by Matt Berges and Mandy Metcalf

Lessons Learned on Energy-Efficient Affordable Housing

Practical insights on combining deep energy retrofits with affordable housing for 12 Cleveland homes

Renovations of older, distressed homes throughout the city of Cleveland are meeting improved green standards because of incentive programs and funding opportunities that encourage better building. But what will it take for existing homes to achieve more dramatic energy reductions in line with evolving energy codes and standards? Can we achieve deep energy reductions cost-effectively in affordable housing? We wanted to find out.

Over the past two years at Environmental Health Watch (EHW), we managed a HUD-funded technical study of green retrofits of 12 affordable homes.

Six of the houses were upgraded to EHW's deep energy retrofit (DER) specs to achieve at least 70% energy-use reductions. The other six were renovated to Cleveland's "Green Building Standard," which included affordable green housing standards established by Enterprise Community Partners (greencommunitiesonline.org) and energy-efficiency standards set by Energy Star v.2. We are monitoring energy usage (actual vs. predicted) and indoor air quality (IAQ) in all 12 homes.

This HUD technical study has two purposes: 1) to compare the effects on indoor air quality of deep energy retrofits and Energy Star v.2 retrofits, and 2) to determine the costs and benefits of deep energy retrofits for affordable housing. We are in the data-collection phase of the study now. The construction work is complete, so we can share our experience with implementing the DERs and our thoughts on the challenges and opportunities

All of the houses in the HUD-sponsored technical study were built in the 1920s and ’30s, and were in need of complete interior gut renovations (left). The six DER houses received continuous exterior insulation as part of the plan to achieve a deeper level of energy reduction. To save money, the plan was to apply the foam over the existing siding, but after the first house treated this way was tested, the decision was made to strip the remaining homes down to the sheathing (above) to achieve better air-sealing numbers.

presented by these types of retrofits.

The homes were developed by a nonprofit community development organization, Cleveland Housing Network (CHN), for lease-purchase to low-income residents. Other partners in the project included the Swetland Center for Environmental Health at Case Western Reserve University’s School of Medicine, and Intwine Connect, a Northeast Ohio tech company.

Some of the key improvements made to these houses include tighter building enclosures, better windows and doors, more efficient mechanical systems, energy-efficient lighting and appliances, energy recovery ventilation, and increased insulation (see illustration, pages 58 and 59).

Although our deep energy retrofits added almost $26,000 to what was already an expensive gut renovation, this kind of investment is necessary to dramatically alter energy usage. We think the extra effort is justified because high-performance houses can save occupants money and improve comfort and indoor air quality while reducing $C0_2$ emissions. DER specs are extreme compared to today’s building requirements, but they are in line with proposed future energy codes. And the price will continue to fall as these features become more common practice.

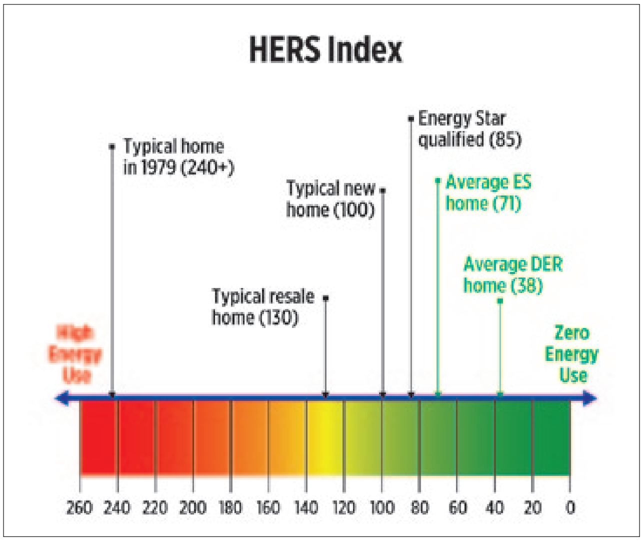
Upgrading the Building Envelope

The six Energy Star houses received well-executed dense-pack cellulose (R-13) blown into wall cavities, and attics were insulated above code levels (R-38 to R-50). Air-sealing was also above average, with final blower-door test-out numbers averaging 1,658 at cfm50 or 6.46 ACH50, which is considered to be in the mid-range for older, renovated homes. Across the six Energy Star houses, numbers ranged from 3.17 to 9.42 ACH50, while HERS scores ranged from 67 to 80, with an average of 71 (see “Measured Performance,” page 60).

