Zero Energy Homes – Built Projects & Programs Chart the Road to Adoption

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ABSTRACT

Thousands of zero energy homes have been built across North America and beyond, but the US homebuilding industry as a whole is ill-prepared to meet established and impending zero-energy policy goals that are targeted at reducing the building sector's impacts on climate change. Achieving those goals will require broadly-based efforts to educate and ignite enthusiasm among building professionals. Completed, successful projects provide the foundation for those efforts.

This paper presents evidence of these successes by documenting the state-of-the-art in residential zero net energy (ZNE) and lessons learned from completed projects. Further, and perhaps more significantly, it illuminates institutional forces driving zero energy design. Two key findings relate to differences between stakeholder programs: the use of energy modeling versus measured performance data; and whether or not offsite renewable energy is allowed. Do these differences foster or inhibit the further development of ZE residential construction? Strong rationales exist for both the use of energy modeling and the use of measured data. Similarly, there are good reasons on both sides of the onsite-offsite debate; however, the reasons not to allow offsite renewables revolve around concerns regarding true additionality of those renewables. This suggests it would behoove the stakeholders to unify around development of a common, rigorous standard for accounting of offsite renewable energy sources.

Introduction

Not long ago, a zero energy home, by any definition, sounded like a pipe dream, or something attainable only by a privileged few. And then California's "big, bold goal" that all new homes will be ZNE by 2020 was announced; since then, governments, utilities, NGOs, architects, and builders all over the state have mobilized and there are now scores of completed homes in California (TRC 2015), and thousands more across North America, that are near, achieving, or exceeding zero net energy (NZEC 2015). All of these are collectively referred to herein as "zero-energy-type" or "ZE" homes, as distinct from the more specific "ZNE" homes.

Advocates and practitioners know that ZE homes are attainable today, but many within the homebuilding industry remain skeptical and ill-prepared to meet mandates established by California, Massachusetts, and numerous municipalities. Successfully meeting those mandates will require well-orchestrated, multi-stakeholder efforts to educate and inspire builders, architects, and engineers. The foundation for that education (and enthusiasm) must be documented, on-the-ground, successes. The first intent of this paper is to present evidence of these successes, and lessons learned, drawing upon the following resources:

- Net Zero Energy Coalition (NZEC) inventory of ZE homes in the US and Canada (NZEC 2015)
- Northeast Sustainable Energy Association and NZEC ZE case study database (NESEA 2016)

- US Department of Energy Tour of Zero (DOE 2016a)
- US Department of Energy Housing Innovation Awards (DOE 2016b)
- New Buildings Institute Getting to Zero Database (NBI 2016)

These repositories represent projects developed by builders large and small, market-rate and affordable, where ZE is being achieved, affordably, well ahead of the 2020 deadline, across the continent. Case studies provided by these early adopters illuminate aspects of design, construction, and innovation that are keys to achieving ZE successfully, including the few, but critical, technology and construction challenges and how they are being addressed by ZE project teams.

The second intent of the paper is to illuminate some of the institutional forces influencing the evolution of residential ZE design – specifically, the stakeholder organizations operating ZE programs – including where they align and where they diverge. Shining a light on these commonalities and divergences has the potential to catalyze further dialogue among these institutions, and perhaps encourage further alignment, in the interest of accelerating the transition to a low-carbon building sector and a bright energy future.

The Numbers

The Net Zero Energy Coalition's inventory of ZE homes in the US and Canada, conducted in the summer and fall of 2015, yielded the following high-level findings:

- 6,177 residential units – completed, under construction, and in design (5,806 in the US and 371 in Canada);
- Out of these totals, roughly half are single-family and the other half are multifamily;
- Approximately 3,000 additional units were in the planning stages;
- The homes are being built in a diversity of North American climates.

Excluding Canadian projects and the projects in design, and instead examining only those units that were either completed or under construction in the US at the time of the inventory, the geographic and climate distribution is shown below in Table 1. This total, 4,024 units, does not include 400 US units reported by RESNET that were undesignated as to location.

