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Field Test Evaluation of Conservation Retrofits of Low-Income, Single-Family Buildings: Combined Building Shell and Heating System Retrofit Audit

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ORNL/CON-228/P3

Energy Division

FIELD TEST EVALUATION OF CONSERVATION RETROFITS OF LOW-INCOME, SINGLE-FAMILY BUILDINGS: COMBINED BUILDING SHELL AND HEATING SYSTEM RETROFIT AUDIT

Lance N. McCold

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EXECUTIVE SUMMARY

Until recently, DOE-funded low-income weatherization activities were limited to infiltration control, insulation, and adding storm windows, with an expenditure limit of $1000 per house. Under these conditions, most retrofit programs operated from a fixed priority list, for example: control infiltration, insulate water heater, add ceiling insulation to some level, and spend the remainder on storm windows. Each house received about the same treatment, and the same amount was spent on each house.

Revised DOE regulations allow an average expenditure per dwelling of $1600 and permit an expanded list of retrofits, including

- heating and cooling system tune-ups, repairs, and modifications;
- installation of thermostat control systems, heat exchangers, and heat pump water heaters; and
- furnace, boiler, and water heater replacements.

This expanded retrofit list provides options for more effective energy savings, but it also complicates the process of selecting the best combination of retrofits.

The DOE Office of Building and Community Systems asked ORNL to develop a procedure for selecting the optimum combination of building shell and heating system retrofits for single-family dwellings. The objective was to obtain maximum energy savings per retrofit dollar expended for the entire group of retrofitted houses. Obviously, no single set combination of retrofits would provide optimum savings for

all housing types or for all climates. The required procedure would have to be a general approach that could be adopted to varied housing types in various parts of the country.

In order to satisfy these requirements, ORNL staff members developed an approach that used information from preretrofit energy audits of the candidate houses to determine the best combination of retrofits for each house to maximize program savings. The procedure allows different combinations of retrofits for different houses and different expenditures per house. The purpose of this report is to describe this Audit-Directed Retrofit Program (ADRP).

The retrofit audit uses characteristics of the house, the climate, and the retrofit to calculate energy savings. The audit includes six heating system retrofits and seven building shell retrofits. The heating system retrofits are (1) intermittent ignition devices (IIDs), (2) electromechanical full-closure vent dampers (requiring use of IIDs), (3) thermally activated vent dampers, (4) secondary condensing heat exchangers, (5) gas power burners, and (6) furnace replacements.

The building shell retrofits are (1) ceiling insulation, (2) wall insulation (blow-in), (3) storm windows, (4) storm doors, (5) sill box insulation, (6) exterior basement wall insulation (R-10), and (7) floor insulation.

The audit also accounts for interactions among retrofits in estimating energy savings.

After each house is audited, it is possible to calculate (1) annual energy savings associated with various retrofits for each house, (2) life-cycle cost benefits (B) for various retrofits for each house, and (3) the installation costs for each retrofit in a given house (C). A

benefit-to-cost ratio (B/C) can then be calculated for each potential retrofit for a given house. These B/Cs can be ranked, from all possible retrofits to all candidate houses, and the top-ranking B/C projects can be selected for installation. This process will maximize program savings for a low-income weatherization project.

The use of B/Cs to rank the comparative value of retrofits is possible because a retrofit B/C for one house is directly comparable with a retrofit B/C for any other house. If a minimum acceptable retrofit B/C is established (e.g., 1.0), then those houses that need more retrofits will receive more and houses that need fewer will receive fewer.

Simple economic considerations indicate that retrofits with B/Cs <1.0 should not be done; but because B/Cs depend strongly on the discount rate used in the calculations, a B/C of 1.0 is not as definitive as it may seem. Other considerations may lead to the choice of a different minimum B/C. For instance, if a state chooses to spend an average of $1000 per house, a different minimum B/C is needed. The easiest way to determine the B/C is to audit a representative sample of houses and select the best retrofits until the desired average expenditure is reached. The B/C of the last retrofit will be a good estimate of the desired minimum B/C.

The audit was designed to be as simple to use as possible. The calculations can be carried out with a hand calculator. The measurements made at the house are also simple. The heating system efficiency measurements are the most complicated, but they are essential if heating system retrofits are to be considered. The best opportunities for

simplifying the audit are in eliminating retrofits that seldom have B/Cs above the minimum and by automating the audit calculations.

The ADRP described in the document is quite general. It can be used for various types of single-family housing in different climates. The approach was field tested in a low-income housing retrofit program in Wisconsin during the winter of 1985-86. Results of this field test are reported in a companion document, ORNL/CON-228/P2.

ABSTRACT

Revised DOE regulations allow greater flexibility in conducting DOE-funded low-income weatherization programs. Certain retrofits to heating and cooling systems for these houses are now permitted, as well as the traditional insulation and infiltration control measures. Also, different amounts of money may be spent on different houses, as long as the average expenditure per house does not exceed $1600.

The expanded list of retrofit options provides an opportunity for increased energy savings, but it also complicates the process of selecting the combination of retrofits, house-by-house, that will yield maximum savings for the weatherization program. DOE asked ORNL to devise a procedure for selecting an optimum combination of building shell and heating system retrofits for single-family dwellings.

To determine the best retrofits for each house that would maximize program savings, ORNL staff members developed an approach that used information from a preretrofit energy audit of candidate houses. Audit results are used to estimate annual energy savings for various retrofits for each house. Life-cycle benefits (B) are calculated, as are the estimated installation costs (C) for given retrofits in given houses. The benefit-to-cost ratios (B/Cs) are then ranked for all possible retrofits to all candidate houses, and the top-ranking B/C retrofits are selected for installation. This process maximizes program savings, and it is adaptable to varied housing types in different climates. The Audit-Directed Retrofit Program (ADRP) was field tested in a low-income

housing retrofit program in Wisconsin during the winter of 1985-86. Results of the field test are reported in a companion document. This report describes the ADRP for the benefit of potential users.

1. INTRODUCTION

Until recently, the DOE-funded low-income Weatherization Assistance Program (WAP) activities were limited to infiltration control, insulation, and adding storm windows, with an expenditure limit of $1000 per house. Under these conditions, most retrofit programs operated from a fixed priority list, for example: control infiltration, insulate water heater, add ceiling insulation to some level, and spend the remainder on storm windows. Each house received about the same treatment, and the same amount was spent on each house.

Revised DOE regulations allow an average expenditure per dwelling of $1600 and permit an expanded list of retrofits, including

- heating and cooling system tune-ups, repairs, and modifications;
- installation of thermostat control systems, heat exchangers, and heat pump water heaters; and
- furnace, boiler, and water heater replacements.

This expanded retrofit list provides options for more effective energy savings, but it also complicates the process of selecting the best combination of retrofits.

The DOE Office of Buildings and Community Systems asked ORNL to develop a procedure for selecting the optimum combination of building shell and heating system retrofits for single-family dwellings. No single combination of retrofits or single priority list will give optimum results more often than occasionally. The optimum combination of retrofits always depends on the characteristics of the house that is to

receive the retrofits. Thus, it is necessary to use a retrofit audit to find the optimum retrofits for individual houses. This report describes the audit.

An audit is a multi-step process illustrated by Fig. 1. The first step is to collect the data on the audited house that will allow estimation of costs and savings of the retrofits. This data collection step is the most visible part of the process. Indeed, many homeowners think that the auditor's observations, measurements, and questions are the audit. While the data collection step is only part of the process, it is a very important step. The audit cannot give accurate results if the data used in it are not accurate. Clearly, the auditors who collect the data need to be well trained. The data collection step is the most time-consuming and therefore the most expensive part of the audit process.

The best way to reduce the audit cost is to streamline the auditors' jobs. Reducing the amount of data they must collect is one good way to do this. For instance, if the retrofit crew is set up to build storm windows on the site, the auditor will not need to measure the windows. Because the audit may not indicate the need for storm windows, it is clearly advantageous to postpone making the measurements until they are needed.

Another method for simplifying the data collection process is to avoid retrofits that are seldom cost effective. When the audit was field tested, storm doors were never found to be a cost-effective retrofit. Floor insulation was found to be needed in only 1 of 35 audited homes. Eliminating possible retrofits from the audit simplifies the entire process.

