Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 1: What are they? What does it mean?

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

I have just finished up a hitch on Governor Patrick's Net Zero Energy Building (NZEB) Task Force. About a year ago, the Governor convened a team of "experts" to craft policy recommendations for the Commonwealth to jump-start this new-ish idea about high-performance building. But I put the term "experts" in quotation marks because, going into these Task Force meetings, barely a handful of us had any experience in NZEB at all, and those that had NZEB cred were largely doing single-family homes. But as we wrap up, I can say that there was a whole lot of learning goin' on! So here (and over a few more e-mails) is what we currently know . . .

So what *is* a NZEB and why do we care?

A net zero energy building is a building that, over a given period of time, will produce as much energy as it needs, or more. That's the basic definition. For our Task Force, an important corollary to this definition is that all the power a NZEB does draw from the grid or produce itself must be from renewable sources.

Now, further definition by negation: NZEB is not "off the grid". There will be times that a NZEB will need to buy power. But to be net zero, there will also be times when the NZEB will sell power back to the grid. NZEB is also not (necessarily) "carbon neutral" building. To be really truly carbon neutral, a building must also offset the carbon emissions caused by the fabrication of the building's components . . . things like the windows and mechanical equipment. This is nearly impossible to do one building at a time. We're coming to understand that carbon neutral is a good goal for a state or a city or corporation or a University or a profession, but for an individual building you have to say "well, we're just talking about carbon neutral *operations*" . . . which is essentially net zero energy.

Yes, NZEB excludes a lot of the other concepts that are important to sustainable design like life-cycle costing, recycled content materials, improved indoor air quality, and so on. But we know a lot about those subjects now. Real building performance against energy targets is (I dare say) *the* aspect of sustainable design that is the most important in light of climate change and the one that we understand the least as practitioners. That's why NZEB is so important.

Finally, a distinction between the four different "flavors" of NZEB: Net Zero Carbon, Net Zero Cost, Net Zero Source and Net Zero Site.

Net Zero Carbon we've touched on. Only igloos and tepees are carbon neutral. Tree houses are close. Net Zero Cost is agnostic as to the power source. If I built a small coal-fired power plant attached to my building and generated more power than I had to buy I could come out net zero cost but not sleep very well at night. Net Zero Source asks to balance a building's power needs as generated at its source. The source energy multiplier for electricity can be three or four times as much as a building's electric meter reads due to transmission losses, and source energy is also agnostic on emissions. Think coal-fired power plants in Ohio. So Net Zero Site is the concept for us: A building that supplies its own (net) (renewable) power needs.

Next: Metrics and Rules of Thumb.

Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 2: Metrics and Rules of Thumb

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

NZEB is first and foremost about *radical* energy use efficiency.

Commercial, academic and multi-family residential buildings use lots of energy. The National Renewable Energy Laboratory (NREL), a forward-thinking division of the US Department of Energy, estimates that the average existing commercial building uses 90 kBTU's/SF/year in all form of energy combined.

Woah, hold up a moment. How about a little refresher on units of measure?

Pop quiz: When you're talking energy use, what unit of measure do you use? Would you say "watts per square foot?" That's generally what we use when we're talking lighting load. It's good because it contains that "per square foot" part so we can use it as design criteria. But it only counts electricity (watts) and it's a static measure of the allowable maximum power of a lighting system. Doesn't really say anything about actual use. Would you say 'kilowatts" or "kilowatt-hours?" That's a gross measurement of electric power actually consumed. A utility would use that number when preparing your bill. But to use it as a design standard, first you need a time period (a month or a year) and then you do the math and divide over floor area. And again, it's electricity only. Then there are "therms" of natural gas and gallons of fuel oil . . . yikes.

Enter the BTU or British Thermal Unit: A unit of the energy content of any kind of power. When used in the design of buildings or spaces, this unit lets us lump all power sources together. When stipulated as "per square foot" *and* "per year", the humble BTU - or kilo-BTU (thousand BTU's for you metric-phobes) - can be used to describe a building's entire energy needs per unit floor area per time period. Period. This is the metric we like!

