Challenges and Opportunities in Deep Envelope Retrofitting

Paul Bertram[1]

ABSTRACT

In today's real estate markets many commercial industrial building owners and managers recognize the business case potential of energy efficiency retrofits including energy cost savings and operating costs, while reducing a building's environmental footprint.

The challenge for existing building energy efficiency is to unlock that vast potential and realize the benefits of a built environment that is comfortable, efficient, and cost-effective. Deep Energy Retrofits (DER) that include the envelope are a challenge because of longer payback and upfront investment. Life cycle costing versus First Costs must be projected with ROI (Return on Investment) and NPV (Net Present Value) for a sound business case.

The case study of the 500-unit Castle Square Apartments, is one of Boston's most critical affordable housing resources and represents a historic milestone toward reducing the carbon footprint of existing buildings through the principles of Deep Energy Retrofit. A portion of the 1960s property, the 192-unit midrise, is the largest Deep Energy Retrofit ever undertaken in the U.S., and predictive modeling demonstrated energy reduction by 72 percent with the envelope representing + 30% of the total. One year of Post Project performance data will be presented compared to the predictive energy modeling along with lessons learned.

The key difference between the Castle Square project and standard renovations is the integrated design approach and super insulated metal panelized shell located on the outside of the building. Details of the assemblies will be presented to demonstrate how the building science for optimized enclosure performance was executed.

---

1. Paul Bertram, FCSI, CDT, Director: Environment, Sustainability, Government Affairs
Kingspan Insulated Panels
726 Summerhil Drive, Deland, FL 32724

Challenges and Opportunities in Deep Envelope Retrofitting

INTRODUCTION

The ACEEE – The American Council for an Energy-Efficient Economy published the “International Energy Efficiency Scorecard” in July of 2012 ranking the US, ninth out of 12 global economies, and noted that the United States in the last decade has made “limited or little progress toward greater energy efficiency at the national level.

The US Department of Energy (D.O.E.), Energy Efficiency & Renewable Energy (EERE) reports that more than $400 billion each year is spent to power homes and commercial buildings, consuming more than 70% of all electricity used in the United States, about 40% of our nation's total energy bill, and contributing to almost 40% of the nation's carbon dioxide emissions. Much of this energy and money is wasted - 20% or more - on average - by poor performing buildings.

The 2009 McKinsey Global Energy & Materials study – Unlocking Energy Efficiency in the U.S. Economy reported that one of the top opportunities to improving the energy efficiency is retrofitting of existing buildings.

The potential to reduce energy consumption in existing and new commercial buildings is enormous. On average, 30% of the energy used in commercial buildings is wasted, according to the U.S. Environmental Protection Agency. According to an article in the ASHRAE Journal, it is estimated that over the next 30 years about 150 billion [ft.sup.2] (13 935 450 000 [m.sup.2]) of existing buildings (roughly half of the entire building stock in the United States) will need to be renovated.

The challenge for existing building energy efficiency is to “unlock” that vast potential and realize the benefits of a built environment that is comfortable, efficient, and cost-effective. Deep Energy Retrofits (DER) that include the envelope are a challenge because of longer payback and upfront investment. Life cycle costing versus First Costs must be projected with ROI (Return on Investment) and NPV (Net Present Value) for a sound business case.

DEEP ENERGY RETROFIT (DER)

The Department of Energy (DOE) defines Deep Retrofit as larger energy savings and improved economics through a holistic, integrated approach that leverages special opportunities in a building’s lifecycle. DOE also categorizes Deep Retrofit, according to their Advanced Energy Retrofit Guide (AERG) Approach, to include: minimum energy savings of 50% that are right-timed with other capital improvements, a Path to net zero and Integrated Design Solutions – passive and mechanical. The term “Deep-Energy Retrofit” may not be familiar to every building professional but the concept certainly is: evaluate poor-performing buildings, execute a number of high-quality renovations of the enclosure and mechanical systems, add renewables where possible and return energy savings of at least 50 percent or more to the owners

DER strategies are fairly straightforward: first, improve the enclosure's insulating value with optimized thermal performance of opaque walls, windows and roof. Then seal against air leaks, minimizing one of the nation's leading causes of building energy loss. Once the enclosure is air tight, thermally optimized, with energy efficient windows, the project team then easily can right size energy conservation measures such as HVAC, lighting, hot water, and building controls. Add renewables, such solar tubes and photovoltaics, to further reduce energy consumption for a path to Net Zero Energy.

In the past, retrofits of existing buildings typically involved the filling of framed cavity walls with insulation; however, the amount of effective thermal resistance that could be added was limited by the existing stud cavity or strapping depth, the insulation material, and the amount of thermal bridging present in the framing.

The addition of insulation to the exterior of existing buildings has been demonstrated to be an effective means to overcome these limitations and provide higher effective R-values for building wall assemblies. The benefits of this approach extend beyond just added thermal resistance; benefits of increased building durability and air tightness are often realized. This concept has led to "Continuous Insulation" code requirements for new construction.

