RETROFIT CONSIDERATIONS IN THE MULTIFAMILY SECTOR

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ABSTRACT

The multifamily sector shows significant potential for retrofit conservation. However, this sector has been ignored because of the programmatic difficulties inherent in the owner/tenant relationship. Over the past three years, Ecotope, Inc. has evaluated technical retrofit potential in about 200 multifamily projects in rural and urban areas across the United States. This work has focused on electrically heated buildings and has included audits, conservation option development, simulation, and billing analysis. The buildings analyzed are typically lowrise and less than 50 units.

This paper summarizes our results and observations, discussing the following points:

1. Window retrofits are the single largest source of conservation potential, providing approximately 50% of total sector savings. The addition of storm windows is widely applicable and generally has a calculated payback of 5 to 15 years.

2. Insulation levels in lowrise multifamily buildings constructed since 1955 are sufficient to preclude a cost-effective wall insulation strategy.

3. With the exception of attics, ceiling insulation retrofits should be installed at reroofing time to insure cost-effectiveness.

4. Infiltration rates tend to be lower in multifamily buildings than in single family homes built to the same standard. Natural air change rates to ambient of 0.3 ACH to 0.4 ACH appear to be typical in Seattle multifamily buildings.

5. Occupant effects are particularly important in monitoring projects, billing analyses, and realization of conservation potential in the multifamily sector, where turnover rates are high. In a small building, turnover or vacancy in one unit may significantly affect results for the building as a whole.

INTRODUCTION

Attention to the multifamily sector has focused on equipment upgrades and retrofits in buildings with fuel-fired central space and water heating systems. These measures typically can achieve 1-3 year paybacks and are often favored by tax incentives. Furthermore, the owner of the building immediately benefits from such a move through lower fuel costs.

In electrically heated multifamily buildings, there are several important barriers to the realization of conservation potential:

- building ownership does not pay the utility bill for space heating;
- there is a lack of technical information and resources regarding the practical conservation options available;
- the bulk of the conservation is available from envelope retrofits which have no subsidies and payback periods of 7-15 years -- well beyond the typical economic criteria of most owners.

Ecotope has evaluated the technical retrofit potential for multifamily buildings (5700 units). This paper focuses on the 140 electrically heated buildings examined in this process. The clients have been publically subsidized housing and the local urban utility concerned about load growth in the sector brought on by electric heat conversion of older buildings. As a result of these clients, much more generous cost-effectiveness criteria were used to identify the energy conservation measures.

BACKGROUND

Over the past three years, Ecotope has completed three projects involving evaluation of multifamily retrofit potential. A brief overview of these projects (and the particular subsectors which they addressed) provides a framework for interpreting the discussion in this paper.

Evaluation of Conservation Potential in the Multifamily Sector

A random sample of 69 buildings (895 units) was chosen from within the Seattle City Light (SCL) service area.[1] The buildings were audited and a list of feasible conservation options was developed. DOE-2 simulations provided estimates of energy savings from the various conservation options for a representative subsample of the buildings. These savings were combined with cost estimates derived from contractor bids to identify cost-effective options. Simulation results were used to calculate savings due to cost-effective measures for the 57 buildings with electric space heat, and savings estimates were extended to the sector using supplemental demographic data. In addition, 3 years of billing data were obtained for each building in the sample.[2] These billing data were analyzed separately to identify significant consumption characteristics such as end use breakdowns, dependence on fuel type and weather, etc. The study was limited to buildings with 5 to 50 units. Current work is extending this study to buildings with more than 50 units.

Private Property Management Firm (PPMF)

Individual plans for cost-effective conservation retrofits were developed for 94 privately managed projects which are generally low income, government rent-subsidized housing typical of 1970s lowrise multifamily construction.[3]

They are located in small towns or rural areas in 26 states. As-built drawings were used to derive heat loss rates and area takeoffs for the buildings; this structural information was supplemented by conversations with resident managers in identifying and evaluating feasible conservation options. Each building was modelled with the daily simulation model SUNDAY[4] to calculate the energy savings attributable to each measure, then the measures were ranked in order of cost-effectiveness by an optimization program. Local energy costs were used in determining which measures were cost-effective.

