Strategic Energy Management for Zero Net Energy Buildings

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ABSTRACT

Strategic Energy Management (SEM) is based on the principle of continual improvement in energy performance. Yet, a high-performance building typically is evaluated using static criteria, such as an asset rating (Home Energy Rating System (HERS) or Energy Rating Index (ERI) score for a home), or an operational rating (ENERGY STAR® rating for a commercial building). Moreover, the focus on mid- and long-term efficiency has been on maintaining performance rather than improving it.

The concept of zero net energy (ZNE) offers a path for introducing SEM more comprehensively into the buildings sector. This paper discusses how it can allow building owners and operators a way to claim higher levels of ZNE performance. This opportunity comes about because of the hierarchy of standards for ZNE that has evolved worldwide.

At the lowest level are definitions of zero energy readiness that focus on achieving a level of energy consumption low enough that it *could* be provided by on-site renewables, whether or not it is at the time. California has embodied in its code a level that zeroes out electricity but does not zero out fossil fuel use or electric heating.

True ZNE on an annual basis is the most widely documented achievement, but zero on an annual basis does not imply zero net carbon (ZNC) emissions. And zero carbon in operations does not count emissions or energy used in construction materials, nor transportation of people to the site.

This paper discusses how SEM can be applied to facilitate increases in the level of ZNE achievement over the years.

Introduction

The concept and practice of ZNE buildings have been an increasingly strong presence in conferences and in recorded energy data throughout the world. ZNE is a relatively new idea, having been introduced in North American discussions early this century as a way to meet the challenge of stabilizing the climate by essentially eliminating the ~35% of global carbon emissions attributable to buildings by 2030.

Various jurisdictions and nonprofit organizations in North America, Europe, Korea, and elsewhere began to formalize definitions of ZNE in the first half of the 2010s. See National Institute of Building Sciences (NIBS) 2015 for a U.S. example. Although these differ in some of the details, they all follow a similar set of principles. The basic concept is that the building's annual energy consumption is less than or equal to the amount of renewable energy it generates. The definitions have a preference (at least) or a requirement (at most) that the renewable energy be generated on-site. To do otherwise would dilute the concept by allowing a building to call itself zero net without doing anything physically but merely buying renewable energy credits or carbon offsets.

The New Buildings Institute (NBI) has collected a database of over 650 ZNE buildings in North America, spread across most states and provinces and spanning a range of occupancy types and sizes (NBI 2020).

While ZNE can apply at either the design stage or the operational stage, operational ZNE is generally preferred because ZNE status is very dependent on occupant behavior, quality operations and maintenance (O&M), and continuing monitoring of data to assure that the design intent of ZNE is met (and improved upon). Of course, it will be hard to achieve metered ZNE if the modeled performance falls short of this goal.

But the ZNE approach by itself misses an opportunity: once a building achieves ZNE certification, there is no incentive to do better. Net positive energy is a good concept, but it misses the idea of a specific, ambitious, quantitative goal that is the key strength of ZNE.

As more experience has been gained with ZNE buildings, and as the magnitude of the climate crisis has become more apparent (IPCC 2018), building designers have begun to look at and produce buildings that go beyond ZNE to the more ambitious goal of ZNC.[1] See World Green Building Council (WGBC) 2020 for some examples in different countries around the world.

As real, operating buildings began to achieve the original goal of annual energy consumption being lower than on-site renewable generation, and as more and more jurisdictions have adopted Renewable Energy Portfolio Standards that require a fixed percentage of utility energy sales come from designated renewable sources, other changes in the energy system began to be observed: electric grids began to rely much more heavily on renewable energy, primarily solar and wind. The patterns of variability of these resources systemwide resulted in the electric system becoming much lower in carbon intensity at some hours of the day, and some days of the year, than at others. This issue is discussed below (See also Figure 1).

ZNE on an annual basis thus began to diverge from ZNC, because the solar energy produced by the building was produced when everyone else was doing so as well. Solar generation now replaces less carbon-intensive generation than would have been the case if it were produced in the evening. ZNC, it became clear, was a more ambitious goal, and many building designers and energy policy makers jumped to this goal to distinguish their creations from the less societally valuable goal of ZNE.