By choosing an aggressive approach of envelope first energy efficiency with a super insulated exterior envelope combined with other energy-reduction measures, the residents of Castle Square Apartments, an affordable-housing community in Boston, engaged an integrated design team to cut energy use by 72%

CASTLE SQUARE DEEP ENERGY RETROFIT (DER)

Figure 1. 1960 view of Castle Square

Located on Tremont Street in Boston's South End and constructed in the 1960s, Castle Square Apartments are a 540,000-square-foot mixed-use property comprised of 500 affordable apartment units and 20,000 square feet of retail space.

In 1987, the Castle Square Tenants Organization (CSTO) was established as a non-profit organization dedicated to preserve Castle Square Apartments as affordable housing for low-and-moderate income residents into perpetuity and provide comprehensive community and social support. The CSTO engaged a team of professionals, each expert in their respective fields, to retrofit the buildings. Construction started December 10th, 2010.

The Castle Square DER integrated building team included: representatives from the CSTO along with Winn Development that own the project along with the Building Science Corporation (BSC) as the enclosure specialists; Elton + Hampton Architects; Portsmouth, Petersen Engineering Inc.; Biome Studio - a zero-energy and sustainability design and development consulting group; and Pinck and Co. as owner's representative. The team targeted 192 apartments totaling 174,425 square feet for the DER. The team's challenge was turning a 1960s building made with porous, un-insulated concrete and brick infill walls (R-3) that featured aluminum slider windows and through-wall A/C units into a modern, tightly constructed energy efficient multifamily building – without moving tenants out during construction.

It is my observation that a critical difference in this building team was the leadership of a design and development consulting group that was independent of the architect, engineers, energy modeler, enclosure specialists and contractor that drove an integrated building team approach that accurately represented the building owner's requirements including financial guidance.

CASTLE SQUARE DEEP ENERGY RETROFIT DESIGN PRINCIPLES

The team, through a series of charrettes that included tenants as well as the design and construction team, established the following 6 guiding principles for the DER.

1. **Super Insulate;** A new super insulated shell, combined with a super insulated reflective roof, high efficiency windows and extensive air sealing to increase the insulation value of the building by a factor of 10.

2. **Air Seal:** Air sealing is necessary to optimize thermal performance. Air sealing includes: caulking cracks and holes to the outdoors and between apartments. It also limits the stack effect, reduces pests and improves indoor air.
    a. The super insulated shell and air sealing is projected to drop heating by 61% and cooling by 68%.

3. **Scale Down Heating & Cooling Equipment:** A super insulated and air sealed building requires only a fraction of the energy to heat and cool. High efficiency heating equipment will drop the building's heating needs by 10%. Insulating pipes and use of high efficiency boilers with indirect hot water heaters will drop hot water energy usage by 41%.

4. **Improve Indoor Air Quality:** Indoor air quality was designed to increase substantially with the use of fresh air trickle vents and renovating the existing ventilation system with duct sealing and new air duct dampers.

5. **Harness the Sun:** Solar thermal hot water reduced the buildings energy usage.

   a. Hot water energy was expected to drop by 37% due to the solar hot water system.

6. **Reduce Plug Load:** Using Energy Star® appliances, fluorescent, and LED lighting fixtures decreased the buildings energy usage.
   a. Energy use of refrigerators and lighting is expected to drop by 53%.

Results: Through predictive modeling and analysis, the Castle Square Deep Energy Retrofit project was projected to reduce the total building energy consumption by 72% against the baseline.

EXISTING BUILDING ANALYSIS

Castle Square originally had no wall insulation with an R-3 wall assembly. After the renovation, the walls were increased to R-40. The roof went from R-20 to R-40. The R-1.3 aluminum clad slider windows were replaced with R-5 fiberglass casement windows.

Extensive energy modeling by Building Science Corporation (BSC), Biome Studio and the Hickory Consortium, estimated the annual energy use for the building with the super-insulated shell & air sealing, new windows, roof retrofit, solar hot water panels and new boiler from two separate modeling approaches.

Initial energy modeling was calculated by BSC with spread sheets using basic
"Q = U x A x delta T" calculations.
Where:
Q: heat transfer rate in Btu/hour,
U: overall heat transfer co-efficient,
A: surface area in square feet, delta
T: temperature difference across surface;
T-inside – T- outside

The modeling provided various options of individual materials including insulated metal panels, windows, roof systems and other building components and assemblies. BSC explored various magnitudes of relevant change in the respective materials for the purpose of providing educated choices to guide the design process. An example, using Insulated Metal Panels (IMPs), various insulated metal panel thickness' were modeled to determine an optimized performance solution that considered demising return on investment and were ultimately chosen over EIFS. What is important to note about the BSC calculations is that these percentages of calculated improvements were on thermal performance of individual materials (wall, windows, roof system) and not whole building percentages of improvement. These calculations of percentages of thermal improvements were then used by Biome Studios for correlation to energy cost savings and whole building energy efficiency modeling (TABLE 1.)..