Table 1. Distribution of US ZE Units by Region and Climate

Region	States	Units	Dominant Climate Types	Climate Zones
AK	AK	2	very cold, sub-arctic	7, 8
Pacific	CA, OR, WA	2755	dry/marine: warm, mixed, cool	3B-C, 4B-C, 5B
Rocky Mts	CO, MT, UT	88	dry: cool, cold, very cold	5B, 6B, 7B
Southwest	AZ, NM, TX	306	dry: hot, warm, mixed	2B, 3B, 4B
Midwest	IA, MI, MN, MO, OH, WI	45	humid: mixed, cool, cold & very cold	4A, 5A, 6A, 7A
Northeast	CT, MA, ME, NH, NY, PA, RI, VT	806	humid: cool & cold	5A, 6A
Southeast	FL, GA, MD, NC, SC, VA	22	humid: hot, warm, mixed	1A, 2A, 3A, 4A

These represent units completed or under construction in the US only (not Canada), and exclude 400 units reported by RESNET, which did not include a location breakdown. *Source:* NZEC 2015.

Lessons Learned

Despite the thousands of ZE units inventoried, the number of fully-documented case studies in common format is still relatively small. There are 41 residential case studies in the NESEA-NZEC database, 77 in the DOE's Tour of Zero (including Housing Innovation Award winners), and 9 in the NBI database, with some overlaps. It is also important to note that the NZEC inventory was compiled via surveys completed by builders, owners, architects, and others involved in creating ZE projects; the actual performance of the inventoried projects has not been verified. In addition to those resources, this paper draws on personal communications with a number of ZE builders and design practitioners who have multiple ZE projects to their credit. The experience of these pioneers is of particular value in advancing the state of understanding about ZE design and construction.

Common Elements

The body of work in residential ZE design, as represented by documented case studies (DOE 2016a, DOE 2016b, NESEA 2016) and direct observation of built examples, reveals strong commonality among projects, independent of location or climate. These are listed below.

1. **Optimized building geometry.** Factors include simple forms, a longer east-west axis, overhangs, and other orientation-specific shading strategies. A simple roof design is of particular importance because it reduces cost, facilitates effective air-sealing and insulation at the upper boundary of the enclosure, and maximizes space for photovoltaics.
2. **High performance enclosures.** Factors include high levels of insulation, careful attention to building science principles, high-performance windows (often triple-glazed), low thermal bridging, and very low infiltration rates. The Passive House approach is frequently cited as the basis for the enclosure design.
3. **Focus on embedded systems.** Projects often feature greater-than-normal attention to framing, plumbing, and electrical systems.
4. **High performance mechanical systems.** Factors include efficient, low-capacity heating and cooling systems, located in conditioned space, along with fresh-air ventilation delivery systems (heat recovery ventilators and energy recovery ventilators).
5. **Efficient water heating**. High-efficiency water heaters – heat pump water heaters in particular – are frequently mentioned, as are efficient hot water distribution strategies.
6. **Best-in-class appliances and lighting.** The most commonly identified electric load factors are highly efficient appliances and high-efficacy lighting, often all-LED.
7. **Performance dashboard.** Many, though not all, projects incorporate some type of visual monitoring system to heighten occupants' awareness of energy consumption and foster conservation behaviors.
8. **Renewable energy.** While an obvious common element for ZE projects, many in the databases that are categorized as ZE-ready do not include onsite renewable energy systems, and some ZE or Net Producer projects – depending on the program or certification program (see Table 3) – may qualify using offsite renewable energy sources or renewable energy credits (RECs).

