Hot Ideas in a Cold Climate: Specs, Savings, and Lessons Learned from a High Performance Homes Program

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ABSTRACT

Four years ago, a statewide energy efficiency utility designed its High Performance Homes (HPH) program as a pathway to achieving net zero energy use in residential new construction. The program is prescriptive, cost-optimized, and requires minimal red tape for compliance. Based in part on lessons learned from the Passive House movement, the offering seeks aggressive adoption of low-load building practices in a cold-climate market. This paper offers program specifications from a 2012 pilot program and discusses outcomes from further assessment of the concept and its implementation, including HPH criteria evolution in response to the pilot program's successes and critiques. The paper presents data on statewide program uptake, compares anticipated energy savings with actual savings, and describes the results of exploration of metrics for predicting/documenting electricity savings. Submetered data is used to evaluate performance of actual homes, including post-occupancy equipment performance, thermal comfort, and indoor air quality.

Background

Efficiency Vermont's Residential New Construction Program

Efficiency Vermont's Residential New Construction (RNC) program was established in 2001, shortly after Efficiency Vermont became the country's first energy efficiency utility. The program serves new-construction single-family and multifamily homes, as well as projects undergoing full gut rehabilitation.

Prior to 2001, Efficiency Vermont's parent company, Vermont Energy Investment Corporation (VEIC), offered energy ratings and ENERGY STAR® certification for newly-constructed homes in Vermont. Since 2001, the RNC service has gone through several updates to support market transformation in tandem with wider acceptance of efficient building practices and Vermont's increasing energy code stringency. The current program structure offers two tiers, the baseline Efficiency Vermont Certified (EVTC) and the more stringent Efficiency Vermont Certified: High Performance Home (HPH). The nationwide ENERGY STAR® Homes certification can be added to either tier.

As a ratepayer-funded energy efficiency utility, in providing certification and technical support at no cost, Efficiency Vermont lessens financial and logistical hurdles for customers and encourages broad participation among building professionals and homeowners. RNC services include one-on-one technical assistance from planning through construction completion, two site visits (pre-drywall and final), an energy rating, energy code compliance assistance, and certification. A $2,000 cash incentive is provided for participants meeting the HPH tier, with lower incentives provided for the baseline (EVTC) offering. Efficiency Vermont's focus on direct customer support continues to foster a deep sense of trust with partners, and for many, objective, third-party technical assistance is viewed as a higher benefit than incentives.

Vermont Comprehensive Energy Plan and the High Performance Home Pilot

The State of Vermont Comprehensive Energy Plan, published in 2011 and updated in 2016, calls for all newly-constructed homes to be net zero energy by 2030 (VDPS 2016). Efficiency Vermont is expected to play a key role in meeting this goal, by increasing overall program participation to advance construction of above-code homes and by advancing the depth of efficiency in each home.

Vermont is fortunate to have numerous builders who seek to maximize energy efficiency and construct net zero energy (and net zero-ready) homes in the state's cold climate. In an effort to bring more homes to high levels of efficiency, Efficiency Vermont created the HPH pilot in 2012. The pilot was funded through an Efficiency Vermont Research and Development budget and provided the opportunity to add a more comprehensive offering to Efficiency Vermont programs. The goals for the project were five-fold:

1. Promote market transformation towards net zero energy homes in alignment with the State of Vermont's comprehensive energy goals.
2. Educate builders, architects, and other building professionals in adopting advanced building techniques.
3. Support all stakeholders in understanding that deeper energy savings are achievable, cost-effective, and have non-energy benefits such as improved comfort, superior indoor air quality, and long-term building durability.
4. Build organizational knowledge of building science via whole-house monitoring, data analysis, and field consultation; share learnings and increase awareness of Efficiency Vermont and VEIC.
5. Create new energy savings opportunities and methodologies for measurement.

High Performance Home Pilot Program

Services

All homes in Efficiency Vermont's RNC program receive technical assistance as described above, in addition to incentives (given to the enrollee, who is typically the builder or homeowner) to reduce the incremental cost of efficiency measures. Homes enrolled into the HPH R&D pilot received additional project support including:

- *Facilitation of Integrated Design Process.* Efficiency Vermont attempted to drive a process that ensured every member was invested in the project from the beginning, was able to provide input at each stage, and had clear understanding of the high performance strategies and the project's overall goals. Open dialogue continued through construction and troubleshooting.

- *Modeling.* Iterative REM/Rate and Passive House Planning Package (PHPP) modeling occurred during design in order to guide decisions. Energy savings potential was weighed against cost analysis to determine least-cost paths; monthly cash flow analysis was considered (e.g. operational energy costs, incremental initial costs' impact on mortgage).
- *Field Verification.* During construction, field verification (typically two visits, but on some homes four or more) ensured details were executed per design. Examples of verified measures include air barrier installation, window flashing, HRV duct installation, blower door tests (to assess and verify air tightness), and ventilation air flow testing to ensure proper balancing and meeting of requirements.
- *Post-Occupancy Monitoring.* A circuit-level energy monitoring system was installed in each home, enabling Efficiency Vermont and homeowners to assess and verify equipment function, maximize operational efficiency, and troubleshoot problems. Data loggers in several homes gathered information on thermal comfort and indoor air quality.