Public Housing Authority (PHA)

Individual plans for cost-effective conservation retrofits were developed for 16 suburban Seattle public housing authority buildings which are subsidized low income senior housing built between 1969 and 1975. They are wood frame low rise buildings and rigid frame high rise buildings of about 70 units per building. Eleven buildings are electrically heated with individual room baseboards. The energy conservation plans are based on audits, SUNDAY simulations and optimizations, as above.[5,6]

Summary characteristics of the 3 building samples are shown in Table I and should be kept in mind as they affect technical retrofit potential.

Table I. Summary of Multifamily Building Samples (electric space heat only).

	SCL		PPMF		PHA	
	Full Sample	Elect Sp Ht	Full Sample	Elect Sp Ht	Full Sample	Elect Sp Ht
# Projects	69	57	94	71	16	11
# Blds	69	57	570	425	16	11
# Units	895	666	3814	2937	1065	817
Typical Size, units	10	9	40/project 6-8/bldg		70	70
Typical Age, years	26	23	8	8	15	15
Electric Cost	$.040		$.013 - .150		$.047	
Location	SCL service area mostly urban		Small towns, rural areas		Suburban Seattle	
Construction	Mostly wd frame < 4 stories		Lowrise wd frame multi-bldg		Mostly 4-7 stories	

Variation in climate and locality for the subset of electrically heated buildings are shown in Table II.

Table II. Localities & Climates of Multifamily Electrically Heated Building Samples.

Sample	# of Buildings	Region*	DDays (avg)	Max	Min
SCL	57	NW	5185		
PHA	11	NW	5185		
PPMF	32	NW	5569	7063	4792
	13	MW	5674	8054	2598
	9	MT	7886	9033	5394
	7	SW	6631	7483	5212
	5	SO	2963	4237	2240
	5	AK	10800	10800	10800

* NW: WA, OR, ID.; MW: SD, OK, KS, IA, KY, MO; MT: MT, UT, CO, WY; SW: CA, NV, AZ, NM; SO: AL, NC; AK: AK

CONSERVATION OPTIONS

Economic Criteria

While a variety of economic criteria were employed in the various samples, all are characterized by a low discount rate over a long economic life. In some cases, the effective simple payback period is 20 years. The SCL criteria were based on its marginal cost of electricity projected over 30 years. A 3% discount rate was used. This reflects the value of the conservation measures as compared to the economic criteria used in evaluating electric power plant investment, thus identifying measures which deserve utility subsidy to aid in installation. The public and subsidized housing projects were evaluated using long term (40 years) financing as a source and projecting a break-even interest rate for such a note. The lower limit on this rate was about 7% using current fuel costs and assuming the general inflation rate equaled the fuel cost escalation rate. In the case of public ownership, cost-effectiveness over the building's life is the basis for measure selection. In most cases, building life expectancy is assumed to be 40 years.

Technical Criteria

Technical evaluation of retrofit conservation options for the multifamily buildings evaluated focused on two issues: 1) structurally feasible and widely applicable retrofit options on individual buildings; and 2) the relative effectiveness of various options in reducing energy consumption across the multifamily sector, i.e. those that provide the majority of potential energy savings in the sector.

Ecotope developed a set of workable conservation options as part of the study undertaken for SCL. These options, with some additions and alterations as necessary, were used in subsequent work for public and private property management agencies. For this discussion, we will focus on the envelope conservation measures although lighting and equipment improvements (e.g., hot water tank insulation, boiler operation and maintenance, exterior and common area lighting) were extensively evaluated and generally represented cost-effective options. We have made retrofit recommendations for 3 somewhat distinct subsectors of multifamily buildings and thus have a good sense of what types of options are most often appropriate. In addition, individual recommendations have been summarized to determine which options are the most significant contributors to total retrofit potential in each subsector.

Optimization

The basic approach to assessing the applicability of envelope conservation measures in particular cases was an optimal conservation methodology developed by Larry Palmiter for evaluating residential conservation packages.[7] This approach involves the generation of a heat loss input to a simulation program which can address the impact of reduction in heat loss rate. For this, DOE-2 and SUNDAY programs were used. DOE-2.1B is a multi-zone, hourly simulation and SUNDAY is a single-zone, daily simulation which provides accurate annual performance prediction with a minimum of user supplied information. Both programs produced similar results. The procedures involve iteratively adjusting the input parameters until the simulation output consumption matches the actual annual energy consumption. This is accomplished by adjusting thermostat settings, infiltration rates, and internal gains estimates, since these are considered to be the least amenable to accurate estimation. The base case building inputs are then altered to reflect the addition of a single conservation option (e.g., storm windows) and the savings noted. The process is repeated for each identified conservation option until a table of costs and benefits is generated. The most cost-effective option is selected and included as a part of the base case. The process is then repeated until a table of conservation options is generated in order of cost-effectiveness.

