstrating the accuracy and robust nature of the Passive House Planning Package software as an energy modeling tool.

The building as a system and its monitored performance results are being used to support the basic curriculum of the entire county school district. It is open to surrounding school jurisdictions, and its real-time data and curriculum are available on the Internet for long-distance teaching. It has sparked the interest and support of the entire region and is well on its way to becoming "a building that teaches."

The CEED was completed in November 2010, received Passive House certification from Passive House Institute US (PHIUS) in February 2011, and received LEED Platinum certification in 2012. This article summarizes the first years' energy and comfort performance. It was a year of discovery and growth, but in short, the building performed every bit as well as expected, thus demonstrating the accuracy and robust nature of the Passive House Planning Package (PHPP) software as an energy modeling tool.

The timber and concrete building is small, with a treated floor area of 3,053 square feet (3,600 by US gross envelope standards). See **tables 1 and 2** (facing page) for R- and U-values and specific demands.

Windows proved to be a challenge. A local window manufacturer stepped up to donate aluminum-clad wood windows with double glazing, and while these windows would have been adequate for the original earth-sheltered design, they fell well short of the performance needed for the Passive House building. When we discussed this with the manufacturer, they modified an existing insulated triple-pane UPVC window product for the project. While they did not achieve the prescribed Passive House U-values, they were close enough. With some modification to both the standard window and the installation, we achieved satisfactory results, with field testing confirming the adequacy of the airtight performance. See **table 3** (facing page) for the window values.

Table 1: R- and U-values

	R value (hr. ft2F/Btu)	U value (W/m2K)
Slab	39.3	0.144
Concrete walls	33.4	0.170
Frame walls with brick	33.5	0.169
Frames walls with EIFS	42.3	0.134
Frame walls with EIFS no windows	45.5	0.125
North roof	68.0	0.084
South roof	59.6	0.095

Table 2: Demand

Specific heat demand	3.69	kBtu/(ft²/yr)	11.64	kWh/(m^{2}a)
Specific cooling demand	1.00	kBtu/(ft²/yr)	3.15	kWh/(m2a)
Specific primary energy demand	32.2	kBtu/(ft²/yr)	101.57	kWh/(m2a)
Depressurization test result	0.57	ACH_{50}	0.57	h^{-1}
Pressurization test result	0.61	ACH_{50}	0.61	h^{-1}
Pressurization test result	0.59	ACH_{50}	0.59	h^{-1}

Table 3: Window Values

Glass SHGC	0.542		Glass SHGC	0.542	
Rcog	7.41	(hr. ft^{2}F/BTU/)	U_{cog}	0.77	(W/m^{2}K)
R frame	3.47	(hr. ft^{2}F/BTU)	U frame	1.63	(W/m^{2}K)
$Y_{Spacer*}$	.026	(BTU/hr.ft.F)	Y_{Spacer}	0.045*	(W/mK)
$Y_{Installation}$	.028	(BTU/hr.ft.F)	$Y_{Installation}$	0,050	(W/mK)

*Note: calculated PSI value was less; default PHPP value was used to be conservative.

Modeling for diverse usage

For the most part, the building is used by one teacher with about 24 students. But as a demonstration project, it must accommodate groups of up to 100 people during tours and events. It was necessary to model the building with this very diverse usage to ensure that it would perform under all conditions. This being the first certified Passive House US public school, it could not be uncomfortable for the occupants, even for the briefest periods. American buildings are typically kept in a very tight comfort range in all climates, in all seasons, with massive heating and cooling systems. This building had to meet this American expectation: we might not have a second chance to prove the Passive House approach to potentially skeptical public policy makers.

We therefore modeled the building with a worst-case scenario of 100-person occupancy in midsummer with high humidity to determine mechanical system loads. We found that under most conditions the building would require only minimal additional heat or cooling, but that under the worst-case design, after our stage-one ground loop, we needed about 2.5 tons (30,000 Btu/hr) cooling to overcome the sensible and latent loading from the occupants. We adopted a two-stage strategy for heating and cooling (mechanical system details are below).

Made in the USA

We had been directed by the school board to use only US-made equipment and materials. This presented a challenge with regards to the energy recovery ventilator (ERV). Most of the time, a small US-made ERV would handle the ventilation demand. During times of larger occupancy, however, a much larger airflow would be required. And a high-efficiency, large-capacity, variable-speed ERV was not available in the United States at the time.

We contacted the US manufacturer of a smaller unit to discuss options, such as operating their units in series. During the discussions, the engineer for the company told our team they were working on the design of a prototype commercial-scale ERV based on their existing technology. In subsequent discussions it was agreed that our team would fund the prototype development, which would then be deployed in the CEED. Over the next nine months, the team created a variable-speed 200–2,000 CFM unit with a projected 90 percent efficiency. The field measurements to date indicate sensible efficiency at low speed of over 95 percent.

The mechanical systems

The mechanical system employs a variable-speed rotary ERV with a two-stage heating and cooling strategy. Stage one is preheating, precooling, and pre-dehumidification provided by a water-to-air heat exchanger in the

At BE13 *"Commercial Passive House Design Principles," both a half-day workshop and a session with Adam Cohen. Go to www.nesea.org/buildingenergy for details.*

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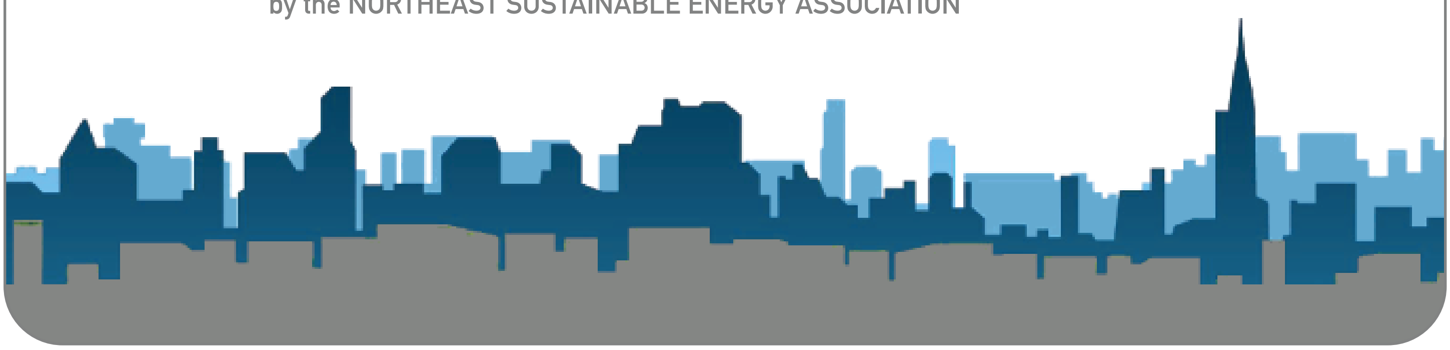


intake of the ERV. This heat exchanger can circulate both solar-heated water and a passive brine ground loop. Stage two is a 3-ton (36,000 BTU/hr), two-stage ground-source heat pump (GSHP), for additional cooling when the occupant load spikes. We discussed using a high-efficiency mini split heat pump unit for the second stage. This would have saved almost $25,000. But because there was no US-made unit, the school board opted for the US-made GSHP.

American buildings are typically kept in a very tight comfort range. We had to meet this expectation: we might not have a second chance to prove the Passive House approach.