Several different versions of ZNC have been proposed by conference speakers at international meetings that include zeroing out construction emissions (the emissions of construction equipment and activities plus the emissions to produce the wood, concrete, steel, etc., used in constructing the building). A complete life cycle analysis (LCA) would also include transportation energy to get people (and goods) to and from the building, as well as other energy intensive inputs such as water.

These more advanced goals allow a more structured way of looking for and targeting continual improvement beyond ZNE. SEM provides such a pathway. This paper suggests a taxonomy for doing this below.

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[1] Carbon is used as a synonym for "greenhouse gas emissions" since some 80% of such emissions are in the form of carbon dioxide. But all greenhouse gases are of interest in defining ZNC, noting that the refrigerants used in most air conditioning systems also produce greenhouse gas emissions, as do the blowing agents used in most types of foam insulation. ZNC is defined in this paper to require hourly calculations of the carbon intensity of electricity. To do otherwise would make the concept virtually identical to that of ZNE, as almost all ZNE buildings in the NBI data base are all-electric. Zero electricity multiplied by any carbon emissions factor whatsoever will yield zero carbon.

Strategic Energy Management

SEM is a process that encourages organizational management to set ambitious goals for improving energy performance on an ongoing basis, and develop a policy and plans, ratified at the top level of management, for meeting them. These goals are ongoing and are often expressed in terms of the rate of annual energy performance improvement per year. A key piece of SEM is a plan with quantified targets, and a process for checking whether the organization is on the path to meeting the target and make adjustments or take corrective action if needed.

Top management support is important because the organization will need to allocate resources, both staff time and money, to meet the targets.

SEM is based largely on the International Organization for Standardization's (ISO) 50001 Standard (ISO 2018) and its supporting guidelines. In North America, many organizations have found it difficult to achieve this level of rigor, and so simplified versions of SEM are also prevalent (CEE 2015; DOE 2020).

For all its strengths, SEM has a key weakness when an organization is trying to demonstrate exemplary social responsibility: it does not set quantitative goals. Thus, an organization with a goal of improving energy performance by only 0.5% per year is just as much in compliance with SEM protocols as one that seeks 7% annual improvement.

This presents an opportunity: combine ZNE, which is a hard goal but lacks a process for going beyond it, with SEM, which presents the reverse set of strength and weakness: a great process but no firm guidance on quantitative energy goals.

This opportunity can be framed humorously by asking: "If 'nothing is better than zero' (Higgins 2011), how can you continually improve?" The *simple* answer is that you can become a net positive contribution to clean energy, but this is not as satisfying as a bright-line concept such as ZNE.

A key element of the success of ZNE as a motivating concept is that it sets a quantified goal that one either achieves or doesn't. Lower energy consumption has always been seen as a positive by the efficiency community, and so has greater on-site renewable generation. What has excited interest in ZNE is that it represents a stretch goal of which those who achieve it can be proud. As more and more buildings meet that stretch goal, which after all is the purpose of ZNE policy, what comes next? We propose that SEM can offer answers.

Both SEM and ZNE are usually based on metered results. Thus, as noted above, the goal of zero requires an efficient building, good O&M, and tenant/landlord cooperation on plug loads such as meal service and information technology (IT). This attention to O&M and conservation must be continuing: achieving ZNE in Year N does not assure ZNE in Year N+1 or N+2, much less N+20. In fact, zero energy buildings commonly lose their "zero energy" performance status as building performance slips over time. The monitoring and assessment of the need for corrective action in order to meet a target—a core principle of SEM—is a natural fit for the ZNE concept.

But the goal of merely *maintaining* ZNE does not have the emotional appeal of using this feedback loop of SEM to strive for *new targets beyond simple ZNE*.

This paper suggests an analytically-rigorous method for encouraging even more ambitious ZNE goals. Its value depends in part on the observation that the original ZNE target is already achieving strong success in the marketplace, because it is unrealistic to propose even more ambitious goals if the basic ZNE goal is too far of a stretch. The next section shows that it is not.

ZNE Buildings

Success Worldwide

North America. In North America, the commercial ZNE building market has grown over 800% over the last decade, from a mere 70 projects up to nearly 650 projects. The leading proof-of-concept projects in the 2000-2010 decade paved the way for the exponential growth and market transformation of ZNE buildings. To date, ZNE projects can be found in all climate zones, nearly every state and province, and span a broad range of building types encompassing the vast majority of buildings found in North America. Figure 1 shows the growth trajectory to ZNE buildings in North America, highlighting the inflection point around the year 2009 when the market experienced significant growth, thanks in part to the leading demonstration projects, forward-thinking designers and owners, and local, city, and state governments adopting policies encouraging and/or mandating ZNE goals for new construction.