Critical Design Considerations

Designers and builders, in documenting aspects of design that require careful attention to succeed with ZE projects, often echo common themes. Among the most often-cited[1] are:

- **Mechanical product selection.** Selecting products that fulfill the specific needs of ZE projects is frequently cited as a critical issue, with appropriate capacity as a notable subset of those concerns. This quote is representative of myriad others: "Whole home ventilation systems for high performance homes are inadequate, and HVAC systems are way too large" (A. Aebi, Greenhill Construction, pers. comm.., March 9, 2016). Karla Butterfield notes more specifically, "Running continuously, we often look for an ERV to do as little as 30 cfm, but it needs to boost up to 100 cfm for the kitchen and a minimum 50 cfm for each bath, to efficiently get rid of contaminants and odors. There are not many ERVs on the market that can do this and we haven't yet found an ERV that can be switched to exhaust-only for the kitchen while keeping baths at continuous" (K. Butterfield, Steven Winter Associates, pers. comm., March 9, 2016).
- **Water heating strategy.** Many ZE projects gravitate to 100% electric power, but are challenged by finding economical and space-efficient electric water heating solutions. This is exacerbated where utility rate structures favor natural gas over electricity.
- **Enclosure approach.** ZE designers are highly attentive to the specifics of enclosure design, and very analytical in identifying ways to improve enclosure performance. Ted Clifton advises, "Include R5 windows – [they are] more effective than more insulation in the roof/walls; get windows as close to enclosure [insulation levels] as possible" (T. Clifton, Zero Energy Plans, pers. comm., March 11, 2016).
- **Aesthetics.** Notwithstanding the importance of a simple form, aesthetics are also important to buyer acceptance. Architect Steve Baczek's top priority is, "…the right look, with the house design as a cohesive picture" (S. Baczek, pers. comm., March 12, 2016). Similarly, builder R. Carter Scott identifies, "attractive design with the local architectural vernacular" as a key success factor (R.C. Scott, pers. comm., March 10, 2016).

Construction Focus Areas

Similarly, two very strong – and very closely related – common themes emerge under the umbrella of construction and implementation:

- **Trades execution.** In this category, there are both positive and negative comments. On the positive side, having a great team is cited as critically important. On the negative side, lack of motivation by contractors is a recurring complaint, as is reluctance to deviate from standard practice. The necessity of good coordination among trades (framing, siding, insulation, HVAC, plumbing, etc.) is also often mentioned.

[1] I conducted a targeted follow-up survey of practitioners who have multi-unit ZE design and/or construction experience in order to gain additional insight into these issues.

- **Quality management.** Not surprisingly given the issues noted immediately above, quality management emerges as a dominant concern, frequently addressed through onsite verification (HERS, etc.).

Innovation

Producing ZE projects isn't business-as-usual, so innovation comes with the territory. There are a number of specific types of innovation that recur among the case studies and personal communications. These are noteworthy as hallmarks of the successful ZE practitioners.

- **Experimentation.** Although the basic toolkit of ZE designers and builders isn't terribly exotic (see "Common Elements"), these pioneers report a fair amount of 'tinkering' to identify and fine-tune the solutions that work the best. This is especially notable in an industry otherwise known for being risk-averse.
- **Collaboration.** There are a number of dimensions to the collaboration that takes place to make ZE projects successful. As mentioned above, coordination among the installation trades is important, as is securing their individual cooperation. Coordination during design is also often cited as important. Less obvious, but also often mentioned, is working closely with suppliers and manufacturers. Energy consultant Sean Armstrong of Redwood Energy also stressed the importance of working for public sector approvals for new technologies (in California).
- **Training.** ZE practitioners are often leaders in their field and become involved in training, whether informal (on-the-job) or formal (workshops and classes), with the aim of improving their project outcomes and mentoring others in pursuing ZE goals.

