Energy Performance of a Renovated Two-Family House in Massachusetts

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ABSTRACT

In 1991, a 90+-year-old, 2,000 ft^2, two-family house in Northampton, Massachusetts, was purchased and rehabilitated, including the incorporation of energy-efficient construction techniques. Energy conservation features of this home include

- *8 in. double stud wall system with damp spray cellulose insulation;*
- *double, low-e gas-filled windows;*
- *air-to-air heat recovery system;*
- *high-efficiency sealed combustion gas-fired hydro-air heating system;*
- *sealed polyethylene air barrier and vapor retarder.*

The house has now been occupied for five years, and billing data exist for that period. Billing data for the previous occupancy do not exist; however, a utility audit was performed prior to purchase. Using computer simulations and billing data, this paper will explore the relationship between the estimated pre-renovation energy consumption of the building, the estimated incremental cost of incorporating the energy efficiency upgrades, and the post-renovation energy consumption.

To help inform others seeking to undertake similar projects, the pros and cons of various decisions that were made will also be explored.

INTRODUCTION

In 1991, a 90+-year-old, 2,000 ft^2, two-family home in Northampton, Massachusetts, was purchased with the intent of rehabilitating the structure into a well-insulated, thermally efficient home with a rental apartment. The opportunity for improvement was significant. The home had been in the same family for approximately 75 years and very little had been done over time to improve, or even maintain, any portion of the building. In a nutshell, the house was a dump.

The building was balloon framed, constructed of rough-cut native lumber. Bearing walls were 2 × 4 @ 16 in. oc, floor and ceiling joists were 2 × 7 @ 16 in. oc, and the roof rafters were 2 × 6 @ 16 in. oc. The building had 1 in. wide board sheathing (some up to 20 in. wide), rosin paper, and cedar clapboards. The paint was peeling severely. Windows were single-pane, double-hung units, with different types of storm windows installed in various locations around the house. The house had a full height basement, with foundation walls made of mortared rubble stone below grade and a brick cap above grade. The roof was hand-split slate over a cedar shake roof.

When purchased, one rental unit was equipped with an approximately 40-year-old heating system composed of a natural gas-fired boiler and hot water baseboard radiation. A tankless coil in the boiler provided the domestic hot water for both rental units. There was also a range with an integral kerosene-fired space heater in the kitchen of the rental units. When the house was purchased, the other rental unit had no heating system; however, there was evidence that a gas-fired combination range and space heater had been installed in the unit. This and standby losses from the other rental unit probably heated this unit. Gas consumption data from the second meter that served the other rental unit were not available.

Gas company records indicated that 2,253 therms of gas had been used in the rental unit with the boiler during the year previous to the purchase of the house. There was no contact with the previous owners to get data on how they operated the

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house or whether they were able to maintain comfort in the home.

SCOPE OF WORK

This property was purchased due to its in-town location, two-family status (allowing for an income-producing apartment to provide cash flow), and low purchase price. The house had very little historic character or interior finishes that were deemed of significant value. The building shell was utilized, as it exceeded the allowable size for the lot, and it was reasonably sound and weather tight. The following work was performed during the renovation:

- Replaced rotted/insect damaged timbers at sills and in basement as needed.
- Shored up and reinforced sections of the structure.
- Opened up interior spaces to allow greater utilization of the first floor.
- Installed second stud wall system inside of exterior walls to allow for 8 in. insulated cavity.
- Insulated the basement walls to provide an additional 900 ft^2 of conditioned floor space in the building.
- Air sealed building to a blower door tested effective leakage area (ELA) of 1 $in.^2$ per 100 ft^2 of thermal shell area at 4 PA (LBL method).
- Installed new hydro-air heating systems for the owners' space and the rental unit, with hot water for heat and domestic purposes supplied by a single sealed combustion, 94% efficient, natural gas-fired water heater.
- Installed separate heat recovery ventilation systems for each unit.
- Installed new electrical and plumbing systems in the building.
- Replaced all existing windows and doors.
- Re-sided building with vertical board and batten siding.