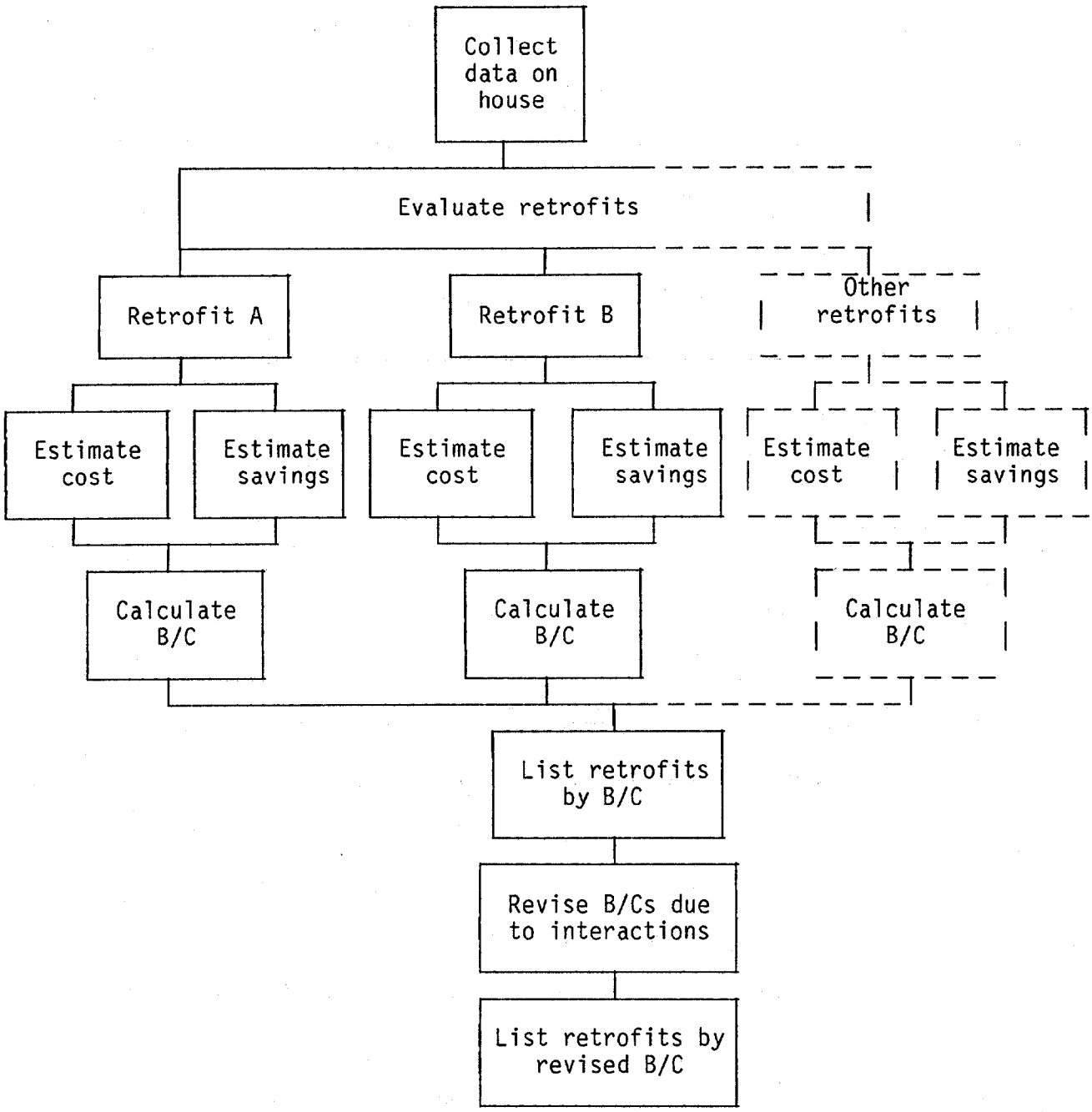

Fig. 1. Audit process for an individual house.

A third way to simplify the data collection process is to employ an easy-to-use data form. The data sheets for this audit are shown in Appendix A. A good deal of effort went into developing this form, but there is room for more refinements. Care was taken not to include more questions than were needed, but certain questions that were not needed to calculate energy savings were included because the audit was used as part of a research project.

As Fig. 1 shows, the cost and energy savings of each retrofit need to be estimated. Retrofit cost estimates are a familiar process and will not be discussed here. Retrofit savings are less familiar and more complex. Section 2 summarizes the calculation process. Appendix B lists the calculation procedures for the retrofits included in this audit. Calculation of the benefit-to-cost ratio (B/C) is another relatively unfamiliar element of this audit. The B/C calculations are discussed in Sect. 3.

Retrofit interactions become important when both heating system and building shell retrofits are used, as in this audit. Interactions between retrofits occur when two retrofits work to save the same energy. For instance, ceiling insulation saves energy by reducing the amount of heat needed to keep a house warm, while improving the efficiency of a furnace reduces the amount of fuel needed to deliver the required heat. Interaction between retrofits causes the energy saved by the combination of retrofits to be less than the sum of the savings each would achieve alone. The method used to account for retrofit interactions is described in Sect. 4.

The final step in the audit process is to list the retrofits in descending order of B/C (Fig. 1). The remaining question is how many retrofits to do.

For the WAP, the question is slightly different: how many retrofits should be done on each house? This has been a long-standing concern in the WAP. It is widely recognized that some houses need retrofits more than others do. The revised DOE regulations that allow expenditures to be averaged across a number of homes give weatherization providers the flexibility needed to spend retrofit dollars where they are most needed. The use of the B/C to rank retrofits offers a new and rational method for allocating retrofit dollars among the houses in the program. Section 5 describes how the audit-derived B/Cs of retrofits can be used in an Audit-Directed Retrofit Program (ADRP).

2. RETROFIT SAVINGS ESTIMATES

A retrofit audit uses characteristics of the house, the climate, and the retrofit to calculate energy savings. For example, energy savings estimates for ceiling insulation are based on the amount of ceiling insulation present in the house, the efficiency of the heating system, the heat retardant characteristics (R-value) of the insulation to be added, and the severity of the climate (heating degree days). Similarly, estimates of heating system retrofit energy savings are typically based on the efficiency of the heating system, the characteristics of the retrofit, and the amount of heating fuel used annually.

This audit takes into consideration six possible heating system retrofits and seven possible building shell retrofits. The heating system retrofits are (1) intermittent ignition devices (IIDs), (2) electromechanical full-closure vent dampers (requiring use of an IID), (3) thermally activated vent dampers, (4) secondary condensing heat exchangers, (5) gas power burners, and (6) furnace replacements.

The building shell retrofits are (1) ceiling insulation, (2) wall insulation (blow-in), (3) storm windows, (4) storm doors, (5) sill box insulation, (6) exterior basement wall insulation (R-10), and (7) floor insulation.

The calculations used to estimate retrofit dollar savings are contained in Appendix B.

Building shell retrofit energy savings are made using the formula

$$\text{Energy savings} = \frac{\text{HDD} \times 24 \times \Delta\text{UA} \times \text{C}}{\text{SSE}}, \qquad (1)$$

where HDD is the annual average number of base 65°F heating degree days, SSE is the steady-state fuel utilization efficiency of the heating system, ΔUA is the retrofit-induced reduction in the heat loss rate of the house (Btu/h-ft^2), and C is an empirical correction factor to account for "errors inherent in the established 18.3°C (65°F) based method."[1]

Equation (1) is different from the equation used by the Residential Conservation Service (RCS) Model Audit[2] in its use of SSE instead of seasonal fuel utilization efficiency (SE). In reference 3 it is argued that SSE is more appropriate than SE because a furnace replaces heat lost by the shell at close to its steady-state efficiency, SSE. The seasonal efficiency, in contrast, includes energy losses by the furnace, such as the fuel consumed by the pilot, that have nothing to do with the building shell.

The characteristics of the house and the retrofit are used to calculate ΔUA. These house characteristics are the data collected by the auditor. The ΔUA is the probable locus of many of the errors in retrofit energy savings estimates. The physical concepts and assumptions on which ΔUA calculations are based are quite simple. In many, these concepts and assumptions may be too simple.

Heat loss through a building member (e.g., a wall) can be compared with the leakage of water through a sieve. If a sieve is lined with a paper towel, the leakage rate is greatly reduced. Adding more paper towels further reduces the leakage rate. If the paper towel has a hole in it or does not cover all the holes in the sieve, most of the water

that leaks out will go through the holes, not through the paper. Clearly, defects of workmanship can reduce the effectiveness of insulation, but it is not possible for an audit to anticipate the extent of defective workmanship.

There are other, more subtle problems with the ΔUA calculations that may lead to over-estimates of energy savings.[3] An example of retrofits that are not adequately understood is the case of spaces, especially basements, that are not intentionally heated but are normally much warmer than the outside air temperature. Imagine a basement that is separated from the house by a door normally kept closed, that has no furnace registers (inlets or outlets) but is kept somewhat warm by the furnace and water heater located there. The problem is to estimate how much energy is saved by insulation or infiltration controls applied in such a basement.

Knowledge of the heat and air entering and exiting such spaces is so limited that estimating energy savings is difficult. It was decided to group building spaces into three categories: conditioned, incidentally heated, and unheated. Conditioned spaces are intentionally heated. Unheated spaces have no internal heat sources and tend to follow the outside air temperature. Incidentally heated spaces have internal heat sources and appear to be closely coupled to conditioned spaces, such as the case of the basement described previously.

