Energy Retrofit of a Typical Three-Story Multifamily Building

Measured Results and Lessons Learned

by Jamie Lyons, PE, and Margo Thompson

THREE-STORY WALK-UP apartment buildings are common throughout the United States. Many of them were built 30 to 40 years ago. Given this vintage, the vast majority of these buildings are prime targets for energy retrofits, along with sorely needed improvements in comfort and indoor air quality (IAQ). In 2012, our company, Newport Partners, oversaw a deep energy retrofit on one of these buildings. The company, working with our partners, designed a retrofit scope to achieve ~50% energy savings while remaining cost-effective and working within the constraints of a tenant-in-place retrofit. We oversaw the implementation of the energy efficiency measures (EEMs) and measured actual performance once the work was completed. In other words, we found out what really happened, and how close our projections were.

Three-story walk-up apartment building at Bay Ridge.

We found that substantial energy savings can be achieved through standard, noninvasive energy improvements—and it doesn't have to cost an arm and a leg! With careful diagnostic testing and energy modeling at the outset, we identified a set of energy efficiency measures that are conventional, are cost-effective, and achieve over 40% energy savings. And the noninvasive nature of the improvements meant that the occupants could remain in their homes during construction.

A LITTLE BACKGROUND ON THE PROJECT

This multifamily development—Bay Ridge Apartments—is located in Annapolis, Maryland. It consists of a total of 186 apartments in 16 separate three-story buildings. (See photo tk.) The apartments are a mix of 700 ft^2 two-bedroom and 925 ft^2 three-bedroom units configured as shown in Figure 1. All of the build-

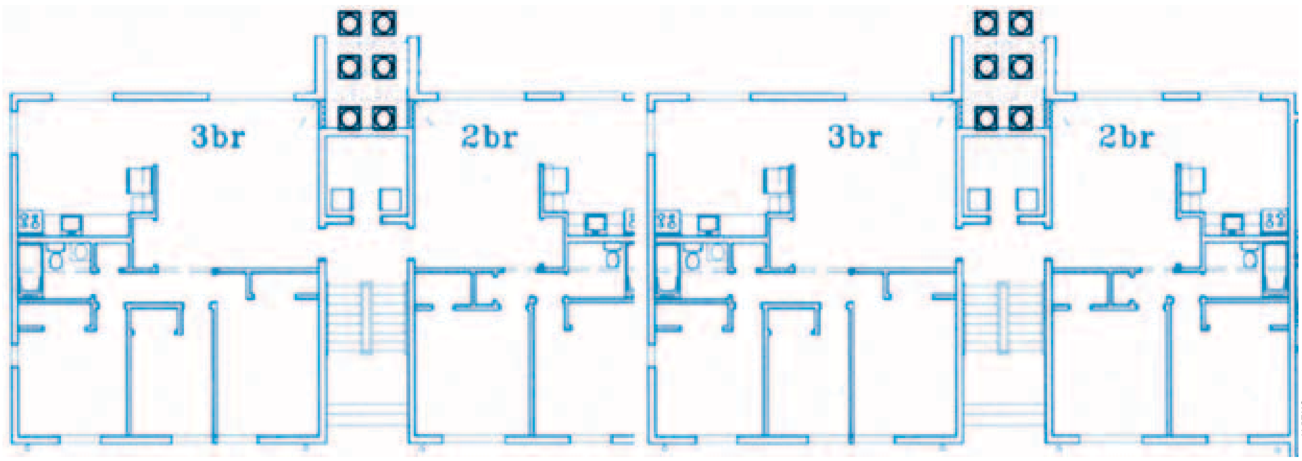

Figure 1. Floor plans for the 2- and 3-bedroom dwellings. Note separate HVAC closet.

ings are constructed of concrete block with brick façades. Each unit has its own gas furnace and split-system A/C equipment for space heating and cooling. Central water-heating equipment is located in a separate mechanical room in each building, accessible only to the property manager. It is important to note that residents pay for their own electricity—that is, their lighting, A/C, and plug-in appliances—but the building owner pays for the natural gas that fuels the dedicated furnaces and central water heater. Therefore, the residents have little motivation to lower the set point on the heating system thermostat, or to conserve hot water.