Institutional Forces

A number of the stakeholder organizations both assisted NZEC with inventory outreach and were key partners in developing the ZE types used to categorize projects in the inventory and in the NESEA-NZEC database. These organizations were recruited to collaborate in the development of these categories in order to ensure that the inventory and database would have the highest possible utility to the largest number of stakeholders, because these organizations all have ZE ratings, programs, labels, or certifications (collectively referred to as "programs"):

- US DOE – Zero Energy Ready Homes (ZERH) (DOE 2016c)
- International Living Future Institute (ILFI) – Net Zero Energy Building Certification (ILFI 2015)
- Earth Advantage Institute – Zero Energy & Zero Energy Ready (EAI 2016)
- North American Passive House Network, as a proxy for Passive House International (PHI) and its programs – PHI 'Classic', 'Plus' & 'Premium' (NAPHN 2016)
- Passive House Institute US (PHIUS) – PHIUS+ (PHIUS 2016)
- Thousand Home Challenge (THC 2014)

Distinctions among the programs are important inasmuch as they influence the direction of further development of ZE residential design and construction, and thus are discussed below.

NZEC's dialogue with these organizations yielded the project categories shown below in Table 2 (determined irrespective of individual program claims, which are described below and listed in Table 3 as "level of achievement"). The ZE-ready category deserves a bit more explanation, as it is something of a catch-all for projects variously described as near-zero, zero-energy capable, and other similar labels. In fact, several programs identified by their respective organizations as representing net zero energy or net positive energy are categorized by NZEC for purposes of its inventory and in the NESEA-NZEC database as "ZE-ready" simply because the basis of the ZE claim is energy modeling rather than measured performance data. Also noteworthy is that NZEC's categories are blind to specific definition of zero net energy (site, source, etc.).

Table 2. Project Performance Categories for NZEC Inventory

Category:	Description:	Qualifying Programs: [i]
Zero energy	Renewable energy system supplies 100% or more of the annual energy demand	• ILFI Net Zero Energy Building Certification • Thousand Home Challenge ZNE
Net producer	Renewable energy system supplies 110% or more of the annual energy demand	N/A
ZE-ready	Renewable energy system can supply 90% or more of the annual energy demand (or could, if/when RE is added or system capacity is increased); AND/OR energy use data are not available [ii]	• DOE ZERH • Earth Advantage Zero Energy & Zero Energy Ready • PHI 'Classic', 'Plus' & 'Premium' • PHIUS+
Thousand Home Challenge	Occupants have earned THC standing for deep energy reductions in existing homes, whether or not they include renewable energy	• Thousand Home Challenge

[i] Projects that have been labeled, certified, or rated under these programs qualify automatically for inclusion in the database, so long as required supporting documentation is provided. Otherwise, projects are categorized based on their supporting documentation.

[ii] California projects modeled based on time-dependent valuation (TDV) fall into this category.

Source: NZEC 2015, 7

These programs, although they all nominally accomplish the same thing – formally conferring ZE stature on a project – differ in some significant respects. First, they recognize different levels of achievement with respect to ZNE: in simplest terms, approaching, at, or above ZNE (the latter are net energy producers on an annual basis). Second, the programs differ as to the basis of validating the claim to achieving ZE (at whichever level) – either energy modeling or a year or more of measured performance data. Third, the programs differ as to which types of renewable energy sources may be counted in meeting their ZE claims. These key program differences are identified in Table 3. The second and third distinctions are discussed below.

Table 3. Zero Energy Program Distinctions

Program	Level of ZNE Achievement	Basis of ZE Claim	Allowable Renewable Energy Sources
DOE ZERH	Approaching	Modeling	Onsite, community, or offsite
ILFI Net Zero Energy Building Certification	At	Measured performance	Offsite only per “scale jumping” criteria – generally nearby; no RECs
Earth Advantage Zero Energy	At	Modeling	Onsite; neighborhood/ community under consideration
Earth Advantage Zero Energy Ready	Approaching	Modeling	Onsite; neighborhood/ community under consideration
PHI ‘Classic’	Approaching	Modeling	Onsite or offsite
PHI ‘Plus’	At	Modeling	Onsite or offsite
PHI ‘Premium’	Above	Modeling	Onsite or offsite
PHIUS+	Approaching	Modeling	Onsite or neighborhood/ community
Thousand Home Challenge (THC)	Approaching	Measured performance	Onsite, or offsite but only if the owner/occupant owns a share of the renewable system and has actual production from the facility
THC Zero Energy	At	Measured performance	Onsite, or offsite but only if the owner/occupant owns a share of the renewable system and has actual production from the facility

One year or more of utility data is required for all programs that require measured performance data.