IMPLEMENTATION

In order to air seal the building, the decision was made to use a polyethylene air/vapor retarder on the inside of the building. It appeared that the installation of the second stud wall would be easier if the existing lath and plaster was removed from the exterior walls only. Surgical demolition of the plaster proved difficult, and in the end approximately 95% of the lath and plaster in the entire building was removed and landfilled. All other systems within the existing walls were also removed during the demolition phase. At this point, it was verified that the building had no insulation in any of the exterior walls. The sheathing, while almost 100 years old, showed no signs of moisture damage. Once the existing finishes had been removed, new stud walls were installed on the inside face of the existing balloon frame walls.

The plaster was also removed where the ceilings were to be insulated. Sometime in the past, 1.5 in. of kraft-faced fiberglass insulation had been installed in the attic over the second floor of the house. This insulation was removed and landfilled. The existing rubble foundation walls were originally uninsulated and were retrofitted by installing 1 in. of foil-faced isocyanurate foam against the existing foundation. A 2 × 4 wall was then framed up, poly and drywall installed, and dry cellulose insulation was dense packed into the remaining cavity.

Once the walls had been framed, the windows and doors were replaced. The new windows are predominantly casement style windows, double low-e with an argon gas fill. The orientation of the building (corners of the house are oriented north - south - east - west) and existing landscaping precluded efforts to incorporate passive solar or sun-tempered strategies or efforts to "tune" the glazing for optimal winter gain or summer heat rejection. Insulated steel doors were used for economic and aesthetic reasons.

Once framing was completed, plumbing, mechanical, and electrical systems were installed. Electrical outlets in the exterior walls are surrounded by "poly pans," and wiring penetrations were foamed or caulked to the pan. An effort was made to keep plumbing out of the exterior walls; however, given the limitations of existing framing systems, certain concessions had to be made. The forced-air system is completely contained within the thermal envelope of the building. A single trunk line transverses the second floor, with short takeoffs supplying warm air to each room. The first floor rooms are supplied by longer branch runs off of a short trunk duct. The apartment is serviced by a separate air handler that also uses longer branch runs off of a short trunk duct. Returns are centrally located on the first and second floor for the main part of the house, and in the living room of the rental unit. Forced air was chosen to allow for installation of air conditioning if necessary and to facilitate integration of the ventilation system. This setup also allowed for the installation of a single heating plant. A 94,000 Btu output high-efficiency, natural gas-fired, sealed combustion domestic water heater was selected to provide heat and hot water for both units. The unit was adequately sized for the loads, and the occupants have never experienced a lack of heat or hot water. An electronic setback thermostat controls each system.

Two heat recovery ventilators were installed, one for each living unit. Exhausts run from the kitchen and bathrooms, and fresh air is supplied to the return air plenum of the forced-air system. The units are two-speed, with 24-hour timers for the low-speed operation and 60-minute crank timer controls in the kitchens and baths for high-speed boost.

Once these systems had been roughed in, the ceilings were sealed with poly and drywalled to hold the loose fill cellulose insulation. The walls were insulated with damp spray cellulose. The insulation was installed in late January, and poly and drywall was applied within three days. No apparent damage has been observed over the last six years from this practice; however, the materials (wide board sheathing, rosin paper, existing clapboards and new board, and batten siding) making up the wall are all very vapor permeable to the exterior, with a high drying potential.

TABLE 1
Total Natural Gas Consumption—Heat, Domestic Hot Water, Cooking, and Clothes Drying

Month	1996		1995		1994	
	Therms Used	Cost of Fuel (excluding Service Charge)	Therms Used	Cost of Fuel (excluding Service Charge)	Therms Used	Cost of Fuel (excluding Service Charge)
Jan.	105	$85.51	83	$80.24	110	$106.44
Feb.	85	$69.23	80	$77.34	99	$98.91
Mar	77	$62.72	60	$58.00	75	$77.29
Apr.	58	$47.25	45	$43.50	53	$54.62
May	31	$17.82	27	$17.61	22	$16.42
June						
July	24	$21.28	16	$17.14	20	$21.62
Aug.						
Sept.	17	$17.44	10	$13.22	26	$26.10
Oct.	28	$16.14	8	$5.22	27	$20.15
Nov.	42	$38.02	39	$34.97	36	$34.79
Dec.	61	$55.22	77	$69.05	63	$60.89
Total	**528**	**$430.63**	**445**	**$416.29**	**531**	**$517.23**

Note: Billing for July includes June usage, and September includes August usage.