The six DER houses received substantial insulation upgrades. Rigid foam board was applied to the exterior in two layers (3 inches total) so that seams could be staggered. When done properly, this upgrade drastically improves airtightness, thermal resistance, and durability all at once. Cavity insulation is a great start, but doesn’t eliminate thermal bridging — the framing makes up 25% to 35% of a cavity wall, creating thermal weak spots that readily conduct heat to the exterior. Without a good exterior air barrier (the foam board in this case), it is very difficult in an old house to improve air-sealing beyond what was achieved in the Energy Star homes (6.46 ACH50 on average).

The added attention to air-sealing and insulation details (including the basement and attic) in the DER homes achieved an average blower-door test result of 623 at cfm50, or 2.15 ACH50. The numbers ranged from 1.61 to 2.75 ACH50, while HERS scores ranged from 34 to 44, with an average of 38.

Attic. The accessible attic spaces in all six of the DER houses were abandoned, which made it easier to air-seal and insulate to R-60. Storage access was discouraged by removing attic staircases in exchange for tightly sealed attic hatches. No mechani-



A HERS score is a measure of a home's energy efficiency based primarily on the results of diagnostic/performance tests using standards established by the Residential Energy Services Network (RESNET). A lower score indicates greater energy efficiency. According to the DOE, a standard new home that exactly meets the energy code scores 100 on the index. The homes in the HUD-sponsored technical study described in this article score well below that.

Four of the DER houses got dense-pack cellulose cavity insulation plus exterior insulation for a combined R-28. The other two DER houses received an additional staggered studwall on the inside, creating a double wall that boosted total wall insulation to R-42.

cal equipment or ductwork was allowed in these spaces. In some Energy Star houses, the attic staircases were left in place and the stairwells insulated, with a platform provided for storage.

In most of the houses, the attic floors had tongue-and-groove flooring over 2x4 or 2x6 second-floor ceiling joists. Once the second-floor ceiling was drywalled, the ceiling joist bays were dense-packed, creating a pretty good air-seal. More insulation was then blown over the top of the floor (up to R-50 in Energy Star houses, and up to R-60 in the DER houses).

Basement. In a DER renovation, basement details are treated with much greater attention than they are in a typical renovation. Controlling below-slab soil gases, moisture, and thermal losses becomes a necessary upgrade to avoid aggravating these problems in a tight house. Much can be accomplished through perfect air-sealing and insulating, though radon has proved able to bypass even the tightest of assemblies (justifying the expense for below-slab passive radon exhaust systems).

In the case of our six DERs, the existing slabs were torn out so that we could make things right from the ground up. Due to the quality and benefit of the added control layers, it was considered to be worth the added cost.

Upgrading Doors and Windows

For this upgrade spec, we asked our existing suppliers for suggestions on how to achieve the lowest U-factor at the most reasonable price that they could provide. In the DER houses, we ended up with affordable Alside vinyl windows with U-factors between 0.18 and 0.22.

In many cases, we were able to reduce the number of windows to help pay for the better units. North-facing windows were avoided or eliminated when there were more than necessary. Some three-window bay sections were removed and replaced with a flush wall and two upgraded casements, which resulted in easier thermal detailing and reduced heat loss.

The added foam (and double studs in two cases) created extra-thick walls that raised a question about where to locate the windows: flush with the outside edge ("outie") or the inside edge ("innie"). While I favor the innie for performance and protection from the elements, the outie costs less because it is very straightforward to install, and more in line with standard practices. We ended up using both approaches (see illustration, page 62).

We specified R-7 doors with thermally broken door frames, but due to timing and availability not all the houses got this upgrade.