Distinction: Basis of Claim

One of the more interesting findings from the NZEC inventory project was not the fact that some programs prefer modeling and others prefer measured performance data, but rather the underlying rationales. A common orthodoxy in the energy efficiency community is that examining measured performance data is the only “real” means of determining whether ZNE performance has successfully been achieved. The logic for this is strong: how do you know if a project is truly capable of achieving zero net energy unless that goal is, in fact, achieved and documented (typically, via utility bills)?

The counterargument, however, also holds some water: namely, that measured performance data reflect the occupants’ behaviors as much as – or more than – reflecting the ability of the home to perform at zero net energy. Modeling, in contrast, holds behavioral factors fixed and thus allows a more objective assessment of the ZE capability of a given design.

Fans of measured data point to the notorious fallibility of models in predicting actual energy use, a point that is difficult to dispute (unless you are a Passive House Planning Package aficionado). Nevertheless, the ‘even playing field’ premise of using modeling rather than measured performance data is legitimate.

Ultimately, which basis is more appropriate may depend on the aim(s) of the specific program or its organizational sponsor. For a public jurisdiction attempting to quantify its progress towards carbon reduction goals, measured performance data are unquestionably of paramount importance. For a non-profit organization whose mission is raising the bar for performance by inspiring and educating building professionals, or a builder whose homes' future occupants are unknown, modeling is entirely appropriate … which isn't to say that every effort should not be made to have the modeling be as accurate as possible. How that might be accomplished and using what modeling approaches, however, is beyond the scope of this paper.

Distinction: Allowable Renewable Energy Sources

The second major point of distinction among the various ZE programs is what type(s) of renewable energy sources may be used in the determination of the project's ZE status. There are three main renewable energy source types, with a few variations (as shown in Table 3):

- Onsite systems (whether on-building or freestanding)
- Offsite, community- or neighborhood-based systems
- Offsite systems, generally utility-scale and typically utilized via RECs

Once again, one of the more interesting aspects of the distinctions among programs is the underlying reasoning. In general, although unstated, the reason for favoring onsite renewable energy is that it is easily verified, and many view accounting at the site boundary to be the purest approach to calculating zero net energy. It is certainly the most straightforward.

However, according to US DOE ZERH Chief Architect Sam Rashkin, "Research suggests utility-scale power plants can be constructed at 50% lower cost per watt, generate up to 50% more power per watt, and are much more likely to be maintained professionally with longer lifetimes. Thus, any public investment in renewables yields substantially more renewable energy with utility-scale projects." He continues, "Renewable energy rebates and tax credits … go primarily to relatively wealthy people … In contrast, incentives for utility-scale renewables yield benefits that go to all rate-payers. Reliable carbon credit programs, utility renewable power purchase programs, and neighborhood distributed generation systems are all great options that we want to encourage" (S. Rashkin, pers. comm., January 7, 2016). These are persuasive points in favor of allowing offsite renewable sources to be counted towards ZE achievement.

Are These Projects Representative?

The sources for NZEC's inventory – primarily its allies, and prominent among them the collaborating stakeholder organizations – carry with them the strong suggestion that the inventoried projects reflect the influences of the respective 'parent' organizations and their ZE programs. While the 408 projects that comprise the 6,177 units cited in the introduction certainly do not represent 100% of the ZE residential units in the US and Canada, they probably do represent a significant majority. The fact that 2,598 (42%) of the 6,177 units are in projects of 10 or more units reinforces this assumption – larger projects are more likely to receive publicity and otherwise become known by the ZE community (NZEC 2015).

Brand Competition: Good or Bad?