Workable Options

Workable options include retrofit measures that are structurally feasible, cost-effective and widely applicable. Structural feasibility is the initial criterion. Generally, retrofit options for electrically heated multifamily buildings are virtually identical to those most commonly recommended in the single family sector.[1] This is because low-rise multifamily buildings are similar in construction to single family residences: they tend to have wood frame construction and to have less than 4 stories. Furthermore, about one third of the large projects (50+ units) in the Seattle area actually can be subsumed into the remainder of the sector because they are either complexes of small buildings, wood framed, or less than 4 stories. The buildings analyzed for the private property management firm are even more uniformly similar to single family structures — they are generally complexes consisting of 2 story buildings, with 6-8 units per building. Almost universally they are wood frame construction, with attics and crawlspace floors.

Not all conservation options identified as structurally feasible are cost-effective even by these standards. Cost-effectiveness depends on the magnitude of the savings (which depends on climate), local energy and local conservation option costs, and the building envelope conditions. The combined effects of structural feasibility and cost-effectiveness are illustrated in Figure 1, which shows, for the 3 multifamily subsectors we evaluated, the percent of buildings to which various conservation options can be applied.

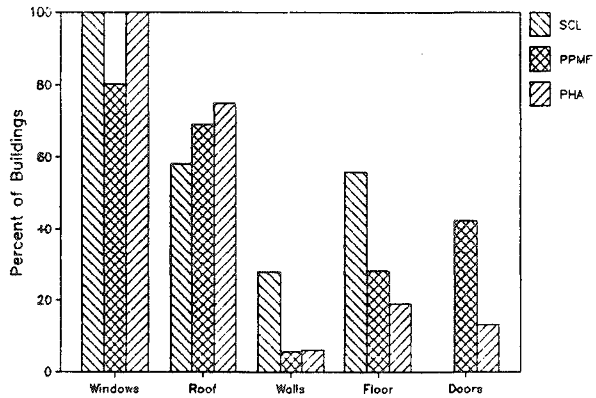

Figure 1. Applicability of conservation options.

WINDOWS. Window retrofits are the most widely applicable option in all 3 building samples. Most buildings built before 1980 have single glazed windows, although other parts of the building envelope may be insulated. Converting single glazing to double glazing through the installation of storm windows, conversion units or replacement windows (cost-effectiveness based on added cost of a double glazed, thermally improved window over a least cost aluminum frame, single glazed window) is cost-effective in most regions. In the Seattle area buildings, window retrofits are applicable in 100% of the buildings (all were constructed before energy codes mandating double glazing were adopted). In the nationwide building subsector, window options are applicable in 75% of the buildings. Some of the remaining buildings were constructed with double glazing or had storm windows already installed; in a few cases the climate was too warm or energy costs were too low to make window retrofits cost-effective. The relationship between climate and the applicability of storm windows, shown in Figure 3, is confounded in this case by wide variations in existing electric energy costs, the quality of existing windows, and the presence of double glazing. In some climates (e.g., Alaska) the existence of installed double glazing does not preclude a cost-effective addition of a third glazing. As a result of these factors, climate appears to play a limited role in determining the cost-effectiveness of window upgrades.

ROOFS. Some type of roof insulation is applicable in well over half the buildings in each subsector. Roof options include blowing additional insulation into attics, blowing insulation into roof cavities under flat roofs, or blocking the roof vents and installing rigid foam insulation. Retrofit attic insulation up to R-38 (R-49 in colder climates) is cost-effective virtually everywhere, regardless of climate and energy costs. Rigid foam roof deck insulation is applicable on flat roofs at reroofing time when reroofing costs are incurred anyway. Installation of foam roof deck involves removal of the existing roof, blocking soffit vents, installing the foam, altering parapet and roof penetration details, then reroofing. The added cost over reroofing of 3" of foam was about $1.20 per square foot.