Insulating unheated spaces generally saves no energy. Insulating incidentally heated spaces is believed to save some energy if the incidentally heated space is in close contact with a conditioned space. In this audit, insulating such spaces is assumed to save somewhat less than one-half as much as insulating a conditioned space. For the purpose

of this audit, an incidentally heated space is defined as a space that connects with a conditioned space, contains heat sources such as a furnace, boiler, or water heater, but has no furnace registers (inlet or outlet), heat exchangers, or portable space heaters. Ultimately, the distinction between an incidentally heated space and a conditioned space must be made by the auditor. The best guide may be the temperature of the space. If the temperature closely follows the temperature of the conditioned space, it should be considered conditioned. If it follows the outdoor temperature more closely, it should be considered an incidentally heated space.

Most heating system savings calculations are not subject to the range of uncertainties found with shell retrofits. The heating system retrofit that appears to be subject to the most uncertainty is the vent damper, which works by reducing heat loss up the chimney when the furnace or boiler is not being fired. The RCS Model Audit uses low and high vent damper energy savings of 7% and 10% of annual space heating fuel consumption. Energy savings from more than 14% to no savings for individual houses have been measured.[4] A range of 0 to 14% savings is too large a range to be characterized by a single value such as 7%. Only one effort to relate vent damper energy savings to characteristics of the house is known to the author,[5] and the accuracy of the method has not been tested.

Vent damper energy savings are believed to result from reducing the infiltration of cold outside air induced by hot air rising up the chimney. The savings depend on furnace or boiler location and on how much infiltration the air escaping up the chimney causes. If a furnace is located in an unheated crawlspace or outside, there should be no

energy savings.* When a furnace is located in a heated living space, a vent damper should save the most possible energy. Unfortunately, neither theory nor experimental results are available to allow predicting savings in this situation. Accurately predicting energy savings of a vent damper in a furnace located in an unheated but closely connected space such as a basement will require a better understanding of vent dampers as well as the heat and air movement between living spaces and such closely coupled spaces.

Equation (1) shows that there are four components (HDD, ΔUA, C, and SSE) in an energy savings estimate. The SSE and ΔUA have been discussed previously. The correction factor, C, can make a great difference in savings estimates. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) recommends values of C between 0.8 and 0.6 (ref. 1) but values between 0.2 and 1.6 have been inferred from measurements on individual houses.[6] Unfortunately, C is not a physical quantity; it cannot be measured or estimated in the course of an audit. In using this audit, we recommend using the ASHRAE value for a particular climate. In the building shell savings calculations, we have used the term "corrected annual heating degree days" has been used. This term refers to the product of C and HDD:

$$\text{corrected annual heating degree days} = C \times HDD \ . \qquad (2)$$

*A vent damper on a boiler in this situation might save some energy by reducing air flow through the boiler.

The best prospect for overcoming shortcomings of the traditional heating degree day method is the variable base degree day (VBDD) method.[1] In terms of the VBDD method, Eq. (1) would be written as

$$\text{Energy savings} = \frac{24 \times \Delta UA \times DD_{Tb}}{SSE}, \tag{3}$$

where DD_{Tb} is the average number of base Tb heating degree days. The principal impediment to use of the VBDD method in retrofit audits is that there is currently no method available for estimating the base temperature, Tb, of a house within the constraints of a practical retrofit audit. ASHRAE describes a method for estimating Tb for a house, but it is too complex to be used in an audit. Additional work to develop and test methods for using the VBDD method in retrofit audits holds promise in improving retrofit savings prediction accuracy.

One final shortcoming of the predictive methods used in this and other audits is that they are presently incapable of accounting for uneven heat distribution in houses. Some houses are heated unevenly by a wood stove or by a poorly designed air, steam, or hot water distribution system. The methods used in virtually all audits assume that the house is evenly heated by a well-designed, forced-air system. Also, most houses have spaces that are not intentionally heated (e.g., basements or closed-off rooms) but that are warmed by the heated portion of the house and the equipment located therein (e.g., furnaces, water heaters, ducts, and pipes). These unintentionally heated spaces can significantly affect the energy savings achieved by retrofits.

Finally, it should be emphasized that the audit, while believed to incorporate the most accurate savings calculations available, is not free from error. Those who use it should be on the lookout for systematic over- (or under-) predictions of savings. Furthermore, a good deal of research remains to be done to make accurate and reliable savings estimates available. This audit was developed as part of a DOE program to increase knowledge of retrofits.

3. BENEFIT-TO-COST RATIO CALCULATION

The B/C is one of several commonly used ways of characterizing the cost effectiveness of investments. The simple payback period (SPP) is a more popular way to characterize retrofits. However, the B/C has three important advantages over the SPP:

- B/C accounts for the life of the retrofit,
- B/C accounts for the time value of money, and
- B/Cs for different retrofits are directly comparable.

The first advantage is easiest to illustrate. Two retrofits with identical SPPs of four years appear by the SPP to be equally good retrofits; but if one has a 3-year and the other a 6-year expected life, it is clear that one is not cost-effective and the other is.

The way B/C accounts for the time value of money can be seen in Eq. (4)

$$B/C = \frac{AS \times P}{C} , \tag{4}$$

where C is the retrofit cost, AS is the net annual monetary savings, and P is the present-worth factor. The present-worth factor incorporates both the time value of money and the expected life of the retrofit. The time value of money is characterized by the discount rate, which in simple terms is the increase in the value of money in 1 year if invested the best available way. For instance, if a bank pays 7% interest, $93

invested today will increase to $100 in a year, and the value of 1 dollar 1 year in the future is $0.93.

There can be disagreement about what the discount rate should be (when the audit was field tested 7% was used). Figure 2 displays the present-worth factor for various retrofit lives and discount rates. It should be noted that small discount rates give more value to future benefits than large discount rates do. The present values of retrofits with short lives are little affected by the discount rate, but those with long lives are strongly affected by the discount rate.

Current WAP regulations call for use of a 0% discount rate,[7] but higher discount rates have significant advantages. With a 0% discount rate, the present value of a retrofit with $90 annual savings and a 6-year life will be identical to that of a retrofit with $30 annual savings and an 18-year life. If both retrofits cost the same, their B/Cs will be identical, and they will be ranked equally; but, in most cases, a retrofit that quickly repays the investment would be preferable. Clearly, using a higher discount rate will give a B/C retrofit that reflects the preferences indicated in this study.

Table 1 can be used to calculate the B/C for a retrofit. The present-worth factors can be taken from Fig. 2 or calculated with the equation in Table 1. This B/C calculation is suitable for most retrofits, but its simplicity is the result of some simplifying assumptions. If the following assumptions do not seem reasonable, a more elaborate calculation procedure should be sought:

- The price of fuel will not increase faster than the general inflation rate.