These added services, including whole house monitoring, helped Efficiency Vermont assess how particular design details and specifications performed in the field when combined with occupant behaviors. Additionally, by spending time onsite working alongside design professionals, engineers, builders, and sub-contractors, Efficiency Vermont was able to evaluate how specifications were implemented and experience firsthand many successes and challenges.

Criteria Development

A primary consideration when developing the HPH specification was whether it should be performance-based (e.g. the Passive House standard), prescriptive, or a combination of the two. After engaging builders and assessing the most effective and efficient way to bring the HPH concept into the mainstream Vermont market, Efficiency Vermont chose a prescriptive approach; the majority of builders believed a clear prescriptive path positioned them for success better than a performance standard that may require significant modeling.

Generally-accepted high performance building strategies include high levels of insulation; thermal bridge-free construction; triple-pane windows; very low air infiltration; ventilation with heat recovery; and ultra-efficient appliances, hot water, and space conditioning systems. Prices of photovoltaic energy generation vs. energy efficiency-equivalent upgrade measures were used in guiding cost-effectiveness. An additional guiding principle in developing prescriptive criteria for Vermont's Zone 6 climate was to ensure that the shell was sufficiently insulated and air-tight such that a modest point-source heat system and heat recovery ventilator (HRV) could supply the space conditioning needs of the home. It was posited that, by improving the shell to the point at which a (conventional) centralized heating system could be omitted, incremental costs could be minimized. Figure 1 demonstrates this graphically with two recent examples.

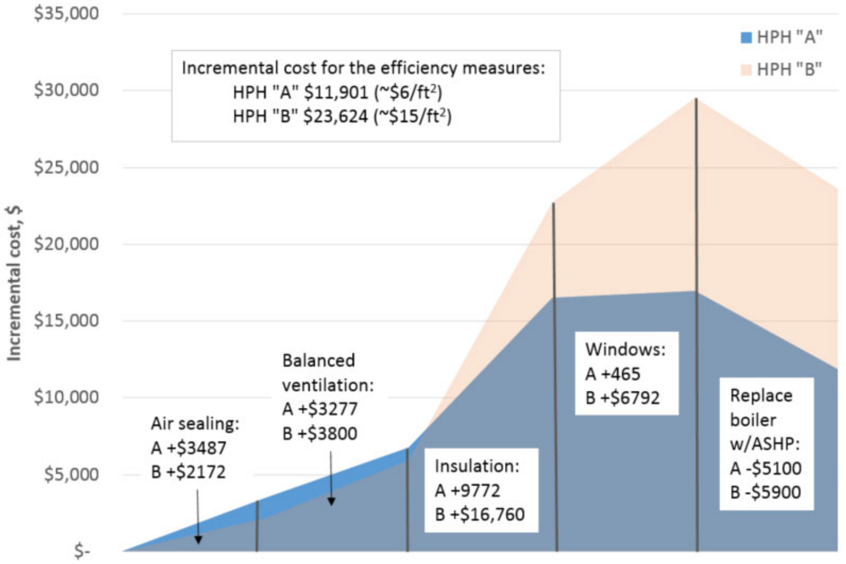

Figure 1. HPH economics based on 2 real-world homes. HPH “A” is an actual 1908 ft^2, 2-story home in Shelburne, VT (HPH-revised vs. EVTC; costing data: Hayward Design Build, Colchester, VT). HPH “B” is a 1600 ft^2, 2-story home in Charlotte, VT (HPH-revised vs. VT code; costing data: Efficiency Vermont, 2015; baseline is a (2011) code-level home (e.g. 85% efficient propane boiler, U-0.32 windows, R-25 walls)).

The HPH specification developed in the pilot included thermal shell requirements (e.g. U-0.19 windows, R-40 walls, and R-30 slab edges) and equipment requirements (e.g. balanced ventilation with 80% or higher sensible recovery efficiency (SRE)); a full list appears later (see Table 1) alongside discussion of subsequent changes to requirements.

HPH Pilot Results

Performance

In 2013, six HPHs with at least a year of monitoring data were evaluated. In comparisons with modeling of our baseline (EVTC) program, HPH submetered data showed reductions in heating and cooling needs, with domestic hot water, clothes drying, lighting, and other appliances accounting for a higher proportion of overall electricity use; heat recovery ventilation accounted for 6% of total electricity.

In comparing actuals against modeled results, REM/Rate consistently predicted higher energy usage than PHPP. With a sample size of six, however, neither software was a clearly superior predictor of actual electricity usage, likely due to actuals’ high dependency on behavior and number of occupants.

Three of the HPHs (each approx. 1300 sf) used single point-source heating via air source heat pumps (ASHPs) coupled with HRVs. Prior to the study, it was unclear whether this would provide desired levels of comfort in Vermont’s climate. Early data indicated that wide room-to-room temperature variations (e.g. 10°F) were possible, but closed doors and non-optimal control strategies (e.g. erroneous ASHP settings) were influential factors. By providing feedback to the homeowners via monitoring data, variations were reduced and/or better understood. Homeowner expectations for comfort were met, though understanding of control methods was important.

Experience with early homes – monitoring data plus anecdotal homeowner feedback – confirmed that point-source heating, when coupled with the HPH specifications, could achieve high levels of comfort in Vermont's harsh climate.