	Total Cost	Costs per Sq. Ft	Costs per Apartment
Total Cost - Super Insulated Shell 72,000 Sq. Ft. - wall area	**$2,499,000**	**$34.71**	**$13,016**
Cost Breakdown			
Air Vapor Barriers	$125,000	$1.74	$652
Metal Panel Furring - Materials	$145,000	$2.01	$755
Metal Panels Furring - Labor	$175,000	$2.44	$915
Mineral Wool Suppression - Materials	$108,000	$1.50	$563
Mineral Wool Suppression - Labor	$72,000	$1.00	$376
Metal Panel Systems - Materials	$1,040,000	$14.44	$5,417
Metal Panel Systems - Installation	$620,000	$8.61	$3,229
Note: Avoided Masonry Repairs	**-$300,000**		

TABLE 1. Cost of Super Insulated Metal Panel Shell

The Hickory Consortium, per LEED 3.0 (2009) requirements, calculated the baseline building performance rating according to the whole building performance rating method in Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda1) using a computer simulation model for the whole building project. The resulting energy models demonstrated an overall energy efficiency improvement of 50% over baseline with a 72 Degrees point set. Based on requirements for LEED Energy & Atmosphere Credit 1 (Optimize Energy Performance) the Castle Square whole building energy modeling demonstrated more than the 26% energy cost savings – qualifying the project for the maximum of 10 credit points.

Whole building predictive energy modeling was conducted on Castle Square, and as discussed later in this paper, there were inconsistencies in the predictive values and actual use values after one year of reporting.

The exterior over cladding (including windows) was predicted to increase the building's insulation value by a factor of 10, which—in combination with air sealing—reduces Castle Square's annual heating and cooling needs by 61 and 68 percent, respectively. The calculations along with a new more efficient boiler and the addition of solar thermal system predicted 72% total energy savings over baseline including a new solar, hot water, thermal system.

The extensive energy modeling calculated the building's heating requirement and determined a smaller mechanical system. The savings in the new mechanical systems costs helped pay for the super insulated shell and air sealing that helped reduce the building's heating and cooling requirements (TABLE 2.).

It is also worth mentioning that in the "Post Project" analysis of the predicted energy savings versus one year of actual energy use, several data points needed correction in the energy modeling and that work, as of this writing, was still in development.

	Midrise (Deep Energy Retrofit)			Midrise (No Shell)		
Gas		Therms	$1.53		Therms	$1.53
Baseline Gas Consumption - Heating (2008)		**78,024**	**$119,377**		**78,024**	**$119,377**
Savings from Enclosure	**60%**	**47,654**	**$72,911**	**23%**	**18,514**	**$28,326**
Roof Insulation	3%	2,591	$3,964	3%	2,591	$3,964
Exterior Super Insulation	33%	26,018	$39,808	0%		
Air Sealing (Air sealing provides two benefits 1) energy savings and 2) eliminates smells between units. Energy benefit shown here results mainly from the exterior shell in the midrise. (No Shell scenario, some of air sealing benefit is not achievable)	8%	6,245	$9,555	4%	3,123	$4,777
Windows	14%	11,167	$17,086	14%	11,167	$17,086
Doors	2%	1,633	$2,498	2%	1,633	$2,498
Savings from Mechanical (Due to efficiency improvements)		**8,016**	**$12,264**		**7,744**	**$11,849**
Ventilation		5,300	$8,109		5,300	$8,109
Heating System Upgrade (Boilers can't run in condensing mode as often in the no shell scenario which reduces overall heating efficiency)		2,716	$4,155		2,444	$3,740
TOTAL Heating Savings (Gas)	**71%**	**55,670**	**$85,175**	**34%**	**26,258**	**$40,175**
Baseline Gas Consumption - Hot Water (2008)		**48,720**	**$74,542**		**48,720**	**$74,542**
Savings from Water Heating System Upgrade	41%	20,061	$30,693	41%	20,061	$30,693
Solar Thermal Savings	37%	18,000	$27,540	37%	18,000	$27,540
(Gas)	**78%**	**38,061**	**$58,233**	**78%**	**38,061**	**$58,233**
TOTAL Hotwater Savings No Solar Thermal (Gas)	**41%**	**20,061**	**$30,693**	**41%**	**20,061**	**$30,693**

TABLE 2. Comparison of Deep Energy Retrofit to no shell upgrade energy cost savings

AIR AND JOINT SEALING

Air testing of the existing structures was required (per LEED) of the first (6) midrise apartments with additional verification of the air leakage target by sampling approximately 10% of apartments. Testing included blower door testing per ASTM E779 – 10. The existing building testing became the baseline for energy efficiency airtightness improvement.