Working with the property owner, Landex Companies; the project sponsors, DOE's Building America Program, the Maryland Energy Administration, and the Maryland Department of Housing and Community Development; the auditor, PEG Environmental Solutions; and the general contractor, Hamel Construction, Newport Partners developed two separate scopes for the project. We developed a base retrofit scope for all 186 apartments. This scope targeted a 30% energy savings relative to preretrofit energy use. We then developed a more challenging deep retrofit scope for one 12-unit building. This scope targeted at least 50% energy savings. While the term deep energy retrofit typically implies extensive improvements to the building envelope, we could not undertake extensive improvements because the residents remained in their apartments while the work was being done. The project partners simply used the terms base and deep scopes as a convenient way to differentiate the two energy packages.

ENERGY EFFICIENCY MEASURES

Starting with a base scope that would achieve roughly 30% energy savings, Newport's job was to identify measures that would achieve additional savings and—of course—do so cost-effectively. To evaluate the effectiveness of potential EEMs, we used

- annual energy and energy cost savings (modeled using REM/Rate);
- implementation costs (estimated in conjunction with the project team); and
- cost-effectiveness (calculated as savings-investment ratio).

The savings-investment ratio (SIR) calculations were especially conservative, because we de-rated the modeled energy savings for each EEM by 15% to account for reduced performance over its useful life. We developed REM/Rate models for the two- and three-bedroom apartment configurations and settled on the three-bedroom exterior unit to represent energy consumption and projected EEM energy and cost savings. We couldn't really true up the modeled energy consumption to actual historical data, since the natural-gas consumption for space and water heating was billed for the entire building, not for each individual unit. Furthermore, most apartments had very inconsistent occupancy, and many of them were vacant for part of the year.

But calculating costs and energy savings was only part of the job. Certain characteristics of the project made additional considerations not only necessary, but often the deciding factor. These considerations included

- compatibility with a tenant-in-place rehab model, where the residents returned to the apartments every evening;
- compatibility with a rehab scope that did not include removing the façade; and
- avoidance of unintended consequences. For instance, installing rigid foam on the interior of the wood-framed walls would have led to moisture problems down the road, given the poly vapor barrier that was located between the wood framing and the concrete block (see Figure 2).

The vetting of potential measures in light of these factors involved extensive dialogue with the general contractor, additional site inspections, and additional analyses, such as temperature and moisture modeling related to adding interior insulation.

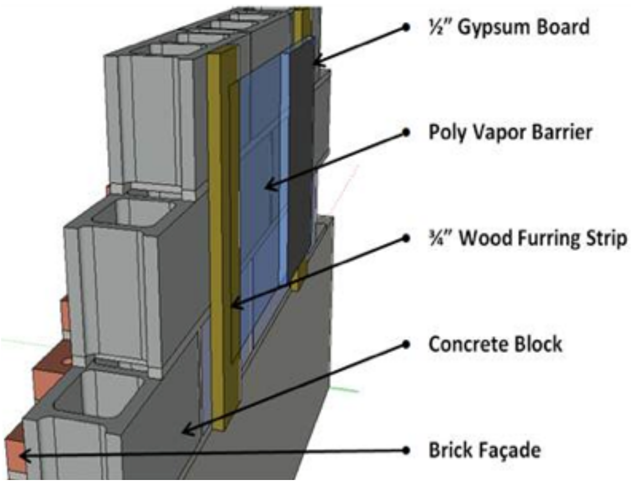

Figure 2. Exterior wall section showing limited depth furring and poly layer on inside face of concrete masonry units (CMU). Adding interior insulation board would have created a cold surface at this poly layer where moisture-laden indoor air leakage would condense.

SOURCE: PEG ENVIRONMENTAL SOLUTIONS

Membrane application followed by SPF application to seal off top of duct bulkhead from attic

Table 1. Sample of Rejected EEMs for the Deep Energy Retrofit Scope

EEM	Description	Primary Reason for Rejection
Add insulation to the interior side of the exterior walls	Install 1 in rigid foam (R-5) to interior gypsum face of all exterior walls, since brick façade and siding were to be left intact. Measure would include extensions for windows, outlets, switches, etc. Cavity insulation was not an option, due to limited depth behind drywall.	Temperature/moisture analysis showed strong risk of winter season condensation within wall assembly, due to interior air leakage to continuous layer of poly vapor retarder within exterior wall assembly.
Install ultra-high-efficiency furnace	Specify 95+% AFUE furnace with ECM blower motor, to go beyond 92.5% AFUE, 2-stage furnace used in base scope.	Hybrid heat pump-furnace system was found to be more cost-effective in terms of SIR.
Upgrade windows	Install U.29, SHGC.27 windows, to go beyond U.35, SHGC.35 windows used in base scope.	Limited energy savings w/SIR < 1 relative to base scope. These results were driven by relatively modest window area and lower design heating/cooling loads.