Post-occupancy monitoring helped identify several technical problems, many of which may have gone unnoticed for years in the absence of monitoring. This was especially true in the case of advanced mechanical systems that were not yet widely adopted. Examples include:

- Short-cycling in air-source heat pumps (e.g. due to thermostat locations, non-ideal user settings, and hardware and/or software idiosyncrasies)
- Short-cycling in ground-source heat pumps (e.g. when there was no demand for heat)
- Low apparent SRE in a number of HRVs (e.g. due to condensation in the heat exchange core, clogged filters, or dampers stuck open or closed)
- Impaired solar hot water system effectiveness (e.g. due to non-ideal setting on tempering valve (by contractor) or sediment in heat exchanger)

The HPH pilot also identified that HPHs have different maintenance needs, especially in regards to HVAC equipment and its optimal performance. In particular, maintaining filters is a critical item that homeowners need to manage. Lessons learned for installation of outside compressors included recommendations for sufficient height (defense against drifting snow), stands (instead of wall brackets, for noise/vibration reduction), hoods (protection from snow and ice), and the need for condensate pan heaters (to reduce ice build-up in extreme conditions).

The ability to troubleshoot not only influenced the HPH program's inclusion of monitoring systems in all subsequent successful completions, it enabled Efficiency Vermont conversations with vendors and manufacturers that resulted in bringing better equipment to the market and optimizing installation and settings. However, the unfortunate reality – especially as the number of monitoring systems increased – was that from a resource standpoint, given other program demands, it was challenging to have an energy consultant reviewing data on a regular basis to gain full value of the investment.

Savings Methodology

Within the Efficiency Vermont RNC programs, both EVTC and HPH claim energy savings through established lighting, ventilation, and appliance (clothes washing, dishwashing, and refrigeration) savings algorithms, in addition to electrical savings in homes with ASHP(s) for space conditioning. The calculation for thermal shell savings resulting from a tight, well-insulated building envelope (including hot water) is more complex, and based on the difference between the actual (REM/Rate-modeled) home and its user-defined reference home (UDRH) equivalent; the current UDRH is based on a 2011 assessment of new construction practices in Vermont (not necessarily code requirements) in the absence of Efficiency Vermont participation. UDRH adjustments were made for 2016 and will be further updated upon completion of a 2016 new homes baseline study.

Efficiency Vermont claims savings for electricity only, except in off-grid homes. Thermal savings count towards the VEIC's Total Resource Benefit (TRB) metric.

HPH Program (2013-Present)

Program Updates

An HPH program aim was to be responsive to the market. As such, several noteworthy changes to prescriptive requirements have occurred since inception. All were aimed at decreasing the incremental cost of HPHs without significant sacrifices in efficiency or comfort. First, the maximum window U-factor was increased from U-0.19 to U-0.21, which allowed the inclusion of lower-priced and/or domestic window options. Second, the flat ceiling requirement decreased from R-80 to R-60; in addition to aligning the flat and sloped requirements, the change increased design flexibility. Third, the below-grade (or below-frost line) slab insulation requirement was relaxed from R-30 to R-20 for both slab edge and under-slab. Fourth, the minimum SRE of the ventilation system was reduced from 80% to 75% in order to permit select lower-priced options, all of them cold-climate tested. Also, appliance requirements are simplified and electric (non-heat pump) water heaters are allowed in particular circumstances.

As a result, current requirements are less stringent than the original program design, which slightly increases modeled energy consumption. Table 1 highlights original and current program requirements and includes a comparison of modeled energy impacts for a representative HPH (“Residence A”, based on an actual 1375 ft^2 home that exceeded initial requirements) that was adjusted in the model to reflect initial vs. current requirements for windows, ventilation efficiency, and ceiling, slab edge, and under-slab R-values.

Table 1. Key prescriptive requirements (updates are in **bold**)

Feature	Initial requirement	Current requirement
Max. window U-factor	U-0.19	**U-0.21**
Max. door U-factor	U-0.25	U-0.25
Min. ceiling R-value	R-80 flat/R-60 sloped	**R-60**
Min. above grade and joist R-value	R-40	R-40
Min. below-grade / frost line / crawlspace R-value	R-30	R-30
Min. exposed floor R-value	R-40	R-40
Min. slab edge R-value	R-30	R-30 slab on grade **R-20 slab below grade**
Min. footing R-value	R-20	**R-8**
Min. under-slab R-value	R-30	R-30 heated and/or on grade **R-20 unheated below grade**
Air leakage	≤ 1.0 ACH50	≤ 1.0 ACH50
Ventilation	Balanced, SRE ≥ 80%	**Balanced, SRE ≥ 75%**
Water heating	ENERGY STAR	ENERGY STAR
Heating and cooling	ENERGY STAR; boilers ≥ 94 AFUE	ENERGY STAR; boilers ≥ 94 AFUE
Lighting	95% ENERGY STAR	95% ENERGY STAR
Appliances	Fridge, dishwasher, and clothes washer: distinct CEE Tier requirements	**All: ENERGY STAR certified**
HERS Index	No requirement	No requirement
Residence A heating requirement	13.3 MMBtu/yr	15.0 MMBtu/yr
Residence A heating demand	11.1 kBtu/hr	11.9 kBtu/hr
Residence A annual energy cost	$1446	$1485
Residence A HERS Index	36	37

With a good sampling of HPHs represented and being monitored in the field, in 2015 Efficiency Vermont incentives for HPHs were amended such that monitoring systems are no longer automatically included. Efficiency Vermont does, however, provide technical assistance to homeowners and builders wishing to install monitoring systems and continues to monitor approx. 50 homes. The information is utilized to improve specifications and performance of existing and future HPHs.