Air testing, plans review and visual inspections were conducted to determine air sealing strategies. Extensive internal air sealing was specified and applied between individual apartments and between the apartments and outdoors. Renovations of apartment corridors, trash closets, elevator vestibules, and other rooms were specified to achieve continuous enclosure air barriers. The limit air leakage into (or out of) the space and verify air leakage control was achieved through various testing. The team opened walls and windowsills and cored the roof. Scopes were run through the ductwork. Building Science Corporation also conducted blower door testing. Assemblies modified or added as part of the renovation scope were constructed to be air, smoke, and gas-tight. Interior demising walls were opened at a point where spray foam insulation could be blown in for additional thermal & acoustical performance.

SUPER INSULATED METAL PANELIZED SHELL

The design team recommended a Deep Energy Retrofit (DER), to the CSTO, including recladding the exterior of the midrise units of the Castle Square project with super insulated metal panelized shell.

Several insulated cladding systems including Exterior Insulation Finishing Systems (EIFS) were modeled and evaluated with Insulated Metal Panels (IMPs) selected as the final cladding solution. Insulated Metal Panels are factory (off-site) manufactured wall and roof cladding components typically consisting of a polyisocyanurate insulation core encapsulated between interior and exterior steel skins with factory-formed pressurized joints providing a homogeneous installation. As a note; mineral fiber insulation options are available but are primarily used for fire wall performance with a lower R-Value per inch. Thermal continuity and performance is achieved across the entire building envelope and the span capability of the composite panel allows attachment to steel framing with minimal thermal bridging.

FIGURE 2. Plans rendering of proposed IMP recladding Retrofit areas

Regarding stated IMP R/U-Values, ASTM 1363 *Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus* is the standard for determining the U-value of the IMP and requires test specimen to include the effect of joint details between adjacent panels; ASTM C518 *Standard Test Method for Steady-State Thermal Transmission at a mean temperature of 75 deg. F*.; is also used for R-Value reporting. The IMPs are also approved for NFPA 285: *Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components*. The two seven-story buildings of the complex were literally wrapped in the super-insulated shell. The IMPs were specified as an R-40 (5 inch), twice what current code required, applied directly over existing exterior concrete and brick.

The IMP interlocking joint (FIGURE 3) is designed to control rainwater penetration and thermal continuity. The joint design incorporates a pressure equalization chamber that also minimizes thermal bridging with superior air tightness. The pressure equalization chamber is shielded from outside by an overlap between two impermeable panel facings thus minimizing rainwater passage into the joint driven by gravity and air pressure difference. Intercepted rainwater is drained effectively back to the exterior.