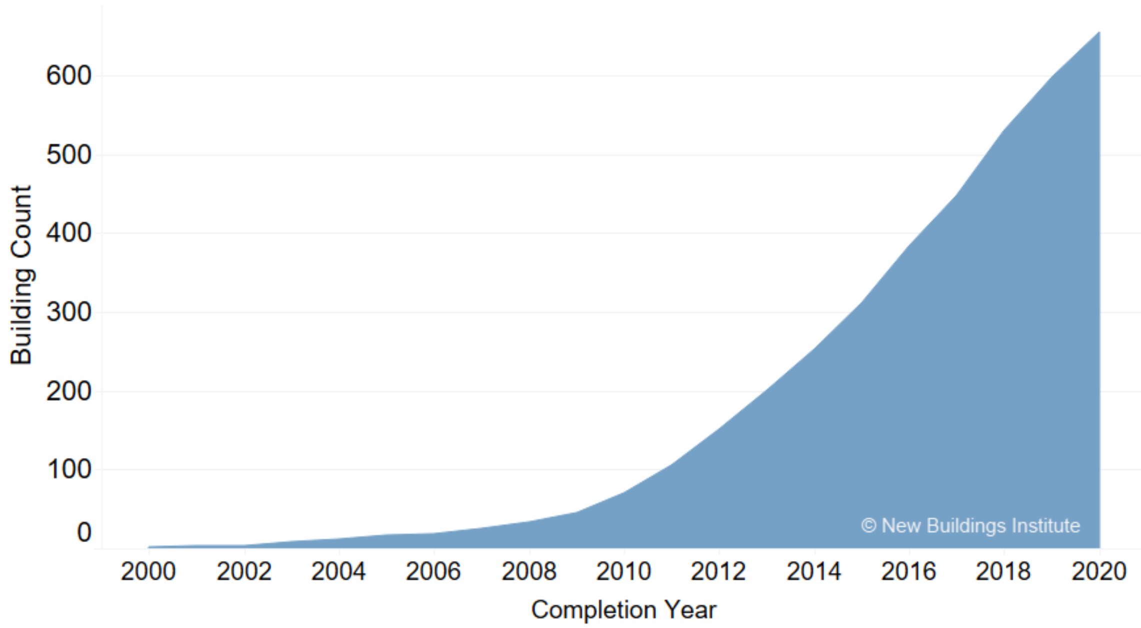

Figure 1: Commercial and Multifamily ZNE Building Market Growth in North America, including projects that have demonstrated ZNE performance and those with publicly stated goals to reach ZNE performance. *Source:* NBI 2020.

Looking forward, the next frontier of building performance is zero carbon emissions, followed by even more aggressive quantified goals, met by sustained performance improvement with tools such as SEM.

Asia. The Republic of Korea has a broad ZNE policy to create new markets in clean energy. The components of this are mandates, certification, alliances to promote ZNE as a concept, and pilot projects.

Mandatory requirements for ZNE are being phased in, with zero energy in new construction starting in 2020 for all public buildings of more than 1,000 square meters (m^2), extending to 500 m^2 in 2025 for public buildings, and for all private buildings of more than 1,000 m^2 in 2025 extending to 500 m^2 in 2030.

Certification is needed to show compliance and will be accomplished through third parties. There are also requirements for how to install meters to promote best practices in O&M.

The certification process developed a new concept of "energy independence rate," defined as:

Energy Independence rate = (energy generation/energy consumption) x 100

This rate is used as a means of encouraging on-site renewables (as opposed, for example, to Renewable Energy Credits) for the calculation of ZNE. Depending on energy independence rate, off-site renewables are counted with a discount factor.

As of January of 2020, 84 Korean buildings were certified. One of the building owners received a ZNE building certification through retrofit. Also included were nine 36-story apartment buildings, which were 155,833 m^2 in total.