In an effort to broaden the reach of High Performance Homes, Efficiency Vermont launched a Mobile Home Replacement program in the aftermath of 2011's Tropical Storm Irene. The outcome was a partnership with a local modular home builder and the development of a cost-optimized HPH offering reflecting the design constraints of mobile homes. While available to market-rate buyers, most built units serve low-income housing needs.

Results

Participation

Through 2015, 47 homes had completed successfully in the HPH program; 7 occurred in 2013, 21 in 2014, and 19 in 2015. Among the completions, about half are modular homes, the majority of which are part of the (low-income) Mobile Home Replacement program.

For 2016, 28 Mobile Home Replacements are expected to complete and a further 36 market-rate HPH projects were enrolled in the program as of the end of February. In total, we anticipate more than 50 HPH completions in 2016.

Electricity Consumption

In summer months, HPH electric usage is lower than that of (baseline) EVTC homes, likely due to more stringent water heating and lighting requirements in addition to a tighter envelope and higher cooling efficiencies; see Figure 2. In months with heating, differences in electric usage (ref: blue vs. orange lines) are masked by the fact that all HPHs have electric (heat pump) space conditioning while the majority of EVTC homes have thermal heating systems that are not accounted for in an electric-only summary. To more accurately compare total energy, metered monthly natural gas usage from aproximately 1400 Efficiency Vermont-enrolled (approx. EVTC-equivalent) homes from 2007-2013 was averaged and converted to kWh-equivalent then combined with electric data (ref: gray line).

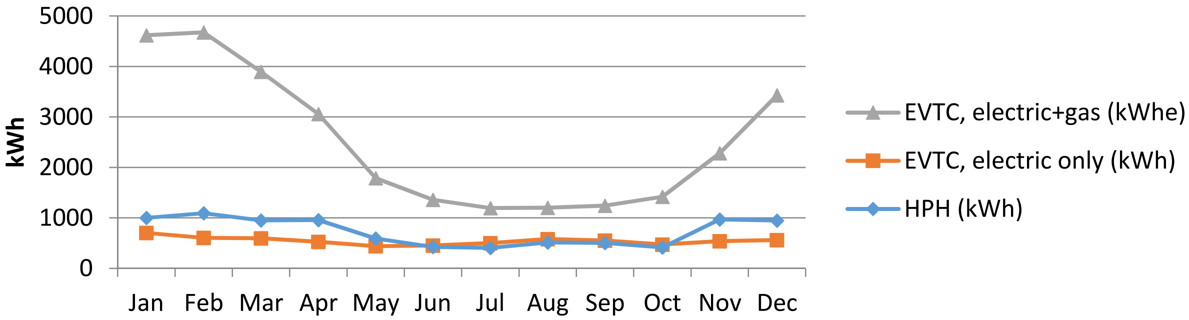

Figure 2. 2015 Monthly electricity consumption (from utility), HPH (n=10, avg. HERS=36) vs. EVTC (n=531, avg. HERS=52). HPH data includes homes with min. 1 year of data; net-metered homes are excluded.

This data indicates an average annual energy cost for the HPH homeowner of $1293, $567 less than the EVTC combined electricity and natural gas cost of $1860. If accounting for the fact that most HPHs avoid natural gas fixed service charges, the HPH savings rise to $812.[1] Due to Vermont's limited natural gas distribution network (just 29.1% of homes), potential HPH energy savings may be even higher for the large percentage of Vermont homeowners who use fuel oil or propane (63.4% and 4.2% of homes, respectively).[2] Note, however, that these HPHs effectively displace natural gas (or other fossil fuels) with heat pump-driven (COP > 1) electricity, which may not be advantageous in all jurisdictions or at all times.[3]

Savings

There are two motivations for exploring savings. The first is to summarize and compare savings claimed between the two tiers of the Efficiency Vermont programs. The second is to assess alternatives to savings verification compared to the (current) resource-intensive creation of REM/Rate models for each project.

Table 2 summarizes average savings (from thermal shell/envelope measures) due to participation in Efficiency Vermont's RNC programs; all numbers are based on REM/Rate models. HPHs permit dramatically higher electric savings claims for two reasons: (1) the non-HPH tier (EVTC) is not significantly more stringent than standard building practice/code and the User Defined Reference Home, and (2) the most typical comparison for HPHs is between a tight, highly-insulated HPH with a very efficient ASHP vs. a standard building using a ASHP with the federal minimum efficiency level (heating seasonal performance factor (HSPF) = 7.7). Savings differences are less pronounced but still significant when adjusting for the thermal savings in non-HPHs.