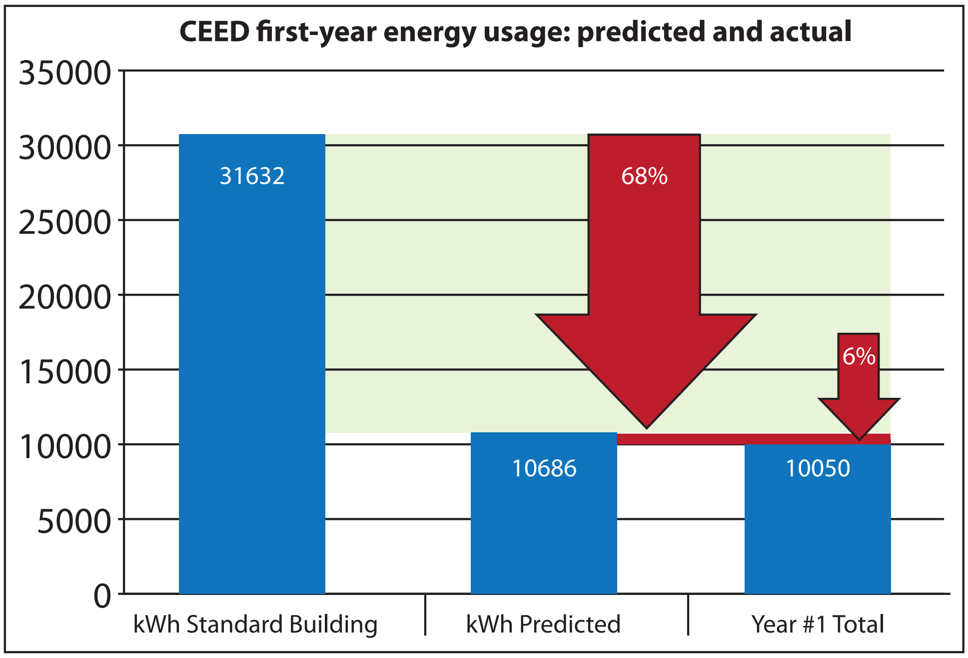


Figure 1: First-year energy usage was very close to predictions.

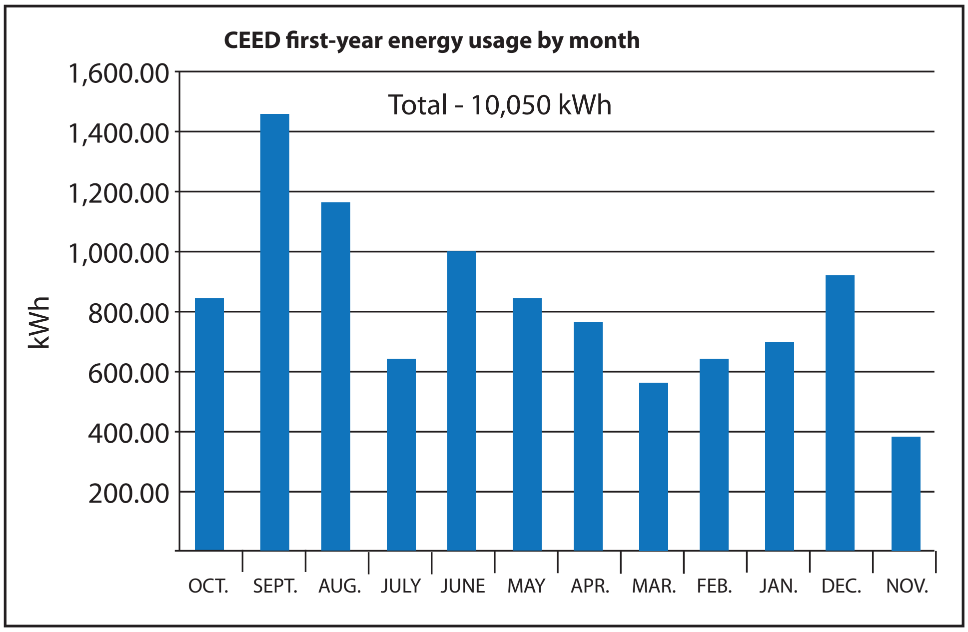


Figure 2: The first 12 months of energy usage was thought to be low due to low usage during initial occupancy—the building had to be flushed with air continuously before students occupied it.

We also integrated a humidistat into the GSHP to combat the possibility of high humidity in summer. This was precautionary; our analyses indicate it probably will not be required with the dehumidification of the stage-one ground loop and the latent transfer of the enthalpy wheel. Additionally, we equipped the ERV with an automatic sensor (economizer) that controls a summer bypass to decrease temperature gain in the summer months.

Control of the system proved to be problematic. US-made integrated controls for this type of system were prohibitively expensive, so we opted for a simple control system. The ERV is controlled by a CO_2 sensor with four preset flow levels. We then installed two digital thermostats, one to control the water-to-air heat exchanger and one to control the heat pump. We could have used a single thermostat, but US "off the shelf" thermostats do not allow for three stages in the cooling mode, which meant we would not have the option of utilizing the two stages on the GSHP—which would ultimately lead to higher energy use. We put the thermostats in sync and programmed a 2°F difference between stage one and stage two.

During the two winters (2010 and 2011) since the CEED was completed, stage-one heating (solar heat delivered through ventilation air) has been sufficient—the stage-two GSHP has not even come on.

First year: on target

When the CEED's first-year data (see **figures 1 and 2**, above) were analyzed, it was determined that the total might have been low due to low usage during initial occupancy—the building had to be flushed with air continuously before students occupied it, per USGBC LEED requirements. We examined the data available to us—the first 16 months of energy usage—and chose to look

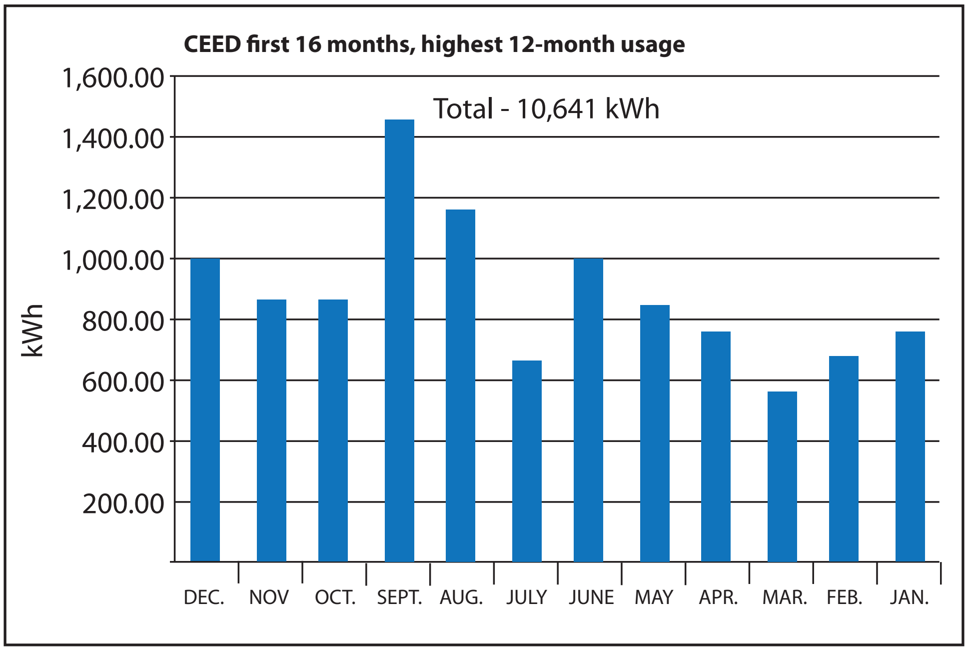


Figure 3: From the 16 months of energy usage available, we chose to look at the highest 12-month aggregate.

at the highest 12-month aggregate (see **figure 3,** above). When examined, this total of 10,641 kWh virtually matched the predicted 10,686 kWh.