Like windows, the relationship between roof insulation retrofits is apparently independent of climate (see Figure 3). It appears that the variations in cost of energy and existing attic and roof deck insulation account for the very weak effect of climate.

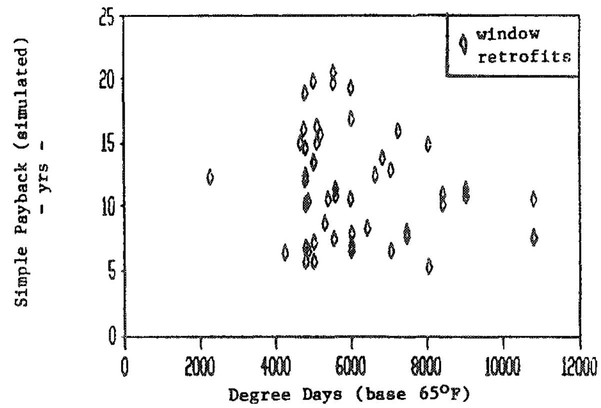

Fig. 2. Cost/benefit of window retrofits by climate (PPMF sample).

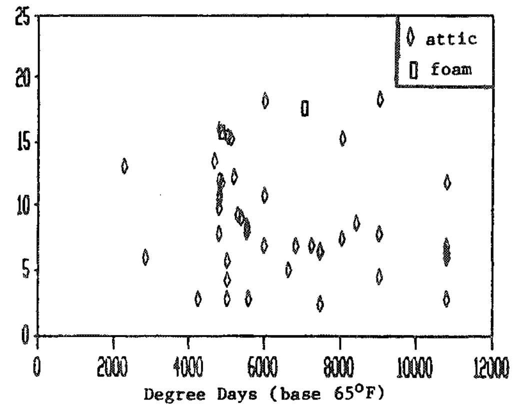

Fig. 3. Cost/benefit of roof retrofits by climate (PPMF sample).

WALLS. The primary wall option for frame buildings is to blow insulation into the stud cavities. This is recommended only if the wall is uninsulated and therefore applicable only in older buildings. It is relatively inexpensive and significantly reduces building heat loss. Other potential wall options include furring out and insulating concrete below grade walls to heated spaces and applying rigid foam to the exterior of masonry buildings. While addition of rigid foam is expensive, it significantly reduces heat loss through concrete walls. However, these options are marginally cost-effective in Seattle, and cost-effectiveness in other areas cannot be generalized.

The applicability of wall options depends largely on a building's age. The SCL sample includes older buildings that could use blown in insulation. In general, the cost-effectiveness of wall insulation was independent of fuel type or climate. For buildings in all 3 samples, 85% already have insulated walls or their construction precludes wall retrofit options. Existing wall insulation was much more common in multifamily buildings than in single family homes of the same era in the Pacific Northwest.

FLOORS. Floor options include installing batts in uninsulated crawlspaces and blowing insulation into uninsulated floor cavities over garages or other unheated spaces. In each sample, 20% to 30% of the buildings have uninsulated crawlspaces. Crawlspace insulation is cost-effective in all cases. A sizable proportion of the SCL buildings have ground floor garages and could use cavity insulation or rigid insulation. Floor options are not generally applicable in buildings with slab-on-grade floors or insulated crawlspaces. These floor types account for the majority of buildings in the PPMF and PHA subsectors.

DOORS. Wood apartment doors can be replaced with insulated core doors. This option is only marginally cost-effective in Seattle and was not considered in the SCL study. However, nationwide it is cost-effective in colder climates (over 6,000 degree days) when units have exterior entryways.

Effect on Savings

In planning retrofit programs, it is useful to know where to focus funding and marketing efforts, i.e, which options provide the majority of energy savings in a subsector. The question of effectiveness involves not only applicability of an option, but also the importance of the relevant building component in the total building heat loss and the extent to which the retrofit reduces the U value of the building component.

Table III shows the savings contribution of each building component as a percentage of total savings for the subsector. Breakdowns are shown for various building envelope measures, and for the envelope as a whole. It should be noted that these results are not directly comparable across building samples because each sample represents a unique subsector of multifamily buildings. Comparing results for the 3 building samples while keeping their differences in mind enables us to identify building components which are uniformly important in multifamily retrofit programs.