Table 2. Thermal shell (modeled) savings summary, baseline vs. HPH participants, through June 2015

	As-Built Savings, EVTC vs. UDRH, n=423			As-Built Savings, HPH vs. UDRH, n=31		
Home size (sq ft)	Electric, kWh	Non-electric, MMBtu	Total, MMBtu	Electric, kWh	Non-electric, MMBtu	Total, MMBtu
< 1500	306	9	10	5436	0.1	19
1500-3000	868	29	32	12107	0.1	41
> 3500	3685	45	58	14738	0	50

Figure 3 shows total electricity consumption from utility data for January 2015 vs. HERS index, for projects with linked utility accounts; sites with electricity generation from renewables are excluded. A first-degree best-fit polynomial has been added for the HPH subset; there is little correlation between HERS and electricity usage; for a summer (not heating-dominated) month, the correlation is even weaker (e.g. R^2=0.057 for August 2015).

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[1] Based on April 2016 rates: Green Mountain Power $0.1474/kWh and Vermont Gas $1.1466/ccf. Vermont Gas has a daily access charge of $0.6701.

[2] U.S. Energy Information Administration, http://apps1.eere.energy.gov/states/residential.cfm/state=VT#sources.

[3] For reference, Vermont's largest residential utility, Green Mountain Power, obtains a combined 33% of its power from hydro and renewables; http://www.greenmountainpower.com/fuel-mix/.

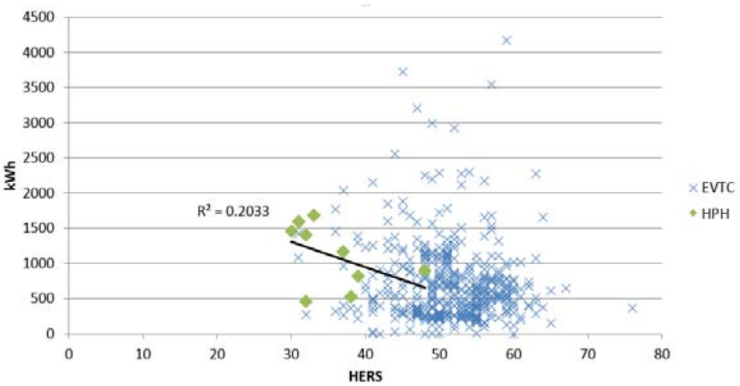

Figure 3. January 2015 electricity consumption (from utility) vs. HERS; EVTC n=505 (2 outliers excluded), HPH n=9.

We do not consider HERS index a suitable metric for determining incentive levels (or substantiating savings), though our savings verification method uses a REM/Rate model – with non-thermal shell characteristics excluded from the thermal shell savings calculation. The result accounts for effective R-values, window characteristics, air leakage rate, etc. but the model requires many “extra” inputs which increase time burden.[4]

We tested simpler methods of predicting thermal shell savings. Figure 4 displays two shell metrics for each HPH depicted in Figure 2. UA is a common measure used in heat loss calculations, equal to the sum of the products of U-factor and area for each thermal shell component. UA* is a proxy for infiltration-adjusted UA (with same units as UA), defined here as

$$UA^{*}\left[\frac{Btu}{hr^{\circ}\mathrm{F}}\right] = UA\left[\frac{Btu}{hr^{\circ}\mathrm{F}}\right] + cfm_{50}\left[\frac{ft^{3}}{min}\right]\cdot\left[\frac{60min}{hr}\right]\cdot\frac{1}{19^{\dagger}}\cdot\frac{0.0177Btu}{ft^{3}{}^{\circ}\mathrm{F}}$$

† Nineteen is an approximate factor for a converting pressurized (measured) to natural air infiltration for a Vermont home.

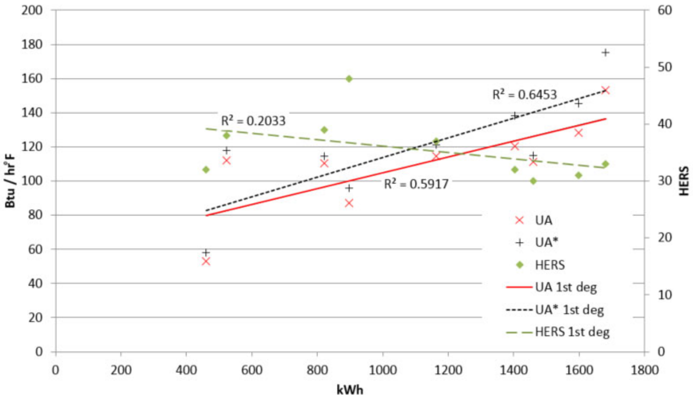

Figure 4. UA, UA*, and HERS vs. January 2015 electricity consumption (from utility), N=10 (HPHs).

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[4] The HERS index is also provided to customers and is thus valued independently of its use in savings verification.

UA* is clearly the best predictor of the 3 metrics for electric savings in all-electric HPHs, with an R^2 of 0.645 – better than simply UA (R^2=0.592). For a non-heating month, as expected the correlation diminishes significantly; for August 2015, R^2 for all three metrics is under 0.100.

To complement Figure 4, which employed utility data, for 16 homes we investigated UA*, UA, and HERS vs. kWh for a winter and summer month using submetered heating equipment data. Unfortunately, there was no apparent correlation between any of the 3 metrics with consumption. Potential reasons include periods of missing/incomplete data, occupancy/behavior (e.g. one 980 ft^2 home has 6 residents and is heated to 84°F in winter), and equipment-related idiosyncrasies such as short-cycling of a heat pump.