While many potential EEMs ended up in the scrap heap, the final package met our three primary goals:

1. It would achieve measurable energy savings.
2. It was cost-effective and in line with the project budget.
3. It was feasible within the constraints of the building, the residents, and the local building regulations.

Table 1 lists a few of the more interesting reasons why some measures were rejected. This information may be useful to planners who are designing similar projects.

THE MEASURES THAT MADE THE CUT

Table 2 summarizes the energy efficiency measures that were included in the base retrofit package, as well as those selected for the deep energy retrofit. The REM/Rate models predicted 35% and 52% energy savings respectively—probably a conservative estimate, since we did not include any utility price escalation. We set energy prices at $0.12/kWh and $1.50/therm. These were regional averages when the project planning was under way (even though the gas number looks quite high now). Notice that some of the measures had an SIR < 1. Because we wanted to address ventilation and IAQ while achieving 50% energy savings, we included some measures, such as whole-house mechanical ventilation, that provided no significant energy benefit.

Table 2. EEMs Selected for Base Energy Retrofit and Deep Energy Retrofit

Building System/ Component	PreretrofitCondition	Base Scope	Deep Scope	SIR *(Deep Scope Relative to Base Scope)*
Attic insulation	R-19	R-49 w/sealing of duct bulkhead	Same as base scope	N/A
Attic air sealing	Leaky	Limited spot air sealing from within top-floor units where leakage sites were accessible (e.g., bath fan housing) as part of overall unit air sealing	Air sealing of attic floor penetrations from attic side w/SPF, including all MEP penetrations, top plates of interior walls; done in addition to limited spot air sealing in base scope	0.5
Windows	U.50, SHGC .40	U.35, SHGC .35	Same as base scope	N/A
Whole-house mechanical ventilation	None	Outside air duct in RA plenum (no run-time controls or damper)	66 W, 61% SRE ERV to provide CFM60 continuous; ASHRAE 62.2-compliant flow rates	0.5
Bathroom ventilation	Nominal CFM_{50} fan >0.6 sone	40W, 110 CFM, 6 in bath exhaust w/ integrated humidity-sensing controls	Same as base scope	N/A
Duct air sealing	Supply trunk not sealed; 3rd-floor units located in open-top bulkhead	Aerosolized duct sealing applied; open-top duct bulkhead in attic sealed and insulated	Same as base scope	N/A
Space heating	80% AFUE gas furnace	92.5% AFUE, 2-stage gas furnace (36/60 kBtu)	Hybrid heat pump-furnace: 8.50 HSPF, 92.5% AFUE, 2-stage furnace backup (36/60 kBtu) w/40°F transition temp; cooling: 15 SEER, 1.5 ton A/C	1.3
Space cooling	10 SEER A/C unit	15 SEER, 1.5 ton A/C		
Domestic water heating	Central gas-fired storage; 100 gal 0.54 EF (serving 12 units)	100 gal central gas-fired storage; 95% thermal efficiency	Solar hot water w/3 flat-panel collectors; closed- loop glycol; solar storage tank upstream of 100 gal 95% thermal efficiency water heater	0.5
Lighting	100% incandescents	100% CFLs for all permanent luminaires	In addition to 100% CFLs for permanent luminaires, supply resident w/CFLs for all plug-in fixtures	13.0
Refrigerator	Non- Energy Star	Energy Star	Energy Star	N/A
Energy feedback system	None	None	Energy Dashboard to educate residents on electrical use	1.8
Predicted energy use reduction		35%	52%	

IMPLEMENTATION, COMMISSIONING, AND SHORT-TERM TESTING

As the work was completed, our team was able to inspect and test the impact of each EEM and the quality of installation. As in many retrofits, some things went as expected while others did not.