The energy usage was as projected for two reasons. The first is the demonstrated accuracy of Passive House Planning Package software for heating and cooling energy prediction. The second is the initial consultations with the intended user of the building to predict plug loads. We expect to see the plug-load portion of the energy usage fluctuate as the usage of the building changes and grows, but the first year certainly has demonstrated the accuracy and robust nature of PHPP as an energy-modeling tool.

Also gratifying for the design team were the results of the thermal comfort survey required by the USGBC LEED process, conducted after 10 months of occupancy. Not a single person reported any dissatisfaction with the thermal comfort of the building. Temperature, humidity, and air quality all passed muster, no matter the season. Another confirmation of the Passive House community's methodologies.

An active design/builder and green building expert, Adam Cohen is a principal partner in Structures Design/Build, LLC, and Passiv Structures, LLC. He is recognized as a national leader in the Passivhaus movement and has presented technical papers at both national and international Passivhaus conferences. His leadership in commercial Passivhaus design has made him a sought-after speaker, consultant, and teacher of advanced courses in Passivhaus ultra-low-energy design.

Peer reviewer *Jordan Goldman is the engineering principal at ZeroEnergy Design, where he serves as a specialist in energy performance consulting, energy modeling, mechanical engineering, and HVAC design. He is a LEED Accredited Professional, a Passive House Consultant, an NAHB Green Verifier, and a HERS Rater.*

Solar's Role in Domestic Water Heating

Solar thermal versus solar electric: Is thermal still better for hot water?

By Everett M. Barber Jr.

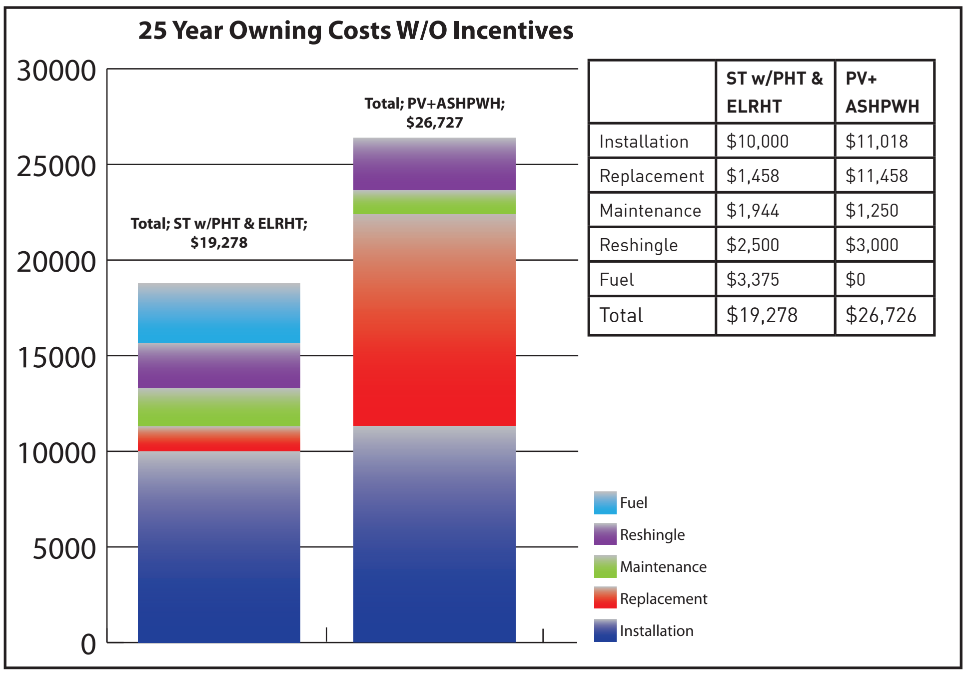
As the installed price for grid-tied solar electric systems continues to decrease, the question arises as to when, or if, the cost of solar electric systems for heating domestic water will drop below that of solar thermal systems (SDHW) used for the same purpose. This two-part peer-reviewed article examines SDHW systems versus grid-tied solar electric systems serving air-source heat-pump water heaters (PV/ASHPWHs). Part one, published in the fall 2012 issue (with supporting data for parts one and two), attempted to quantify the first costs of the two systems. Part two, below, attempts to quantify cost of ownership.*
—The editors

In part one, we saw that in the United States, the installed cost of the most costly SDHW system we could find ($12,000) is already greater than that of a PV/ASHPWH ($5.00/watt DC + $3000 ASHPWH) that provides the same amount of hot water. In other parts of the country, where the installed cost of a SDHW system is in the $7,000 to $8,000 range, the cost of a PV/ASHPWH must drop to between $2.50 and $3.00/watt before the two systems are equal in first cost. It remains to be seen whether the most costly SDHW systems will drop with competition.

But how do the two systems compare in terms of owning costs?

Although the majority of consumers make their buying decision based on first cost, a substantial minority often decide based on the owning costs. Components of the owning cost include engineering, such as roof structure assessment for a solar array; tree trimming or removal; installation of the system and any related systems; fuel to operate the appliance; expected maintenance; incentives for purchase, if any; expected longevity; replacement; and other costs related to long-term use.

As a generalization, and using 25 years as the period of ownership, the SDHW system presently has the lower owning cost. However, as described below, a number of variables will affect the long-term outcome of this race. To make a straightforward comparison between the two system types, each was considered as a stand-alone. In reality, the PV/ASHPWH may be sold as part of a larger solar electric system for whole-house loads. In that case, the cost of PV system components would be a portion of the cost of the larger



	ST w/PHT & ELRHT	PV+ ASHPWH
Installation	$10,000	$11,018
Replacement	$1,458	$11,458
Maintenance	$1,944	$1,250
Reshingle	$2,500	$3,000
Fuel	$3,375	$0
Total	$19,278	$26,726

Incentives were not included in this analysis because they vary so widely. If they are evenly balanced between solar thermal and solar electric, then the solar thermal system is likely to remain the less costly choice for some years.

Thanks to David White for suggesting this chart format

* Note that domestic water is defined here as potable water used for personal hygiene and for washing dishes and clothes—not water used for swimming pools or for space heating. The latter types of loads are more likely to be met with large SDHW systems used in conjunction with other types of domestic water heaters—oil- or gas-fired, for example. Further, very small loads (5 to 10 gallons a day) are most likely to be met with small electric-resistance water heaters. Solar installations for commercial water heating—apartment buildings, laundries, athletic centers, industrial processes, pool heating—are not considered here.