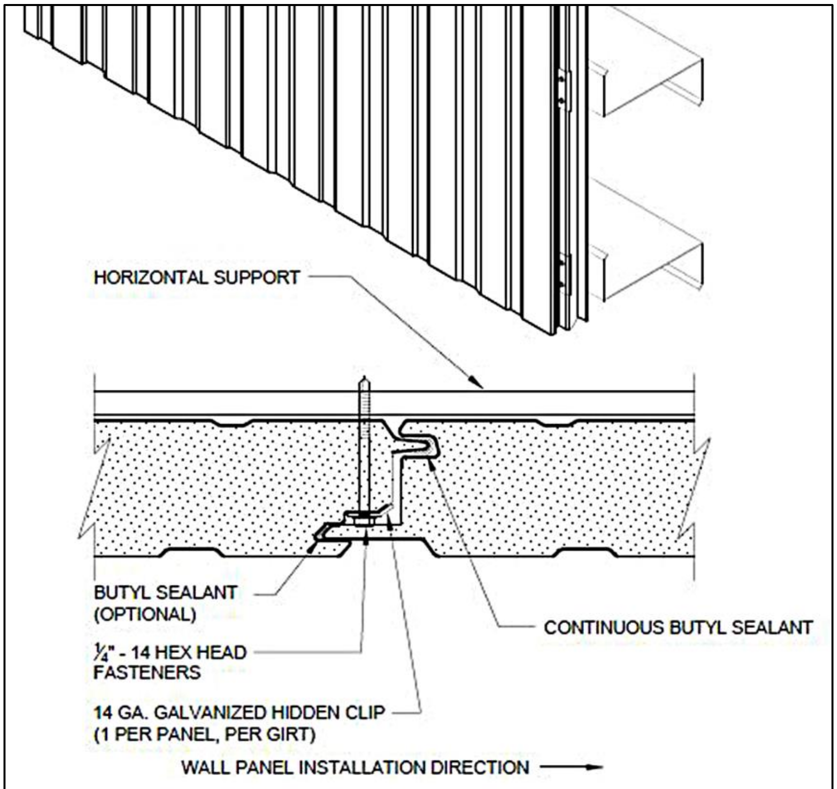

FIGURE 3. Details of Insulated Metal Panel attachment

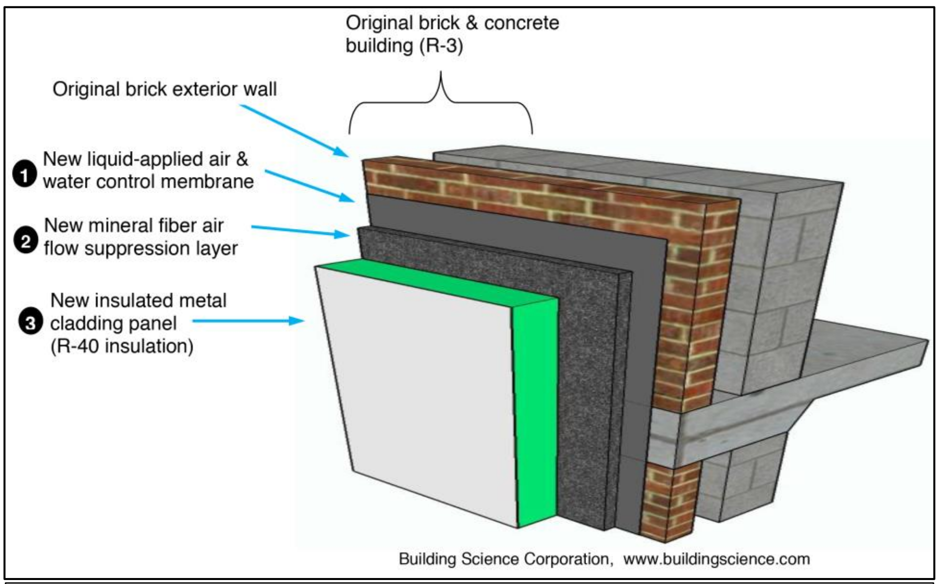

FIGURE 4. Opaque Wall Assembly Drawing

Insulated Metal Panels for Castle Square utilized a secondary Water Resistive Barrier (WRB) and air barrier behind the panels. Fundamental to this design is that the primary control layers for water management and air flow control are located behind the IMP, and all materials inboard of these control layers are considered interior of the building

(FIGURE 4.). The IMP functions as both the exterior cladding system and primary thermal resistance layer. Continuity of the thermal insulation is maintained between the control layers and the back of the IMP with the addition of Mineral Fiber insulation. This system design has built in upfront redundancies for optimized performance (Figure 5.).

Water management is through a dedicated WRB installed behind the IMPs with 1 1/2" thick mineral fiber fire resistant insulation installed horizontally in 2' x 4' panels between furring rows. All flashings and interfaces with the other enclosure elements must be connected to the WRB. While the mineral fiber insulation will reduce the potential for drainage, concerns of water retention in the system are minimal (FIGURE 5.).

The air flow control is maintained through an air barrier that is continuous with all other enclosure elements, and located exterior of the existing structure. A single integrated self-adhered and liquid applied membrane/air barrier system can be integrated as the WRB system to perform both functions.

Inward vapor drive is predominantly controlled by the impermeability of the IMP, however, due to the potential for air movement behind the panels, alternate control layers could be included at the WRB location (such as through the use of a vapor impermeable SBS membrane). Alternately, the enclosure can be designed based on a vapor “flow through approach”, to allow for unrestricted diffusion inwards (ie. no interior Class I or Class II vapor retarder) and a vapor permeable WRB and air barrier can be used (this is not recommended if interior vapor barriers or low permeability materials are currently in the existing wall assembly).

Outward vapor control is achieved by controlling the condensing surface temperature. Unlike the first approach (using the IMP as the complete enclosure), the condensing surface in this assembly is behind the WRB and air barrier. This configuration typically provides even less risk of condensation accumulation in the assembly.

FIGURE 5.Shows the liquid WRB over original brick with fire resistant insulation, new windows and super insulated metal panel installation