Air Leakage Reduction

Air sealing the building shell was a major target for energy savings, with very leaky preretrofit blower door levels, ranging from 15 to more than 19 ACH_{50} (see Table 3). Air sealing resulted in a 63% infiltration reduction in the deep-scope units. Note, however, that the improvement over the base-scope reduction was pretty small. This was because it became more

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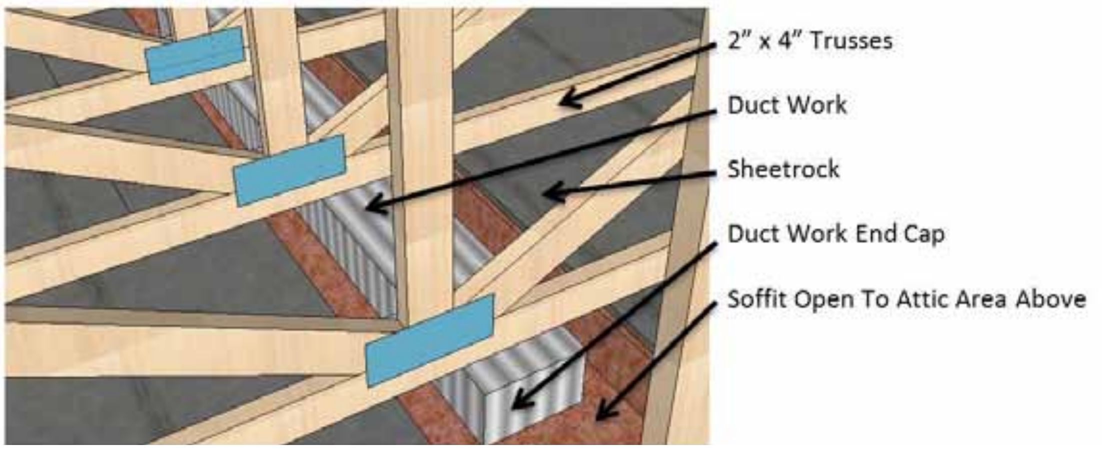

Figure 3. Diagram of duct bulkhead open to the attic space.

As Table 3 indicates, our guarded blower door test results showed that 81–82% of the total leakage was leakage to the outdoors. This seemed rather skewed, since the ratio of exterior to interior surface area was much lower—varying from 24% to 66%, depending on where the apartment was located. While we didn't expect an exact correlation between the air leakage ratio and the surface area ratio—our results appeared high. We think this is because the interior units adjacent to stairwells had no guarding across the firewalls. Some of the air leakage that appeared to be leakage to the outdoors was probably traveling past the firewall into apartments on the other side. Setting up guarded tests, gaining access to apartments, and using appropriate leakage numbers in models are all challenges for this type of project.

difficult to obtain big improvements once the major leaks were sealed. We did, however, see improvements attributable to the additional attic-side air sealing conducted on the deep-scope building alone. Third-floor units in this building averaged about 6.4 ACH_{50}, while third-floor units in the base-scope building averaged 7.3 ACH_{50}.

Challenges of Air Leakage Testing in Multifamily Buildings

Anyone who has conducted blower door testing in multifamily buildings is familiar with the difficulties involved in setting up the tests properly, so as to get accurate and useful results. This is especially true in older buildings, where it may be hard to identify all the air leakage pathways. This was certainly our experience at Bay Ridge.

We wanted to distinguish between air leakage to the outdoors and air leakage between apartments. This required that we do both guarded and unguarded testing. Unguarded testing is pretty straightforward. You simply set up the blower door in the hallway door of the apartment in question and run the test as usual. The results you obtain reflect total leakage; they do not indicate whether the leakage is to the outdoors or to another apartment. A guarded test, on the other hand, requires several blower doors set up to pressurize the apartment in question as well as adjacent apartments. It can be difficult to identify all of the hidden leakage pathways from an apartment to other conditioned spaces—which is necessary to set up a guarded test.

Duct Leakage Reduction

The initial inspection of the attic in the deep-scope building revealed that a bulkhead containing a primary HVAC trunk line was completely open to the attic along its entire length as well as at both ends (see Figure 3). Not only was any air leaking from the duct migrating directly into the attic, but the uninsulated duct was exposed to the harsh attic temperatures. In addition to wasting energy, this condition created comfort and IAQ problems. Therefore, we enclosed the bulkhead with a membrane and covered the membrane with spray foam to create an air-sealed lid on the bulkhead. The exposed spray foam insulation was code compliant because the attic was separated from the interior of the building by a minimum of ½-inch of gypsum board on the ceiling.