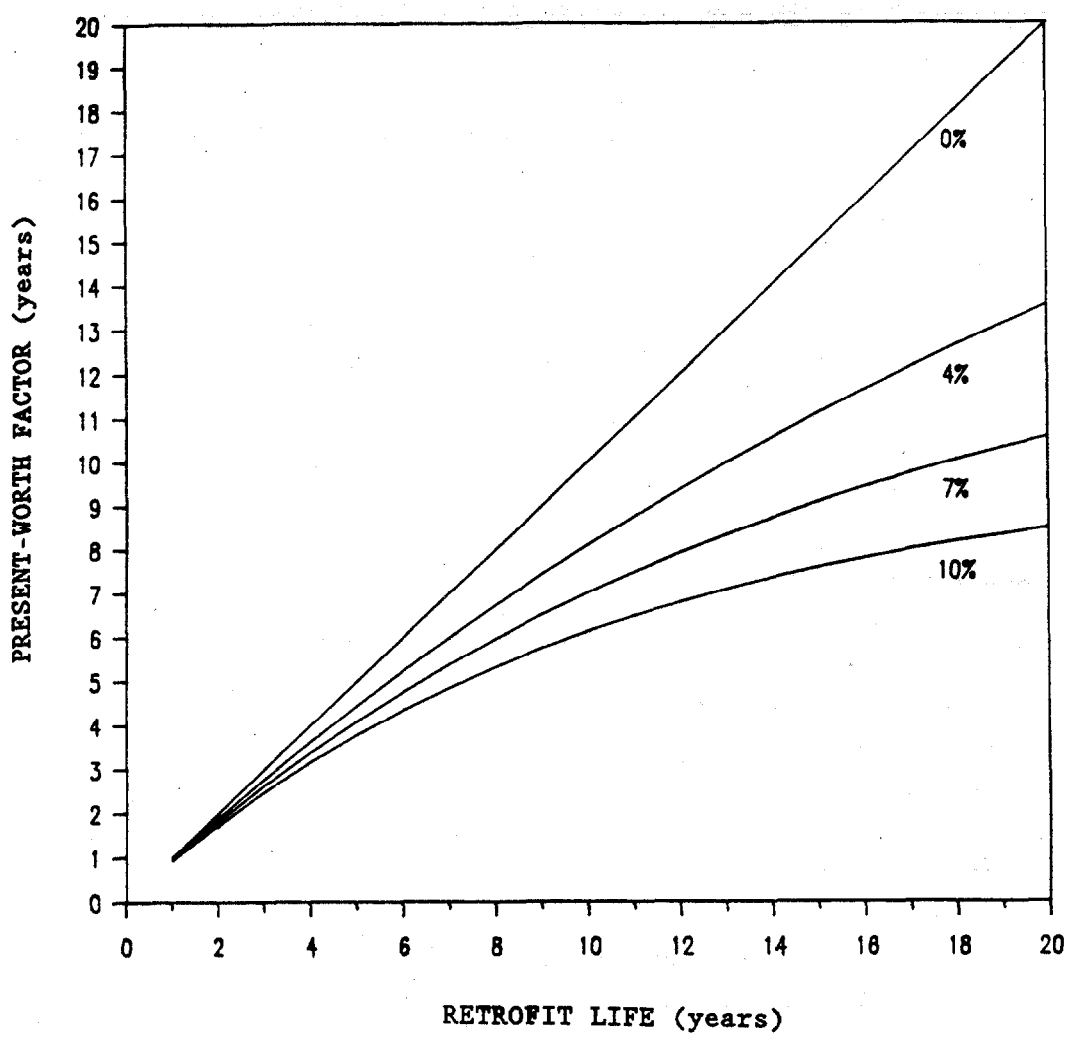

Fig. 2. Present-worth factors as a function of expected retrofit life for discount rates of 0, 4, 7, and 10%.

- The retrofit will continue to perform as well as when new until the end of its life.
- Periodic maintenance will be no more costly after the retrofit than before.
- The discount rate will not change with time.

Table 1. Discounted benefit-to-cost ratio calculation

(A)	Net annual monetary savings (annual savings less annual operating cost increase)	$_____ per year
(B)	Expected life of building or equipment retrofit is applied	_____ years
(C)	Expected life of retrofit device	_____ years
(D)	Expected life (B or C, whichever is smaller)	_____ years
(E)	Present-worth factor[a]	_____ years
(F)	Total expected benefits (A x E)	$_____
(G)	Retrofit cost (installed)	$_____
	Benefit/cost ratio (F ÷ G)	

[a]Use Fig. 2 or, if another discount rate is preferred, use the following equation:

$$\text{Present-worth factor} = \frac{(1 + d)^n - 1}{d(1 + d)n},$$

where d is the annual discount rate and n is the expected life of the retrofit in years (item D above).

4. RETROFIT INTERACTIONS

Retrofits interact in two ways. Some retrofits are mutually exclusive. For example, putting an IID on an old furnace and replacing the old furnace with a new one are incompatible retrofits. Avoiding this kind of interaction is easy; do one or the other. A complicated retrofit interaction occurs between compatible retrofits such as adding ceiling insulation and replacing the old furnace. In this case, the savings of the two retrofits together are less than the sum of the savings of each retrofit performed separately.

Three important questions can be asked about the latter interaction:

- What are the total savings (accounting for interactions)?
- What dollar amounts of savings are attributible to each retrofit?
- How are interacting retrofits ranked?

The answers to the questions follow from three observations:

- The savings resulting from the first retrofit are unaffected by interactions.
- The savings associated with the second retrofit can be calculated in the normal way if the house description is updated after the first retrofit.
- Retrofits should be performed in order of B/C starting with the highest.

Most audits do not account for interactions because the procedure for including them is somewhat complicated. A computerized version of the audit can reduce the amount of computational effort that goes into the interactions; it also can be programmed to account for interactions automatically. The first step is to calculate B/Cs for each retrofit as described in the previous section and record them on a worksheet similar to Table 2. The second step is to sort the retrofits by B/C onto a worksheet laid out like Table 3. The first retrofit (the one with the highest B/C) will never be affected by interactions. If the second retrofit does not interact with the first, its savings will also be unaffected by interactions. The first retrofit that interacts with a higher-ranked retrofit will have its savings reduced. The interactions between retrofits included in the audit are categorized in Table 4.

The method of reducing retrofit savings due to interactions is best explained by example. Table 5 summarizes an example in which shell retrofits rank highest. The house began with a 73% efficient furnace and an annual heating energy consumption of about 1200 therms. The initial values given in Table 5 do not include interactions. The first interaction causes a change in the gas power burner savings because the two shell insulation retrofits above it substantially reduce (by about one-third) the amount of heat the furnace needs to produce. After the first interaction, wall insulation between the house and attached garage has a larger B/C than the power burner does. The last part of Table 5 shows the final ordering and interaction effects. Note that the power burner's B/C drops further after the garage-house common wall is insulated. Note also that storm window savings and B/C drop slightly

Table 2. Worksheet for retrofit characteristics before considering interactions

Retrofit name	B/C	Cost ($)

Table 3. Retrofit interaction worksheet

Retrofit name	Annual energy savings	B/C	Annual heating energy consumption	Steady-state heating system efficiency
			Initial values	
			Postretrofit values	

Table 4. Retrofit interaction categories

Retrofit / Retrofit	Ceiling insulation	Wall insulation	Storm windows	Storm doors	Floor insulation	Ext. basement wall insul.	IID	E/M vent damper	Thermal vent damper	Secondary condensing heat exchanger	Replacement furnace	Gas power burner
Ceiling insulation												
Wall insulation	N[a]											
Storm windows	N	N										
Storm doors	N	N	N									
Floor insulation	N	N	N	N								
Ext. basement wall insul.	N	N	N	N	N							
IID	N	N	N	N	N	N						
E/M vent damper	N	N	N	N	N	N	[b]					
Thermal vent damper	N	N	N	N	N	N	N	C				
Secondary condensing heat exchanger	I	I	I	I	I	I	N	C	C			
Replacement furnace	I	I	I	I	I	I	C	C	C	C		
Gas power burner	I	I	I	I	I	I	C	C	C	C	C	

[a]Key: I = Interacting retrofits, N = Noninteracting retrofits, C = Retrofit not compatible with retrofit of interest

[b]For safety reasons, electromechanical (E/M) vent dampers must be installed with IIDs, but IIDs may be installed without E/M vent dampers.

Table 5. Example interaction calculation

Retrofit name	Annual energy savings (therms)	B/C	Annual heating energy consumption (therms)	Steady-state heating system efficiency (%)
			Initial values	
			1170	73
		Before interaction		
Ceiling insulation	188	6.94	982	73
Wall insulation (exterior)	199	2.86	783	73
Gas power burner	NA	2.63	NA	80
Wall insulation (attached garage)	45	1.64	NA	73
Storm windows	238	0.81	NA	73
		First interaction		
Ceiling insulation	188	6.94	982	73
Wall insulation (exterior)	199	2.96	783	73
Gas power burner	NA	1.60	NA	80
		First reordering and second interaction		
Ceiling insulation	188	6.94	982	73
Wall insulation	199	2.86	783	73
Wall insulation (attached garage)	45	1.64	738	73
Gas power burner	NA	1.25	NA	80
Storm windows	217	0.74	NA	80

after the storm window savings interaction with the power burner is included.

The interaction procedure that can be generalized from the example includes the following steps:

1. Calculate the savings and B/C for each retrofit, assuming no interactions.
2. Recalculate the savings of the first retrofit that interacts with the retrofits above it (i.e., the ones with higher B/Cs).
3. Re-sort retrofits and recalculate savings of interacting retrofits.
4. Re-sort retrofits.
5. Go on to the next retrofit that interacts with the ones above.

The process could continue at length, but in practice the B/Cs soon drop below one, and heating systems retrofits beyond one or two are mutually incompatible.

5. AUDIT-DIRECTED RETROFIT PROGRAM

It is widely recognized that some homes treated under the WAP need retrofits more than others do. The revised DOE regulations that allow weatherization expenses to be averaged across a number of homes give weatherization providers the flexibility to spend retrofit dollars where they are most needed. After the regulations were in effect, the principal remaining impediment to more effective allocation of retrofit dollars was the need for a method of allocating resources among houses.

The use of B/Cs to characterize the cost effectiveness of retrofits permits a new and rational method for allocating retrofit dollars among the houses in the program. This new method is based on three facts:

- The cost effectiveness of each retrofit for each house can be characterized by a B/C.
- Retrofit B/Cs are directly comparable to each other, regardless of which houses are evaluated for the retrofits.
- Houses that need more retrofits will have retrofits with higher B/Cs.

