Net Zero + Low Income + Innovative Thinking = Residential Energy Efficiency of the Future

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ABSTRACT

Zero-energy homes are becoming a hot commodity in the energy efficiency community, yet most stakeholders aren't thinking about them as a practical solution for affordable housing. But this alignment is precisely the focus of a non-profit organization and a statewide energy efficiency utility that it operates. Together, they are moving the affordable residential building market into new territory.

The utility, Efficiency Vermont, designed a high-performance home (HPH) pilot program in 2012 as a prescriptive, cost-optimized, climate-appropriate pathway to net zero energy use in residential new construction. Concurrently, it designed a low-income HPH program in collaboration with the Vermont Housing & Conservation Board to offer Zero Energy Modular™ (ZEM™) homes to low- and moderate-income buyers and affordable housing providers.

ZEM homes fill a gap in the small-home market and address the drawbacks of manufactured housing—often the only feasible option for low-income homebuyers. Manufactured-home buyers typically face depreciation, high energy costs, inferior indoor air quality, questionable durability and resiliency, and exclusion from qualifying for traditional mortgage products. ZEM homes offer outstanding energy performance, rooftop solar PV, ventilation that provides superior air quality, exceptional durability, and finishes that minimize off-gassing. One 14-ZEM home community even added battery storage to each home for back-up power; the homeowners benefit from energy resiliency while the local electric utility benefits from the development's load management capability. The solar + storage modular housing combination could also benefit communities after disruptive, natural disasters.

This paper offers an overview of program design, technical specifications, case studies, and analysis of these homes. It looks at their energy use, thermal comfort, and indoor air quality. The authors illustrate the practicality and scalability of ZEM homes, and describe unique ZEM financing models and a new entity, ZEM Enterprise. They also introduce the "pop-up" ZEM factory concept.

Introduction

Background

In 2012, a statewide energy efficiency utility, Efficiency Vermont - operated by VEIC, launched the Modular Housing Innovation Project with the nonprofit Vermont Housing & Conservation Board. The project was a response to the devastation from Tropical Storm Irene in 2011, in which more than 100 sections of highway and dozens of bridges had been destroyed, statewide. Irene fueled ongoing concerns about Vermont's manufactured housing stock.[1] Major problems to be addressed with these types of homes were high energy costs, poor indoor air

[1]Irene damaged or destroyed an estimated 550 manufactured or mobile homes—15 percent of the 3,500 affected dwellings statewide (National Weather Service n.d.; Luciano, Baker, and Hamshaw 2013).

quality, low levels of durability, depreciation of homes, and vulnerability to severe weather events. This project brought together stakeholders from affordable housing, energy, and weatherization sectors; and from academia, philanthropy, and State government. Together, they evaluated approaches to better serve Vermont's low- and moderate-income (LMI) homeowners and tenants. The effort resulted in the creation of a pilot program to deliver 10 of VEIC's Zero Energy Modular™ (ZEM™) homes to low-income homebuyers in mobile home parks, statewide.

Concurrently with the modular home effort, Efficiency Vermont developed its *Efficiency Vermont Certified: High Performance Homes* (HPH) program for the residential new construction market. The HPH program specified insulation and air tightness levels, and guides appliance, lighting, ventilation, and heating and cooling system choices. Together, these factors can make a significant difference in a new home's long-term durability, healthfulness, comfort, indoor air quality, energy use, and resale value. The overall aim was to provide a prescriptive path for partners to bring the following benefits to their customers:

- Zero-energy ready
- All-electric operations, including heating
- Option to use point-source heating and cooling
- High levels of indoor comfort
- Optimal indoor air quality through balanced ventilation
- High levels of building durability and resilience

ZEM homes were designed to meet the new HPH standard. This approach aligned with the State's legislated housing and energy goals by:

- Demonstrating that the goals laid out in Vermont's *Comprehensive Energy Plan* (30 percent of new construction is zero energy by 2020; 100 percent by 2030 [State of Vermont 2016]) are achievable, even in the lowest income sector
- Providing LMI buyers with an opportunity to build equity in a way that is not possible with manufactured and other low-quality housing
- Supporting affordable housing partners in developing healthful, affordable rental housing
- Providing a sustainable, long-term solution for non-profit and co-op mobile home parks to fill vacant lots, improving the overall quality of housing stock, and ensuring that parks remain viable and affordable
- Creating "green" jobs, strengthening regional supply chains, and offering the economic development impact associated with a new business

Specifications and Services

Table 1 shows current HPH prescriptive requirements that resulted from a process that included numerous stakeholders and has included several subsequent revisions based on ongoing feedback and evaluation. All ZEM homes meet these requirements.