Now, back to NREL. The smart guys at NREL say that the typical commercial

Now, back to NREL. The smart guys at NREL say that the typical commercial building burns 90 kBTU's per square foot per year, and given the state of technologies available today, for this building to become net zero as a rule of thumb it has to burn not more than 30 kBTU's per square foot per year . . . *a two thirds reduction!* Double yikes!

But when you think about it, what would be the point of loading an inefficient building up with tons of Photovoltaics (PVs) or wind turbines to try to make it net zero? It's kind of pointless unless efficiency is addressed first. And besides, you'd need a couple football-field's worth of PVs to meet the power needs of a bare-bones, 20-year-old, three-story suburban office building . . . OK, I made that part up, but NZEB is not possible without radical energy efficiency first.

Radical, you say? One of our project teams thinks otherwise! Our crafty engineers (Fitzemeyer & Tocci) and our ace design team have already benchmarked the schematic store prototype at about 50 kBTU/SF/yr and think high-30s is do-able without rocket-science technology. In fact, they say that the new ASHRAE standard referenced by the International Building Code and International Energy Conservation Code recently adopted by the Commonwealth of Massachusetts (hooray for the Green Communities Act!) requires new buildings to be in the 50s anyway . . .

So stay tuned!

Next: Use Sectors and Site Energy

Bergmeyer Associates, Inc.
Architecture and Interiors

51 Sleeper Street
Boston, MA 02210

tel 617 542 1025
fax 617 542 1026

Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 3: Site Energy and Use Sectors

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

So we know that the first part of NZEB is radical energy efficiency. The second part is on-site power generation.

All the world's energy comes from the sun. Coal and oil and gas that we dig out of the ground was once plant material that sucked down sunlight, died, got buried and over a really long time was turned into something else: fossil fuels. The plants and animals that became our lunch today got their fuel from the same place. Wind and ocean currents are caused by the uneven heating of the earth's ecosystem by . . . the sun.

We're a smart, resilient species. You have to imagine that at some point we'll figure out how to get power for our buildings from the sun directly, too, without burning stuff first.

We have. Photovoltaics (or PVs) are it. Photovoltaic cells, either the old-school crystal silicon panels or new-school thin film technology, soak up sunlight and convert it to electricity. That simple. Sunlight is made up of photons, small particles of energy, and PV cell traps these photons between layers where the photons can "agitate" a semiconductor material and make electrons move around. Think batteries that use light to produce electricity. They can "stand alone" like a solar-powered generator, can be connected to a back-up battery or storage device like a fuel cell, or be connected into an electric utility "grid". PVs, especially building-integrated PVs (or BIPVs), are what make net zero energy buildings go.

Here come the questions: What about wind as a source of site energy? What about geothermal? What about cogeneration? What about solar hot water heating? Good questions one and all. We'll come back to them.

First, take a look at commercial building energy use. We can put the total energy requirements for a small retail or commercial building (like the project mentioned in Chapter 2) into five piles: Space heating, lighting, space cooling, plug and process, and fans. Some studies lump a few of these together, but this is the breakdown that American Society of Heating, Refrigerating and Air-Conditioning Engineers (we know them as ASHRAE) uses in their "Advanced Energy Design Guide for Small Retail Buildings." Notably absent from this breakdown is hot water heating. Again, we'll come back to that one.

The percentages for these five energy use sectors vary widely by climate zone and design aspects. For a small retail building in Chicago (same Climate Zone as Boston) with one façade of storefront, say, the percent of building energy used by sector looks like this:

Space heating: 40%
Lighting: 35%
Space cooling: 15%
Plug loads: 5%
Fans: 5%

A freestanding bank building will probably have more windows and therefore a higher percentage for its space cooling load. It may also have a higher percentage of plug load if it uses lots of computers. But across the commercial building spectrum, the two biggest questions are typically how to meet a building's space heating and lighting demands. This is primarily what makes PVs (at least for now) the biggest answer.