PERFORMANCE

The operating costs for heating this building have ranged between approximately $320 and $400 per year for 2,900 ft^2 (2,000 ft^2 above grade and 900 ft^2 below grade) of conditioned floor area. There have been no moisture-related failures or problems with the house. Ice dams are minimal to nonexistent during periods of heavy snow and cold. Indoor relative humidity remains at about 35% in the winter, and the house is kept at 70°F throughout the winter. The temperature is set back in the evenings and during the day, totaling about nine hours of system "off" time per day. The temperature generally drops about 5°F during the setback periods.

In summer, the building is very comfortable. Passive night cooling is employed by opening the windows after sundown and closing them in the morning. The casement windows catch breezes effectively, and it is only during extended periods of hot, humid weather that the interior becomes muggy. Air conditioning has not been installed to date. If AC is installed, it is anticipated that a 1.5 ton unit would be needed, as dehumidification is the primary concern, not temperature control.

RESULTS

In an effort to keep analysis very simplified and therefore relevant to the majority of users considering undertaking this type of retrofit, Table 1 is a rough "back of the envelope" analysis of the gas consumption for pre- and post-retrofit.

Using the June through September consumption as the "base load" (domestic hot water, cooking, and clothes drying), the estimated cost of the base load is approximately $110 per year. From this, the annual heating cost can be estimated as shown in Table 2.

These annual costs represent about a 66% reduction in total cost of gas from the previous owners' usage. It should also be recognized that the total gas consumption for the entire building was not verified prior to renovation and that the previous consumption could have been even higher when one considers the possible use of the gas range/space heater in the second unit.

TABLE 2
Estimated Annual Savings—Pre-Retrofit vs. Post-Retrofit Conditions

	1996	1995	1994
Approximate Average "Base Load" Cost	$110.00	$110.00	$110.00
Approximate Annual Heating Cost	$320.63	$316.29	$407.23
Previous Owners' Estimated Cost, 2253 therms @ $0.75 per therm	$1689.75	$1689.75	$1689.75
Approximate Annual Savings	**$1259.12**	**$1263.46**	**1175.52**

TABLE 3
Estimated Incremental Costs (Labor and Materials)

Double Stud Walls	$3,900.00
Extra Insulation	$1,200.00
Air Sealing Envelope	$2,000.00
Extra One Month Carrying Cost	$800.00
Ventilation Systems	$3,500.00
Total	**$11,400.00**

An estimate of incremental cost is given in Table 3, compared to a conventional gut rehab of the building. These costs are based on national average cost data for materials and labor and do not reflect the cost savings realized by any sweat equity labor.

If this incremental amount is financed at 8% over a 30-year mortgage as part of the construction financing of the project (at $7.34 per $1,000 borrowed), the additional cost on a monthly basis could be calculated as:

$$\$11{,}400 \times \$7.34 \text{ per } \$1{,}000 = \$83.68 \text{ per month or } \$1004.16 \text{ per year.}$$

Energy savings compared to pre-retrofit conditions are in the $1,200 per year range. Given the level of rehab that took place in this building, it appears that the super insulation, air sealing, and ventilation were an extremely cost-effective upgrade. This was reinforced by a realtor, who gave the house a $12,000 increase in value compared to other older houses with minimal energy efficiency features.

DISCUSSION

It should be recognized that the data here are based on the actual experience of only one individual situation. As such, it is important to recognize the limitations of this case study and not to use it as a generic "prescription" for other similar projects. The scope of this project was a significant rehab and included much sweat equity on my part. However, based on this example, it is evident that in significant rehabilitation projects, a positive cash flow can be realized when comprehensive upgrades are made to the entire building as a system, as opposed to simply looking at measure-by-measure retrofits. In addition, several other options exist to reduce the cost of this type of rehab, with potentially similar results. Based on this experience, I would recommend the following strategies to others seeking to undertake a similar project.