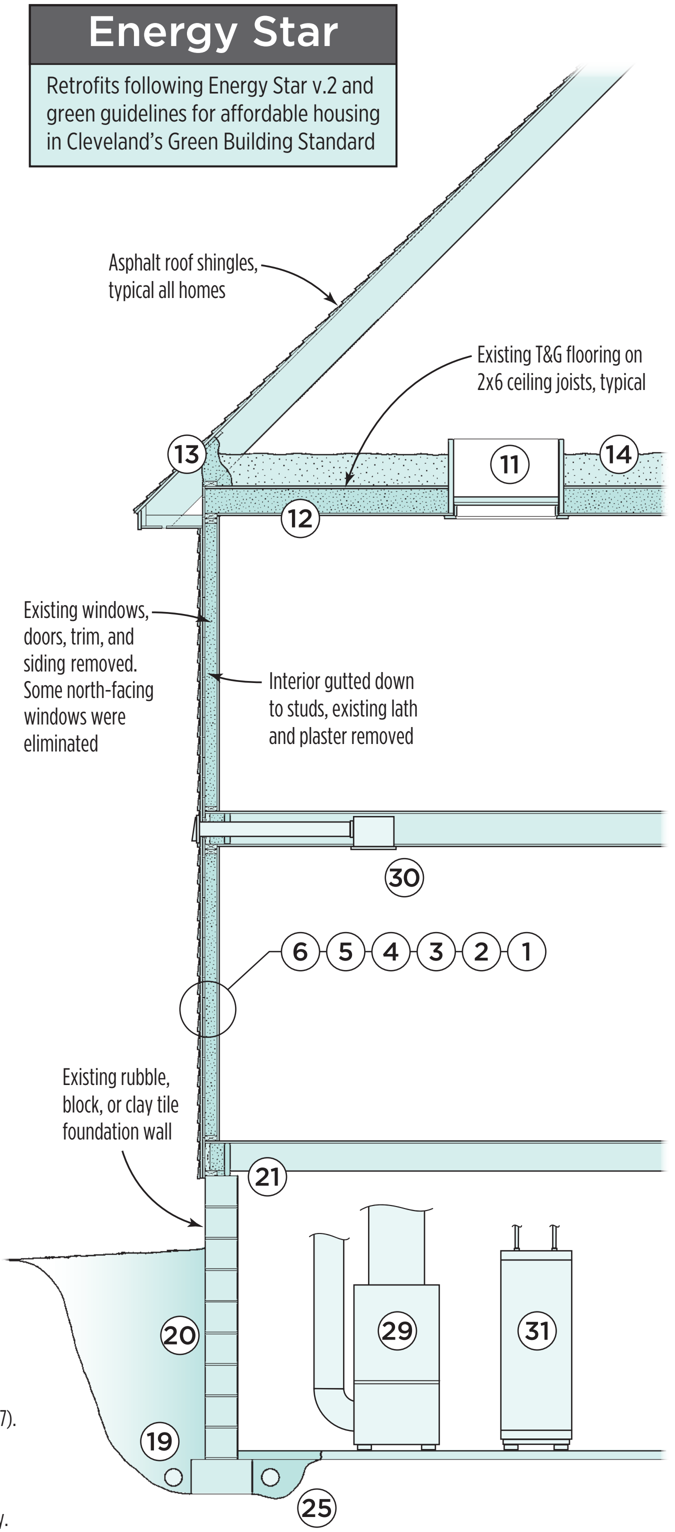
Hvac Systems

The six Energy Star houses were supplied with typical exhaust-only ventilation, using point-source bath fans to meet the ASHRAE 62.2-1989 ventilation standard. These fans run continuously on low speed and have a motion sensor to boost speed when the bathroom is occupied. In the six DER houses, a balanced energy recovery ventilation (ERV) system was used instead of exhaust-only ventilation.

Heating and cooling. We used three different hvac systems in the 12 retrofitted houses. The standard system in the six Energy Star houses was a natural-gas power-vented 71,000-Btu/hr furnace with 13-SEER AC. The peak heating loads were projected to

Key Improvements to Test Homes

Six homes in the HUD-funded technical study were renovated to Energy Star standards, and six to a more demanding deep energy retrofit specification. All 12 homes are being monitored to compare actual to projected performance, and to evaluate the costs and benefits of the two different standards.



Energy Star

Retrofits following Energy Star v.2 and green guidelines for affordable housing in Cleveland's Green Building Standard

Building Envelope

Energy Star	① Dense-pack cellulose (R-13) blown into stud bays
	② Existing board sheathing, seams air-sealed with foam
	③ Housewrap installed over board sheathing
	④ Window U-value = 0.3 to 0.31
	⑤ Walls furred out with 1x vertical strapping
	⑥ New vinyl siding and trim
DER Upgrade	⑦ Existing stud bays dense-packed (R-13)(1)
	⑧ Two layers of $1\frac{1}{2}$" rigid XPS (R-15) foam placed over existing board sheathing acts as thermal/air barrier. Seams staggered and woven at corners; all seams taped.
	⑨ Housewrap installed over foam
	⑩ Window U-value = 0.18 to 0.22