To socialize the value of ZNE, Korea launched the ZNE Building Convergence Alliance, comprised of experts from different fields, in 2016. This brought together technical people and decision-makers from government, private enterprise, university, research institutes, etc., to exchange data on experiences with construction technologies, renewable energy, IT, facilities, as tools to achieve ZNE.

Korea also sponsored ZNE Pilot Projects by district, including pilot business districts for new towns and cities, with plans for expansion based on results, and is looking at both public and private apartments and commercial buildings.

The experience outlined above suggests the following broad trends to Korean policy makers:

1. There is a value to raising awareness of ZNE to building owners and managers; and sharing efficient operational management information and best practices.
2. Barriers to implementing ZNE buildings include not only the initial investment cost, but also cost increases from assuring better energy management after installation, due to lack of expertise and field experience.
3. It is urgent to prove the economic savings quantitatively through measuring and sharing data to make the success of ZNE building economics credible.
4. Cooperation in establishing an international roadmap considering technology and economic aspects by country size and building subject can help overcome the barriers.
5. Economical zero-energy buildings can be realized in varied regions and uses based on metered data.

Expert Opinion on Goals and Achievements

As the challenge of stabilizing climate becomes more salient (IPCC 2018), clean energy leaders from the buildings sector are recognizing that:

- Buildings are some ~35% of carbon emissions in most countries, (IEA 2017) so meeting climate goals is dependent on achieving nearly-complete elimination of such emissions by the year ~2030; and
- Buildings are one of the easier efficiency resources to acquire, compared to industry and transportation, in part because efficiency integrates so well with decarbonization of fuels and control of the timing of electricity consumption to match the availability of renewable energy both on-site and on the grid (E3 2018) (discussed next).

These observations are the historical origin of the ZNE concept, but they also direct leaders in the field to say that ZNE is not enough, and that we really need to go to ZNC. This target turns out to be much more challenging to achieve, as will be summarized next.

Some thought leaders are suggesting that even ZNC isn't enough, because it ignores the energy and emissions in the supply chain of the construction of the building—mainly the emissions associated with the steel, aluminum, glass, etc., needed for the components of the building (WBBC 2019). These emissions are large: for China, over 20% of its industrial energy is associated with manufacturing such supplies. Further, reducing them cuts emissions now, during the time when the impacts are largest due to industry's current dependence on fossil fuels and dirtier electricity than will be the case in the future. By contrast, the savings from ZNC buildings accumulate slowly over the years.

A few analysts, including one of the authors, have suggested that an additional important part of the LCA of building operation is the transportation emissions associated with travel to and from the building, and the movement of goods (Goldstein et al. 2010). Water can also involve substantial life cycle carbon emissions.

Climbing the Ladder of Ambition for ZNE

This section discusses and defines four levels of ZNE that can serve as future targets for SEM energy plans. They are, in order of difficulty to achieve:

- ZNE as defined by 2020-vintage national and nonprofit organization standards.
- ZNC, as calculated using the marginal emissions from the electric grid to which the building is connected.
- ZNC including supply chain emissions from constructing the building.
- ZNC including also transportation energy of people (and goods, if relevant) to and from the building. Thus, for a home, it includes the emissions of the cars that are predictably needed for transporting the occupants, which can be predicted statistically.

ZNE

As noted above, the various definitions of ZNE are well-harmonized with each other. They all look at annual energy consumption on the meter and annual renewable energy production on site. Nuances such as how energy is accounted or what is meant by renewables have not made much of a difference in practice, even though they might have in theory. For example, defining what is meant by "renewable energy" is complex when one is referring to utility-scale generation resources, but for buildings the examples in the NBI database almost all use solar photovoltaic (PV) cells exclusively, so there is no confusion. Energy consumption could be defined in terms of primary energy or site energy, but in practice almost all documented ZNE buildings are all-electric, so the difference doesn't matter.

One could also define on-site in a variety of ways, leading to different outcomes, but in practice, ZNE buildings typically generate all their solar energy within the narrowest definition of on-site, and those that don't typically use community solar systems that are off-site but nearby and directly connected by distribution wires to the site.

ZNC

As suggested above, ZNC carbon is a much more difficult goal than ZNE. This can be seen in Figure 2.