The principle of this new method, called the Audit-Directed Retrofit Program (ADRP), is to let retrofits compete against each other.

As a result of an audit, homeowners would like to end up with a list of retrofits ordered by B/C (see Table 6, for example). The decision regarding which retrofits to do is based on how much money can be spent and how low a B/C is acceptable. The ADRP puts all the retrofits for all houses on the list.

Table 6. Sample retrofit ranking

B/C	Retrofit	Cost ($)
2.73	C	650
1.36	D	1400
1.21	E	275
1.09	H	400
0.98	A	825
0.95	F	300
0.89	G	600
0.73	B	550

It is impractical for a state or weatherization provider to put all the individual retrofits for all the houses it retrofits on a list at one time to decide how far down the retrofit list to go. Fortunately, that is not necessary. Choosing a minimum B/C will allow auditors to order all the retrofits that exceed the B/C for each house they audit.

Selecting the minimum retrofit B/C is not difficult. Simple economic considerations argue against doing retrofits with B/Cs <1.0. (B/Cs depend strongly on the discount rate used in the calculations, so a B/C of 1.0 is not as definitive as it may seem.) Other considerations may lead to the choice of a different minimum B/C. For instance, if a state has chosen to spend an average of $1000 per house, a different B/C will most likely be needed. The easiest way to determine this B/C is to audit a representative sample of houses and select the best retrofits until the desired average expenditure is reached. The B/C of the last retrofit will be a good estimate of the desired minimum B/C.

Selecting a minimum B/C might be accomplished in this way:

- Audit 10 houses.
- Put all the retrofits on a list like that in Table 6, listed in order of declining B/C. Only the case and B/C are needed, not retrofit names.

- Find the B/C above which all the retrofits (with higher B/Cs) cost the desired amount of money (10 × target average expenditure per house).
- Perform all the retrofits with B/Cs above the minimum.
- Audit and retrofit 40 more houses.
- Make a new list of the retrofits of all 50 houses and find a new minimum B/C.
- Use the new B/C for the remainder of the houses that year.

Frequent revisions of the minimum B/C will give actual expenditures that closely match the desired expenditures. This procedure is more tedious than difficult. A state could use a similar procedure to set a statewide minimum B/C.

REFERENCES

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3. L. N. McCold, J. A. Schlegel, and D. C. Hewitt, "Technical and Practical Problems in Developing and Implementing an Improved Retrofit Audit," Proceedings for the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, Vol. 7, Santa Cruz, Calif., 1986, p. 146.

4. T. S. Zawacki et al., Effect of Building Characteristics on Gas Appliance Performance and End-Use Efficiency, Final Report, December 1, 1980-October 31, 1981, GRI-80/0110, Institute of Gas Technology, May 1982.

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6. R. D. Fischer et al., "Degree-Day Method for Simplified Energy Analysis," ASHRAE Trans., 88, Pt. 2, 1982.

7. 10 CFR 440.21(b), U.S. Federal Register, Vol. 49, No. 19, January 27, 1984, p. 3634.

Appendix A

AUDIT DATA SHEETS

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AUDIT DATA SHEET

DATE OF AUDIT _____

AUDITOR NAME _____

AGENCY _____

HOUSEHOLD INFO

NAME _____

ADDRESS _____

_____ ZIP _____

PHONE NUMBER (___)_____

NUMBER OF OCCUPANTS–TOTAL_____

PRE-SCHOOL____

SCHOOL AGE____

RETIRED_____

OTHER ADULT____

HOW MANY OCCUPANTS ARE GENERALLY HOME DURING WEEK DAYS? _____

ELECTRIC UTILITY_____

GAS UTILITY_____

HOUSE DESCRIPTION

AGE OF HOUSE _____ YEARS

TYPE: S-F DETACHED ____, OTHER(DESC.) _____

_____

STYLE: ONE-STORY____, TWO-STORY _____,

THREE-STORY ____, SPLIT LEVEL _____

ONE & A HALF STORY _____

AREA (SQUARE FEET) _____

FOUNDATION: BASEMENT _____, SLAB _____,

CRAWL SPACE _____,

OTHER (DESC.)_____

TYPE OF GARAGE: ATTACHED ____, REMOVED ___

UNDERNEATH HEATED SPACE _____

APPLIANCES

	NONE	ELEC	GAS	OTHER	LOCATION
WATER HEATER	____	____	____	____	_____
COOKING RANGE	____	____	____	____	_____
CLOTHES WASHER	____	____	____	____	_____
CLOTHES DRYER	____	____	____	____	_____
REFRIGERATOR	____	____	____	____	_____
FREEZER	____	____	____	____	_____
DEHUMIDIFIER	____	____	____	____	_____
DISHWASHER	____	____	____	____	_____
AIR CONDITIONER	____	____	____	____	_____
OTHER_____	____	____	____	____	_____
OTHER_____	____	____	____	____	_____

SECONDARY HEATING SYSTEMS:

	NONE	DAILY USE	WEEKLY USE	OCCASIONAL USE
WOOD STOVE	____	____	____	____
ELECTRIC HEATER	____	____	____	____
FIREPLACE	____	____	____	____
KEROSENE HEATER	____	____	____	____

HEATING SYSTEM

THERMOSTAT; NONE___, NORMAL___, CLOCK____, OBSERVED SETTING_____DEGREES,

DOES THE HOME OWNER TURN THE PILOT LIGHT OFF IN THE SUMMER: YES____, NO ____, NA _____

APPROXIMATE AGE OF FURNACE OR BOILER;_____YEARS.

HEATING SYSTEM TYPE; GAS FURNACE___, GAS BOILER (STEAM) ___, GAS BOILER (HOT WATER) ___
OTHER _____

HAS THIS SYSTEM BEEN CONVERTED FROM COAL ___, OR OIL ___

IS THE SYSTEM IN WORKABLE CONDITION; YES____., NO(DESC)_____

LOCATION OF UNIT; UNCONDITIONED BASEMENT____, MAIN LIVING AREA____, SEPERATE FURNACE
ROOM _____, OTHER(DESC)_____

NAMEPLATE INFORMATION: MANUFACTURER_____,MODEL_____
SEER _____, INPUT RATING_____BTUs, OUTPUT_____BTUs

VISUAL INSPECTION

HEAT EXCHANGER; OK____, DIRT ____, EXCESSIVE RUST ____;

DRAFT DIVERTER; OK____, SOOT ____

BURNER; OK ___, DIRT ____, SOOT ____, EXCESSIVE RUST ____; ARE FLAME PORTS BLOCKED_____

FLUE PIPE CONDITION; OK___ ,IF NOT, DESCRIBE _____

_____

CONDITION OF FILTER; CLEAN___, DIRTY___, CLOGGED___,DOES NOT FIT___, MISSING___

FILTER SIZE _____ BY_____ BY _____

CONDITION OF BLOWER; CLEAN___, DIRTY____, CLOGGED____, CAN'T SEE ____, NA_____

BLOWER BELT CONDITION; OK___, LOOSE____, WORN____, NA_____ENERGY EFFICIENCY FEATURES;

VENT DAMPER___, IID____,OTHER(SPECIFY)_____

ANY UNUSUAL FEATURES_____

IS THERE A GAS WATER HEATER; YES ___, NO ___: IS IT VENTED IN THE SAME FLUE; YES ___, NO ___

DISTIBUTION SYSTEM

DISTRIBUTION SYSTEM; FORCED AIR___, GRAVITY AIR___,PUMPED HYDRONIC___,
GRAVITY HYDRONIC___, NO DUCTWORK OR PIPES_____
OTHER(SPECIFY) _____

LENGTH OF DISTRIBUTION RUNS IN <u>UNHEATED</u> SPACES;INSULATED _____FT.
UNINSULATED_____FT.

ANY HOLES, LEAKS,OR LOOSE JOINTS IN DUCT RUNS;NO___, YES(DESCRIBE)_____

_____

SIZE OF SUPPLY PLENUM (CROSSSECTION) _____

LEAK TEST RESULTS; OK____, MINOR ___, MAJOR____

FLUE GAS ANALYSIS, SUPPLY AND RETURN AIR

MEASURED FURNACE INPUT, 1/2___, 1____. OR 2____ CUBIC FEET IN _____SECONDS

	TEMP	% OXYGEN	% CO_2	DRAFT/VEL
SUPPLY PLENUM	_____ DEG	__XXXXX__ % OR	__XXXX__%	_____ FT/MIN
RETURN PLENUM	_____ DEG	__XXXXX__ % OR	__XXXX__%	__XXXXX__ IN
FLUE BEFORE DIVERTOR	_____ DEG	_____ % OR	_____%	__XXXXX__ IN
FLUE AFTER DIVERTOR	_____ DEG	_____ % OR	_____%	_____ IN

ROOM TEMPERATURE _____ DEG. NET STACK TEMP.(AFTER DIV) _____ DEG.