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Table 1. Key prescriptive requirements

Feature	Requirement
Max. window U-factor	U-0.21
Max. door U-factor	U-0.25
Min. ceiling R-value	R-60
Min. above grade and joist R-value	R-40
Min. below-grade / frost line / crawlspace R-value	R-30
Min. exposed floor R-value	R-40
Air leakage	≤ 1.0 ACH50
Ventilation	Balanced system, flow rate meets ASHRAE 62.2, sensible recovery efficiency (SRE) ≥ 75%
Water heating	ENERGY STAR®
Heating and cooling	ENERGY STAR
Lighting	95% ENERGY STAR
Appliances (all)	ENERGY STAR
HERS Index	No requirement

To encourage high compliance, enrollees in the programs that require these specifications receive a high level of service, including extensive guidance and technical support from a dedicated energy consultant, and cash-back incentives upon successful completion. Early projects also received assistance in designing and installing a comprehensive monitoring system to assess and verify temperature and indoor air quality data, and energy use data.

The ZEM Home

Design Challenges

ZEM homes had additional, unique design challenges that required special attention above and beyond those of many homes aspiring to attain the HPH specification. See Table 2.

Table 2. ZEM challenges and strategies

Challenge	Strategy
Existing mobile home footprints are often long and narrow (for example, 14’x70’), yielding poor surface-area-to-floor-area ratios	Minimize heating / cooling loads via higher levels of insulation, reduced thermal bridges, increased air tightness, triple-glazed windows
Lot orientation frequently means that a long axis is not east-west, thus reducing the potential for passive solar design	Optimize glazing area, U-factor, and solar heat gain coefficient for all orientations
Limited storage / mechanical room space because the homes are small and typically lack basements or garages	Architects carefully incorporated closets and a right-sized mechanical room into each floor plan
Homes compartmentalized to accommodate 2-3 bedrooms, 1-2 bathrooms, plus storage / mechanicals – all in under 1,000 sf	HVAC systems are carefully designed to avoid comfort and indoor air quality issues; fresh, conditioned air to all living spaces

Challenge	Strategy
Completed home size limit (13'6" height, 16'0" width) to comply with road regulations and avoid expensive extra services	Size restrictions for each site guide design; structural integrity and weight accounted for in transport and for setting in place by crane
In many neighborhoods, underground utilities and space constraints for excavation complicate site preparation	Auger-driven piers used; because this exposes the underside to outside conditions, it gets a similar level of detailing as the walls and roof

The HUD Approach

The manufactured housing industry falls under a federal mandate that requires the U.S. Department of Housing and Urban Development (HUD) to oversee and set the standards for this housing type. In 1976, the National Manufactured Housing Construction and Safety Standards Act of 1974 went into effect, requiring that mobile homes meet stricter durability standards. From that point forward, the industry referred to their homes as *manufactured homes,* as opposed to *mobile homes*, which had become stigmatized due to poor durability and performance.

The HUD Code for manufactured homes, which covers "home design and construction, strength and durability, fire resistance, and energy efficiency," was last revised in 1994 (when improvements were made to the energy efficiency, ventilation, and wind-resistance standards). Yet, there have been many code revisions for other housing types since then.

In 2014, the U.S. Department of Energy (DOE) issued a Notice of Intent to establish a negotiated rulemaking working group (WG) under the Appliance Standards and Rulemaking Federal Advisory Committee. The objective was to negotiate proposed federal standards for energy efficiency in manufactured homes. The WG reached consensus on proposed energy efficiency standards for manufactured housing, but these standards have not yet been adopted.