Monitoring data

As discussed previously, monitoring systems have proven invaluable for troubleshooting and learning. Below are examples of data available via monitoring equipment for select HPHs. Residence A (same as featured in Table 1) is a 2-story, 1375 ft^2 home with an unfinished basement. Figure 5 displays the electricity consumption dashboard; any of these circuits can be drilled into for deeper investigation.

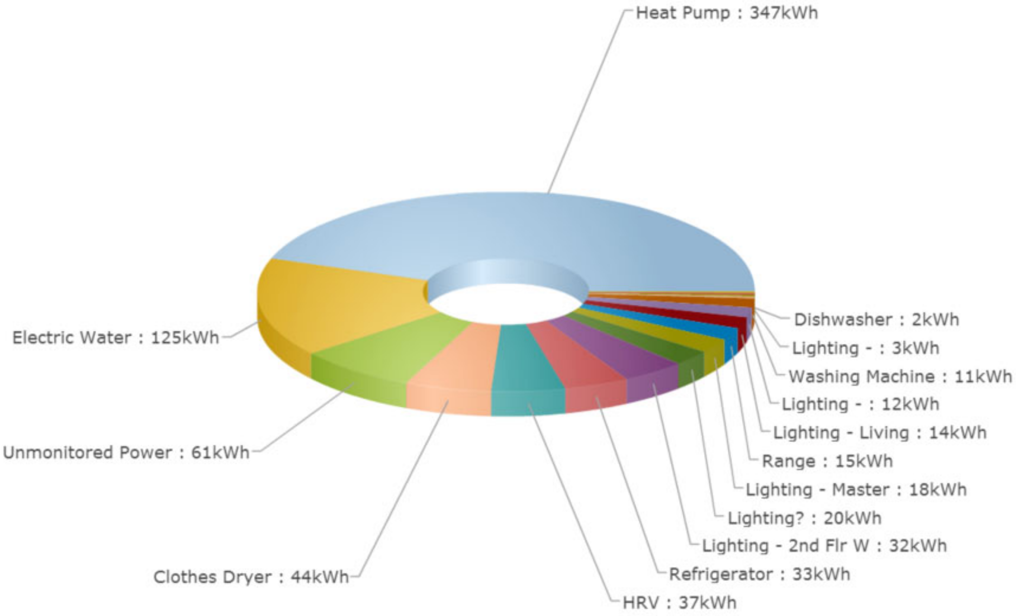


Figure 5. Residence A electricity consumption, Jan 31 – Feb 29, 2016.

Collected data is explored in various ways. Figure 6, for example, shows room-by-room temperatures and the electricity consumption of Residence A’s space conditioning systems against ambient temperature during a month of cold weather. Note that the five rooms in the living space track within 6-8°F and the (unconditioned) basement does not drop below 60°F.

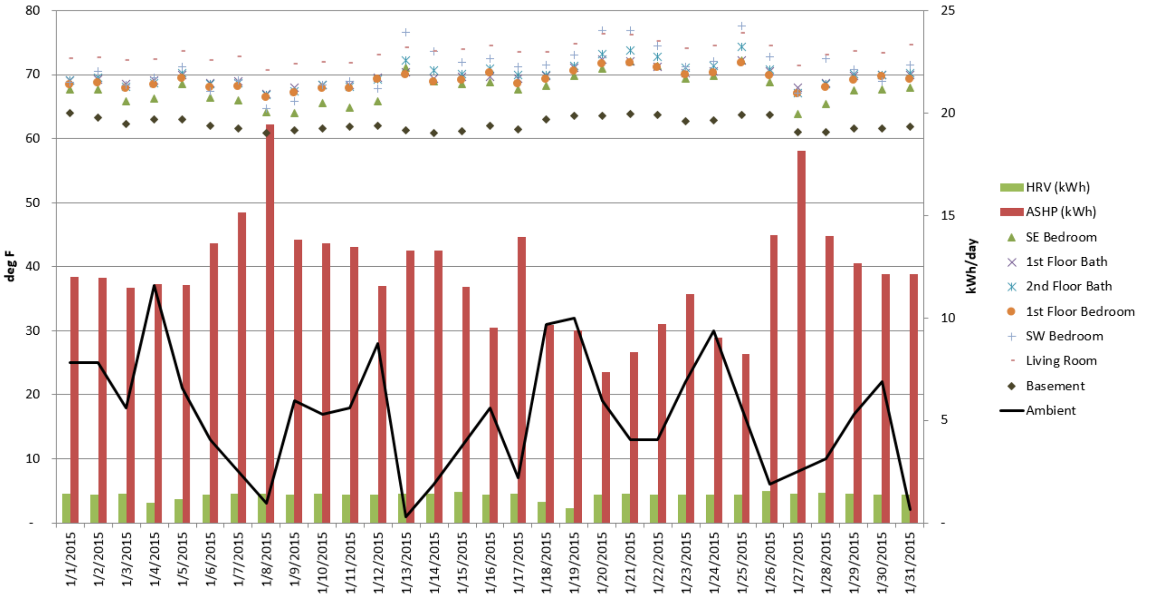
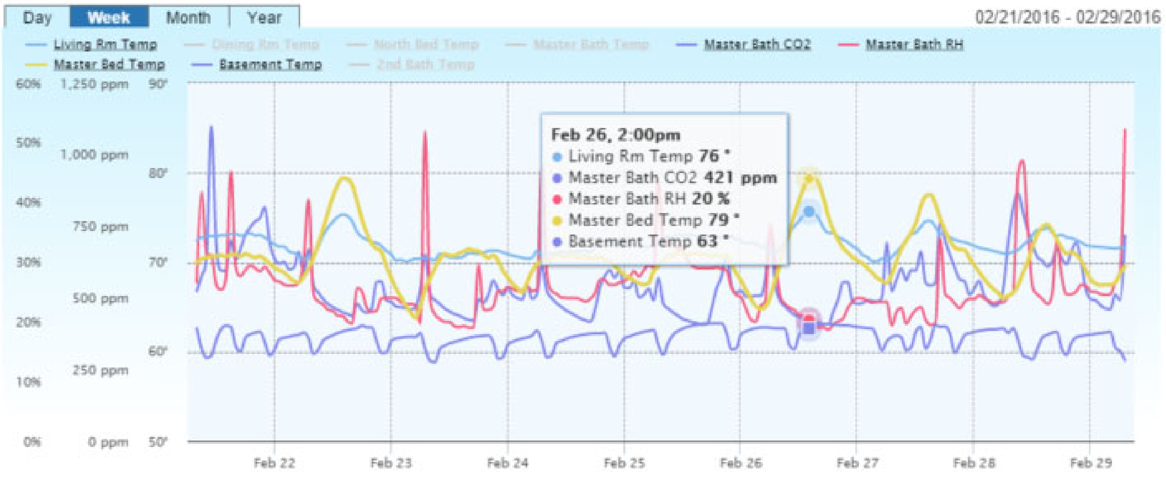


