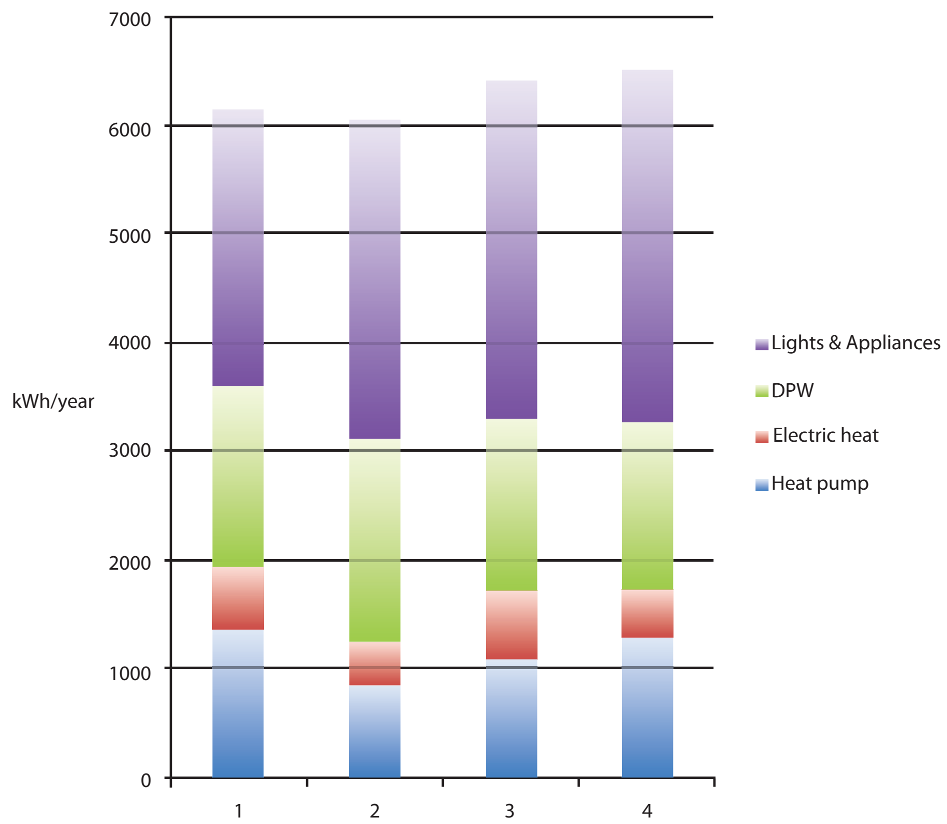
13 Best Practices for Zero Net Energy Buildings

With ZNEBs becoming more common in NESEA country, we can begin to codify the strategies they share

By Marc Rosenbaum

A zero net energy building is one that uses no more energy annually than its renewable energy system generates. It imports energy when site resources are insufficient, and it exports energy when what's generated exceeds the building's usage. Once very challenging to accomplish, ZNEBs are becoming more common in NESEA's region. As this happens, it's apparent that there are strategies that most of these buildings share, that permit us to begin to codify best practices for these homes and other buildings. As you'll see, the energy system itself comes last.



Four years of energy use data from one net zero house: lights and appliances, not heat, consume the most energy.

1. Educate and motivate the occupants

Motivating and educating the occupants in their role in the achievement of ZNE performance—the need to pay attention—is the first best practice. Building performance consultant Andy Shapiro said it best: "There's no such thing as a net zero house, just net zero families."

In small sets of similar houses, we've measured hot-water usage that varies by a 3:1 ratio in gallons per person per day, and lighting/plug/appliance loads that vary 2:1 in terms of kWh per person per day. In larger buildings, we've seen cooling used from the first hot day in May until the first cool day in the fall, versus a pattern of lower usage that is clearly the result of people choosing to use cooling only on true "dog days" and otherwise taking a windows-open approach with passive and low-energy strategies such as ceiling fans.

2. Focus on all energy uses, not just heating

I recall about 25 years ago working with a builder who had built his own house and being very impressed with how little fuel it was using. Then one day I went there. In a bedroom that he used as an office, there were six 100-watt recessed lights. I realized that the house was significantly heated by electricity, and that to assess how well our buildings were doing, we needed to report all energy used. Heating energy in buildings following these best practices may be only 20 percent to 35 percent of total energy used on-site. So with ZNEBs, we account for all usage and design other energy-using systems such as hot water and lighting as carefully as we design the building enclosure.

Photo: Solaire Generation. Chart: Marc Rosenbaum

3. Orient the building well and exclude or admit the sun as needed seasonally

In new construction, the building stretches out east-west, and glazing is concentrated on the south and minimized on the east and west. In houses, it's minimized on the north as well, but in nonresidential construction it may not be, as lighting is a more significant energy use and daylighting can be accomplished well with north light.