Meanwhile, manufactured housing is still generally perceived to be the best, if not easiest, approach to delivering unsubsidized affordable housing to homebuyers across the country. Yet, although buyers of manufactured homes pay a relatively low initial price for the unit, outdated HUD Code standards can cause them to pay much higher long-term costs associated with poor building quality, and high energy and maintenance costs. Further, the units often quickly depreciate in value.

The ENERGY STAR standard exists for HUD manufactured homes (EPA 2017), but it is a very different standard from the ENERGY STAR standard for modular and stick-built homes. An ENERGY STAR HUD manufactured home still doesn't meet even the minimum standards set forth in the IECC 2009 code, which most states have adopted for modular and stick-built homes. Figure 1 shows each of the home types discussed here.

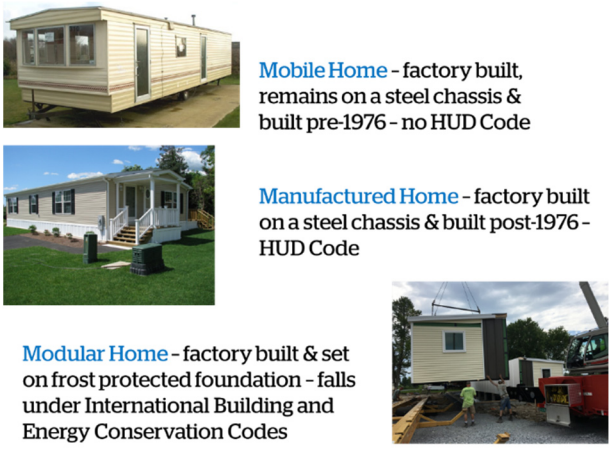

Figure 1. Key characteristics of mobile, manufactured, and modular homes.

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ZEM Design & Construction

ZEM homes are designed to provide an alternative to HUD manufactured homes. ZEM specifications target the dual benefits of quantifiable energy efficiency with many beneficial non-energy impacts.

In contrast to most manufactured homes, ZEM homes do not remain on a steel chassis, but are installed directly on frost-protected foundations or piers, anchored to the site. Most ZEM homes combine the zero-energy-ready design with rooftop, grid-tied photovoltaic (PV) systems. In addition to meeting Efficiency Vermont's HPH standard, they exceed IECC 2015, the DOE's Zero Energy Ready Homes standard, and the ENERGY STAR Homes standard, reducing modeled energy use by approximately 90 percent when compared to all standards. The homes also comply with the EPA's Indoor airPLUS program.

The fact that ZEM homes are built in a climate-controlled factory provides many benefits that improve the construction process over stick-built construction; for example, problems associated with weather, material and equipment storage, complex timelines, worker safety, and material waste. Modular building also enhances contractors' ability to achieve affordability, replicability, quality control, and other production efficiencies. Figure 2 shows a representative ZEM home.

Figure 2. A ZEM home sited in a cooperatively owned park.

ZEM Impacts

Through May 2018, Efficiency Vermont's ZEM program has delivered 85 homes across Vermont since its 2013 launch.

ZEM homes have low or no net energy costs. They also have non-energy co-benefits, such as superb (tested) air quality, higher-quality materials and construction practices, and the potential to retain more value over time, given the absence of depreciation factors present for manufactured homes.[2] ZEM homes qualify for traditional mortgage market instruments while enabling stable monthly energy costs. Further, a purpose-built ZEM factory in the small town of Wilder, Vermont (Vermod Homes) entered the construction market in 2013 and now accounts for 20+ full-time jobs in a rural community; it employs a direct-sales model and constantly evolving lean manufacturing principles. This ZEM factory provides local economic development and represents a scalable opportunity to create new small-scale social enterprises.

The positive environmental impact of transforming the residential housing sector to zero energy is enormous. ZEM homes indicate that zero-energy homes can meet the highest standards

[2] Although the manufactured housing industry frequently asserts that their homes hold their value, or even appreciate in some cases, those claims are typically based on sales data, which can be affected by land value and home improvement measures undertaken by the owners. The Total Component Estimating System (CoreLogic) measures depreciation rates for manufactured homes, according to their condition, at http://rcthelp.msbexpress.net/English_WebHelp/2/Help/Depreciation_Tables_Manufactured_Housing.htm.

for health and quality, while remaining accessible and affordable to LMI buyers. Delivering this kind of radical innovation to vulnerable Vermont homeowners and affordable housing groups lays the foundation for a far more just, inclusive, and broad-based environmental movement than we have seen to date.