Foundation Wall

Energy Star	⑲ Existing foundation excavated down to footing, perimeter drains added
	⑳ Walls left uninsulated; exterior face waterproofed(2)
	㉑ Rim-joist area filled with dense-pack cellulose
DER Upgrade	㉒ Foundation walls insulated/waterproofed(3)
	㉓ Insulation at grade protected by coil flashing or cement parge coat
	㉔ Rim-joist area sealed with dense-pack cellulose encapsulated in pieces of rigid insulation or sprayed with closed-cell

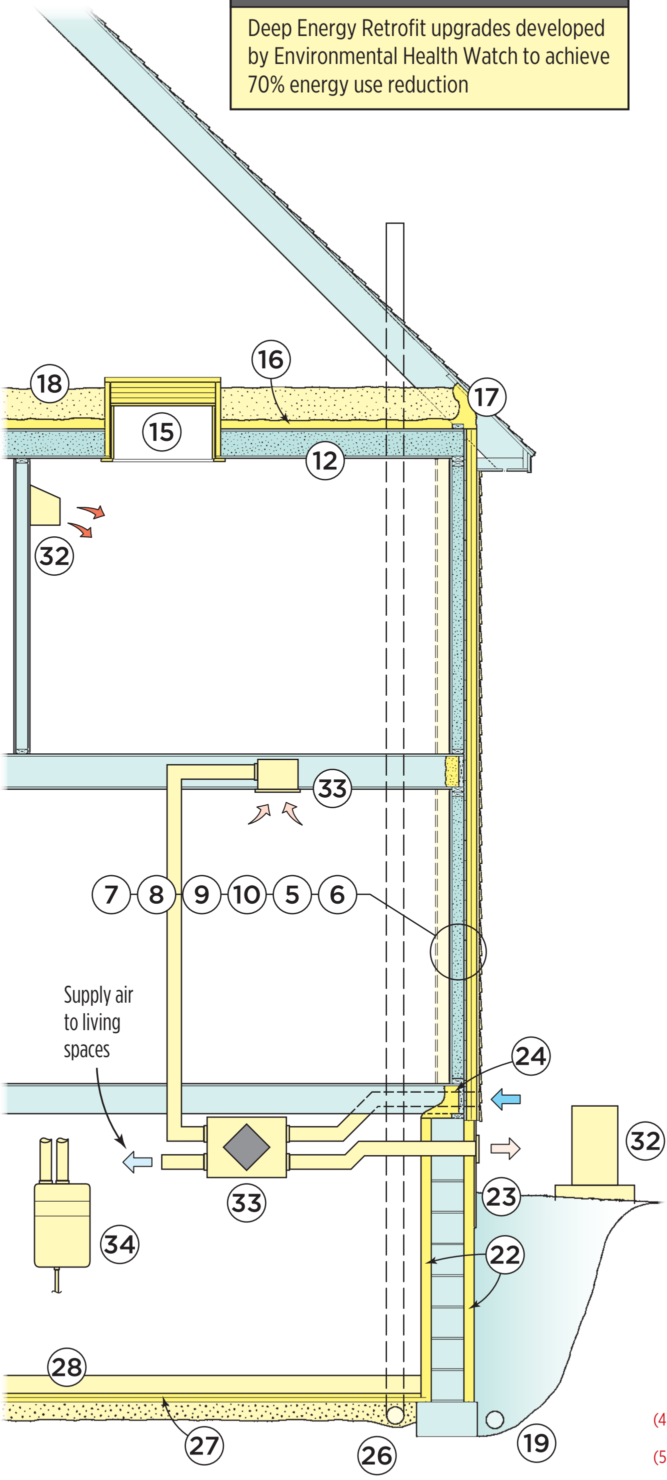
(1) Exterior double studwalls built in two DER homes. Walls insulated with dense-pack cellulose (R-27).

(2) On two Energy Star homes, fiberglass-reinforced plastic (FRP) wall panels were installed to interior side in lieu of exterior waterproofing.

(3) Rubble foundations received 2" to 3" of closed-cell spray foam (approx. R-15) on outside face only. Two layers of $1\frac{1}{2}$" rigid XPS foam (R-15) were installed on both sides of existing block walls. Seams were staggered and woven at corners; all seams were taped. Walls with interior foam were furred out with metal studs and cementitious board. In both cases, the exterior foam served as a drainage plane.