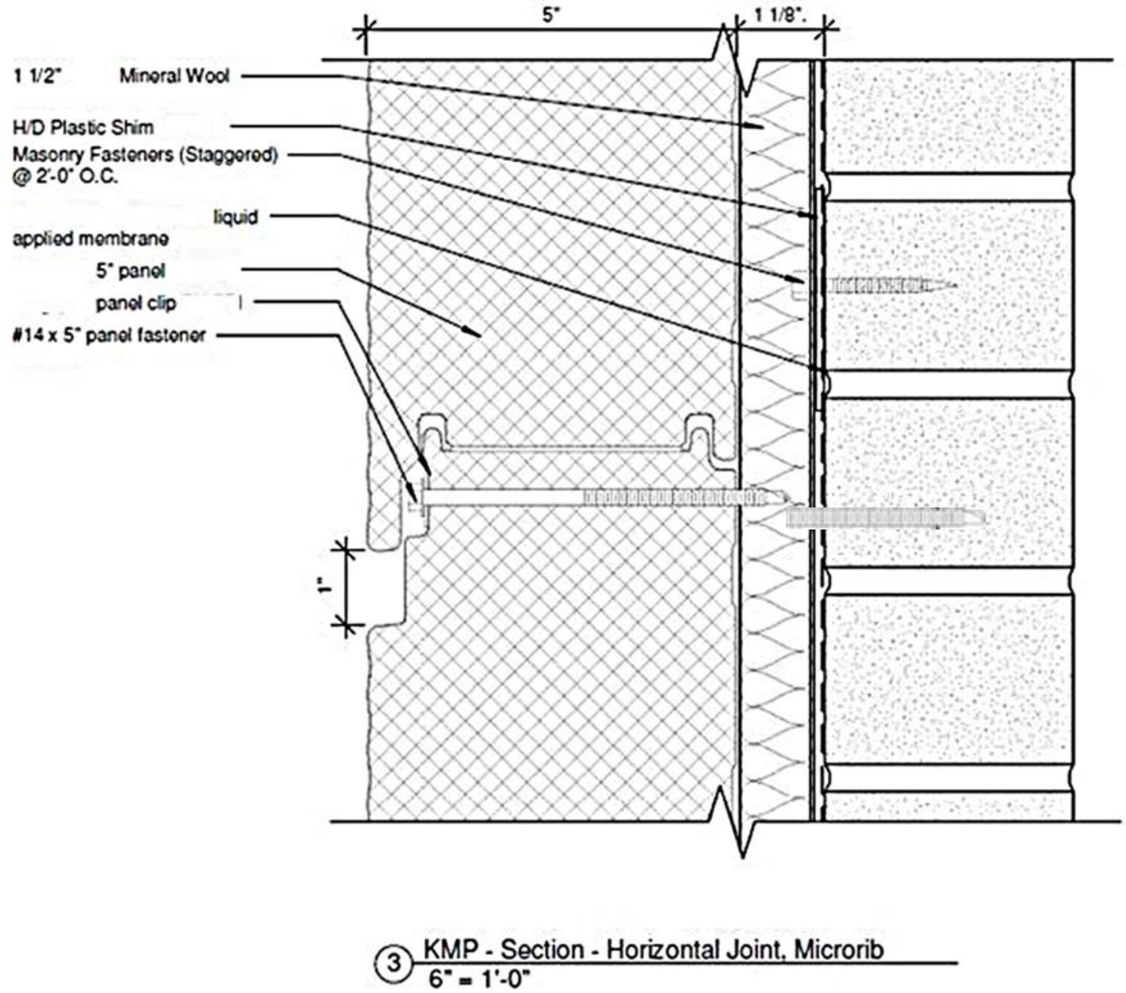

FIGURE 6. Installation IMP Base with Membrane

Vapor management is maintained through the fundamental nature of the panel. Inward [illegible]rd vapor control and condensation resistance is maintained through control of the condensing surface temperature. With the panel installed over a previously un-insulated building (Figures 6), there would be no concerns of interstitial condensation in any climate zone for any commonly available panel thickness.

Hygrothermal Therm and WUFI models were helpful in understanding an optimized design as described above. One recommendation included modeling a worst case scenario to establish a conservative performance recommendation.

A field mockup was constructed per the Architect’s direction to include window, flashings, waterproofing, of joints, anchorage system, sealants, edge conditions, closures and other details as may be required for a weather tight installation. This was not a “functional” model but it was used to visually demonstrate how the assembly should be constructed.

The newly established Building Enclosure ASTM E2813 Standard for Building Enclosure Commissioning includes FUNCTIONAL PERFORMANCE TESTING that includes both mock-up and installed work (field) testing and would have been ideal to ensure proper installation and performance of assemblies.

FIGURE 7. Castle Square Mid Rise Units with Super Insulated Cladding, new R-5 Windows , Highly Reflective TPO roof with additional insulation and Solar Collector for hot water

OTHER KEY ENVELOPE COMPONENTS:

1. **Accent & fascia panels:** Aluminum composite accent & fascia panels were specified to be installed over the fluid applied air/vapor barrier membrane. The panels were fabricated from 4mm aluminum composite material with polyethylene core (FGURE 7.)
2. **Windows:** The Casement windows were specified with an R-5 as Double Glazed with Argon gas. ASTM E 774, Class A with High-Performance Coatings: Low E (low emissivity).
3. **The Roof:** Existing roof assemblies consisted of mechanically attached EPDM installed over 2.8" Polyisocyanurate insulation. The roof decks were cast-in-place concrete. The existing EPDM membrane was removed by slicing the membrane on two (2) sides of the seam attachment, leaving 6"- 8" of membrane in place along with the insulation. The existing stone ballast and flashing were removed.

New taperd polyisocyanurate insulation was installed over the existing flat polyisocyanurate insulation to achieve R- 40. On midrise roofs additional insulation was provided of approximately 10" up penthouse walls and to 2nd level decks to match thickness of new insulated wall panels (TABLE 3.).