Living in ZEM homes has enabled many residents, previously unable to access cutting-edge programs and technology, to feel that they are participating in an environmental movement in a more meaningful way than they could by just turning off lights, reusing plastic bags, and adding a little insulation to their home if or when money allowed. Some of these owners are viewed as early adopters within their communities, with pride evident as they show off heat pumps, solar panels, and battery storage systems to visitors. The benefits of a more inclusive environmental movement are hard to quantify, but imperative to promote.

The ZEM Program provides economic benefits on several levels in Vermont: within households, within affordable housing organizations, and among small businesses, statewide. Within households, ZEM residents experience stable monthly costs and are protected from the fluctuating heating and cooling demands of extreme temperatures, in addition to being better protected from spikes in energy costs. Further, ZEM homes make it possible for owners to build personal equity in their homes and, through the "housing first" model, give renters an opportunity to stabilize their financial situations.

Affordable housing organizations benefit because their members can be collective owners of rental ZEM homes in their mobile home parks. To date, utility costs are included in the rents of all ZEM rental homes, and rental owners have been able to depend on solar credits to buffer or eliminate the typical burdens of tenants' unpredictable energy use. When taking on a role as park owners, affordable housing organizations must bear the burden of lost lot rental income on vacant lots, the blight of abandoned homes, and social stigma associated with poor housing stock. Additional burdens can result when they attempt to help park residents who can't get ahead of the health, maintenance, safety, accessibility, comfort, and affordability issues associated with living in their mobile or manufactured homes. To this end, in 2018 the ZEM Program is placing a greater emphasis on helping affordable housing partners reimagine the park model—by applying the affordable ZEM rental initiative and practicing more systematic outreach with current park residents. In this way, affordable housing organizations are now in a position to add high-quality housing to their rental portfolios while supporting the continued operation of their parks.

The ZEM Program has supported statewide economic development in several ways. In addition to the 20 full-time "green" jobs at Vermod Homes, the factory has a constant stream of interns, college students on field trips, and others who become inspired to enter the zero-energy housing world. Concurrently, the factory has created demand for skilled workers and helped build the labor capacity for expected future needs.

Finally, the ZEM Program supports the regional supply chain for high-performance building materials, cutting-edge mechanical systems, battery storage, and PV panels. Program and factory staff are constantly working with suppliers on improving products so they can better meet the needs of zero-energy design and construction, with particular focus on the constraint of affordability. By creating much broader demand for formerly niche products and contributing to more widespread expertise, the ZEM Program enormously benefits the state in its progress toward its goal of 100 percent zero-energy residential new construction by 2030.

Case Study: A ZEM Home and Neighborhood

One ZEM Home: Cheaper at Twice the Price

A family in eastern Vermont was living in a 1983 manufactured home within a mobile home park. When they decided they were tired of high energy bills, discomfort, and constant maintenance issues, the head of household worked with the mobile home park owner, a non-profit housing trust, to reserve a vacant lot within the same neighborhood, and began to investigate new housing options.

Enter the ZEM Program: The homeowner enrolled in a homeownership training class and worked with the housing trust to evaluate their financial situation. After learning about ZEM homes, the family worked with the ZEM builder and determined a model and features compatible with their living situation. When they were pre-approved for the homeownership loan and financing, they officially ordered the ZEM home.

As shown in Figure 3, the ZEM home provided for a *lower* total ownership cost per month compared to a new manufactured home, when both mortgage and energy costs are considered.

The typical ZEM home package in Vermont combines a small contribution to closing costs (approximately $2,500), a typical low-interest 30-year mortgage, a homeownership loan, and energy efficiency and renewable energy incentives (the Efficiency Vermont portion provides $8,500 per home). The homeownership loan is a $35,000 loan with zero interest, and payment deferred until the home is sold. Table 3 provides a breakdown of all relevant costs of homeownership in a ZEM vs. a manufactured home.