Detailed Assumptions: 25-Year Owning Cost		
	ST incl. PHTank	**PV/ASHPWH**
Total cost 25 yrs	$19,278	$26,727
Water heating load/yr	3.2 occs.; 20 gpd	3.2 occs.; 20 gpd
Solar fraction	0.8	1.0
Fuel cost	$0.13/kWh	$0
Fuel cost escalation	0%	0%
Installed $ sol. sys.	$10,000	$8,019
Installed $ ASHPWH	not apply	$3,000
Supplemental fuel $	$3,375	$0
FITC	not used	not used
State rebate	not used	not used
Local SREC	not apply	not used
Replace conventional htr.	$700 every 12 yrs	not apply
Replace ASHPWH	not apply	$2500 every 10 yrs
Replace inverter	not apply	$2500 every 12 yrs
Replace solar array	not required	not required
ST system maintenance	$700 every 9 yrs	not apply
PV system maintenance	not apply	$300. every 5 yrs
R&R array: reshingle	$2500 every 20 yrs	$3000 every 20 yrs
Tree shade removal	ignored	ignored

system. The same goes for maintenance costs. This could make the owning cost of the PV/ASHPWH system much closer to, if not less than, that of the SDHW system. A SDHW system is typically sold as a stand-alone system, and thus repair costs would not be prorated. However, like the PV/ASHPWH, it may also be sold as part of a larger solar thermal space-heating system, in which case they could be prorated. The longevity of the ASHPWH is critical to the outcome of this comparison. ASHPWHs might last only 7 to 8 years on average, because the compressor fails, or the microcomputer fails, or the tank leaks, or the heat exchanger is fouled by deposits. The more often the system or its components must be replaced, the higher the 25-year owning cost.

The decline in PV system installation price is certainly ongoing, but where the installed price, currently about $5.00/watt DC, will level off is anyone's guess. Also uncertain is the impact that tariffs, imposed on China to offset their dumping of PV modules and cells in the United States, will have on the continued decline in PV system costs. Unlike PV prices, SDHW system prices seem to vary widely across the country, with contractors charging what the market will bear.

> The impact that tariffs imposed on China will have on the continued decline in PV system costs is uncertain.

Finally, state and local incentives—not included in this analysis—will play a significant role in which system type is less costly. If incentives are evenly balanced between solar thermal and solar electric, then the solar thermal system is likely to remain the less costly choice for some years.

The details of these considerations, along with supporting data, are below.

Two systems

The graph on the facing page shows the estimates of the cost of ownership of two types of solar water heating systems over a 25-year period. One is an SDHW system that includes the solar preheat tank, and a separate storage-type electric resistance water heater as the supplemental heater. The other is a PV/ASHPWH, with an electric resistance supplemental heater in the same storage tank that is heated by the heat pump. The table summarizes the assumptions used here. For the specific assumptions used, see the table "Detailed Assumptions," at left.

Fuel cost

An estimate of the fuel cost to operate a given appliance is usually made by calculating the load, in this case the water heating load, and by using published data for the efficiency of the appliance (or, in its absence, measured fuel-cost data).

Incentives

Various incentives meant to stimulate the use of renewable energy equipment have been enacted at both the federal and state levels. While incentives can be very effective tools for promoting one technology over another, they are far from permanent. Some incentives reduce the first cost of an installation, while others reduce the owning cost. An

At BE13 *"Solar Heating," a session with Everett Barber and others. Go to www.nesea.org/buildingenergy for details.*

Peer Review

"The technologies are in close competition"

By David White

I'm honored to have assisted Everett Barber with this article and to have learned from his wealth of experience with water heating systems, as well as his dedication to thorough research.

I agree with all of the article's assumptions, with one exception: assuming the PV system is of typical 4 to 5 kW size, I would attribute only about one-third of inverter replacement and roof reshingling to the water heater. Making this adjustment to the cost-of-ownership analysis brings the PV/HPWH option almost to cost parity. I think the technologies are in close competition, and I hope this will drive excellence in the market. I expect the favorite for a given project will depend on the following factors, in order of importance:

• Repair and replacement costs of heat-pump water heater. This made up around 20 percent of cost of ownership in the analysis, and the new generation of devices may prove much better or worse than assumed.

• Capital budget and subsidies specific to the project. On real projects these are very influential, although it remains useful to compare the cost of the two technologies independent of government support.

• The predetermined use of PV on the project. This will affect domestic hot-water system incremental cost and its impact on overall project complexity.

• Rooftop and/or interior space limitations. Especially related to the thermal and acoustical design issues with heat-pump water heaters.

• Future management of a renewable energy grid (and associated pricing). Currently SDHW does the least to unbalance the grid, but in the future PV/HPWH may actively stabilize it.

• Price and availability of various types of SDHW backup heating fuel.

• Specific project goals, e.g. net zero.

David White has been practicing building-energy efficiency since 1998. Through his office, Right Environments, he designs enclosures and mechanical systems for state-of-the-art residential buildings in the Northeast. He is an assistant professor at Parsons the New School for Design, where he teaches environmental technology to architecture students. He has taught the Passive House Planning Package and THERM software to professional trainees since 2009, and he is currently collaborating with the German Passive House Institute on adaptation of the PHPP for humid climates.

example of the former is the Federal Income Tax Credit (FITC), which allows solar system buyers to subtract 30 percent of the installed cost of a system from their federal income taxes. The present solar FITC is set to expire at the end of 2016. An example of the latter is the production credit, such as Solar Renewable Energy Credits, or SRECs. This gives system owners a credit for the energy produced by the system over some period of time—15 years, for instance.

Incentives were not included in this analysis because they vary so widely from state to state and from one technology to another. (For detailed, current information on federal, state, and local incentives, go to www.dsireusa.org and search the region of interest.)

Longevity

How long does a solar system last? The average life of nearly any product is represented by a bell-shaped curve whose peak is the "average" life. Some products fail sooner than average, others fail years later.

Assume that the SDHW system is an indirect, forced-circulation system, probably the most common type in the United States. Well-built collectors should last 50 years. The life of the solar preheat tank will depend on its construction, the chemistry of the water it contains, its maximum temperature, and other variables. A range for average tank life might be 8 to 15 years (more on this below). The balance of system components, such as the coolant, circulator, pump control and sensors, and exterior pipe insulation, can be expected to last at least 20 years.

Assume that the solar electric systems considered here are for residential use and are grid-tied without battery backup. The solar electric system may be paired with a conventional storage-type electric resistance water heater (PV/ERWH) or with an ASHPWH.

The solar electric modules should last 20 years, at least. They may last longer, but there is very little experience with them much beyond 20 years. The longevity of inverters is a question. Of 24 systems I have been tracking for up to 8 years, about 40 percent of the inverters have needed replacement. Improvement in product quality is ongoing.

For this analysis, an average life for an inverter was assumed to be 12 years. Manufacturers' warranties are typically 5 to 10 years, but longer are available at additional cost. The balance of system components, such as the wiring and combiner box and roof flashing, should last at least 20 years. See below for more about the expected life of tanks and the ASHPWH.

Hot-water storage tanks are used with the solar thermal system and both solar electric system configurations. Construction varies, but the most common domestic hot-water tank by far is made of hot-rolled steel with a glass frit lining fired to the interior. The life of such a glass-lined steel tank depends on its construction and to a large extent on the water chemistry. If the water to be heated is acidic, with a pH between 5.0 and 6.0, it may last no more than 7 to 9 years. If the pH is greater than 7.0, then it may last 15 years, perhaps longer. Note that most domestic hot-water tanks carry a 5-year warranty. Some manufacturers offer a 10-year warranty, at extra cost.