DER Upgrade

Deep Energy Retrofit upgrades developed by Environmental Health Watch to achieve 70% energy use reduction



Attic

Energy Star	(11) Existing attic stairs removed, uninsulated access hatches installed (4)
	(12) Joist bays were dense-packed (R-20) after ceiling was drywalled
	(13) Heel portion of rafter bays sealed with dense-pack cellulose
	(14) Blown-in loose-fill insulation (R-30) installed on top of attic floor
DER Upgrade	(15) New insulated access hatches installed; encased in rigid insulation (R-50)
	(16) Attic air-sealing achieved with 2″ closed-cell foam sprayed across entire attic floor (5)
	(17) Heel portion of rafter bays sealed with spray foam, connecting the wall and attic air barriers
	(18) Loose-fill insulation (R-40) blown on top of existing T&G flooring or spray-foam air barrier

Basement Slab

Energy Star	(25) Existing 2″ rat slabs cut to accommodate below-slab perimeter drainage (6)
DER Upgrade	(26) Existing slabs removed. Passive subslab radon mitigation systems installed in layer of 4″ gravel.
	(27) Two layers of 1″ XPS insulation (R-10) installed on top of gravel, integrated with wall insulation. Seams staggered and woven at corners; all seams taped.
	(28) New 4″ reinforced slab poured over XPS insulation

Mechanicals

Energy Star	(29) **Heat/cooling:** 70-kBtu furnace with a 13-SEER AC
	(30) **Ventilation:** Point-source bath fans running on continuous low speed, with a motion sensor to boost speed during bathroom occupancy
	(31) **DHW:** Electric hot-water heater, typical
DER Upgrade	(32) **Heat/cooling:** Combination electric heat-pump/gas hot-water circulation system or mini-split/heat pump (7)
	(33) **Ventilation:** ERV system; stale air continuously pulled out of kitchen and bathrooms, fresh air ducted and supplied to living spaces and bedrooms
	(34) **DHW:** tankless condensing boiler

(4) Existing stairs left in place in two Energy Star houses, complicating installation of the thermal barrier.

(5) Two homes were treated differently: An uninterrupted drywall ceiling was installed before interior walls.

(6) Energy Star homes that tested positive for radon received active subslab radon mitigation systems.

(7) Mini-split/heat pump installed in three most efficient DER homes with lowest heat loads.

Measured Performance

House	HERS Score	Air @ cfm50	Sq. Ft.	ACH50	Annual Load (MMBtu)	Projected Load (kBtu/hr)	Projected Operating Cost/yr.
ES 1	80	2,985	2,399	9.42	94.2	47.9	$2,794
ES 2	67	1,167	2,674	3.17	68.9	37.7	2,604
ES 3	71	1,623	2,708	4.47	79.1	41.7	2,639
ES 4	75	1,687	2,250	5.73	75.5	56.3	2,472
ES 5	67	1,197	2,538	8.19	54.4	31.5	2,371
ES 6	68	1,290	2,001	7.76	57.8	31.1	2,269
Avg.	71	1,658	2,428	6.46	71.7	41.03	$2,525
DER 1	37	511	2,268	1.93	5.3	9.8	$1,406
DER 2	37	441	2,091	1.62	4.5	11.7	1,368
DER 3	44	793	2,250	2.68	10.7	15.5	1,858
DER 4	38	832	2,344	2.75	8.2	14.8	1,509
DER 5	38	644	2,073	2.30	6.8	12.7	1,420
DER 6	34	518	2,535	1.61	3.5	11.8	1,552
Avg.	38	623	2,260	2.15	6.5	12.72	$1,519
ES vs. DER	-46%				-91%	-69%	-40%

House-by-house performance data shows that, compared with the Energy Star (ES) houses, the additional steps taken in the deep energy retrofit (DER) houses significantly reduced energy usage and projected operating cost.

average 41,000 Btu/hr in the Energy Star houses.

In the DER houses, projected peak heating loads were reduced by 69% on average to 12,700 Btu/hour. This amounted to a 91% reduction in the annual heating requirement (MMBtu), so we were looking for much smaller capacity systems.