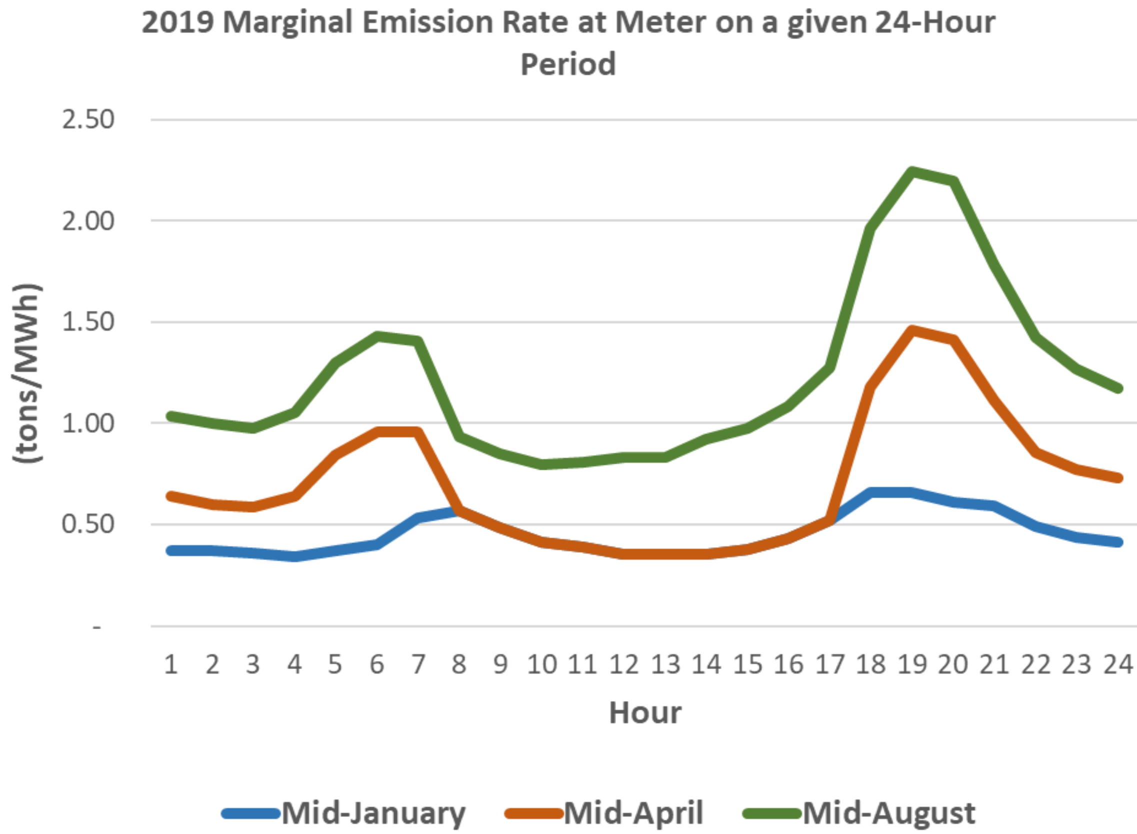

Figure 2: Carbon consequences of energy consumption: three daily patterns by season in 2019. *Source:* California Public Utilities Commission: Avoided Cost Calculator (2019 Avoided Cost Calculator in xlsm format).

This figure shows the carbon intensity of California electricity for typical days in three seasons in 2019.

From this figure we see two issues:

- Since building energy use in summer tends to increase over the course of the day, with substantial energy consumption, particularly for residential buildings, occurring after the solar resource is mostly gone, disproportionately high levels of consumption occur at the time when the marginal impacts of this consumption are the highest. We see a similar problem with building warm-up in early mornings in winter.
- The renewable energy used at the building site to meet the ZNE or ZNC goals follows an approximate sine curve and tends to displace low-impact electricity. This is not an accident: the REASON electricity is so low in impact when the sun shines is that everyone else on the grid, and especially the utility itself, is generating solar electricity. This effect is predicted to intensify over the years as solar generation on both sides of the utility meter grows.

Thus, the carbon emissions attributable to a ZNE or ZNC building will be higher than predicted with an assumption that a kilowatt-hour (kWh) has the same impact regardless of when it is consumed; AND the reduction in emissions from the solar on site is less than would be predicted in this fashion.