STEADY STATE EFFICIENCY _____% CO _____PPM OR SAFE____, UNSAFE_____

ESTIMATED REMAINING LIFETIME: LESS THAN 5 YEARS _____

GREATER THAN 5 YEARS BUT LESS THAN 10 YEARS _____,

GREATER THAN 10 YEARS _____

BASEMENT & FLOOR INFO

PERIMETER_____FT. RIM JOIST INSULATED; YES____NO _____

EXPOSED FOUNDATION HEIGHT(AVG)_____PERIMETER INSULATED; YES ___, NO ____

OBSTRUCTIONS TO EXTERIOR INSULATION; YES ___, NO____DESCRIBE OBSTRUCTIONS AND

ESTIMATE % IMPACT _____ _____%

FOUNDATION TYPE; BLOCK___, POURED____, STONE ___ OTHER _____

IS IT POSSIBLE TO PROPERLY FLASH RIGID INSULATION: NO ___, 1 IN. YES __, 2 IN. YES ___

CONDITION OF FOUNDATION: GOOD _____, FAIR ____. , POOR _____

IS BASEMENT; INTENTIONALLY HEATED ____, UNCONDITIONED___, OR UNHEATED _____

FLOOR AREAS (BOTTOM FLOOR ONLY);

AREA	SQUARE FEET	INSULATION VALUE	% CARPETED	TYPE OF AREA BELOW(E.G.SLAB)
1	_____	_____R	_____%	_____
2	_____	_____R	_____%	_____

IS CRAWL SPACE VENTED? NA ___, YES ___ ,NO ____

IS FLOOR INSULATION ___, EXTERIOR PERIMETER INSULATION ____, OR INTERIOR PERIMETER INSULATION ____ RECOMMENDED IN CRAWL SPACE AREAS ?

IF INTERIOR PERIMETER INSULATION, ESTIMATE SQUARE FEET REQUIRED _____SQ. FT.'

NUMBER OF BASEMENT WINDOWS _____

DO BASEMENT WINDOWS HAVE STORMS? YES ____, NO _____

DOORS AND WINDOWS

NUMBER OF EXTERIOR DOORS; WITH STORMS ____ WITHOUT STORMS ____, TOTAL _____

TYPES OF DOORS WITHOUT STORMS: METAL INSULATED ____, SOLID CORE ____, HOLLOW CORE OR PANELED OR MORE THAN 30% GLASS _____

SINGLE GLAZED GLASS PATIO DOORS; YES ___, NO ___; DOUBLE GLAZED; YES ____, NO ____

WINDOWS: **NO STORMS**

NUMBER OF SMALL WINDOWS WITHOUT STORMS _____ X 9= _____ SQUARE FEET

NUMBER OF MEDIUM WINDOWS WITHOUT STORMS _____ X 16= _____ SQUARE FEET

NUMBER OF LARGE WINDOWS WITHOUT STORMS _____ X 30 = _____ SQUARE FEET

TOTAL NO STORMS = _____ SQUARE FEET

WITH STORMS

NUMBER OF SMALL WINDOWS WITH STORMS _____ X 9= _____ SQUARE FEET

NUMBER OF MEDIUM WINDOWS WITH STORMS _____ X 16= _____ SQUARE FEET

NUMBER OF LARGE WINDOWS WITH STORMS _____ X 30 = _____ SQUARE FEET

TOTAL WITH STORMS = _____ SQUARE FEET

GENERAL CONDITION OF WINDOWS; GOOD ____, FAIR ____, POOR _____

WALL INFORMATION

TYPE OF WALL CONSTRUCTION: FRAME(PLATFORM) ____, FRAME (BALLOON) ____ BLOCK ____, OTHER (DESCRIBE) _____

PERIMETER _____ FEET; AVERAGE HEATED SHELL WALL HEIGHT _____ FEET:

GROSS WALL AREA _____ SQUARE FEET

ARE WALLS INSULATED; YES ____ (PERCENT INSULATED _____%), NO ____

SIDING TYPE (PERCENTAGES) ; _____% WOOD, _____% BRICK, STONE OR BLOCK _____% SHINGLE, _____% SLATE, _____% STUCCO _____% ALUMINUM, STEEL OR VINYL, _____% OTHER

IS THERE AN ATTACHED GARAGE; YES ___, NO ___ IF YES, ESTIMATED SQUARE FEET OF WALL SHARED WITH GARAGE AREA, _____ SQUARE FEET

MOISTURE

ANY SIGNS OF SERIOUS MOISTURE PROBLEM (E. G. ROT, MILDEW); YES ___ NO ____

ANY STANDING WATER IN THE BASEMENT OR CRAWL SPACE AREA; YES ____ NO ____

DO WINDOWS SHOW SIGNS OF EXCESS CONDENSATION; YES _____ NO _____

ARE ANY OF THE FOLLOWING PRESENT? HUMIDIFIER____, DAMP BASEMENT WALLS ____,
BARE EARTH FLOOR IN BASEMENT OR CRAWL SPACE ____,
UNVENTED CLOTHES DRYER _____, MANY LARGE PLANTS (MORE THAN SIX)_____,
OPERABLE BATHROOM VENT: YES ___, NO____ OPERABLE KITCHEN VENT: YES ___, NO____

CEILING AND ATTIC

CEILING AREA	AREA(SQ. FT.)	INSULATION VALUE	NOTES
1	_____	_____ R	_____
2	_____	_____R	_____
KNEEWALL	_____	_____R	_____
KNEEWALL FLOOR	_____	_____R	_____

IS A VAPOR BARRIER PRESENT? YES ___,NO ____
ADDITIONAL VENTING NEEEDED? YES___, NO ____
ESTIMATED NEW SQUARE FEET VENTILATION NEEDED _____(ADDITIONAL)
ANY ROOF LEAKS, YES ____, NO _____ LOCATION_____

INFILTRATION

BLOWER DOOR TEST RESULTS; ACH AT 50 pa_____

WEATHERSTRIPPING (USE GRID TO LOCATE):

PRIMARY DOORS ____, LOCATION(S)_____
PRIMARY WINDOWS ____, LOCATION(S) _____
_____
BASEMENT WINDOWS _____, LOCATION(S) _____
ATTIC HATCH _____,

REPLACEMENT OR RECONSTRUCTION

PRIMARY DOORS ____, LOCATION(S)_____
PRIMARY WINDOWS ____, LOCATION(S) _____
_____
BASEMENT WINDOWS _____, LOCATION(S) _____
WALL AREAS _____, LOCATIONS _____

CAULKING AND BLOCKAGE

PRIMARY DOORS ____, LOCATION(S)_____
PRIMARY WINDOWS ____, LOCATION(S) _____
_____PULLEY SEALS?_____
GLAZING REPLACMENT ____, LOCATION _____
BASEMENT WINDOWS _____, LOCATION(S) _____
SILL PLATE ____, LOCATION _____
FOUNDATION CRACKS ____, LOCATION _____

BASEBOARD _____, LOCATION _____

PLUMBING PENETRATIONS ____, LOCATION _____

ELECTRICAL PENETRATIONS ___, LOCATION _____

DESCRIBE ANY OTHER LEAKAGE AREAS _____

_____

_____

_____

OTHER

DESCRIBE ANY SPECIAL PROBLEMS, REHABILATATION NEEDS OR SPECIFIC SUGGESTIONS.

PHOTOGRAPHS

ATTACH PHOTOGRAPHS OF ANY SPECIAL PROBLEM AREAS.

Appendix B

RETROFIT FUEL DOLLAR SAVINGS CALCULATIONS

Building Shell Retrofits

The building shell retrofit calculations are based on the RCS Model Audit[1] and the 1981 ASHRAE Fundamentals Handbook.[2] For reasons noted in the text, steady-state heating system efficiency is used in these calculations where seasonal heating system efficiency is more conventional.[3] The calculation procedures are largely self-explanatory. Notes have been added where needed.

All of these building shell retrofits use "corrected annual heating degree days," defined by Eq. (2) in the text. See ref. 2 for the appropriate correction factor for your locale.

Ceiling Insulation

Table B.1a. General procedure for estimating the heating season savings from adding certain levels of ceiling insulation

(A)	Ceiling area	_____	ft^2
(B)	Heating system steady-state efficiency	_____	(fraction)
(C)	Corrected annual heating degree days	_____	HDD
(D)	Heating fuel price	$_____	per 10^6 Btu
	Existing ceiling insulation R-value	_____	
(E)	Reduction in attic/ceiling U-value from Table B.1b	_____	Btu/h-°F-ft^2
(F)	Annual savings ($A \times C \times 24 \times D \times E \div 10^6 \div B$)	$_____	

Table B.1b. Reduction in overall attic-ceiling U-value

Initial insulation level	With the addition of R-19 insulation (Btu/h-°F-ft^2)	With the addition of insulation to achieve R-38 (Btu/h-°F-ft^2)
R-0	0.34	0.36
R-5	0.094	0.105
R-7	0.061	0.070
R-11	0.044	0.049
R-13	0.034	0.038
R-19	0.020	0.020

Wall Cavity Insulation

Table B.2 shows the general procedure for estimating heating season savings from adding blown-in cellulose wall cavity insulation to a 3.5-in. uninsulated wall.