Table III. Component Contributions to Total Subsector Energy Savings (%)

	SCL	PPMF	PHA
Windows	62	47	70
Roof	14	23	16
Wall	18	1	8
Floor	6	20	3
Door	--	9	3
TOTAL ENVELOPE	100 (91)*	100 (80)*	100 (88)*

* Savings as percent of all conservation options including lighting and domestic hot water.

Window options are the single largest source of conservation retrofit potential. In the case of the SCL and PHA buildings, windows alone are responsible for 50%-67% of total potential savings, and are 3 to 4 times more important than the next most significant component. There are several reasons for this. First, as shown in Figure 1, window options are the most widely applicable retrofit options. Residential buildings built before 1980 mostly have single glazed windows; most of these buildings can be readily converted to double glazing with the addition of storm windows or conversion units. Second, windows generally have much higher heat loss rates than do surrounding components. Adding a layer of glass to a single glazed window can cut its heat loss rate in half, thus providing the opportunity for considerable energy savings. Third, windows represent a higher proportion of the total building shell area and the total building heat loss in taller buildings. (In a typical two story building, glass represents 8% of the building envelope and 53% of the total building heat loss excluding infiltration; in a 10 story building, the impact of glass increases to 15% of total building envelope, and 68% of building heat loss.) This is accentuated by the relative unimportance of infiltration-driven heat loss in this sector.[8] Window retrofits therefore become more significant in multi-story buildings. These 3 factors combine to give windows the primary role in retrofit conservation potential.

While windows remain the most significant component in the PPMF buildings, they are not as overwhelmingly dominant. As discussed earlier, window retrofits were applicable in only 75% of the buildings in this sample, mainly because of existing double glazed or storm windows. In addition, most of the buildings in this sample had 1 to 2 stories, while the SCL buildings generally had 3 to 4 stories, and the PHA buildings typically had 6 to 7 stories.

The various roof retrofit options provide the next largest contribution to potential savings, accounting for 13% to 20% of total savings. Their impact is relatively uniform across subsectors. However, although roof options are applicable in well over half of the buildings in each subsector, they are generally less cost-effective than window retrofits. This is partially due to the fact that many roof retrofits involve adding more insulation in attics or cavities where some insulation already exists; the impact on overall U value is not as large as it is when a single-glazed window is retrofit.

The contributions of wall and floor options vary significantly across the building samples. Wall options are important in those subsectors where insulation may be blown into hollow frame walls. The older wood frame buildings in the SCL sample explain the relatively high wall savings figure for that subsector while the newer and generally already wall-insulated buildings explain the inapplicability of wall retrofits in the other 2 sectos. Floor measures are important only in the PPMF sample, where most buildings have crawlspaces. In the SCL sample, floor measures were relatively insignificant; while applicable in over half of the buildings, they provided only 5% of the savings.

INFILTRATION

Little is known about typical infiltration rates in multifamily buildings. It is unwise to generalize from tests of single family residences because apartment airflow patterns are potentially very different than those in single-family buildings. For example, there can be significant airflow from unit to unit within a building as well as outside air infiltration. Studies indicate that typical infiltration rates in apartment buildings may be significantly lower than those in single family homes built to the same standard. Tests conducted at Princeton on single story buildings with 4 to 7 units showed natural air change rates ranging from 0.1 to 0.3 air changes per hour (ACH) after some retrofit work. Blower door tests of a 20-25 year old, 6 story building with R-11 walls and single glazed aluminum windows showed a maximum leakage rate of 4 ACH at 50 Pascals, which would translate to a natural rate of 0.3 ACH or less [personal communication, Kenneth Gadsby, Center for Energy & Environmental Studies, Princeton, NJ].