This results in ZNC requiring either more renewable energy than would be needed on an equal-impact-of-a-kWh basis OR controlling the energy consumption (and to a lesser extent the solar energy production) to align the time of use to the lowest-impact hours, or the time of production to the highest-impact hours. This could be achieved by charging heat pump water heaters in the early morning and turning the heating system off at about 6pm, or by charging electric cars at low impact hours and avoiding charging—or even discharging—the batteries into the grid at high-impact hours. Buildings may also shift their energy consumption patterns by pre-conditioning the interior space to reduce energy consumption during high-carbon hours on the grid. Energy flexibility in buildings to support grid operations and avoid carbon emissions is an emerging topic in the building industry, with many entities researching the topic and developing metrics to quantify the benefit of energy flexibility.

This requirement for more renewable energy raises the question of the potential use of carbon offsets. This question has been dealt with in existing ZNE definitions by disallowing or discouraging the use of offsite renewables not directly connected to and controlled by the building. A similar set of restrictions of prohibitions on offsets are likely to be needed in rigorous definitions of ZNC so that the same goal—building and operating buildings better—is encouraged, rather than just directing purchasing managers to spend money and pass off to others the moral responsibility for truly reducing emissions (Pope Francis 2015).

ZNC Including the Construction Supply Chain

Construction emissions from the supply chain, as calculated by LCA methods, can be very large for typical construction. In one prototypical analysis, the construction supply chain emissions are about equal to 50 years of annual emissions for a very energy efficient building (Goldstein 2019). Thus, this level of ZNE appears considerably more ambitious than annual ZNE or ZNC. To make the situation even worse, the emissions are incurred before the building is first occupied, so, from this ZNC perspective, all buildings start deeply "in debt" and will take many years of net negative emissions impacts to pay it off.

A schematic calculation of what it would take to meet this level of ZNC suggests that even with continual improvement in energy performance of 5% annually, a typical building that meets the lowest level of ZNE initially would never pay back the construction emissions. It suggests that five or even ten times as much solar would be needed to meet the target in ~25 years.

Note, however, that this calculation was based on typical construction, with no attempt made to choose construction materials and sources that minimize supply chain emissions, due to a lack of information on how to do so at the time.

As the supply chain concept takes hold in the marketplace, we expect to see, first of all, choices by building designers that save supply chain emissions; and second, in response, the introduction of new materials choices (or sometimes just the same materials produced in a less emissions-intensive way) that can allow substantial reductions in supply chain energy/emissions. Just the first factor alone could reduce supply chain emissions by some 30%, based on the goals of major corporations that are doing so for some of their big projects. There is a rapidly growing literature and datasets on reducing construction energy in the supply chain (CLF 2020 and WGBC 2019).

In the longer term, the potential appears dramatically higher. Some construction materials sequester carbon that would otherwise have been emitted, and thus have negative net emissions (Magwood 2019). If building designers can exploit these opportunities, we may find that ZNC, including the supply chain, is easier to accomplish (i.e., requires less solar energy and thus is applicable to more sites) than ZNC for operations only. Moreover, the savings are front-loaded, which helps the planet meet the goals of the Paris Agreement more readily (IPCC 2018).

One could imagine that a building that is designed for state-of-the-art negative supply chain emissions could start out at the level of ZNC for construction and proceed to improve its operational energy consumption over time to achieve ZNE and then ZNC from operations in future years.

ZNC Including Transportation

Zeroing out transportation energy will require about as much additional solar or equivalent improvement in efficiency as the amount needed to zero out the energy on an annual basis, assuming typical location and fuel economy of cars (Goldstein and Bacchus 2012). But the easiest ways of achieving this are to build in a location-efficient neighborhood—one that has lower car ownership and distance driven, and to electrify the remaining cars. It is straightforward to calculate automobile ownership and use for residential buildings. Holtzclaw 2002 describes one methodology for doing so, and its results show that car ownership and usage depend strongly on the compactness of the neighborhood and the level of transit service. Transportation needs can also be computed for commercial buildings (Goldstein and Bacchus 2012).

Building in location-efficient neighborhoods makes it simpler to provide the infrastructure so that the (usually only one) car that is needed is electric and is charged at the best times of day.