For the first three DER houses, we used fully ducted electric heat-pump and gas-powered hot-water combination systems. These systems use traditional ductwork, with an air handler tied to a heat and AC coil instead of a furnace. Their primary source of energy comes from the electric heat pump. For backup heat (and when this option is more efficient than the outside heat pump), water heated by a Navian 98% efficient condensing tankless hot-water heater circulates through the heat coil/air handler.

In the DER homes, existing slabs were removed so that new plumbing, a passive radon-mitigation system, and rigid foam insulation could be installed. The interior foundation wall foam was applied prior to the slab pour, making it easier to keep the below-slab foam "pan," as shown here, continuous with and connected to the wall foam.

For the last three DER houses (those with double studwalls and the lowest heat loads) we used wall-mounted ductless mini-split air-source heat pumps. This setup relies on point-source heating and cooling, along with minimal heat loss and internal circulation fans for distribution and circulation (see photo, page 63).

Lessons Learned

The experience of installing these different hvac systems taught us some things about what does and doesn't work for energy-efficient affordable housing. The assumption going into the job was that reducing the heat load by 69% would result in cost savings for the mechanicals, and that smaller hvac systems would help pay for the super insulation and other upgrades. In reality, we ended up paying a few thousand more for the smaller-load systems.

The hvac systems presented a number of challenges. Standard systems are clearly easier, despite the fact that they are all too large for the loads that we were trying to manage. You can get

Most foundations in the DER houses needed waterproofing anyway, creating an opportunity to add foam to all of the foundation exteriors. Most received a double layer of rigid foam (far left); in two cases, spray foam — which served as a drainage plane — was the better choice (left).

pretty good efficiency out of a new furnace at a very low cost, so there is not much room for savings with alternative systems. They don't yet make furnaces small enough to be right-sized for super-efficient homes, so we were forced to either make the house less efficient or try out options beyond the typical furnace.

Occupant learning curve. Despite our confidence in the heat-load and system-capacity projections, there was great concern for how the mini-split systems would work out for the average occupant. On paper, they are sufficient to keep the house comfortable, but most people are used to large, oversized furnaces that can blast the house to 80°F in a short time. But mini-split systems work differently. They are sized closer to the projected load of the home, and therefore the system may struggle to keep up with occupant expectations. We provided education about the heating systems, but the families were not necessarily interested in changing their habits just for the sake of this study. Mastering the programmable thermostat was also a challenge for some of the residents, though in many cases, it was device failures that created the problem (the thermostats would not hold the correct time, and they messed up the heat schedule so badly people gave up on programming them).

Also, ongoing maintenance costs of the mini-splits were a concern for CHN, the developer. CHN believes that ongoing maintenance costs will be higher overall, due to the limited number of experienced installers for the newer systems.

Contractor learning curve. The most cost-efficient and energy-efficient option might not be the best option — at least not yet. A typical furnace is robust and can run for years with a dirty filter. It is powerful and oversized, so it reacts quickly to extreme conditions. It is cheap and available, and it is fairly simple for any hvac contractor to install, repair, or replace.

By contrast, the mini-split/ERV system — which is the most efficient and should be one of the most affordable options, considering the simple install and reduced duct work — presented the most problems. Few local hvac contractors and suppliers had experience with this product, and the challenge of getting these systems designed and running properly on the first attempt was more expensive than we expected, reducing our projected savings.

Overall, the hvac upgrade cost on the DER homes (mini-split/ERV system) was roughly $3,000 more than the base system (furnace and exhaust-only bath fans). About two-thirds of this was the cost of the ERV, with the rest going to a consultant for basic commissioning (mainly balancing of exhaust and intake ventilation rates), a process with which the installers and developer were not familiar. (Commissioning — a formal quality-assurance process that ensures the equipment operates as designed — was not seen as part of the standard scope-of-work and was an upgrade, which many of the hvac contractors were unable to provide.)

Ventilation vs. comfort. The original idea of delivering fresh air directly to the bedrooms proved to be problematic in our DER mini-split houses. When the bedroom doors were closed, cool air delivered to the rooms in winter led to complaints of discomfort. We used "bath fans" in the common space near the mini-splits to increase circulation of conditioned air to the bedrooms, but it was not enough to offset the chilling effect of the ERV air.