The longevity of ASHPWHs is difficult to prognosticate indeed, since we have no long-term experience with them. If we base their expected service life on experience in the 1970s and 1980s, then 2 to 3 years might be a realistic estimate. However, it is likely that the major appliance manufacturers now producing them have improved their longevity. Another aspect of ASHPWHs is installation and service. They're typically installed by a plumber but must be serviced by a technician with a refrigeration mechanic's or

continued on page 42

The Real Costs and Benefits of Solar Electricity

Solar is delivering on its promise today, but our utility policy and regulatory framework is lagging behind

By Fred Unger

We've been hearing for years that solar energy generation is too expensive. But utility pricing mechanisms don't reflect the actual costs and benefits of the resources that provide our energy. Current electricity prices reflect neither the costly "externalities" of fossil- and nuclear-fueled generation, nor the real benefits of solar to ratepayers and to the electric utility system. When both are assessed appropriately, a new picture emerges: solar energy is an abundant, reliable, cost-effective, and low-risk energy solution that saves ratepayers money.

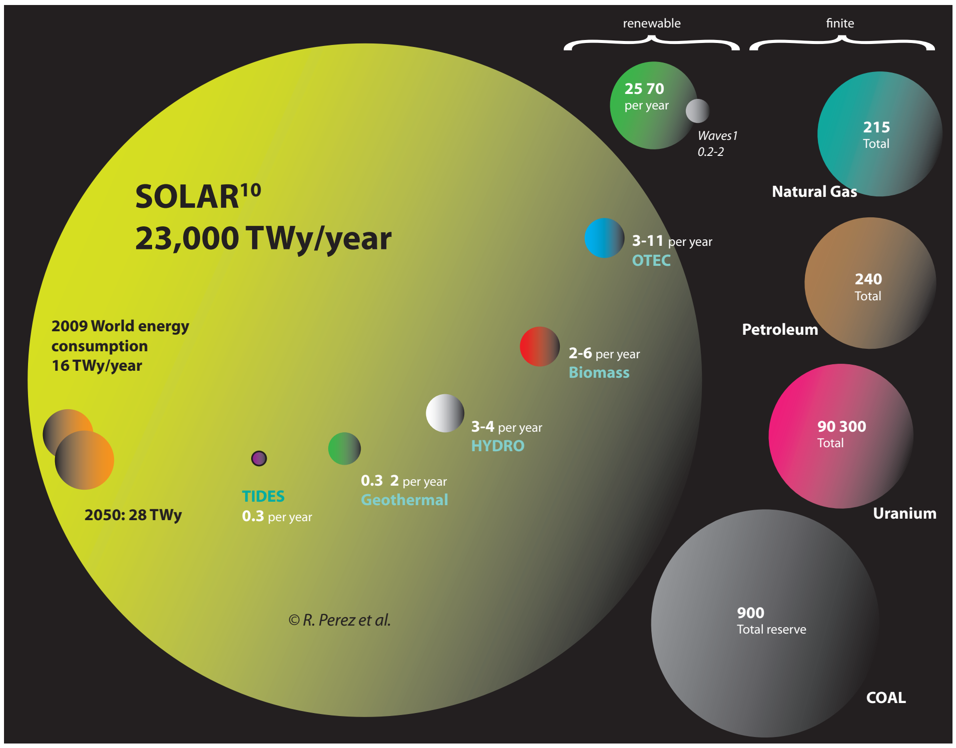
Solar is plentiful

Public policy around energy should start with a clear understanding of the resources available. Despite recent advances in fossil energy extraction technologies, solar remains by far the most plentiful energy resource available to society. The chart[1] at right offers a compelling overview of the relative scale of available energy resources.

Solar helps reduce peak loads

Solar electricity generation reduces costs to all ratepayers at periods of high electricity demand. SUNY Atmospheric Sciences Research Center professor Richard Perez and his associates show that peak demand on the US grid is driven primarily by air conditioning usage, which in turn is driven by the sun. They prove that because peak demand occurs around the same time that solar generators are performing at maximum output, solar is uniquely suited to providing energy when the grid is close to peak demand and prices are high.[2]

Wholesale electricity prices in New England averaged less than 3.4 cents per kilowatt hour (kWh) for the 12 months ending October 31, 2012. But there were 233 hours in the year that real-time prices were more than double the average, reaching as high as 41.5 cents per kWh for New England as a whole, 56 cents in the Boston area load zone, 55.7 cents in Rhode Island, and 56.9 cents in Connecticut.[3] Because solar generation reduces



Solar is our most plentiful energy resource. Total known recoverable reserves in 2007 are shown for finite resources, while annual available energy is shown for renewable resources. All resources shown in terawatt-years.

Courtesy of Dr. Richard Perez

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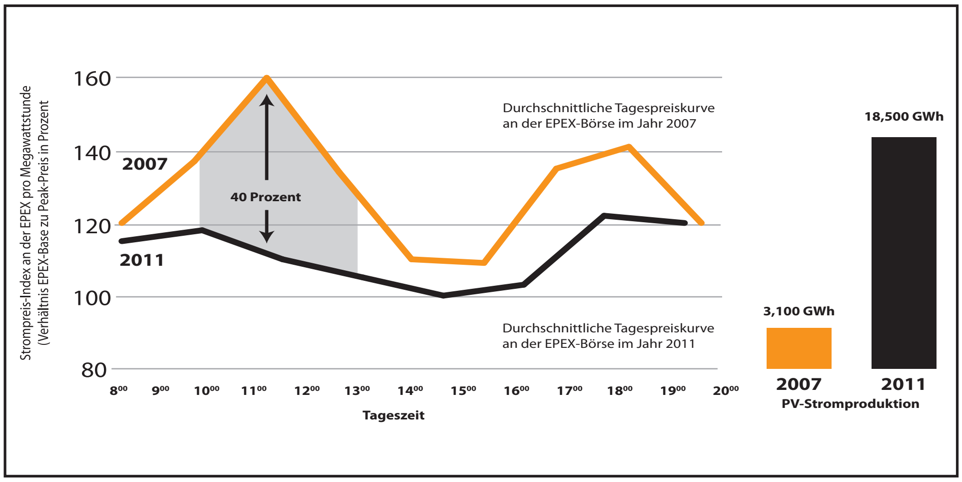
3. Hourly Zonal Information - 2011 & 2012 SMD Hourly Data (2012), ISO New England, http://iso-ne.com/markets/hstdata/znl_info/hourly/index.html



The average daily price curve for energy in Germany on the European Power Exchange shows how solar power has reduced the price of electricity by up to 40 percent during peak hours.

demand for electricity needed from gas-fueled generating plants at times when wholesale electricity costs are highest, it provides substantial savings for ratepayers. This benefit is overlooked in policy, regulatory, and rate discussions.

A net gain for ratepayers

International and US studies show that investments in solar technology can provide a net economic benefit to ratepayers.

In Germany, the Institute for Future Energy Systems has found that solar power has reduced the price of electricity by 10 percent on average, and by up to 40 percent during peak hours, when costs are typically highest.[4] German prices during afternoon hours are running lower than at 2 a.m.[5] The chart above[6] shows the average daily price curve for energy in Germany on EPEX, the European Power Exchange.