Roof area	Existing Insulation	New Overlay Insulation	Attachment method
Mid Rise Upper	2" Exp. Polystyrene	5" Polyisocyanurate	Mech. Fastened
Mid Rise Penthouses	2" Exp. Polystyrene	5" Polyisocyanurate	Mech. Fastened
Mid Rise Plaza Decks	3.2" Polyisocyanurate *	Tapered Polyisocyanurate	Mech. Fastened
Building 26/27	2.8" Polyisocyanurate	5" Polyisocyanurate	Mech. Fastened

*Removed and replaced with tapered insulation, 1/8" per foot slope.

TABLE 3. Roof Improvements

Thermoplastic Single-Ply TPO membrane roofing was specified with a.060 mechanically attached field sheet. The flashing Sheet was .060 TPO with an exposed face color (Energy White). Each building has 756 square feet of solar thermal hot water collectors on the roof. Currently the energy offsets of those collectors that should increase total energy savings are being recalculated due to several non- functioning units (that have since been corrected) and errors in the modeling that were found during the one year analysis.

MIDRISE DEEP ENERGY RETROFIT ONE YEAR RESULTS

Preliminary gas consumption data from June 2012 – July 2013 shows (TABLE 4) that rather than achieving 65% annual gas savings (as per design projections), the buildings are currently achieving 53% annual gas savings. This is an improvement on the 48% annual gas savings that was reported in March 2013 and the 51% annual savings reported in May 2013. *Note—Data was normalized for weather so that this year's data could be compared to annual gas consumption from 2008— 2010.* The design projection of 65% total reduction in gas consumption (heat and hot water savings) is being re-evaluated due to performance issues related regarding the solar thermal system.

Hot Water Design projections predicted hot water savings of 56%. In reality, hot water savings in the summer of 2013 (after the solar thermal system was repaired) was 55%. During the post-construction period, meters were not correctly reading data until about June 2012.

WHAT CAUSED DIFFERENCES BETWEEN PREDICTED ENERGY EFFICIENCY AND ACTUAL?

Although the midrise buildings aren't reporting their 65% gas savings design target, there is opportunity to get closer to targeted energy savings goals. The predicted energy modeling savings were based on a lower design temp (68 degrees) than actual that was 71 degrees.

So what is happening on the heating side?

REALITY

	MIDRISE Buildings (192 units)		
	Therms	**MMBTU**	**$**

TOTAL Baseline Gas Usage (2008)	126,744	12,674	$193,918	
Current Heating Energy Use Baseline	78,024	7,802	$119,377	
Savings from Enclosure	47,654	4,765	$72,911	
Mechanical Savings	8,016	802	$12,264	
Total Heating Savings	55,670	5,567	$85,175	
TOTAL Heating Savings as a Percentage Baseline	**71%**			→ **48%-64%**
Current Hot Water Use Baseline	48,720	4,872	$74,542	
Savings from Water Heating System Upgrade	20,061	2,006	$30,693	
Solar Thermal Savings	7,164	716	$10,961	
Total Hot Water Savings	27,225	2,723	$41,654	
Total Hot Water Savings as a Percentage of Baseline	**56%**			→ **55%**
			$0	
Total Gas Savings (Scenario 1 - With Solar Thermal)	**82,895**	**8,290**	**$126,829**	
Scenario 1: Post Improvement Gas Usage (with Solar Thermal)	43,849		$67,089	
Total Heat and Hot Water Savings	**65%**			→ **53%**

TABLE 4. Heat Design projections predicted 71% total heating savings. In reality, heating savings between October 2012 – May 2013 range from 48% to 64%, depending on the month and the building

First, a decision was made by the residents of Castle Square to operate the building at a much higher temperature than it was designed. Petersen Engineering assumed a boiler set point to deliver 71 degree heat to apartments. Because of resident demand, a decision was made (without notification to all members of the team) in December 2011 to deliver 75 degree heat to residents despite the average cost increase of $77,000 or half of the projected gas savings! Resident requests for this higher temperature was likely due to somewhat uncomfortable conditions in the apartments, because the shell was not complete and construction was still underway. Unfortunately, this higher temperature was maintained after construction completion. Thermostats weren't limited to 72 degrees until the following year – January 2012. This higher temperature set point effected gas consumption for 5 of the nine heating season months in the analyzed year.   Some residents continue to override their thermostats to enjoy tropical conditions in their apartments.

The primary issue impacting heat savings goals are opened windows. Despite being able to control their heat using energy star thermostats and an excellent ventilation system, residents frequently leave their windows open, even in freezing temperatures.

Originally the project did not have a commissioning agent. They were added to the team in the summer of 2013, over a year after construction was complete, and potentially have an opportunity for a positive outcome on energy efficiency improvements that will likely change current data reporting to be closer to the predicted performance. Finally, the commissioning agent identified some other issues in the midrise heating plants that could be tweaked to improve performance (complicated boiler controls, etc.).