In addition, we air sealed all the ducts, using an aerosolized duct sealant system. We also replaced a leaky, water -damaged plywood return plenum with an insulated sheet-metal plenum. Overall, these duct-sealing efforts were very successful; duct leakage at CFM_{25} pre-retrofit was 481, compared to post-retrofit leakage in the base and deep energy retrofit buildings of 180—a 63% improvement.

Table 3. Building Leakage: Blower Door Test Results

	Max ACH_{50}*	Min ACH_{50}*	Avg ACH_{50}*	Avg ACH_{50} Reduction	Avg ACH_{50} of 3rd-Floor Units	Ratio of Outdoor to Total Leakage†
Preretrofit condition	19.4	14.8	17.1			
Postretrofit base-scope units (n = 18)	8.4	5.1	7.0	61%	7.3	82%
Postretrofit Deep-scope units (n = 11)	8.3	5.2	6.4	63%	6.4	81%

** Leakage to outdoors only, based on guarded blower door testing. This value was used in calculating energy savings from air sealing, not total (or unguarded) blower door leakage.*

† Value determined by comparing guarded blower door results to unguarded blower door results.

HVAC UPGRADE

The preretrofit HVAC systems were approximately 15-year-old furnaces and split-system A/C units. Labeled efficiency levels were 80% AFUE and 10 SEER, respectively. The base-scope retrofit upgraded these systems to a two-stage, 92.5% AFUE condensing furnace and a 15 SEER split A/C system. Given the utility rates, and the building's location in a mixed climate zone (4,700 HDD; 17°F heating design temperature), our team investigated hybrid heating options involving both electric and natural gas. We ruled out a heat pump-only approach because the electrical service to the apartments lacked the capacity required for electric-resistance backup heating.

Our energy-modeling and economic analysis concluded that upgrading the base-scope HVAC equipment to a hybrid heat pump-furnace was a cost-effective, energy-saving measure with an SIR of 1.3. Although the nominal efficiencies were similar, the 8.5 heating seasonal performance factor (HSPF) heat pump offered operational cost savings in the win ter. The heat pump would satisfy space-heating needs until the outdoor temperatures dropped below about 40°F. Then the system would shift to furnace mode, using natural gas to satisfy the heating load. Given that the base scope already included a 15 SEER split A/C system and a high-efficiency furnace, the marginal cost to upgrade to the hybrid heat pump system was reasonable at $975.

As we said earlier, electricity at the Bay Ridge development is metered at the apartment level, and the residents pay their own electric utility bills. Natural gas, however, is metered at the building level and is paid by the building owner. So when we shifted part of the winter heating to the electric heat pump, the economic benefit went to the building owner. Therefore, we conducted further analysis to estimate the impact of this shift on the residents with respect to monthly expenses.

Modeling indicated that postretrofit, the deep-scope residents would end up paying $102 more per year in electricity costs than the base-scope residents (see Table 4). This was because for about 60% of the heating season, the deep-scope units would be electrically heated with the heat pump portion of the hybrid system. However, the overall electric bills for these units were about $100 lower annually than they were preretrofit. So the overall efficiency improvement of the entire unit more than offset the bump-up in electricity use for heating. This shows why it is important to consider the implications of fuel-switching EEMs, including changes to residents' net utility costs, and the potential impact of costs on allowable rents in affordable-housing developments.

While we always hope for relatively smooth sailing for any project, we did encounter a few problems during the commissioning and monitoring stages. Our on-site monitoring of gas and electrical consumption at the individual apartments' space-conditioning equipment showed that the hybrid heat pump-furnace system was not cycling on at the intended outdoor transition temperature. We discovered that there had been some miscommunication between the general contractor and the

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heating subcontractor, so the settings had to be readjusted. If we had missed this, the units would have remained in heat pump-only mode for some time—which would have had a significant impact on both energy use and comfort.

We also saw that wintertime indoor temperatures were quite high—in the low 80s—in several apartments at some times. Although we were not able to go back and interview the residents, we suspect that additional resident training might have helped them to understand the new thermostats, and the impact of set point on their electric bills. An initial training had been only lightly attended.

MEASURED ENERGY SAVINGS—WHAT REALLY HAPPENED

Once the retrofits were complete, we installed monitoring equipment in two base-scope apartments and two deep-scope apartments. While the apartments were similar in many ways—they were oriented alike, for example—the occupancy levels were variable. In some cases, the old residents had moved out and new residents had moved in after the retrofit.