Lighting, of course, only runs on electricity. Check. Space can be heated by other fuel sources like natural gas or heating oil, but these aren't renewable energy sources and are therefore disqualified if the goal is net zero energy building. Must be renewable, remember?

Back to our other site energy power generation suggestions. Solar hot water heating counts as renewable, but water heating is an infinitesimally small load for commercial buildings. Works fine for single-family homes. "Geothermal" as we commonly know it is a misnomer for ground-source heat pumps: A technology that uses the thermally moderating property of the earth to make a conventional HVAC system run on less fuel or less power . . . but in itself it isn't a source of renewable energy. Cogeneration or combined heat and power is a highly efficient way to generate electricity on-site, but cogen runs on natural gas. Out. Those little wind-powered microturbines can power your parking lot lighting, maybe. The big multi-megawatt turbines are just so-o-o-o expensive and they're often prohibited by zoning. Good for utilities, not right for individual buildings.

But we're in New England, you say! It's cold and dark a lot of the time! Yes, but remember NZEB's are *not* "off the grid". There will be times in the life of a NZEB (like cold dark winter mornings) when they *will* have to buy power from the utility. But there will also be those hot summer afternoons when the PV's will be cranking. As long as the buy/sell equation balances, we're at net zero energy. And part of the potential for commercial buildings to go net zero is the obvious overlap between power needs and building use: You can turn off the lights at 5:30 and set back the thermostat. When the sun goes down, you don't need nearly as much power.

So PVs are it. We'll talk size and cost of PVs - among other things - next.

Next: Design Principles

Bergmeyer Associates, Inc.
Architecture and Interiors

51 Sleeper Street
Boston, MA 02210

tel 617 542 1025
fax 617 542 1026

Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 4: Design Principles

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

Now that you're all well-informed about Net Zero Energy Buildings, you probably want to know how these exotic structures are designed, right? This fourth e-mail is on design principles

The *sine qua non* of NZEB is an **integrated design process**!! All designers must be around the table and contributing ideas from the get-go, and that includes a client that "gets it", clever engineers, someone to do cost estimating, and an expert in photovoltaics. You absolutely need energy modeling. Daylight modeling is a good thing to have, too, as is fundamental building systems commissioning. Dialogue must flow freely.

First, consider the **building envelope** (archi-speak for the walls, windows, roof, and floor). This may seem obvious, but NZEB starts with a super-insulated super-tight exterior. We measure resistance to heat loss in walls and roofs with an "R Value". By code in our climate zone, walls need to be rated in the R-13 to R-17 range. By adding insulation and making assemblies thicker, we should be thinking R-26 for walls. Roofs should get into the R-40s. Windows need to crank down their Solar Heat Gain Coefficient and boost their insulating value as well. Only 30% to 40% of the total wall area should be glass. We in Massachusetts are also particularly focused on reducing air infiltration as measured in "air changes per hour" or ACH. A typical building baseline is 0.5 ACH, we need to be at 0.35 ACH or less.

After we've beefed up the building envelope, focus on **lighting.** This is simple. Use less artificial lighting! Effective use of those limited window areas, brightly reflective interior surfaces, efficient lamps and ballasts, task over general illumination, motion-sensors, we know these strategies. (We used them in the design of our own office!) End result: we need to get from about 1.0 watts per square foot of lighting load to 0.8 W/sf or less.

Now, consider **plug and process loads.** This demand often gets overlooked by designers because it's the owners' and users' stuff that creates it. But managing this demand counts towards NZEB. First, all equipment should be Energy Star rated. Especially refrigerators. Just like at home, equipment should be turned off when not in use. Ban 3-D computer screen savers, they use twice as much power as a cute photo of your dog. And ditch the soda machine! Biggest energy hog in the building.