Given all of the above, the inevitable result is a mix of 'competing brands' or flavors of ZE in the marketplace. With considerable effort being exercised by the stakeholder organizations to advance the cause of ZE residential development, this diversity of approach will continue to be a major force in shaping ZE projects in the coming years. So while diversity is generally viewed as desirable and US culture looks favorably on brand competition as a cornerstone of capitalism, it's worth considering whether the major points of divergence among the various ZE programs promote desirable outcomes in the built environment.

Modeled Versus Measured

The principal arguments for the use of modeling and the use of measured energy performance were set forth earlier in this paper. One further point is noteworthy: in addition to the level-playing-field argument in favor of modeling, there is a practical reality underlying most programs' choice of modeling as their basis for evaluating energy performance. For the most part, these are market transformation programs – that is, they aim to influence building performance by offering the lure of favorable market position through product differentiation, legitimized by the program's third-party imprimatur. This is a critical point; a rating or certification conferred a year or more after the building is occupied will not directly assist a for-profit developer with sales or leasing. So for these programs, modeling is a purely pragmatic decision, made with the goal of influencing market actors.

Does this mean the two programs that instead rely on measured performance data should change? Each of these programs fulfills a unique function in the ZE and efficiency ecosystem.

ILFI's Net Zero Energy Building Certification is part of its Living Building Challenge (LBC) suite of programs, and LBC stands as the clear aspirational standard-bearer in the panoply of green building programs in the US; its unique function is to set (and hold) the 'high bar' for performance. In its case, then, the central question is whether measured energy performance does in fact represent the high bar? While this is somewhat debatable (see discussion above under "Notable Distinction #1: Basis of Claim"), the use of measured data is defensible inasmuch as we need built, demonstrated zero-energy-performing buildings. The proof is in the pudding.

The Thousand Home Challenge is also unique in providing a framework for homeowners to dramatically reduce energy consumption. From the THC website, "The goal of the Thousand Home Challenge is to demonstrate the potential to reduce total annual site energy consumption of existing North American homes by 70% or more" (THC 2014). Energy reductions achieved in the program may be due either to modifications to the home itself or to operational/behavior changes, or a combination of both approaches. As occupied, operating buildings, measured data are clearly the only appropriate or practical means of determining success.

Thus both ILFI's Net Zero Energy Building Certification and THC have solid rationales for using measured data as the basis for their respective ZE claims. We need to know that buildings can operate at zero net energy in real life, not just on paper. In this instance, diversity is indeed healthy and appropriate, and there is no compelling reason for uniformity of approach to energy evaluation among all the ZE programs.

Offsite versus Onsite

In this debate, the reasons underlying many of the programs' respective positions must be inferred, because little has been published on this subject. The first and obvious reason for programs that credit only onsite renewable energy systems is a practical one of accounting – recording energy use and production at the project site is certainly the most straightforward means of performance validation; onsite systems are also required by the DOE 'common definition for ZEBs' (DOE 2015). However, many personal communications with colleagues in this arena indicate that accountability is perhaps the overriding concern – is it possible to legitimately associate a portion of the capacity of an offsite renewable energy source to a particular ZE project? This concern is implicit in the source restrictions cited by ILFI (offsite only per "scale jumping" criteria – generally nearby; no RECs), PHIUS (onsite or neighborhood/ community), and THC (offsite but only if the owner/occupant owns a share of the renewable system and has actual production from the facility).

Many energy professionals express skepticism that use of RECs, in particular, will yield true additionality – that is, that purchasing RECs will result in the creation of new renewable energy resources. Even in his pitch for agnosticism as to the source of renewable energy for ZE projects cited above, Sam Rashkin qualified his endorsement by referring to "reliable" carbon credit programs.

It is worth noting that for organizations and programs, such as DOE, that focus on zero-energy ready homes – i.e., homes that theoretically could achieve zero net energy with the addition of renewable energy capacity but do not yet have that capacity in place – it is easier to be agnostic about the energy sources, since they are only future potentials.