Table B.2. Wall cavity insulation savings estimation procedure

(A)	Gross wall area	_____ ft^2
(B)	Window and door area	_____ ft^2
(C)	Net wall area (A-B)	_____ ft^2
(D)	Corrected annual heating degree days	_____ HDD
(E)	Heating fuel price	$_____ per 10^6 Btu
(F)	Heating system steady-state efficiency	_____ (fraction)
(G)	Energy savings factor:[a] brick or stone siding	2.4 Btu/ft^2-HDD
	other sidings	3.2 Btu/ft^2-HDD
	walls shared by an unheated garage	2.1 Btu/ft^2-HDD
(H)	Annual heating fuel bill savings ($C \times D \times E \times G - F - 10^6$)	$_____

[a]The savings factor is based on adding blown-in cellulose to a 3.5-in. wall cavity.

Storm Windows

Table B.3 is a savings estimation procedure for storm windows. The estimate is based on applying an exterior storm window to a single-pane window in good condition. Infiltration reduction is not included in this estimate. It is possible to reduce infiltration through a leaky prime window by putting on a storm window, but it is difficult to estimate the magnitude of such a reduction in infiltration. On the other hand, if the prime window is leaky, the savings in conduction heat loss will be less than that predicted in Table B.3 because Table B.3 is based on the assumption that the air between the prime window and the storm window is trapped there. If the prime window has a significant air leakage problem, it is almost certainly more cost effective to solve that problem directly than to use a storm window to control the infiltation.

Table B.3. Storm window savings estimation procedure[a]

(A)	Corrected annual heating degree days (HDD)	_____
(B)	Heating system steady-state efficiency	_____ (fraction)
(C)	Heating fuel price	$_____ per 10^6 Btu
(D)	Annual heating fuel bill savings per square foot of window ($A \times 24 \times C \times 0.6 \div B \div 10^6$)	$_____ per ft^2
(E)	Total window area	_____ ft^2
(F)	Total annual savings ($D \times E$)	$_____

[a]This estimate is based on applying an exterior storm window to a single-pane window that is in good condition.

Storm Doors

Table B.4a shows the savings estimation procedure for storm doors. The savings for each door is calculated separately, because the savings and therefore the benefit-to-cost ratio may be better for some doors than for others.

Table B.4a. Storm door savings estimation procedure

(A)	Corrected annual heating degree days	_____	
(B)	Heating system steady-state efficiency	_____	(fraction)
(C)	Heating fuel price	$_____	per 10^6 Btu
(D)	$A \times C \div B \div 10^6$	_____	HDD-$/Btu

Existing door type (Table 4b)	(E) Savings factor (Table 4b) (Btu/ft^2-HDD)	(F) Door area (ft^2)	Annual savings (D × E × F)

(I) Total savings $_____

Table B.4b. Storm door savings factors

Door thickness (inches)	Existing door description	Existing door type	Savings factor[a] (Btu/ft^2-HDD)
	Wood doors		
1-3/8	Hollow core flush door	1	3.60
1-3/8	Solid core flush door	2	2.64
1-3/8	Panel door with 7/16-in. panels	3	4.80
1-3/4	Hollow core flush door	4	3.36
	With single glazing	5	4.80
1-3/4	Solid core flush door	6	1.92
	With single glazing	7	3.36
	With insulation glass	8	2.40
1-3/4	Panel door with 7/16-in. panels	9	4.32
	With single glazing	10	6.24
	With insulating glass	11	3.84
1-3/4	Panel door with 1-1/8-in. panels	12	2.64
	With single glazing	13	5.52
	With insulating glass	14	3.12
2-1/4	Solid core flush door	15	1.44
	With single glazing	16	2.88
	With insulating glass	17	1.92
	Metal doors		
1-3/4	Solid urethane foam core With thermal break	18	0.48
1-3/4	Solid urethane foam core Without thermal break	19	2.64

[a]Metal storm doors are assumed in each case.

Source: ASHRAE Handbook of Fundamentals 1985, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1985.

Floor Insulation

Table B.5a is a savings estimation procedure for placing floor insulation between the floor joists above an unheated crawl space or basement. If the unheated basement has a furnace, a boiler, a water heater, uninsulated pipes, or warm air ducts, the savings could be much less than estimated by Table B.5a. On the other hand, if the crawl space is not enclosed (that is, if outside air can freely move into and out of the crawl space) the savings may be up to twice as large as Table B.5b suggests.

Table B.5a. Floor insulation savings estimation procedure

(A)	Corrected annual heating degree days	_____	HDD
(B)	Heating system steady-state efficiency	_____	(fraction)
(C)	Heating fuel price	$_____	per 10^6 Btu
(D)	Area of floor to be insulated	_____	ft^2
(E)	Carpeted area of floor to be insulated	_____	ft^2
(F)	Non-carpeted floor area	_____	ft^2
(G)	Floor insulation to be added: 3.5 in. (R-11)	_____	6 in. (R-19) ___
(H)	Carpeted floor savings factor (Table B.5b)	_____	
(I)	Non-carpeted floor savings factor (Table B.5b)	_____	
(J)	Carpeted floor savings ($A \times C \times E \times H \div 10^6 \div B$)	$_____	
(K)	Non-carpeted floor savings ($A \times C \times F \times I \div 10^6 \div B$)	$_____	
(L)	Total floor insulation savings (J + K)	$_____	

Table B.5b. Floor insulation savings factor[a] (Btu/ft^2-HDD)

	Insulation added	
	R-11	R-19
Carpeted	1.4	1.7
Not carpeted	2.7	3.0

[a]Based upon an initially uninsulated floor and an unheated basement, crawl space, or garage below.

Exterior Basement Wall Insulation

Table B.6a shows the procedure used to estimate the energy savings of insulating basement walls. Insulating below grade is more expensive and saves less energy than insulating exposed basement walls, so savings estimates are calculated separately. When insulating the exposed wall, it may be necessary to bury the bottom 2-3 in. of the insulation. These top 2-3 in. of buried wall can be considered exposed wall for calculation purposes.

Table B.6a. Exterior basement wall insulation savings

(A)	Corrected annual heating degree days	_____	HDD
(B)	Heating system steady-state efficiency	_____	(fraction)
(C)	Heating fuel price	$_____	per 10^6 Btu
(D)	Above grade exposed basement wall area	_____	ft^2
(E)	Exposed wall savings factor (from Table B.6b)	_____	Btu/ft^2-HDD
(F)	Annual heating fuel bill savings $(A \times C \times D \times E \div 10^6 \div B)$	$_____	
(G)	Length of buried wall to be insulated	_____	ft
(H)	Depth insulation is to be buried	_____	ft
(I)	Buried wall savings factor (from Table B.6b)	_____	Btu/ft^2-HDD
(J)	Annual heating fuel bill savings $(A \times C \times G \times H \times I \div 10^6 \div B)$	$_____	

Table B.6b. Basement wall insulation savings factors

Wall/basement type	Insulation added	
	R-5 (1 in.) (Btu/ft^2-HDD)	R-10 (2 in.) (Btu/ft^2-HDD)
Intentionally heated basement		
Exposed wall	8.6	10.1
Buried wall	2.4	3.2
Incidentally heated basement[a]		
Exposed wall	2.9	3.4
Buried wall	0.8	1.1

[a]Insulating an incidentally heated basement is assumed to save one-third the energy saved by insulating an intentionally heated basement.

Sill Box Insulation

The sill box is the area above the top of the foundation and below the bottom of the floor formed by the floor joists and the exterior sheathing. Insulating the sill box will reduce conductive heat loss from the basement and may reduce infiltration into the basement and living space. The savings estimation procedure in Table B.7 includes conductive heat loss only. Infiltration control requires caulking; and the savings, though virtually impossible to estimate by this method, could be substantial.

Table B.7. Sill box insulation savings estimation

(A)	Corrected annual heating degree days	_____	HDD
(B)	Heating system steady-state efficiency	_____	(fraction)
(C)	Heating fuel price	$_____	per 10^6 Btu
(D)	Perimeter length	_____	ft
(E)	Sill box height	_____	ft
(F)	Savings factor:		
	Conditioned basement	3.7	Btu/ft^2-HDD
	Incidentally heated basement	1.2	Btu/ft^2-HDD
(G)	Annual fuel bill savings ($A \times C \times D \times E \times F - 10^6 - B$	$_____	

Note: Sill box insulation is R-19 batt insulation stuffed into the sill box.