Larger buildings have narrower floor plates to maximize daylighting. South glazing is often equipped with fixed or movable shading to limit cooling loads in warmer weather. It's worth noting that as lighting gets ever more efficient and the cost of sophisticated lighting controls drops, daylighting may be harder to justify on a strictly energetic basis. The additional glazing usually adds heating and cooling load, and the energy impact of heating, cooling, and lighting must be assessed together. I predict that daylighting will come to be viewed as a way to create delightful, healthy spaces for people, rather than as a way to conserve energy.

4. Minimize cooling loads

The typical ZNEB is built with mechanical cooling (see no. 8, heat pumps), yet the load is minimized and passive- or low-energy measures are used to boost comfort. Loads are reduced as described above—with orientation, glazing distribution, and shading—and in some cases also with glazings that selectively admit much more visible light than solar heat. Efficient lighting, controls, appliances, and equipment (see no. 11 and no. 12) reduce energy consumption directly while also reducing cooling loads. Strategies like ceiling fans and operable windows aid comfort.

5. Build a superinsulated, thermal-bridge-free envelope

Superinsulation has been with us now for forty years or so, and although it's far from standard practice in the region, it's a basic component of ZNEBs.

ZNEBs have a complete thermal boundary that includes the below-grade areas. Slab-on-grade, basement slab, and foundation wall insulation values range from R-20 to as high as R-40. This ensures that subgrade spaces are fully within the thermal boundary of the building and, without heating, operate at temperatures close to that of the conditioned space, making them warm and dry and quite usable to the occupants.

Above grade, wall R-values seem to cluster around R-40, lower in larger buildings in the less severe heating climates and higher in single-family homes in the northerly locations. Roofs are built at values at least as high, and if trusses are used, the R-values are usually at least 60 and sometimes as high as 100.

6. Build it airtight

For the first time, the building code may be getting serious about airtightness, but ZNEBs are going way beyond code requirements. Construction documents have dedicated air-barrier drawings, and project specifications set quantified airtightness targets and how and when the projects are to be tested.

People doing blower-door testing quality assurance find themselves investing in C- and even D-rings for their blower doors, so they can test very tight ZNE homes—some are coming in at below 100 CFM50. Even more fascinating is that the best retrofit projects are achieving results equal to the best new construction. Many companies building ZNEBs, like South Mountain Co., where I work, have crews that have made Passive House airtightness standard practice—they don't break a sweat over it.

7. Use triple-glazed windows with insulated sash and frames

Windows have always been the weak point of the thermal envelope, and that is still the case, but the standards have risen. ZNEBs are using triple-glazed (or, in rare cases, quad-glazed) windows with overall R-values ranging from the mid-5s to 7 or more. Glazings with center-of-glass R-values of 8 to 9 or even more are available, using ever more sophisticated low-emissivity coatings and low-conductivity argon or krypton in the gaps between lites. In the Northeast, usually it makes sense to trade off a bit of insulating value for increased solar heat gain, especially on the south facade.

Best practice for windows extends to insulated sash and frames. Most ZNEBs use one of a handful of North American windows with fiberglass or vinyl frame components filled with polyurethane foam, or European tilt-turn windows (some tilt-turns are now made in North America) in which sash and frame are either multicellular vinyl (lowest cost), thermally broken aluminum, or beefy wood with thermal breaks of high-density foam or cork. This is the only way to achieve these high overall R-values. Compared to almost all North American wood and vinyl windows, the high-performance windows used in ZNEBs have deeper glazing pockets, from 1⅜ inches to as much as 2 inches deep.

8. Heat and cool with electrically driven air-source heat pumps

ZNEBs are powered by onsite renewably generated electricity, principally produced by solar electric systems. In most cases, they are all-electric buildings, without fossil fuels or combus-

The tightest net zero homes are coming in at below 100 CFM50 on blower-door tests, compelling testers to invest in C-, D-, and even E-rings (shown here).

Photo: Brice Delhougne, South Mountain Company

tion. This certainly makes the ZNE math simple: Did the building produce at least as much electricity as it consumed, or not?

Using fuels besides electricity entails some bookkeeping to claim ZNE, and a decision on whether to base the ZNE approach on site energy or source energy (aka primary energy).[1] If the latter, source energy factors for each fuel imported and exported must be calculated. Using source energy as a basis means that less renewable electricity needs to be exported to offset, say, imported natural gas. (Assuming the grid primary energy factor is 3—3 units of primary energy used for every one unit of energy delivered to the site—then exported electricity is worth 3 units of primary energy.) It also means that different regions will have different results, depending on how clean the grid is, as the source energy factor for a primarily coal-powered grid is quite different from that for a grid powered by a mix of natural gas, hydro, and wind.