Real-time monitoring at the apartment level included gas and electric consumption at the hybrid heat pump, electric consumption of the ERV, gallons of hot water consumed, total electrical consumption at the panel, and indoor temperature and humidity. We also reviewed pre- and post-utility bills. One of the three-bedroom deep-scope apartments had been more consistently occupied than the other so we used that apartment to estimate pre- and post-retrofit energy and cost savings in the deep-scope units. We used the field-monitoring data along with the utility bill information to calculate the realized percentage savings via the following methodology (see "A Note on the Data Analysis"):

1. Calculate regression of pre- and post-retrofit monthly energy use as a function of monthly average outdoor temperature.
2. Apply the resulting equations for each period to an annual set of average monthly temperatures (based on a 30-year data set from the National Oceanic and Atmospheric Administration).
3. Sum the monthly energy consumption values to achieve annual totals.
4. Calculate the percent savings.

A NOTE ON THE DATA ANALYSIS

Because we were comparing pre- and post- energy consumption in relation to two different sets of average monthly outdoor temperatures, we first normalized the consumption data in Btu by HDD. To achieve an apples-to-apples comparison for pre- and post- energy consumption, we then pegged Btu/HDD for each period to a common 30-year average monthly temperature data set.

Figure 4 illustrates the percent energy use as a function of outdoor temperature and shows a pre- versus post- energy savings of 43% for the deep-scope unit. A 43% savings is good—but it also isn't the 52% savings we had initially projected. There are several possible reasons for the difference:

- We may have been too conservative regarding the performance of the existing space-heating equipment, and so have overestimated energy consumption in the preretrofit period.
- We may have overestimated hot-water consumption in the REM models.
- We may have been too optimistic regarding the effect of the energy-monitoring system on resident behavior. We assumed that installing this system would result in a 10% electricity savings.
- The installed ERV consumed over twice as much energy (1 MMBtu per year) as the specified ERV (0.5 MMBtu per year) under continuous operation.

Even with the lower-than-projected energy savings, a savings realization rate of 82% (= 43% savings realized/52% savings modeled) is quite good for an affordable multifamily building energy retrofit. While the energy modeling is a must-do in order to choose the best EEMs at the outset, the uncertainty of the available information, combined with the unpredictability of occupant behavior and actual site conditions, make precise predictions pretty tough to achieve. Practitioners can apply conservative safety factors to help ensure that project energy goals will be met.

Table 4. Energy Savings and Cost Analysis of Hybrid Heat Pump System

Scope	HVAC	Total Annual Heating Energy (MMBtu)	Annual Electricity Cost	Total Annual Heating Energy Cost (to Resident)	Annual Natural-Gas Cost (to Property Owner)
Base	92.5% AFUE, 36/60 kBtu furnace; 15 SEER, 1.5 ton A/C	30.4	$512	$20	$492
Deep	92.5% AFUE, 36/60 kBtu furnace; 15 SEER, 8.5 HSPF, 1.5 ton HP	22.1	$401	$122	$279

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WHAT WE CAN TAKE AWAY FROM THIS PROJECT OR: WHAT CAN WE?

While there were a few hiccups during the Bay Ridge project, it was a great success overall, thanks to the combined efforts of the project team. The measures installed improved comfort and IAQ for the residents, reduced annual operating costs for both residents and owner, and provided a body of solid information to help owners and developers of affordable housing choose cost-effective strategies for improving the performance of multifamily buildings. Our findings show that substantial energy savings can be realized through fairly straightforward EEMs that can be implemented during partial occupancy, and that provide comfort and durability benefits as well. These EEMs Our EEMs were not severely invasive and did not require displacement of occupants during construction. Sealing major (but accessible) air leaks in the building envelope, sealing ducts and bulkheads, replacing aging space conditioning with a hybrid system, upgrading water-heating equipment and adding a small solar system, replacing windows, and insulating attics are relatively standard energy improvements that can be a win-win proposition for everyone l involved.

>> learn more

Visit the Newport Partners web site at www.newportpartners.com.

To see the full report on the Bay Ridge Deep Energy Retrofit project, visit the NREL web site at www.nrel.gov/docs/fy13osti/59172.pdf.

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