A recent study suggests that in Texas, major deployment of solar in 2011 would have saved ratepayers between 20.6 cents and 33.3 cents per kWh of solar energy produced.[7]

In Massachusetts, a 2008 study by Synapse Energy Economics Inc.[8] projects that if solar were to meet just 1 percent of the state's demand by 2020, it would displace 356 GWh of purchases from the wholesale market. Since solar production and peak electrical demand more or less coincide, the reduction of peak demand would drop the state's average annual wholesale market prices by 0.4 percent. That may sound small, but multiplied by the remaining projected 68,094 GWh load, the benefit to Massachusetts customers would be about $23 million.[9] Since solar in Massachusetts affects the entire ISO New England electricity supply, that investment would provide a price suppression benefit to New England ratepayers of 14 cents per kWh of solar generated. And that is before valuing the energy, the environmental benefits, the long-term price volatility hedge, and other factors that should be included to appropriately price solar energy.

In estimating the societal benefits of solar PV, Perez et al account for savings to the utility system via cost reductions associated with peak demand, increased grid resilience, and other benefits that generally aren't considered in electricity market pricing. They suggest that the total value to ratepayers is between 15 and 41 cents.[10, 11]

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Courtesy of Dr. Uwe Leprich

RELATIVE RISK EXPOSURE OF NEW GENERATION RESOURCES							
Resource	Initial Cost Risk	Fuel, O&M Cost Risk	New Regulation Risk	Carbon Price Risk	Water Constraint Risk	Capital Shock Risk	Planning Risk
Biomass	Medium	Medium	Medium	Medium	High	Medium	Medium
Biomass w/ incentives	Medium	Medium	Medium	Medium	High	Low	Medium
Biomass Co-firing	Low	Low	Medium	Low	High	Low	Low
Coal IGCC	High	Medium	Medium	Medium	High	Medium	Medium
Coal IGCC w/ incentives	High	Medium	Medium	Medium	High	Low	Medium
Coal IGCC-CCS	High	Medium	Medium	Low	High	High	High
Coal IGCC-CCS w/ incentives	High	Medium	Medium	Low	High	Medium	High
Efficiency	Low	None	Low	None	None	Low	None
Geothermal	Medium	None	Medium	None	High	Medium	Medium
Geothermal w/ incentives	Medium	None	Medium	None	High	Low	Medium
Large Solar PV	Low	None	Low	None	None	Medium	Low
Large Solar PV w/ incentives	Low	None	Low	None	None	Low	Low
Natural Gas CC	Medium	High	Medium	Medium	Medium	Medium	Medium
Natural Gas CC-CCS	High	Medium	Medium	Low	High	High	Medium
Nuclear	Very High	Medium	High	None	High	Very High	High
Nuclear w/ incentives	Very High	Medium	High	None	High	High	Medium
Onshore Wind	Low	None	Low	None	None	Low	Low
Onshore Wind w/ incentives	Low	None	Low	None	None	None	Low
Pulverized Coal	Medium	Medium	High	Very High	High	Medium	Medium
Solar - Distributed	Low	None	Low	None	None	Low	Low
Solar Thermal	Medium	None	Low	None	High	Medium	Medium
Solar Thermal w/ incentives	Medium	None	Low	None	High	Low	Medium

Distributed solar has the lowest risk profile of any generation resource, thus tempering electricity price increases and volatility.

Utility operators and regulators often express concern about the impact of intermittent resources on grid reliability and power quality. The German experience has made the strong case for a modernized grid that utilizes solar and other distributed generation to stabilize the system. On Saturday, May 26, 2012, in Germany, solar provided energy equivalent to 20 large nuclear plants running at full capacity. For the first time anywhere, solar provided 50 percent of the peak load. [14] Renewables International reports [15] that since shutting down 8 of its 17 nuclear plants and substituting renewables, the German grid has experienced the least downtime on record. As the article asserts, "Germany clearly demonstrates that a very high level of grid reliability is feasible with a high penetration level of intermittent wind and solar power."

Less risk, more grid and price stability

Solar also reduces the risk of electrical system disruption during high-demand periods, when problems are most likely. Research by Perez and Steven Letendre indicates that distributed photovoltaics could help prevent major power outages and moderate peak pricing in wholesale energy markets. They argue, "Dispersed, grid-connected PV systems' contribution to the electric industry should be understood in the context of both grid support and as a provider of electricity during the hours of peak demand."[12]

Ronald J. Binz, chairman of the Colorado Public Utilities Commission from 2007 to 2011, and his associates support this view in an extensive study on utility risk mitigation. They conclude, "The US electric utility industry has entered what may be the most uncertain, complex and risky period in its history. . . . These challenges call for new utility business models and new regulatory paradigms." The first of seven primary risk-reduction strategies identified in this report is to diversify utility supply portfolios "with an emphasis on low-carbon resources and energy efficiency."[13] Binz et al summarize the risks of various energy technologies in the chart above, which shows distributed solar to have the lowest risk profile of any generation resource.

Pricing of solar energy is highly predictable, offering ratepayers a hedge against fuel-price volatility.

Because solar generators have no fuel and minimal operating and maintenance costs, almost all the cost of solar goes toward repayment of initial capital investment. Thus pricing of solar energy is highly predictable and can be fixed long-term, providing ratepayers a hedge against fuel-price volatility.

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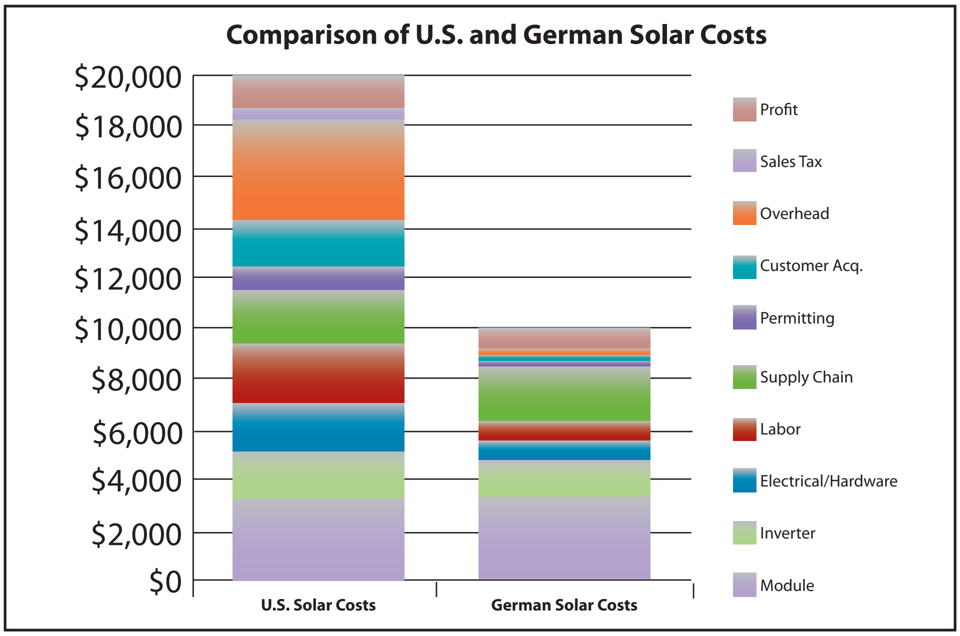
16. Quote and solar production statistics provided by e-mail from Jigar Shah.

Courtesy of Ceres



"Hard costs" are way down, but "soft costs" are higher than necessary. The installed cost of residential solar systems in the United States is about twice that of comparable systems in Germany.