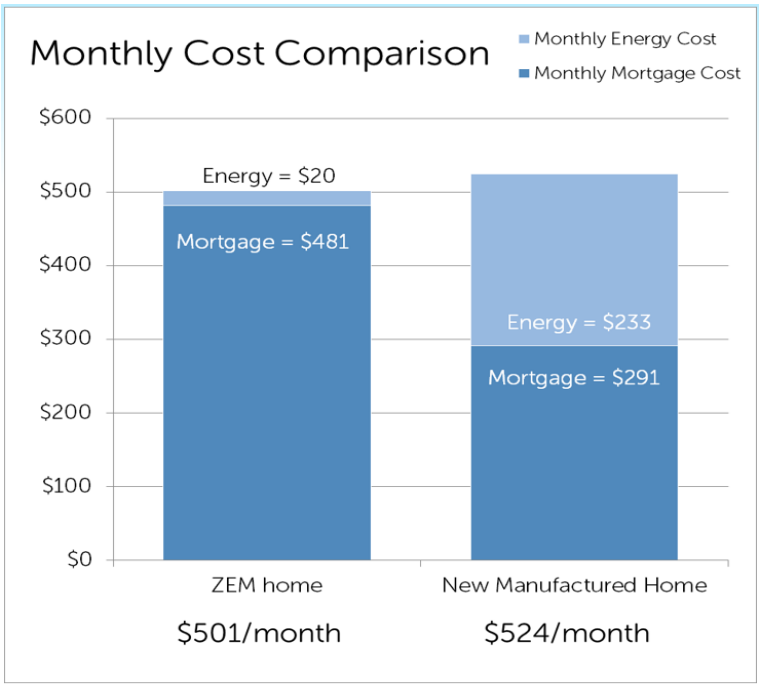

Figure 3. Monthly cost comparison between a ZEM home and a new manufactured home.

Table 1. Comparative costs of a standard-size ZEM home and a new, manufactured home

2-bed / 2-bath home, 14’ x 70’	ZEM home	New manufactured home
Base cost	$116,400	$56,000
Vermont sales tax	$4,190	$3,360
Foundation / site work	$18,500	$9,500
Delivery and set	$7,000	$2,000
7 kW solar array	$17,500	N / A

2-bed / 2-bath home, 14' x 70'	ZEM home	New manufactured home
Solar incentive[3]	-$7,000	N / A
Efficiency Vermont incentive[4]	-$8,500	$0
Champlain Housing Trust homeownership loan[5]	-$35,000	-$27,500
Final cost to finance	$113,000	$43,360
Monthly mortgage payment	$481	$291
Terms	USDA: 3.25% for 30 years, $2,500 required at closing	6.5% for 20 years
Monthly energy cost (heat and electricity)	$20 (utility service fee)	$233
Total monthly cost	**$501**	**$524**

Although this residence produces a little less energy than it consumes each year, the State's net metering regulations mean the credit from the homeowner's PV tariff covers the additional energy use,[6] as shown in Figure 4.