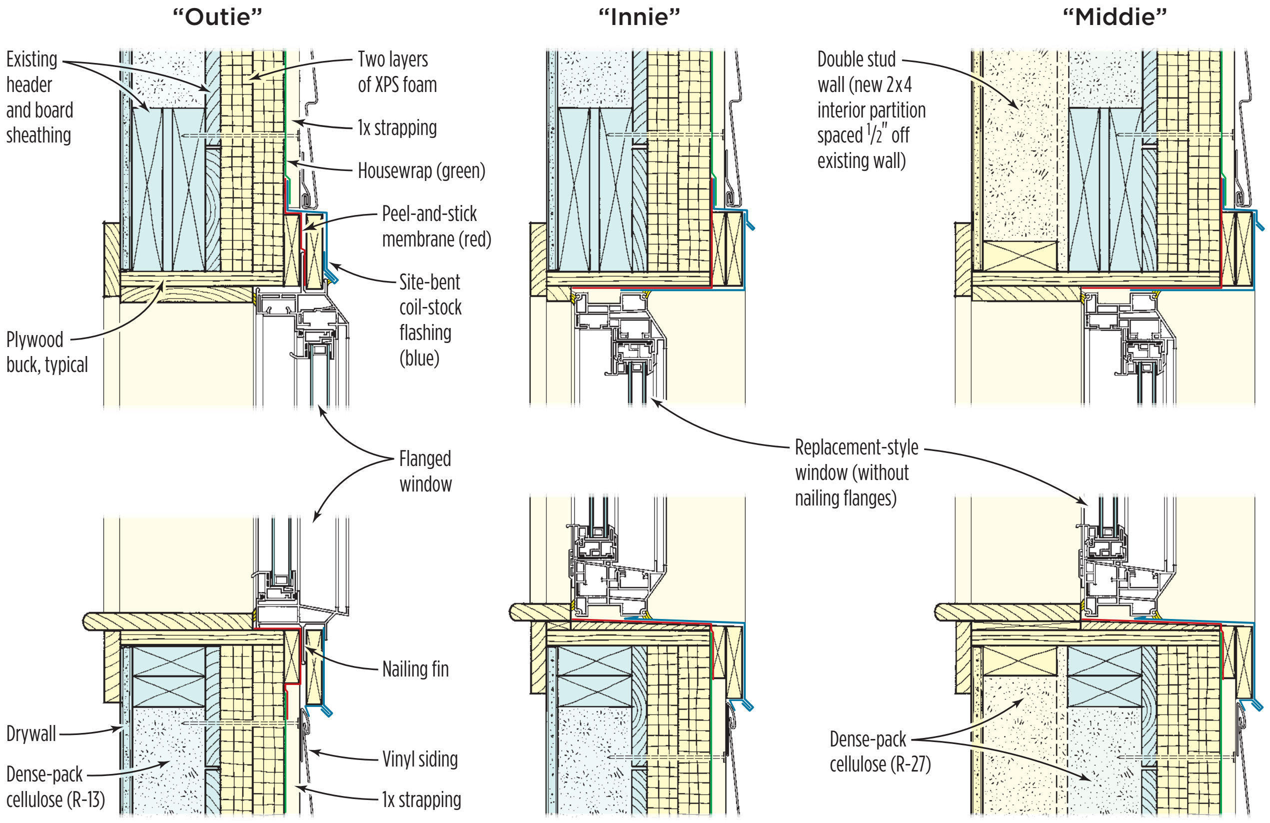
To correct this, we disconnected the fresh-air supply to the bedrooms, allowing it to dump into the basement instead. This way, the cooler fresh air mixes with backup heat at the point when the heat pump becomes less efficient. In other cases, we diverted the fresh-air supply, dumping it out under or near the mini-split heat source to be mixed there. (In the ducted houses this was not an issue, since the fresh air blows into the cold-air return, where it is further filtered, heated, and mixed with the house air.)

With a more efficient ERV, incoming air temperatures would not be quite as cold. For this project, we were trying to find the balance between price and efficiency and locally available equipment. In the future, however, we would likely use a more efficient ERV, with simplified and reduced ductwork that might balance out the upgrade cost.

Also, occupant education and property management efforts must include some attention to maintenance of the ERV system. If filters are not cleaned, the potential exists for reduced airflow and functionality. While the need to clean filters on an ERV is less frequent than with a typical furnace, the need for ensuring fresh air is much more important in a DER, or otherwise tight house.