Pioneering examples of ZNE houses used ground-source heat pumps for space conditioning. These days, best practice has evolved to using inverter-driven mini split air-source heat pumps. The tremendous cost advantage of these systems allows designers to put more resources toward the building enclosure and the renewable energy system. They are also reliable, easy to zone, and come as a complete turnkey package including sophisticated (and sometimes mystifying) controls. I have mini-splits providing heating and cooling in homes, schools, and office buildings in climates as cold as northern New Hampshire and Vermont.

9. Use heat recovery ventilation

All buildings need ventilation, and once they are superinsulated, the ventilation load looms large, especially in nonresidential buildings with higher occupancy. ZNEBs use heat recovery ventilation, with or without moisture recovery, to dramatically lower the thermal load of ventilation. In larger buildings, the usual approach is to use an enthalpy wheel; in houses, fixed-plate cores are the rule. The best equipment, which once again comes to us via Europe thanks to the Passive House movement, achieves heat recovery efficiency of as much as 90 percent while using variable-speed motors to keep parasitic electrical usage down.

10. Make hot water with heat pumps or solar thermal

As with the building enclosure, conservation is the first strategy, so ZNEBs are designed to be parsimonious with hot water. Low-flow fixtures predominate, and water-efficient

This interior wall and foamed ceiling shows a very high-efficiency European heat recovery ventilator and associated fitting for fresh air supply.

Photo: Marc Rosenbaum, South Mountain Company

washers and dishwashers are chosen. There is no clear winner in making hot water. ZNEBs use either a solar thermal system with (usually) electric auxiliary, or an air-to-water heat-pump water heater (HPWH). We are waiting for the state-of-the-art Japanese HPWHs to arrive in North America, as they use CO_2 as the refrigerant, put the condenser outdoors instead of in the basement, and are more efficient.

If an HPWH is chosen, additional solar electric capacity must be provided to offset the electrical usage (although capacity must be supplied for the auxiliary energy used by the solar thermal system as well). As solar electric costs have fallen, the pendulum has swung to the HPWHs, and I predict that this trend will accelerate when the CO_2-based units arrive. Roof aperture is usually at a premium on ZNEBs, so the designer has to compare the utility of thermal versus electrical collection.

11. Use efficient lighting and lighting controls

The progress in LED lighting has been breathtaking. In ZNE homes, LEDs have been making a big dent in the niche formerly occupied by compact fluorescents, primarily due to light quality rather than straight-up energy savings. In nonresidential ZNEBs, the workhorse super-T8 fluorescent lamps and electronic dimming ballasts are still found in most larger spaces. Controls that keep lighting off when spaces are unoccupied and dim lights when daylight is available are the norm. ZNEBs are being lit with 0.7 watt per square foot or even less, and actual peak lighting loads are lower still.

12. Select the most efficient appliances and equipment

As thermal loads are reduced and heat pumps are used to satisfy them, using one unit of energy to deliver two to three units of energy to the space or water, plug loads may emerge as the largest single energy load in homes and some nonresidential occupancies.

In homes, selecting efficient equipment for cooking (induction cooktops, convection ovens, microwaves), washing clothes and dishes, storing food, entertainment (TVs, audio equipment), and communications (modem, cable equipment, laptops) is a clear best practice. Keeping them off when not in use is even more important. In office and school environments, the higher density of computers, screens, printers, etc. means that these items are selected to be as efficient as possible and are equipped with controls that help ensure that they are off during unoccupied hours.

That piece of equipment at the top of the efficiency ratings may seem expensive, but the calculation has to compare the incremental cost of those energy savings with the incremental cost of the larger renewable energy system needed to drive the less efficient alternative.

13. Provide a renewable energy system to power the building

Yes, this is a best practice too! The choice in most cases is solar electricity, and the falling price of this technology helps keep it in the lead. Buildings 10,000 to 15,000 square feet and under usually mount the array on the roof; larger buildings often require some ground-mounted capacity as well, sometimes installed on auxiliary buildings or on parking canopies. As prices fall, apertures that may have some shading or don't face close to south become worth considering.

Last but not least is a renewable energy system. As prices fall, less-than-perfect apertures that have shading or don't face close to south become worth considering.

Cost comparisons: tradeoff or trap?

In an ideal process, the costs of conserving energy are traded off with the costs of generating it onsite. However, there are potential traps here. What if the cost of solar electricity fell so low that it didn't pay to superinsulate buildings? We'd lose the comfort and durability aspects of this type of construction. The sophistication of the cost comparison also has to consider the service lifetime of the items being compared. It makes sense to compare the cost-per-unit energy of solar electric capacity against a more efficient refrigerator, because the lifespan of the two technologies are comparable. Comparing solar capacity against investments in the thermal enclosure is different—we expect the enclosure investments to far outlast any equipment, so that needs to be accounted for.

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Notes

1. Related article: "Getting Real About Primary Energy," by Katrin Klingenberg, in the spring 2013 issue.

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