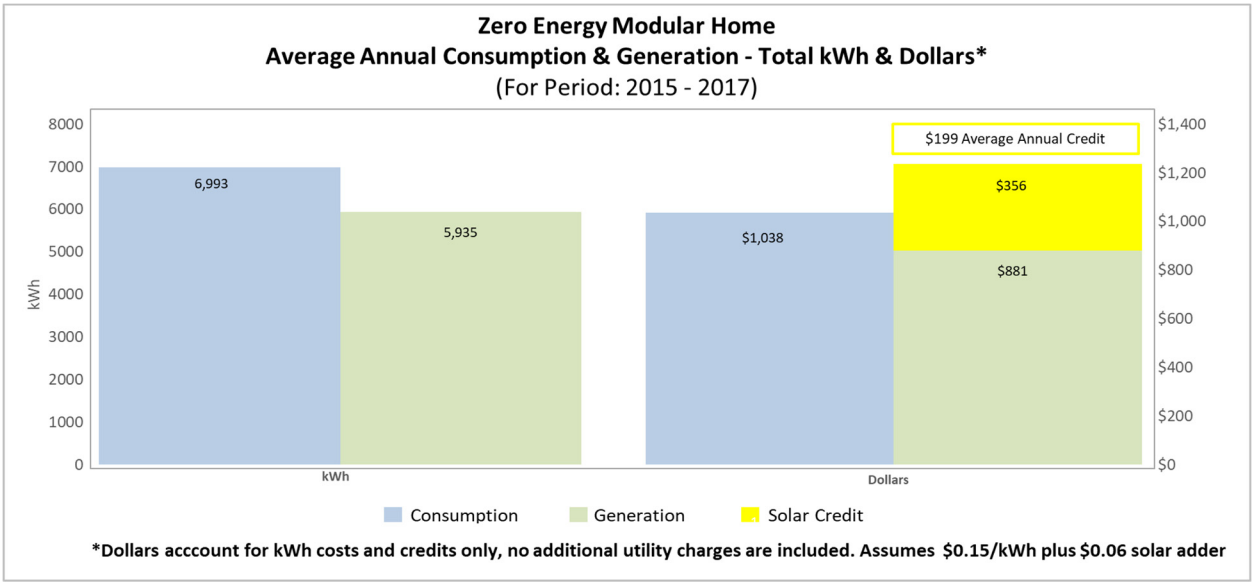

Figure 4. The unit produces approximately 1,000 kWh less than it consumes, but the PV tariff creates an annual credit.

In addition to the obvious energy benefits, the home also provides high levels of comfort, optimal indoor air quality, and low maintenance demands. Figure 5 captures one week's worth of temperature data in winter, showing that indoor temperature variation is low. This is due to the

[3] $1 per Watt.
[4] Limited to homebuyers at or below 80 percent of area median income (AMI).
[5] Limited to homebuyers at or below 120 percent of AMI.
[6] In Vermont, the net-metering regulations at the time of this purchase required the electric utility to cover the retail rate of each kWh produced by a homeowner's PV, and to pay a PV tariff, approximately $0.05 per kWh.

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high levels of insulation, triple-glazed windows, air tightness, and heating/air distribution offered by the point-source cold-climate heat pump paired with energy recovery ventilation.