At present, according to the US EPA, "There are two approaches to verifying REC ownership and the right to make environmental claims: REC contracts and an audit of the chain of custody [and] REC tracking systems. Both of these approaches help buyers avoid double counting and double claims and ensure against fraud. Of the two, REC tracking systems provide greater transparency when tracking RECs from their point of creation to their point of final use [but] tracking systems only monitor wholesale transactions — individual retail green power customers do not generally hold accounts in tracking systems unless they make very large purchases" (EPA 2016).

Unlike the modeled/measured debate, this discussion highlights a distinct opportunity for a unified front in the ZE community. Clearly, there are shared concerns surrounding the legitimacy of accounting and accountability for offsite renewable energy sources, and there are numerous scenarios where onsite or local/community-based renewable energy options will not be viable, whether for technical or economic reasons. Thus it may behoove the ZE stakeholder organizations to pursue development of a common, rigorous standard for the use of RECs. Furthermore, the combined political weight of the stakeholder organizations is substantial and could be leveraged to good effect, influencing the creation of a robust mechanism to support all the affected programs.

There is also a potential for a number of municipalities to add their might to such a campaign. In March 2016, 15 cities gathered in New York under the aegis of the Urban Sustainability Directors' Network and the Climate-Neutral Cities Alliance, along with Architecture 2030 and NZEC, to discuss their carbon reduction goals and strategies and explore potential collaborative efforts.[2] Here also concerns were expressed about the additionality of RECs and the importance of ensuring legitimate accounting for them in pursuit of public carbon reduction goals. These cities represent major population centers; should they join with the ZE stakeholder organizations in establishing a policy or standard governing the use of RECs, the collective impact would be substantial.

A possible partner in the development of a ZE project/program REC usage standard may be the Environmental Tracking Network of North America (ETNNA), which, according to its website, "is designed to bring together tracking system representatives with governmental, community and voluntary market participants to engage in dialogue to increase compatibility between systems and better support both compliance and voluntary markets" (ETNNA 2015).

Conclusions

The first goal of this paper was to identify common lessons learned – building elements, design considerations, construction focus areas, and aspects of innovation – by the designers and builders of completed ZE homes, in service of more rapid dissemination of those lessons and faster adoption of ZE design and construction. Those lessons are summarized below, in Table 4.

Table 4. Lessons Learned from Zero Energy Homes

<table>
<tr><td rowspan="3">Common elements included in ZE projects:
1. Optimized building geometry
2. High performance enclosures
3. Focus on embedded systems
4. High performance HVAC
5. Efficient DHW
6. Best-in-class plug loads
7. Performance dashboard
8. Renewable energy</td><td>Critical design considerations:
• Mechanical product selection
• Water heating strategy
• Enclosure approach
• Look</td></tr>
<tr><td>Construction focus areas:
• Trades execution
• Quality management</td></tr>
<tr><td>Innovation:
• Experimentation
• Collaboration
• Training</td></tr>
</table>

The second goal of the paper was to highlight some of the institutional forces at work in the ZE arena – specifically, the stakeholder organizations operating ZE programs – and identify opportunities for greater consensus among them. The clearest target for collaboration herein identified is a robust standard for the accounting of offsite renewable energy resources claimed in zero-energy projects, for adoption by both ZE programs and municipalities.

Transforming the residential construction market to zero energy is doable, but it is going to take *visible* examples to accelerate that transformation in a meaningful time frame to combat climate change. We now know that many built examples exist, with more underway. Bringing greater visibility to the successful built examples will confer greater confidence to new

[2] I participated in this meeting, hence these comments are drawn from direct experience.

developers and builders contemplating the leap to zero energy. Offering greater clarity to key aspects of ZE design and construction can also facilitate this transition. And a consensus standard for offsite renewable energy accounting could pave the way towards more economical and equitable access to renewable energy for ZE projects.

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