On to the **heating, ventilating, and air-conditioning (HVAC) system**. Bonus question: Why reduce lighting and plug loads *before* you design the HVAC system? But of course. Lighting and equipment are a big source of heat, adding to a building's cooling load. We can't begin to cover the myriad strategies that go into making an HVAC system perform more efficiently, but consider these sweeping generalizations: Don't heat and cool space like tall ceiling cavities where there are no people. Put the heating/cooling elements where the people are. Think radiant floor. Try to *eliminate* fans and pumps. Much of the energy in HVAC systems is in pushing heat around. Consider natural ventilation for summertime cooling. Consider pushing that indoor environment comfort zone . . . we can wear sweaters in the winter and bag the sports coats in the summer.

Almost last are **passive strategies.** This doesn't mean avoiding that person you really don't want to confront . . . it's making those visionary design moves that will shade south-facing glazing in the summer but allow light to penetrate and reflect in the winter. It's designing that big masonry wall so that it will absorb winter sunlight and radiate at night like the earth itself. This step is where daylight modeling comes in handy.

Now we add the **photovoltaics.** But how much? PV "arrays" are sized by the Kilowatt, or their capacity to generate electricity (which is the same unit we use to measure the consumption of electricity, laws of thermodynamics being what they are). We need an expert to size a PV array to meet the needs of a reduced kBTU/SF/year load. But, for example, an entirely off-the-grid NZEB house typically has a 3 to 5 Kw PV array. Artists For Humanity, that building over there in South Boston with the biggest PV array in the city, has a 49 Kw array. Our store’s needs would be between these.

Finally, two very important rules of thumb: You need 100 square feet of roof per kilowatt of PVs, and PVs currently cost $7,500 per Kw installed. These figures are supplied by the Massachusetts Technology Collaborative's (MTC) Renewable Energy Trust. So if we're after a 20 Kw array, it'll need 2,000 square feet of roof and cost us about $150,000. But the MTC also administers a grant program called "Commonwealth Solar" that can rebate a building owner up to $3.125 per *watt,* or, in this case, knocking $62,500 off the price.

But . . . isn't all this just too *expensive* to build? A brand new report from NAIOP, a brass-tacks commercial real estate group, studied the cost and simple payback periods of four-story model office buildings, one of which was in Chicago. Although the pumped-up roof and wall insulation alone would take several decades to "pay back", boiler efficiency and improved infiltration measures pay back in only 3 or 4 years. And - here's the important part - the whole package of energy efficiency measures (like the ones we've just described) paid back in *only 8.8 years* . . . and that's without generating its own electricity.

So, mister client, how long are you going to own and operate this building? More than ten years? Probably. Case closed.

Next: The Business Case

Bergmeyer Associates, Inc.
Architecture and Interiors

51 Sleeper Street
Boston, MA 02210

tel 617 542 1025
fax 617 542 1026

Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 5: The Business Case

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

One of the questions most frequently asked of the NZEB advocate is how to justify the added cost. Unlike going for LEED Certification, you really can't do NZEB on incremental changes. Enhanced building envelope, improvements to heating and cooling systems, lighting controls, energy management systems and all that (not to mention the rooftop photovoltaics) mean more bucks. But rather than turn this into a philosophical diatribe, let's just look at the various strategies we have at our disposal and see what might work.

The easiest case to make is **simple payback**. How long will it take for accumulated annual savings to exceed additional initial cost? Let's say we're designing a small commercial building in the $2 million range. If we wanted to go LEED Gold, it might add 5% (at most!) or $100,000 to the cost for enhancements including a higher-performing mechanical system that will save money on electricity. If we save $2,500 per year on electricity, this $100K would take 40 years to "pay back," much longer (unfortunately!) than the building will probably be owned. But if the cost for the mechanical upgrades alone is only $25,000 of that $100K, this cost would pay back in . . . right, 10 years. Sounds better. And how do we demonstrate simple payback on those other LEED enhancements like low VOC-emitting finishes? Can't do it with this metric.