Heating System Retrofits

Most of the heating system retrofit savings estimates use the measured steady-state efficiency of the existing heating system and the anticipated efficiency of the retrofitted system. Using seasonal efficiency is more conventional in calculations of this type, but no practical method of measuring seasonal efficiency during an audit is available. The result of using steady-state efficiency is that smaller savings are usually estimated. Where appropriate, these calculations include savings for the functional equivalents of intermittent ignition devices and vent dampers.

Most savings estimates also use the pre-retrofit space heating gas consumption. The best way to estimate the heating bill is to examine gas bills for an entire year. Examine bills for the months when the space heating system is not operating and calculate the average daily non-heating gas consumption. Multiply this number by 365 to get the annual non-heating gas consumption. Subtract the annual non-heating gas consumption from one year's total gas consumption. The difference is approximately the annual space heating gas consumption of the house.

The pre-retrofit furnace gas consumption will influence the savings from the retrofits considerably. A large house with a large heating bill will show larger annual savings than a small house with a small heating bill. Care should be taken to ensure that the annual space heating gas consumption estimate (annual pre-retrofit furnace gas consumption) is as accurate as possible.

Secondary Condensing Heat Exchanger (SCHE)

Table B.8 gives the procedure for estimating savings from adding an SCHE to a gas furnace. The procedure includes estimates of the periodic electric consumption of the SCHE because it uses significant amounts of electricity.

Table B.8. Estimate of dollar savings from adding a secondary condensing heat exchanger (SCHE) to a gas furnace

(A)	Steady-state efficiency with an SCHE	90%
(B)	Pre-retrofit steady-state efficiency (from flue loss test)	_____ %
(C)	Percent fuel use reduction, (A - B)/A =	_____ %
(D)	Annual pre-retrofit gas consumption of the furnace	_____ 10^6 Btu
(E)	Residential natural gas price	$_____/$10^6$ Btu
(F)	Fuel cost savings (C × D × E)	$_____
(G)	Furnace fuel input rate	_____ Btu/h
(H)	Estimated burner on-time [D × B × 10^6/(G × A)]	_____ h
(I)	Electricity consumption rate of SCHE	0.49 kW
(J)	Residential electricity price	$_____/kWh
(K)	Heat extractor electricity cost (H × I × J)	$_____
(L)	Net annual dollar savings (F - K)	$_____

Source: R. J. McDonald and J. D. Nally, Technical Assessment of a Direct Contact Heat Exchanger as an Energy Conservation Retrofit Option, BNL 51978, Brookhaven National Laboratory, December 1985.

Intermittent Ignition Device

This retrofit is applicable to any gas furnace with a standing pilot. If the homeowner lights the pilot at the beginning of each heating season and extinguishes it at the end of the heating season, an intermittent ignition device (IID) is unlikely to be beneficial. Tables B.9a and B.9b are used to estimate the annual savings of an IID. (Note

that this is the one retrofit savings calculation that uses actual heating degree days, not corrected heating degree days.)

Table B.9a. Estimated gas savings from the use of an intermittent ignition device on a gas furnace

(A)	Do occupants turn the pilot off at the end of the heating season?	Yes ___ No ___
(B)	Average annual heating degree days	_____
(C)	Annual gas savings from A, B, and Table B.9b	_____ million Btu
(D)	Residential gas price	$_____ per 10^6 Btu
(E)	Annual intermittent ignition device cost savings (C × D)	$_____

Table B.9b. Annual gas savings by installing an intermittent ignition device on a gas furnace

Average annual HDD	Savings (10^6 Btu)	
	Continuous pilot	Pilot off during summer
500	6.7	0.4
1500	6.2	1.0
2500	5.7	1.4
3500	5.3	2.0
4500	5.2	2.4
5500	5.1	2.6
6500	5.0	2.7
7500	4.9	2.8

Note: Use HDD, not corrected HDD.

Source: Residential Conservation Service, Model Audit Manual, ORNL/CON-103, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1983, p. AC-8.

Vent Damper

A great deal more needs to be known before reliable estimates of savings can be made for the vent damper retrofit. However, the procedure shown in Table B.10a produces energy savings estimates that should seldom be larger than the actual savings. The values in Table B.10b were derived after reviewing the extensive but inconclusive literature (see refs. 3, 4, and 5).

The largest part of vent damper savings is believed to result from reductions in off-cycle air losses up the chimney. If the heating system is in an unconditioned space, the air lost up the chimney during off-cycles is of no concern. Flame retention burners on oil-fired systems and secondary air-restricting burners for gas systems are not significantly affected by vent dampers, because very little air is drawn up the chimney during off-cycles.

Where more than one appliance is attached to a single chimney, each appliance must have a vent damper. The electromechanical vent damper is believed to be the most effective type, but it cannot be installed if there is a pilot.

Table B.10a. Vent damper savings

(A)	Is the heating system an oil-fired furnace or boiler with a flame retention burner? Yes ___ No ___ If yes, the savings will be negligible; put zero in the space for E. If yes, proceed.	
(B)	Is the furnace or boiler in a conditioned space? Yes ___ No ___ If no, the savings will be negligible; put zero in the space E. If yes, proceed.	
(C)	Annual space heating fuel bill	$_____
(D)	Vent damper percent savings (from Table B.9b)	_____ %
(E)	Annual vent damper savings ($C \times D \div 100$)	$_____

Table B.10b. Vent damper energy savings estimates

Type of vent damper	Number of appliances on chimney	
	1	2
Electromechanical[a]	5%	6%
Thermal-flapper	3.5%	4.5%
Thermal-prong	2.5%	3.5%

[a]Note that this type of vent damper cannot be used with a pilot.

Furnace Replacement

When the existing furnace is in poor condition, it may be cost effective to replace it with a new, higher efficiency model. If the new furnace is a conventional model, one with a lower heating capacity than the old furnace will save even more money and energy.

Table B.11 shows the procedure for estimating the savings produced by a new furnace. The principal data needed for this procedure are (1) the typical annual heating fuel bill, (2) the measured steady-state efficiency of the existing furnace, and (3) several characteristics of the new furnace. Only furnaces that include an IID should be considered.

Table B.11. Estimate of dollar savings from replacing an old gas furnace with a new gas furnace

(A)	New furnace fuel input rate	_____	Btu/h
(B)	New furnace steady-state heat output rate	_____	Btu/h
(C)	Steady-state efficiency of new furnace (100 × B/A)	_____	%
(D)	Steady-state efficiency of old furnace (from flue loss test)	_____	%
(E)	Fractional fuel use reduction, 1 - D/C	_____	
(F)	Annual pre-retrofit furnace gas consumption	_____	10^6 Btu
(G)	Operating energy savings, E × F	_____	10^6 Btu
(H)	If the new furnace has a vent damper and the old furnace does NOT have a vent damper, and the furnace is located in a heated space, then the vent damper savings is 0.05 × F. Otherwise, it is zero.	_____	10^6 Btu
(I)	Intermittent ignition energy savings (Tables B.9a and B.9b)	_____	10^6 Btu
(J)	Total annual new furnace energy savings (G + H + I)	_____	10^6 Btu
(K)	Residential natural gas price	$_____	/10^6 Btu
(L)	Annual fuel cost savings, J × K	$_____	

Gas Power Burner

The gas power burner is a retrofit applicable to some coal or oil furnaces/boilers that have been converted to burn gas. The power burner provides higher efficiency than conventional burners in such furnaces/boilers. In addition, it does not use a pilot light and has smaller off-cycle losses than a conventional burner. After applicability of a particular burner has been determined, Table B.12 can be used to estimate the savings from replacing the conventional burner with a power burner.

Table B.12. Estimate of dollar savings from replacing an old gas burner on a converted oil or coal furnace with a new gas power burner

(A)	Steady-state efficiency of furnace with a gas power burner	80 %
(B)	Steady-state efficiency of old furnace (from flue loss test)	_____ %
(C)	Fractional fuel use reduction, 1 - B/A	_____
(D)	Annual pre-retrofit furnace gas consumption	_____ 10^6 Btu
(E)	Operating energy savings, C × D	_____ 10^6 Btu
(F)	If the old furnace does NOT have a vent damper and the furnace is located in a heated space, then the off-cycle savings are 0.05 × D. Otherwise, they are zero.	_____ 10^6 Btu
(G)	If the old burner used a pilot light, then the energy savings from eliminating it are calculated in Tables B.9a and B.9b.	_____ 10^6 Btu
(H)	Total annual new furnace energy savings (E + F + G)	_____ 10^6 Btu
(I)	Residential natural gas price	$_____/$10^6$ Btu
(J)	Annual fuel cost savings, H × I	$_____

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