Courtesy of Barry Cinnamon

As the solar industry grows, costs drop

In 2011, over $93 billion was invested in new solar projects globally—significantly more than in new natural gas, coal, or nuclear generating plants. In 2012, global solar installations grew by an additional 30 percent. As the industry grows, efficiency of scale drives down costs.

"Hard costs" have dropped dramatically. Panel costs, which were around $4 per watt in 2008, were under a dollar in 2012.

Capital costs are also dropping. Solar has the lowest technology risk or performance risk of any generating technology, explains Jigar Shah, founder of SunEdison, now one of the largest solar development companies in the world: "With zero fuel risk and creditworthy maintenance providers, capital markets are starting to compare solar projects to low-risk bonds, leading to much lower costs of capital than other energy investments." [16]

However, "soft costs" for permitting, interconnection, subsidy compliance, and labor-related regulations are higher than necessary. Rocky Mountain Institute has found that in Colorado, such costs can account for up to 40 percent of the installed price of a PV system.[17] As illustrated by the chart at left, Akeena Solar founder Barry

Cinnamon has shown that the installed cost of residential solar systems in the United States is about twice that of comparable systems in Germany.[18] While the disparity is not nearly as extreme with larger systems, soft costs are high in most of the United States, often due to well-intended policies that add unnecessary complexity. Reducing regulatory burdens and bringing down the soft costs of solar will increase solar's benefit to ratepayers and should be a policy priority.

We need a new policy and regulatory perspective

The International Energy Agency World Energy Outlook 2012 report projects that renewables will become the world's second-largest source of power generation by 2015 and approach coal as the primary source of global electricity by 2035.[19] Solar, wind, and biomass now provide 25 percent of Germany's electricity, and the German government has set a target of 80 percent by 2050.[20] Here in the United States, we have yet to even acknowledge the value solar energy provides in our regulated electricity market systems.

Increasing the contribution of solar generation to the electrical grid will reduce costs, risk, and price volatility for ratepayers, increase grid reliability, and significantly reduce the environmental impacts of our energy system. We couldn't really ask for much more, could we?

Increasing the contribution of solar generation to the electrical grid will reduce costs, risk, and price volatility for ratepayers, increase grid reliability, and significantly reduce the environmental impacts of our energy system.

If electricity prices reflected the real costs of conventional fuels and the full benefits of solar energy to ratepayers, and regulatory obstacles to efficient solar deployment were streamlined, solar would be growing even faster than it already is, without the need for today's complex and inefficient subsidies.

Deeper consideration of these significant solar benefits could help inspire development of utility regulatory paradigms better suited for the 21st century.

Fred Unger has been involved with NESEA since 1979. He served on the board for six years and chaired the BuildingEnergy conference in 2003. He has worked as a builder and real estate developer. For the last five years he has managed operations for a solar project development company with 62 interconnected systems operating and many more in development. His company website is www.heartwoodsolutions.com.

Peer reviewers: *Warren Leon, Richard Perez, Jigar Shah, Barry Cinnamon, Seth Handy, John Abrams, Pentti Alto, Rob Meyers, Bill Ferguson, Scott Englander, Fran Cummings, Joel Gordes.*

Special thanks *to past NESEA Board member Dr. Richard Perez for so much of the primary research that this article depends on.*

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Zero Energy and Beyond in Devens, MA

A MassDevelopment residential community showcases homes that produce more energy than they use

By R. Carter Scott

My Massachusetts-based company, Transformations Inc., had already built several double-studded homes with Home Energy Rating System (HERS) indexes as low as -4 when MassDevelopment—the state's finance and development authority—was looking to showcase sustainable housing in 2009. They put out a request for qualifications for developer/builders to design and build moderately priced single- and multifamily homes at their Devens, MA, residential community. The goal: to provide an example of sustainably built zero or near-zero net energy housing that was practical and replicable in the state.

At Transformations, we enjoy being on the creative edge of energy-efficient building, and part of our mission is to share what we learn with others. The MassDevelopment project presented an opportunity to take things to the next level—to continue the innovations and help get the word out on affordable zero-energy homes. We seized that opportunity, and we made the most of it. Here's the story.

Not as traditional as it looks: This saltbox-style home's expansive rear roof (seen on the next page) is covered with PV.

The dream team gets the job

I contacted Betsy Pettit of Building Science Corporation (BSC) and asked her if we could get assistance under the Department of Energy's Building America program. Building America is a public/private partnership working to accelerate the development and adoption of innovative building processes and technologies for production housing, and BSC leads one of the program's five teams. They have many staff members who have considerable experience with energy efficient enclosures. I proposed to advance zero-energy homes via the Devens sustainable housing project and two other Transformations developments. Betsy agreed and proceeded to line up talent within her company: Kohta Ueno, Daniel Bergey, and Honorata Wytrykowska.

We started with a charette at Joe and Betsy's barn in Westford—10 engineers and 4 architects. I invited several building-science engineers and architects whom I had worked with in the past: Marc Rosenbaum, Mark Kelly, Mike Duclos, Ben Nickerson, and Paul Panish. In addition, Rick Gilles, Bryan Urban from Fraunhofer, and Luke McKneally from Solar Design Associates came out to help. Joe Lstiburek and John Straube rounded out BSC talent at the charette.

We used the 2008 Farmhouse, a Transformations design that had been built in Townsend, as a base model and picked it apart. We were looking for ways to increase efficiency, bring down costs, and improve the aesthetics of the homes. With all of the group's intense conversations, it took five hours to get though about 25 slides! Ventilation (heat recovery ventilator versus bathroom exhaust fans), keeping the basement in the thermal envelope, and roof-integrated photovoltaics (leaking concerns, cost concerns) were among the topics discussed.

We submitted the resulting proposal, and MassDevelopment chose

Transformations to build the eight single-family homes at Devens, and in the summer of 2011 we began construction on the first two. The first home was sold by October. We had planned on a three-and-a-half-year build-out, but by the following October, all eight homes were either sold or under agreement. Zero-energy homes and the great Harvard public schools seemed to be a potent combination.

Cooler than a pool: This backyard PV system was estimated to produce enough extra power annually to run a Chevy Volt 30,000 miles.

Getting to zero energy

Walls. All of the home designs started with our standard superinsulated shell. We built 12-inch-thick, double-studded above-grade exterior walls with 2x4s at 16 inches on center (OC) for the outside walls, a 5-inch gap, and 2x4s at 16 inches OC for the inside walls. We filled this with low-density (open-cell) foam for an R-value of 45.6 (R-3.8/inch). The attics were sprayed with 18 inches of cellulose for an R-value of 63.

Basement. We added about 3.5 inches of high-density (closed-cell) foam on the basement foundation walls for an R-Value of 20 (R-6/inch) and put 2-inch rigid XPS under the slab for R-10. This was a result of the charette and the analysis with BSC.

Windows. Triple-glazed windows (mostly from Harvey Industries) with a U-value of 0.21 (about R-5).

Hot water. We took Betsy's suggestion of a propane Navien instantaneous hot-water heater in the basement.

Heating and cooling. Mitsubishi dual-stage air-source heat pumps (MSZ-FE12NA indoor units and MUZ-FE12NA outdoor units). These units have a Seasonal Energy Efficiency Ratio (SEER) rating of 23 for cooling and a HSPF rating of 10.6 for heating. They put out 92 percent of their rated capacity at 5 degrees F and 58 percent down at -13 degrees F. We chose these mini-splits because of price (around $3,000 installed per floor), efficiency, and reliability.