Measurement and Verification to Date

In checking with the independent design and development consulting group regarding improvements made by utilizing ongoing Measurement & Verification of energy performance data that is being recorded, it was surmised that little to no further actions have been made.

CONCLUDING REMARKS ON THE CASTLE SQUARE DER PROJECT

Any existing building project that is delivering 50% + retrofit building energy efficiency improvement is considered a success. Financing was key to this specific project and Federal Low Income Housing Tax Credits were available along with a host of other funding for the renovation that made it possible to deliver.

The cost of a Deep Energy Retrofit can be analyzed in a number of different ways. One way is to analyze total cost of the work (labor & materials) from start to finish. The total cost of the Castle Square Deep Energy Retrofit was $8,177,783 for 192 apartments or $42,593 per apartment. This includes the cost of everything from the super insulated metal panels to heating, cooling, and hot water improvements.

The question of "What if you were going to re-face/re-side the building anyway?" came up in evaluating the project's options related to costs, and R.O.I. The modeled payback on the super insulated metal panel exterior was estimated at 25 years. Incremental cost is defined as the difference between cost of work that would have been done anyway and the Deep Energy Retrofit scope of work. Castle Square was to be renovated; therefore, the total incremental cost of the Deep Energy Retrofit at Castle Square was $3,460,486 for 192 apartments or $18,023 per apartment. As indicted in the Final Increment Cost graph, paybacks ranged between 24 – 33.9 years depending on the specific area of improvement (TABLE 5.)

	Incremental Cost	Savings - Therms	Savings $	Direct Payback (Years)
Roof Insulation	$45,273			
Exterior Wall Insulation (R-40)	$2,199,000			
Glazing	$74,000			
Air Sealing	**$160,000**			
Subtotal - Enclosure	$2,478,273	47,654	$72,911	33.99
Mechanical - Heating & Hot Water	$253,800			
Ventilation	**$132,000**			
Subtotal -	$385,800	28,077	$42,958	8.98

Mechanicals				
Solar Thermal	**$596,413**	18,000	$27.540.00	21.66
Total	**$3,460,486**	**93,731**	**$143.408.43**	**24.13**

TABLE 5. Final Incremental Retrofit Costs

Castle Square was certified as LEED® Platinum and won the Vanguard Award from the National Affordable Housing Management Association (NAHMA). The Vanguard Award is given each year in order "to recognize newly developed or significantly rehabbed affordable multifamily housing communities that showcase quality design and financing." Also Boston Mayor Thomas M. Menino presented the Castle Square Tenants Organization and Winn Development with the 2012 Green Residential Award for Sustainability/Climate Action Leadership.

REFERENCES:

ACEEE: **United Kingdom Tops in Energy Efficiency, U.S. Lags in 9th Place**
http://www.aceee.org/press/2012/07/aceee-united-kingdom-tops-energy-eff

Unlocking Energy Efficiency in the U.S. Economy; The McKinsey Global Energy & Materials study 2009:
http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/unlocking_energy_efficiency_in_the_us_economy

Deep Energy Retrofit Profile: Castle Square Apartments on Track to Reduce Energy by 73%; Design Cost Data (DCD) 2012
http://www.dcd.com/insights/insights_nd_2012_1.html

Improving energy efficiency in existing buildings ASHRAE Journal, Holness 2008.

Office of Energy Efficiency & Renewable Energy (EERE)
Advanced Energy Retrofit Guides (AERGs)
http://www.energy.gov/eere/buildings/advanced-energy-retrofit-guides

BIBLIOGRAPHY

U.S. Department of Energy's (DOE) Building America program
http://www1.eere.energy.gov/buildings/residential/ba_index.html

Castle Square Tenants Organization
http://cstoboston.org/

U.S. Department of Energy's (DOE) Building America program
http://www1.eere.energy.gov/buildings/residential/ba_index.html

Castle Square Deep RetroFit
http://www.castledeepenergy.com/

Insulated metal Panels: Metal Construction Association
http://www.metalconstruction.org/imp/

Using Insulated Metal Panels as Part of a Building Enclosure Energy Retrofit – Building Science Corporation, Baker 2012

Final Report on the Evaluation of Constant Airflow Regulators (CAR) in Multi-Family Multi-Story Central Ventilation Systems.NAHBRC (2008).

How Do Buildings Stack Up? BSI-075: Lstiburek, 2014/02/13

Air Flow Control in Buildings: BSD-014: Straube, 2008/05/09

KEY WORDS:

Deep Energy Retrofit, Life Cycle Costing, Predictive Energy Modeling, Building Science, R-Value, Wall Assemblies, Continuous Insulation, Insulated Metal Panels, Air Leakage, Air Seal, Heat transfer rate, Exterior Cladding, Polyisocynaurate (Polyiso), Hygrothermal, Vapor Impermeable, Water Resistant barrier (WRB)