And what about a NZEB? Let's tag those upgrades (including the PVs) at $400K. Even if our energy costs go to zero, we're still probably in the 40 to 50 year simple payback range. The reality today is that incremental costs of more than a few percent are hard to justify in simple payback terms. NZEB doesn't "pencil out" in simple payback terms just yet.

Next is **life cycle costing**. This is where it starts to get interesting. (Accounting? Interesting? Yes! And important! The NZEB advocates must be able to speak the language of the money guys!) The term "life cycle cost" usually refers to the cost/benefits of a thing over its entire useful "life". So if we assume this commercial building will be owned for 20 years, we can add up 20 years of operating savings (include maintenance costs and all fuel costs in this kind of analysis) and compare that number to the incremental cost of construction. This is significant because of the very important variable that simple payback doesn't include: How long is this building meant to *last*?

Another definition of life cycle costing measures the environmental impacts (external costs) of extraction and disposal of building components along with construction and operation costs. A really smart group of people in Switzerland called the International Organization for Standardization (or ISO) publish a protocol called **ISO-14040.** This standard establishes a true Life Cycle Assessment for building products. All well and very good, but to say that ISO-14040 is not widely used in the American building and construction industry is a vast understatement.

The economists' favorite way to look at an investment is in **net present value (NPV)** terms. NPV asks how the total cash flow (expense versus income) of a project over a period of time compares to an assumed rate of return. The question NPV addresses is: If I invest money in a thing that's supposed to make money over time, will it perform better than just buying a bunch of indexed mutual funds? OK, maybe this standard is a little easier to beat these days! But if you NPV a base-case building versus a NZEB building, the longer the building will last and the better the energy savings, at some point the NZEB will be a better investment than the just-meets-code structure.

But let's think about this for a moment. Why do we simply attempt to balance increased construction costs with decreased operating expenses? Because that's all we can reliably measure? But why does someone design and build a building in the first place? To make money? Generate income? To appreciate in value? Of course. All those calculations go into a client's go/no-go decision. So why separate the business case for green or net zero energy building from these important calculations? Would a LEED Certified or net zero energy building perform better on all these metrics? You betcha.

Add to that: NZEBs come with a potential income stream that's independent of the building's function! You may be able become net energy *positive,* selling power back to the utility. If you own enough buildings creating excess capacity, you may at some point be able to sell Renewable Energy Credits (RECs) to a public utility under regulatory pressure to increase their renewable portfolio standards. And in some bright, shiny future, a multi- NZEB owner may be able to sell carbon credits under "cap and trade" regulations - depending on how they're defined. (The Regional Greenhouse Gas Initiative (RGGI) that Massachusetts is part of only applies to businesses in the "power sector”. The Obama Administration is still working on the terms of their proposed national plan.)

So hear me out. If someone could be so bold as to attribute even *small* improvements to business generation, employee productivity and increased appreciation in property value from a NZEB to the expense-versus-income side of a 20-year net present value calculation, the building would sell itself all day.

There you have it: The Holy Grail of business cases!

Convinced? Thought so.

Bergmeyer Associates, Inc.
Architecture and Interiors

51 Sleeper Street
Boston, MA 02210

tel 617 542 1025
fax 617 542 1026

Bergmeyer

Net Zero Energy Buildings: What We Know

Chapter 6: Final Thoughts - For Now!

by Michael R. Davis, AIA, LEED AP

Member, Zero Net Energy Buildings Task Force

First, a hearty thank you to everyone who has been following our missives on Net Zero Energy Building. We hope that we have been able to contribute to the collective wisdom on this fascinating and important subject. In closing – and after working on our own near-net zero energy projects for the past several months – a few important lessons have settled out that didn't make the first five reports. Here goes:

First lesson: "Beating code" is not all that difficult, but it's also the wrong metric for getting to net zero energy building. Why? What follows is a little "Energy Code 101" (you engineers can skip this part!). Most modern building energy codes (including the International Energy Conservation Code or IECC, which is fast becoming the gold standard of codes), offer two compliance methods: The performance method and the prescriptive method. The performance method is not based on interpretive dancing, it's based on energy modeling. It's not the popular compliance option. The more commonly used prescriptive method gives you a thoroughly exhaustive checklist of wall, roof, and window parts plus a list of every building system that uses energy. Under the prescriptive method, all the design team has to do is meet each of the criteria in every checklist like minimum R-values for opaque building enclosure assemblies and maximum allowances for lighting power density, that kind of thing. It gets highly technical really fast, particularly when you get to space heating and air conditioning equipment efficiencies, so don't try this at home without good, smart engineers. But still, even a good checklist is only a checklist.

So why this audacious claim that the code is easy to beat? Because after you check all those boxes and do the math, you *discover* how much energy your building is designed to use. And whatever that number is, it meets code. If you then make one tweak to the building envelope and one crank to the mechanical system, ta-da, you have beaten the code.

Right now, we're designing a small commercial building with a state-of-the-art variable refrigerant volume heating and cooling system and substantially reduced lighting power density thanks to some cleverly placed clerestory skylighting and passive solar control. Our target energy consumption of 52 kBTU/SF/year is *fifty percent* better than the code would allow us to build, but we can't quite close the demand-side gap with PV's. The building's power demands are still quite a ways from the 30 k/BTU/SF/year that we think we need to be a NZEB. So if you're gunning for NZEB, forget "beating code". The right metric to use is that bottom line: How much energy will the building use?

Next lesson: PV's (photovoltaic arrays) are equipment! This sounds nothing at all like headline news, does it? But it goes to the making of the business case. From the accountant's point of view, a shiny new net-zero energy building is not a single thing, and trying to make one business case for the whole thing may not be the best approach because . . . y'see, PV's can be counted as equipment like computers or telephones. This is good for the PV's because as equipment can be depreciated, making their stand-alone pay-back equation (augmented by the value of electricity generated and underwritten by subsidy) an easier case to make. PV's as equipment pay back much better than PV's as part of the sticks-and-bricks costs like high-performance glazing, which cannot be depreciated. So one size (or one business case) does not fit all.

But here's another lesson: The cost of buying electricity is (still) much less than the cost of generating your own electricity. Therefore, despite their attractive business-case potential, building-integrated photovoltaics still need financial subsidy to be competitive. And as the availability of rebates and subsidies vary widely from state to state, this web site – the Database of State Incentives for Renewable Energy – is a handy guide to subsidies and rebates on a state-by-state basis. It's invaluable to the NZEB advocate:

http://www.dsireusa.org

If you haven't seen this website before, meticulously updated by nice people at the N.C. Solar Center, North Carolina State University College of Engineering, you'll thank us! Use it early and often. While we're at it, it would also be a big help if we could get someone to pass uniform National interconnection and net metering laws . . . and give us a modern radial "smart" grid . . . and an extension to the Federal 30% Business Energy Tax Credit . . . but we digress.

Final lesson: The biggest obstacle to NZEB is not technology or money, it's knowledge. Designing a building that generates as much power as it needs in a year doesn't require skills that aren't usually found on a good design team chasing LEED Certification. Sadly, most of us just aren't fluent enough in the fundamentals of building energy use. How low can we go? We don't feasibly know. We don't really know how the buildings and spaces we design are supposed to perform. We don't measure the performance of the buildings and spaces we've already designed. But adaptation is the key to survival, and architects are a smart, resilient bunch. We can and will get there, and if we share what we learn we'll all get there faster.

That's it for now. We'll keep working at NZEB; we hope you will, too.

Bergmeyer Associates, Inc.
Architecture and Interiors

51 Sleeper Street
Boston, MA
02210

tel 617 542 1025
fax 617 542 1026