We modeled the homes with RemRate software and found that they produced a HERS index of around 40. To get to zero energy, we typically added a roof-mounted 7.92 kW solar electric (PV) system. The Greek Revival, Victorian, and Farmhouse designs had the gable end to the street so the long roof could face south. We wanted to both have a good street view and maximize the PV system. These homes have three bedrooms as a standard, and a bonus room that can be finished off later as a fourth bedroom, office, or recreation room. HERS indexes came in at 7 and 8 on these designs. Without the bonus room in the heated envelope, the HERS index came in at 0.

Going further: net producing homes

With a zero net energy home, you eliminate your share of the 48 percent of carbon emissions that come from the building sector—and you don't have any utility bills to pay. We now can go beyond this and start to address the 33 percent of carbon emissions that come from the transportation sector.

By increasing the roof area relative to the living area, Transformations built homes that produce considerably more energy than they use. The lots were laid out such that the rear of three of the homes would face south. We evaluated the traditional forms and decided that the ranch and saltbox styles could take best advantage of this roof area.

By increasing the roof area relative to the living area, we built homes that produce more energy than they use.

These homes allowed for a first-floor master bedroom, which was becoming more popular. They also let us put the PV system on the back of the garage as well as the main roof. A custom version of a saltbox model with an 18.33 kW PV system was completed in the spring of 2012. The final certified HERS index was -21. It was estimated to produce 10,200 kW hours more than it consumed annually—enough to power a Nissan Leaf or Chevy Volt for 30,000 miles, given a .34 kWh/mile average. Another saltbox built on speculation sold for $360,000 in the late summer of 2012. It had a first-floor master bedroom and two upstairs bedrooms. With its 16.31 kW PV system, it had a HERS index of -37. The ranch model was customized and completed in the fall of 2012. Its 17.28 kW PV system gave it a HERS rating of -36.

Resiliency gets put to the test

The 12-inch-thick walls not only reduce energy usage, but also allow the interior temperature to coast down gently during winter power outages. We had data loggers in one of our superinsulated, airtight homes in Townsend when it was without power for seven days in the December 2008 ice storm. In an eight-hour overnight period, with the temperatures in the 20s outside, the home lost just 3.6 degrees F. Many others in town suffered broken pipes.

Further, we can now offer vehicle-to-home back-up power. I recently purchased a 2 kW "plug out" inverter that runs off my Prius to power my essential loads during power outages.

Monitoring for moisture and comfort

How do 12-inch-thick walls perform over time? What happens with moisture in these walls? How does the low-density foam compare with cellulose? Are home owners comfortable with one point-source heating and cooling per floor? How is air infiltration reduced in these homes? We looked at these questions and others. To give some answers to these questions, BSC prepared, and recently submitted to the National Renewable Energy Laboratory (NREL), a 70-page technical report. The study confirmed a suspicion that the cellulose walls would contain more moisture than the low-density foam

walls (28 percent versus 18 percent in the north wall). It also confirmed that most home owners were comfortable with just one point of heating and cooling per floor.

In sum: another model community

The Devens project has been a resounding success on many levels. These homes met the goals of MassDevelopment, which was pleased with the aesthetics, the pace of homes sales, and the energy efficiency. MassDevelopment sponsored two zero-energy home workshops to help get the word out to other builders and developers. The buyers were happy to have well-built homes and little to no energy cost, and in some cases, credits as high a $100 per month. The DOE extended the Building America program for BSC to continue our work together. And Transformations was pleased with another model community designed and built to advance energy efficient construction in the Northeast.

R. Carter Scott is president of Transformations Inc., a Massachusetts company that develops and builds zero-energy residential communities, builds zero-energy custom homes, and installs solar electric systems for home owners, other builders, and commercial clients. www.transformations-inc.com

***Peer reviewer** Andrew Webster is a designer and project manager at Coldham & Hartman Architects in Amherst, MA.*

Solar's Role in Domestic Water Heating
from page 31

heating contractor's license. The new systems include the heat-pump compressor, evaporator, condenser, storage tank, microprocessor, and supplemental electric resistance heater as an integral unit. They are indeed a tightly integrated system. If the tank leaks, the entire unit must be replaced. If the compressor fails, it is likely that the entire unit will have to be replaced. For the owning cost analysis, a 10-year life was assumed, since most of the units carry a limited 10-year warranty. There is a very informative online forum on ASHPWHs that I recommend to anyone considering them: http://www.thetankatwaterheaterrescue.com/forums/forum3/2544-1.html. There is also a recent (June 26, 2012) comprehensive study by Steven Winter Associates: "Heat Pump Water Heater, Evaluation of Field Installed Performance."

Other costs and considerations

In some localities, before a solar array can be placed on the roof, the local building inspector may require an opinion letter from a licensed structural engineer vouching for the structural integrity of the roof. The opinion letter can cost between $700 and $1,500.

Shingled roofs typically need reshingling every 20 to 25 years. If a solar array is installed over shingles, it should be removed when a new layer is applied or when shingles are replaced. The removal and remounting can be a significant and unexpected cost to the home owner.

Tree shade can significantly reduce the expected output of a solar array. Even after deciduous trees have lost their leaves, reductions of between 30 percent and 65 percent are common from tree branches without leaves. Tree or limb removal can be costly.

The longevity of a given ASHPWH system will be affected by the service tech's decision to repair or replace the system. While the least cost to the home owner may be the repair of a component by a knowledgeable technician, it is often easier—and more profitable—for a technician, especially a less knowledgeable one, to replace an entire system than to figure out how to make the repair.

Where available roof area is a factor, the greater output-per-unit area of a solar thermal system may influence the water heating system choice.

ASHPWHs draw heat from the surrounding atmosphere. If that heat is supplied by the house heating system, it will lower the system's effective COP (coefficient of performance). In most of the country, the ASHPWHs must be located indoors, in a space 1,000 cubic feet or larger. Removal of heat from that space cools and dehumidifies it year-round. During the cooling season, that heat and moisture removal are usually welcome. During the heating season, that heat removal will add to the cost of heating the house.

Where available roof area is a factor, the greater output-per-unit area of a solar thermal system may influence the water heating system choice. A solar thermal system will put out at least four times as much energy per square foot as a PV/ERWH, and about 1.5 times as much compared to a PV/ASHPWH.

Factors beyond the designer's control: The SDHW will not perform well when the system owner fails to notice that it is not collecting heat and the supplemental heater is automatically providing all of the hot water. The PV/ASHPWH system will not perform well if placed in a closet or other small space, or when the owner fails to change the intake air filters regularly, or does not notice that the ASHP has stopped heating the tank and the electric resistance element is doing all the water heating. Import tariffs of between 30 percent and 250 percent, if imposed, will have a dramatic impact on the installed cost of PV systems.

Learn more: *Portions of this article were omitted due to space constraints. For an extended version, please contact the author directly: everett.barber@gmail.com.*

Everett M. Barber recently coauthored Convert Your Home to Solar Energy, *a consumer's guide to solar applications (Taunton Press). He is now working on a design guide for commercial and industrial solar thermal systems. He was founder and past president of Sunsearch Inc., a solar thermal/solar electric design, build, and service firm in southern New England (1975–2007), as well as an associate professor (adjunct/retired) of building environmental technologies at Yale School of Architecture (1972–1998).*

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