1. I would never do the interior stud wall again. Instead, I would work with a wall assembly that retained much of the original materials. I would leave the lath and plaster on the majority of the existing wall and strip chases where new plumbing and wiring would need to be run. These chases could also be used to access the stud cavities for insulating. I would strap each edge of the plaster when cutting the chases to secure it and minimize damage. This would have significantly increased the thermal mass of the house and would have eliminated lots of waste (time and construction debris).
2. To air seal the walls, I would have relied on an exterior vapor-permeable house wrap over the existing cedar siding. This would have been taped, caulked, and sealed. Continuity could have been maintained at the top plate connections by cutting back the sheathing to expose the top of the stud wall. The air barrier could then be sealed to the top plate.
3. Air sealing the ceiling would have been done from above, using blower door directed air sealing after installation of the electrical, plumbing, and mechanical systems, using foam or caulk. Ceilings would have been finished by installing strapping over the plaster and hanging new drywall.
4. From an energy and aesthetic standpoint, the windows work very well. A slight bit of condensation is observed at the lower edge of the glazing on very cold days. The biggest problem is the long-term stability of 3 ft wide casement windows. Some seem to open and close perfectly, while others seem to have sagged out of square and are very difficult to fully close. Some actually need to be pushed shut from the outside. This may be due to the installation in an older home that is not square and true; however, it seems that those windows that are left open for extended periods of time are more susceptible to this problem than those that are only opened intermittently.
5. In an effort to minimize the air distribution system and keep it contained within the conditioned envelope, performance suffered. The system has supplies to each room, with two central returns. Because the doors on the bedrooms are not used, this was not considered to be an issue at the time of construction. The aspect ratio of the trunk duct in the second floor is about 6:1, and the take-offs are only 6 in. to 8 in. long before connecting with the register. While the system provides heat adequately and uniformly, it is plagued with velocity and blower noise. All the ducts are steel, and none is lined near the air handler. Due to the very short and straight duct runs, fan noise is audible from just about anywhere in the house. In addition, the heat-recovery ventilator (HRV) fresh air supply is located very close to the return air grille. Due to this fact, the HRV can be heard even when it is running at low speed.
   While everything is sized according to the Air Conditioning Contractors of America's (ACCA) *Manual J* and *Manual D*, the system is noisy. To minimize this, the supply and return trunk ducts for the second floor should have been installed in the attic with flex ducts for supplies. This would probably have reduced the noise levels on the second floor considerably and would have allowed for supply and return air in each room. In retrospect, air sealing these ducts would have been a relatively minor issue, and the ducts could have been buried in loose fill insulation to minimize heat loss.

Sound insulation should have been installed in the supply and return plenums and a longer trunk duct provided on the first floor.

CONCLUSION

The rehab of existing buildings into significantly more energy-efficient structures is a viable alternative to new construction. When other impacts, such as community, infrastructure, and embodied energy, are considered, it in fact appears to be a highly desirable strategy. Indeed, by taking a systems approach to comprehensive remodeling, existing buildings can be assured of a long life and low operating costs.

The cost-effectiveness of renovating a building must take into account the energy consumption before renovation and the use of future energy savings to pay the financing on comprehensive improvements, not simply look at measure-by-measure improvements. It is only in this way that the building and the occupants can get both the benefits of an energy-efficient, thermally improved shell with greater comfort and durability and better indoor air quality.

Options that should be considered as part of a comprehensive systems rehabilitation include:

- Additional insulation (beyond what the existing structure may be able to accommodate) on the interior or exterior of the building.
- Assessment of the wetting and drying potential of additional insulation materials used, in relation to climate and location of the material in the building.
- The replacement of existing windows or glazing with newer, high-performance units appropriate for the climate.
- Undertaking significant air sealing of the building to minimize unwanted airflow into insulated cavities of the building.
- Incorporating controlled mechanical ventilation system to exhaust stale air and replace it with fresh air.
- Integrating ventilation with air distribution systems.
- Replacement of heating and domestic hot water systems with high-efficiency integrated appliances.
- Investigation of the cost savings possible with downsizing/eliminating mechanical systems (smaller air conditioning, reduced or eliminated boiler) due to significantly improved thermal shell.