Figure 6. Residence A room temperatures and space conditioning electricity consumption, January 2015.

Roughly half of HPHs have additional indoor air quality (IAQ) monitoring capability, including relative humidity (RH), carbon dioxide (CO_2), and volatile organic compounds (VOCs). Figure 7 shows additional IAQ data for Residence B, a 2536 ft^2 HPH.



Feb 26, 2:00pm
- Living Rm Temp **76 °**
- Master Bath CO2 **421 ppm**
- Master Bath RH **20 %**
- Master Bed Temp **79 °**
- Basement Temp **63 °**

Figure 7. Residence B temperature and air quality data, Feb 21-29, 2016.

Note the spikes in the master bath RH (pink line) each morning; these are indicative of showering. The south-facing master bedroom reaches nearly 80°F (yellow line) in early afternoon on sunny days. CO_2 remains at acceptable levels, but increases during periods that the bedroom is occupied (top purple line).

Figure 8 displays a histogram showing the low frequency of elevated CO_2 and VOC levels in 17 HPHs. An indoor CO_2 level of 1000 ppm or less is often cited as a target for avoiding outcomes such as drowsiness and complaints of poor air.

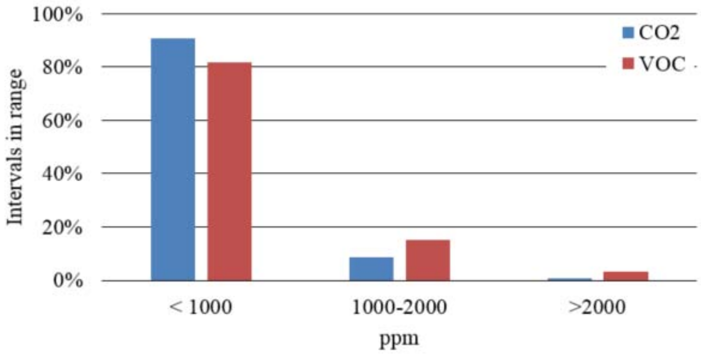


Figure 8. Histogram for CO_2 (N=16) and VOCs (N=13) in 16 HPHs; based on 3-minute interval data, Jan 3-9, 2016. VOC data expressed in CO_2 equivalent.

Discussion and challenges

REM/Rate is an acceptable predictor of electricity usage in (all-electric) HPHs and we consider it an effective tool for comparative analyses such as evaluating impacts of proposed changes to program criteria or a specific home. When preparing financial analyses, we frequently utilize REM/Rate for annual energy cost predictions, contingent on entry of accurate cost inputs by energy source. However, building a REM/Rate model for each project is resource intensive and many inputs are unnecessary for our program savings quantification; in addition to a simplified UA-plus-infiltration approach, we are also considering a prescriptive method (e.g. bins corresponding to home size range and certification level, each with a discrete savings number based on sampling).

Performance-wise, point-source heating in HPHs is generally considered acceptable by occupants, though homeowner engagement (e.g. opening doors, informed control strategies) or innovative solutions (e.g. all Mobile Home Replacements use a demand-controlled conditioning ventilation system that provides additional heating/cooling capacity and distributes the point-source conditioned air throughout the home) are useful for optimal comfort. Monitoring of IAQ has helped verify that these tight, well-insulated homes operate with acceptable IAQ – well within acceptable VOC/CO_2 levels. This is likely a function of the HPH requirement for balanced heat recovery ventilation and designed ductwork.