Dependence on mechanical ventilation. In a very tight home, occupants depend on mechanical ventilation to deliver fresh air and remove contaminants, moisture, and odors. When ventilation stops working, IAQ suffers. The need to ensure that the ventilation stays on in our tight DERs presented some challenges that we are still evaluating. For example, during a few of our home visits, we discovered some instances where the ERV system was not running. In one case, when addressing a complaint about a "stuffy" house, we found that the ERV unit was unplugged. In another, the occupant suggested that things seemed different since she cleaned her ERV filter; in fact, the ERV was off. As it turned out, two of the six ERV units we installed require that you hit the reset button after opening the ERV cabinet, but we didn't know about this and didn't warn the occupant. These experi-

DER Window Details



Several approaches were used to mount windows in the extra-thick walls. Windows mounted toward the inside ("innies") or middle ("middies") of the wall are better protected from the elements but are difficult to install properly; "outies" are more exposed, but they're easier to install because the details are similar to conventional window alignment. Various types of self-adhering membranes and brake-bent profiles were used to flash the openings.

ences are relevant for any project with an increased focus on airtightness.

Occupant control. The ASHRAE 62.2 standard makes ventilation automatic, taking it out of the hands of the occupant. This has been determined to be a safe approach toward ensuring good IAQ, although there are challenges in that the ventilation rate is certainly too low when there is a house full of people smoking or cooking, and it is probably too high when no one is home. It would be nice to give the occupants more control over their ventilation, if we could trust that they would use it "right." It would be even better if the ventilation controls were based on IAQ levels (for example, if measured CO_2 and VOC levels in the home would turn on the ventilation), with boost switches provided for cooking, showering, smoking, and so on.

Demand-controlled ventilation has long been used in commercial buildings, but now there are some residential systems being developed. Ventilation does consume a lot of energy, and that is something to be considered as part of an overall energy reduction strategy. Under-ventilation can be dangerous, but over-ventilation can wipe out all of the energy savings gained from an airtight, super-insulated shell. For now, ASHRAE 62.2 is the accepted balance between the two.

Cost Considerations

These DER upgrades added nearly $26,000 to what was already a substantial gut renovation. This added cost would be a problem for most market-rate builders and developers, since the sales price of a house is based on its appraisal, which is based on comparable sales. Comparable sales are hard to find in a depressed housing market, so spending this much extra could be considered "over-improvement" from a short-term investment standpoint. For a developer without subsidy, it is impossible to stay in business if costs are higher than sales prices.

Return on investment. Achieving Energy Star standards took the homes from HERS scores in the 180 range to the low 70s. The Energy Star homes initially operated at an estimated average cost of $7,842 per year, and that was reduced to an estimated average cost of $2,525 per year.

Spending the extra $25,775 on the DER homes further reduced operating cost to an average projected annual cost of $1,519, and reduced HERS scores to an average of 38. The simple payback on that investment is 26 years, but rising utility costs and reduced installation costs (as experience is gained and these practices become more commonplace) could shrink the payback period quickly.

We hope that, with enough successful case studies, the energy-savings payoff of retrofit strategies like this one can become a part of how buyers, lenders, and appraisers assign value to houses. There will always be resistance to improved performance specs that cost more up-front but don't immediately translate into higher sales prices. But the DER homes have other benefits as well — including durability and controlled indoor air quality — that are more difficult to measure. Over time, we hope builders can overcome resistance by educating clients on all of the benefits of DER.

In the most efficient DER homes, wall-mounted mini-splits were used in the first- and second-floor hallways. Bath fans were installed nearby to pull conditioned air from the hallways into the bedrooms, but comfort issues led to relocation of air outlets from the continuously running ERV.

Upgrade Costs for DER Houses*

Remove existing siding	$2,000
Misc. framing	$500
Exterior wall foam, mat'ls & labor	$12,600
Under-slab foam, mat'ls & labor	$600
Foundation insulation & finish	$3,000
Window upgrades	$900
Entry door upgrade	$375
Insulation (attic & interior)	$1,000
Tankless hot-water heater	$1,800
Hvac (ERV and commissioning)	$3,000
Total avg. DER upgrade cost	$25,775

*Incl. builder markup

The largest additional cost in the DER upgrades was for rigid foam insulation at the foundations and slabs and on the exterior walls (siding costs are excluded because siding had to be replaced anyway). At current fuel prices, the total upgrade cost pays back at a rate of about $1,000 per year. The authors consider the improvements to occupant comfort and building longevity to be worth the investment.

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