This level of ZNC responds to the widely-voiced criticism that even a highly-efficient ZNE home located remotely from any services in a low-density area is not truly green because the impacts of driving are so high. Note that a significant fraction of the impacts of driving cars still occurs even when the propulsion fuel is emissions-free, because of the supply chain energy/emissions of the system of roads, fuel supply, auto manufacture and repair, and parking spaces.

With this taxonomy of ZNE and ZNC claims, we see that the electricity used to charge an electric car is not counted for ZNE purposes until we look at this highest level of ZNC including transportation. This makes sense because it is arbitrary to count electricity used for cars while ignoring gasoline (and other fuels). We could, however, for ZNC in operations, count the savings in emissions from charging a car at advantageous hours and discharging its batteries when the grid is dirtiest.

Conclusions: A Planned Advance to Higher Levels of ZNE

This paper has suggested four levels of ZNE, functioning like rungs on a ladder. These levels are not original to the paper, but reflect a consistency of concepts that are discussed at ZNE and energy efficiency meetings and conferences worldwide. While they are not often compared to each other, there appears to be little or no controversy about what each level means, or how it should be calculated, at least at the higher levels of generality addressed here.

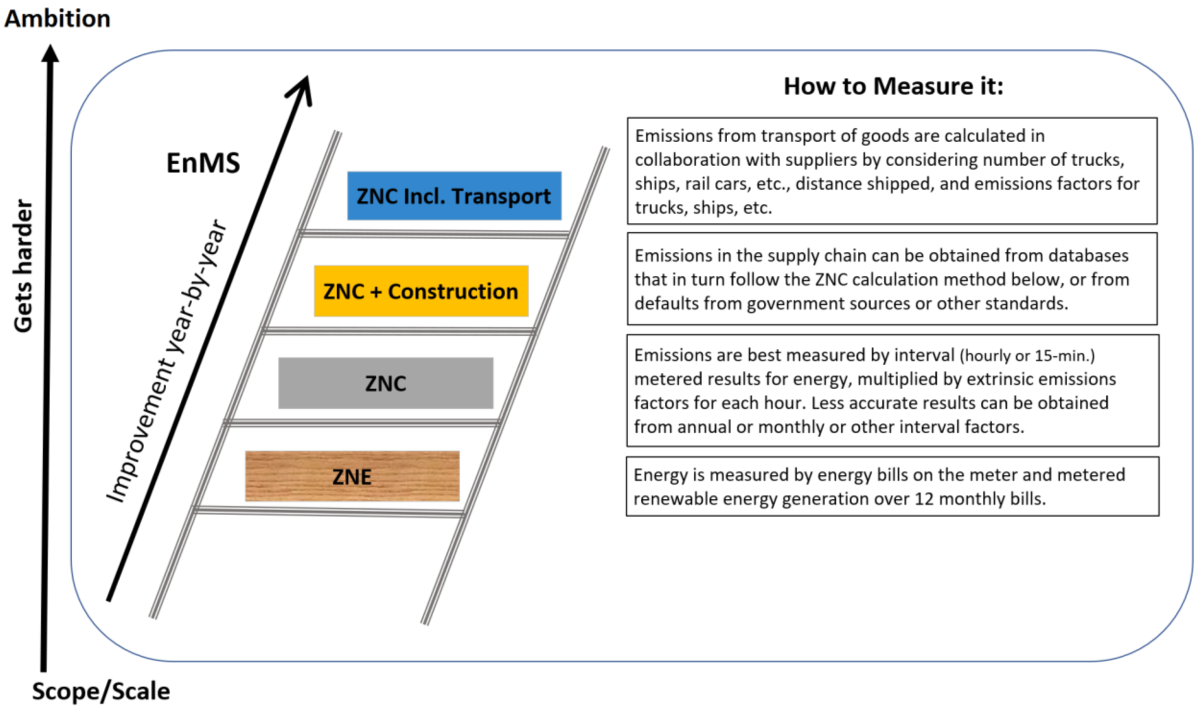

Figure 3. The ladder of ZNE accomplishment: schematic illustration

This paper instead suggests that the four can be connected by the SEM principle of continual improvement, analogous to the verticals on a ladder (see Figure 3). A building could be designed to achieve ZNE during its first or second year of operation, and to progress to ZNC and the higher levels at future years that are part of the SEM energy planning process. The SEM requirement to track results and take corrective action, if needed, can then assure that future targets will be met.

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