The issue of infiltration was addressed in the study completed for SCL. Analysis of billing data suggested that infiltration rates were generally lower than would be assumed for single family homes of similar construction. Blower door tests on a typical building supported this conclusion. The billing analysis was based on the premise that with 100% efficient electric heat, space heat consumption per degree day in a building should be roughly equivalent to that building's total heat loss rate, conductivity plus infiltration. The consumption per degree day for the 57 buildings in the sample with electric space heat was derived by regressing total building electricity use against degree days for billing periods with noticeable space heat.[2] The amount of heat loss due to infiltration is a large unknown if the infiltration rates are not measured. We used several alternative infiltration rates and concluded that rates of about 0.3 ACH provided the best fit. While the billing analysis could not be used to determine actual infiltration rates in these buildings, results strongly suggested that typical infiltration rates are significantly lower then generally assumed, and that rates are uniformly low for a variety of building construction types and ages.

In an attempt to check the validity of these conclusions, infiltration measurements were completed on a typical 25 year old, 12 unit, 3 story apartment building from the SCL sample.[1] Infiltration rates in each unit were measured with a blower door on 2 separate occasions several months apart.

Investigation while the units were depressurized revealed significant airflow through common walls and from the outside. Since the blower door measurement includes both infiltration sources, we corrected the measured results to remove airflow between units using ASHRAE's "method of cracks" accounting of leakage [ASHRAE Fundamentals 1985, Chapter 22]. Corrected values were about 65 to 75% of measured values, depending on a unit's location in the building. The measured infiltration rates ranged from 0.59 to 0.29 ACH in various units, with a median of 0.45 ACH, representing an upper limit on outdoor infiltration. Corrected infiltration values ranged from 0.40 to 0.23

ACH, with a median value of 0.33 ACH -- probably a low range estimate. Actual outdoor infiltration probably falls somewhere between 0.3 and 0.4 ACH which is consistent with the billing analysis results discussed earlier.[8]

Results from one building cannot be used to make generalizations. However, evidence of low infiltration rates in multifamily buildings is mounting, and the advisability of retrofits that specifically reduce infiltration should be examined as they may have little incidental impact on infiltration or on overall heat loss given the initial low infiltration rates.

OCCUPANT EFFECTS

As is commonly understood, occupant behavior plays a vital role in building energy consumption and may affect consumption more than the thermal characteristics of the building. This is widely seen in analysis of data from both single family homes and multifamily buildings.[2] In smaller multifamily buildings (5-15 units), unusual consumption patterns in 1 unit can significantly bias total building consumption figures, adversely affecting the analyst's ability to predict retrofit savings, relate consumption to other parameters, etc. This is exacerbated by the high turnover rate typical of multifamily buildings. In the SCL sample, billing analysis indicated that tenants occupy a unit for 16 to 19 months, on average. Also, 2 to 3 month vacancies are often typical. These variations coupled with the impact occupant behavior can have on consumption adversely affect the consistency of data collected from apartment buildings. Obviously, the impact of any particular unit on total building consumption is reduced in larger buildings.

Particular care and attention is needed in evaluating multifamily data because it is so difficult to obtain a continuous, consistent set of billing or monitored data. Building simulations are more effective if a standardized set of conditions is developed and modelled than if the analyst attempts to match bills. Wherever possible, data should be normalized to remove effects of occupant changes and vacancies. Finally, savings estimates should have a wide margin of uncertainty due to the impact of occupant behavior.

CONCLUSIONS

1. Window retrofits are the largest source of conservation potential, accounting for 40-70% of total sector savings -- 2 to 4 times more than any other component. Conversion to double glazing is widely applicable and cost-effective in virtually all climates.

2. Roof retrofits are the second most productive source of conservation savings, providing 13-20% of total potential savings. Blowing additional insulation (up to R-38) into attics is universally cost-effective. Retrofit options for flat roofs (cavity insulation or foam deck) should be installed at reroofing for maximum cost-effectivness.

3. Multifamily buildings constructed between 1955 and 1975 typically have more insulation in ceilings and walls than single family homes of the same era. Insulation levels are generally sufficient to preclude cost-effective wall retrofit strategies, except perhaps in colder climates.

4. Given equivalent construction, infiltration rates tend to be lower in multifamily buildings than in single family homes. Natural airchange rates of 0.3 to 0.4 ACH may be typical in Seattle multifamily buildings. Given these generally low infiltration rates, building retrofits that specifically reduce infiltration may not be indicated.

5. High turnover and vacancy rates in the multifamily sector, coupled with the strong occupant impact on consumption, adversely affect the quality of multifamily energy consumption data. Billing data, monitored data and building simulations should be normalized when possible to minimize such effects.

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