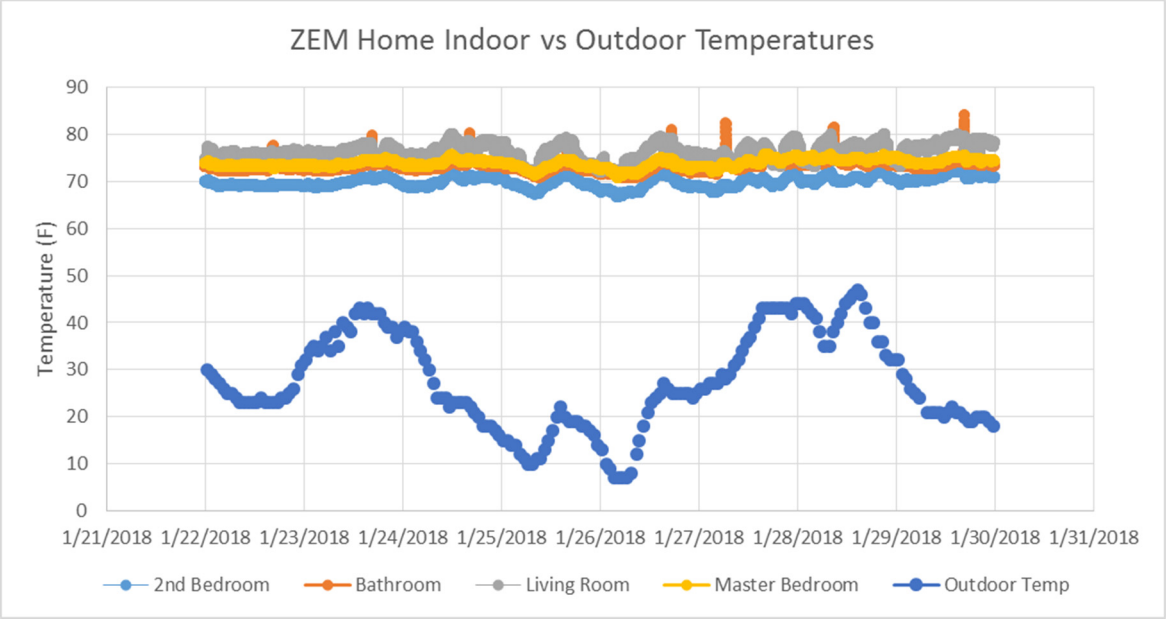

Figure 1. The indoor temperature ranges, compared to outdoor temperature fluctuations, inside a ZEM home reflect the effectiveness of the high-performance measures.

Balanced ventilation with demand-controlled operation leads to exceptional indoor air quality. Figure 6 demonstrates how the ventilation system keeps the levels of indoor volatile organic compounds (VOCs) and CO_2 below 1,000 ppm for over 95 percent of the time.[7] This is because the ventilation system monitors the return air from the home and brings in fresh air if or when that (user-defined) level is exceeded.

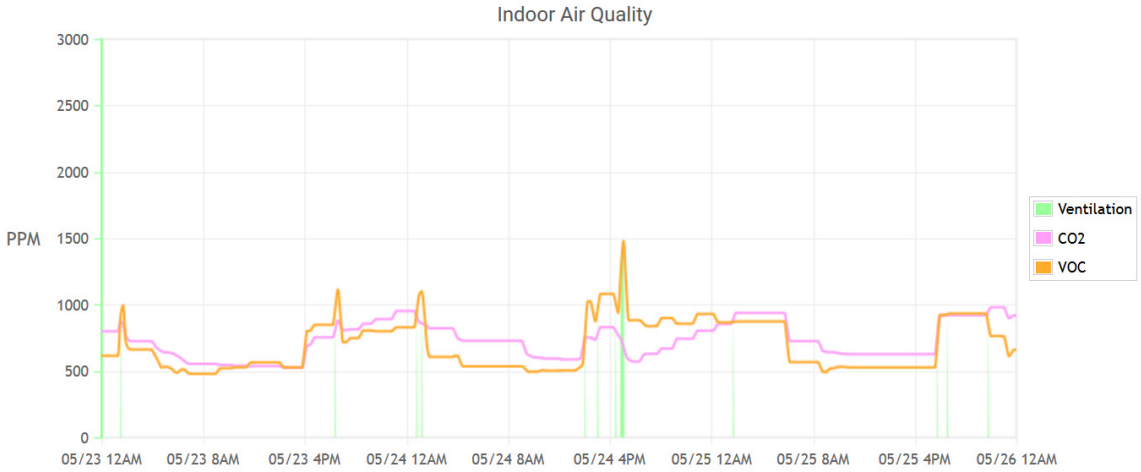

Figure 6. Three days of indoor air quality, measured at return on ERV during the heating season.

[7] For reference, a research paper published in 2017 found that 86 percent of existing homes tested (19 of 22) exceeded 2,000 ppm for CO_2 levels during a 4-day study.

As is the case with all ZEM homes, this residence meets the EPA's specifications for Low-Emissions Materials under the Indoor airPLUS program. These specifications include measures to limit human exposure indoors to individual VOCs of potential concern for human health effects. Composite wood products such as cabinetry, plywood, and particle board, interior paints and finishes, and adhesives and sealants are all low-VOC or no-VOC products with appropriate certifications.

With regard to maintenance, ZEM homes were intentionally designed to reduce upkeep and maintain durability. For example, exterior details move water away from the building via 12-inch overhangs at the eaves, a 2-foot gravel drip edge pitched away from the home, exposed concrete at least 12 inches above grade, and a vented drainage plane behind the siding. The metal, composite, or vinyl exterior finishes reduce maintenance; composite wood trim is resistant to mold, rot, and pests; and architectural shingles or rubber membrane roofs have extended lifetimes.

It is difficult to quantify the dollars saved, but these non-energy benefits to the homes' occupants are real, and complement the realized financial impact from energy savings.