The 19 HPH completions in 2015 represent 7% of all Efficiency Vermont Certified homes that year. While this is an all-time high – and 2016 is expected to at least double its number of HPHs – there remain challenges in achieving a significantly higher market share. The first is economics. Partner feedback indicates higher upfront costs for a HPH over a code-level home (note, however, the high variance indicated by the two examples in Figure 1). There can be net positive monthly cash flow when factoring in energy savings and a 30-year mortgage. However, even for homeowners with ability to make larger down payments, there is no guarantee of obtaining the additional financing needed for incremental efficiency upgrades. Historically, appraisers don’t add value for efficiency if they can’t demonstrate that it will lead to an increased market price (as shown through comparable sales).

A second obstacle is logistical. The building industry tends towards conservatism, and many builders hesitate to depart from “what they know.” Higher levels of insulation and air tightness require changes to standard building practice, additional training and/or coordination of crews, and potential discomfort with the transition. This is compounded by accompanying investments in different equipment and technologies. However, successful HPHs cannot be approached piecemeal: if built tight, a building must be properly ventilated; to remove the need for an expensive central heating system, several key measures must occur (see Figure 1).

The third primary challenge lies with technology. Building professionals must have tolerance of the "new," whether products or approaches; this adds risk – and a responsibility for post-occupancy follow-up. From the homeowner standpoint, too, there may be financial risk relating to equipment and building durability. Significantly, there is also a burden of learning: innovative HPHs do not necessarily have the same operational requirements as typical homes. For example, there may be more or different filters to change and air source heat pumps may require different control strategies (via equipment settings or room tempering via open doors). HPHs might not be the right fit for the unwilling homeowner.

Challenges notwithstanding, the HPH program continues to gain interest among Vermont builders and homeowners. Data shows that the homes are performing as expected in terms of energy use, and customer satisfaction with the health, comfort, and durability of their home is high. A crucial next step is shifting high performance building techniques from early adopters to a point where they become standard building practice. In order to achieve this goal Efficiency Vermont is focused on the following external strategies:

- Facilitate high performance peer exchange forums among the building community.
- Explore new ways to cost-optimize the high performance building approach; continued energy monitoring of different home designs will inform this work.
- Increase program and case study exposure via web site, papers, and conferences.
- Continue work with lenders, appraisers, and others in the real estate profession to document the value of energy efficiency.
- Create marketing documents that show net positive cash flow when factoring energy costs into the total cost of ownership; this will help builders and developers "sell" the value of energy efficiency to customers.
- Increase homeowner education to ensure mechanical systems run properly, including long-term monitoring of IAQ.
- Increase trainings for HVAC contractors to ensure that mechanical systems can be serviced properly.

Internal to Efficiency Vermont, potential strategies include:

- Evaluate/prove savings methodologies that are less time-intensive than current methods.
- Explore alternatives to data monitoring – both equipment and feedback mechanisms – to reduce resource intensity while retaining ability for technical support.
- Evaluate methods for incorporating other complementary measures such as embodied energy, water usage, and healthy materials.

Conclusions

The HPH program has succeeded in one of Efficiency Vermont's key goals for the program: promoting market transformation towards net zero. In addition to helping to educate builders, architects, and other building professionals, organizational knowledge has increased to a point where most of our 12-person residential energy consultants now handle HPH projects. While we have not yet reached a point where a majority of stakeholders understand that deep energy savings in new homes are achievable, cost-effective, and have tangible non-energy benefits, Efficiency Vermont is continuing to address barriers and is starting to see some appraisers and lenders representing the value of energy efficiency in the total cost of the home. In 2016, a small number of HPHs will be built on speculation for the first time we know of in Vermont – an indicator of progress. We believe that program flexibility and subsequent cost-benefit analyses have been critical to success.

Through 2015, 47 homes had completed successfully in the HPH program, and data indicate that actual electricity savings are close to modeled results. HPHs have increased Efficiency Vermont's capacity for claiming savings by a dramatic amount on a per-home basis. This is countered by the additional resources devoted to the projects, but we are hopeful that lower time investment savings methods – which we continue to explore in 2016 – will partially offset this.

Thermal comfort in point-source heated HPHs is acceptable by most occupants (many of whom are early adopters), though it is not clear that the space conditioning strategy in its current genesis is mainstream-ready. Monitoring of air quality indicates that the homes are performing well without high energy penalties.

Economic, logistical, and technological challenges still exist; further cost-optimization, partner engagement, and exploration of new equipment/controls and strategies is certainly warranted for continued success and program uptake. Internally, the high level of technical support required for our prescriptive approach (and savings verification) also requires evolution to make it sustainable in the longer term.

The 2016 increase in HPH program participation, coupled with strategies to further advance market transformation, shows great promise for the future of the program. As more building and real estate professionals understand the value and positive economics of these homes, many existing barriers are expected to decline; as more HPHs enter the market public exposure to their benefits will increase. We hope that these factors are synergetic, resulting in greater demand for High Performance Homes that will get Vermont closer to achieving its goal of net zero homes by 2030.

References

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