Many ZEM Homes: Mobile Home Park Re-development

A project known as McKnight Lane is a mobile home park re-development full of ZEM homes. Originating as a 14-unit mobile home park, residents owned their homes but leased the land from a park owner. Over time, the homes fell into disrepair; one resident after another

Figure 7. McKnight Lane layout, showing ZEM homes on existing lots.

moved on, abandoning their homes. When an affordable housing trust, Addison County Community Trust (ACCT), acquired the park in 2017, no one lived there, yet 13 empty mobile homes remained on the property. ACCT removed all of the existing homes, reconfigured the lot lines to comply with the town's setback requirements, and installed 14 new ZEM homes in a 7-duplex configuration. Figure 7 shows the development's layout.

Today, ACCT owns, manages, and maintains this 14-unit community, which serves low-income tenants. Each unit incorporates the ZEM home features described above, but each home's 6 kW rooftop solar PV system is also complemented by 6 kWh of electricity storage via high-capacity batteries that store excess power (generated by the solar panels) for use when it is needed most. Not only do the McKnight Lane tenants have access to some of the most affordable, energy-efficient rental housing available anywhere, they also receive the benefits of resilient power.

When a power outage puts neighboring homes in the dark, the solar + storage system at McKnight Lane has an automatic transfer switch that allows the system to isolate itself from the grid and continue to power critical loads in the home until utility power is restored. When power is restored, the energy storage system automatically reconnects and sends power to the grid as usual under normal circumstances. In other words, residents will have power to stay safe and comfortable, even during an outage. And as with all ZEM homes, even during an extended outage, the highly insulated thermal shell of the units will retain heat long after the vast majority of homes would cool down. Figure 8 shows two of the duplexes (four units).

Figure 2. Two of the duplex units at McKnight Lane.

The solar + storage system in these ZEM homes is designed to be fully operational with no action needed from the tenants. The systems are monitored electronically by Green Mountain Power, the local electric utility, and by the battery manufacturer sonnenBatterie. Vermod, a ZEM builder in Vermont, plans to incorporate battery storage into more of its homes so that it can offer these benefits to more homebuyers and affordable housing agencies.

Scaling Up: The Future of ZEM

Over the past four years, Vermod has built more than 80 ZEM homes, placing them in mobile home parks and on private land across Vermont, with plans to deliver and install another 30+ units in 2018. Vermod, in collaboration with Efficiency Vermont and the Vermont Housing & Conservation Board, has also partnered with the Vermont Manufacturing Extension Center (VMEC) to apply lean thinking to their factory processes. Using value stream mapping and lean manufacturing principles, the team is continuing to optimize many facets of the business. This learning will be open-sourced and directly transferable to ZEM efforts beyond Vermont.

VEIC has several initiatives under way to build upon the ZEM success story in Vermont. There is tremendous interest beyond the state's borders, and the ZEM Team has been working on detailed business models to ensure the success of future ZEM initiatives. To improve VEIC's

ZEM package for potential member ZEM factories, VEIC is collaborating with Vermod, VMEC, and outside consultants to create business models and factory designs for an economic development growth model: pop-up ZEM factories.

VEIC also has a business model for a new entity, ZEM Enterprise, a social enterprise that uses commercial strategies to achieve improvements in financial, social, and environmental well-being on a community scale. VEIC has designed ZEM Enterprise to manage all ZEM initiatives. ZEM Enterprise could fulfill crucial start-up and support services for network members, including factory design and business model, access to capital and financing, ongoing technical assistance, and maintenance of the ZEM network.

ZEM Enterprise will help achieve improvements in health, environmental quality, and economic well-being for LMI homeowners and tenants by promoting ZEM homes through member ZEM factories. In addition, the ZEM factories, as local social enterprises, will help improve economic well-being on a larger scale within rural communities. Important building blocks can be set up with business models that emphasize social entrepreneurship, serve employees and owners, offer affordable housing, strengthen local communities, put a priority on cooperation instead of competition, and encourage stewardship of the environment.

With significant benefits to both communities and residents, ZEM is poised to re-define affordable housing and offer a path out of poverty to our most vulnerable populations.

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