A METHOD OF RATING THE THERMAL EFFICIENCY OF A HOME ENVELOPE RELATIVE TO AN ENERGY EFFICIENT STANDARD

Robert S. Blancett

Associate Member

ABSTRACT

A method was developed for rating the thermal efficiency of a home envelope relative to energy efficient standards. The method was developed at the request of the United States League of Savings Associations for use by real estate appraisers or lending officials and is a Class B type audit procedure. A scorecard is utilized where points are awarded for energy conserving features of a home envelope. The scorecard is used to compare points awarded to points based on an energy efficient standard. Homes with a low relative rating are identified as potential retrofit candidates. Retrofit measures are assigned a priority relative to cost of the retrofit and benefits obtained. The method considers envelope retrofit options which reduce heating requirements.

INTRODUCTION

Recent price increases in the cost of home heating fuels have driven homeowners to find ways of reducing the energy that is consumed to heat and cool their residences. The government has responded to decreasing domestic fuel supplies by encouraging energy conservation. An industry group concerned with the energy problem and its affect on homeowners is the first mortgage lending industry.

Mortgage lenders are increasingly aware of the benefits of holding loans on energy efficient homes. An energy efficient home results in lower monthly utility cash outlays for the homeowner. Coupled with principal, interest, taxes, and insurance (PITI) the monthly utility costs govern the ability of a homeowner to meet his monthly financial obligations. Lenders are realizing that an energy efficient home represents a more secure loan on a property or increases the size of a loan that a buyer can assume.

Lenders, however, are confronted with the following two fundamental questions:

What constitutes an energy efficient home?

How should lending practices account for it?

Officials of the United States League of Savings Associations solicited suggestions on a method by which a real estate appraiser or loan officer could estimate the relative thermal efficiency of a new or resale home. This paper is in response to the Savings Association request. Presented is a simple method developed to analyze the relative thermal performance of a home envelope.

Robert S. Blancett, Supervisor, Owens-Corning Fiberglas, Granville, Ohio

The work reported was done in the 1978 time frame and was based on insulation standards appropriate at that time. New standards have emerged since then primarily from government agencies such as the Department of Energy and the Federal Housing Authority. Owens-Corning at the same time has been re-evaluating their insulation standards based on current fuel and construction costs, projected inflation rates and advanced dynamic calculation methodologies for predicting the thermal behavior of residences. The work reported here is simply a method of reducing standards to an audit format and therefore is applicable to any set of standards.

METHODOLOGY

The initial step in developing a home rating method was identifying energy related variables. The scope of the task restricted the number of variables that could be included in the analysis. Two decisions were made. First, the analysis was restricted to the house envelope. This was done so that all variables would be weather dependent. Certainly other factors have significant influence on overall energy consumption. Occupant lifestyle, thermostat settings, heating and cooling plant, and house orientation can cause large variations in energy use among similarly constructed homes (1, 2). Inclusion of these variables was simply beyond the scope of this project. Sophisticated programs such as the National Bureau of Standards Load Determination (NBSLD) and Updated Project Conserve Home Energy Audit System (HEAS) are available for detailed energy analysis (3, 4). These programs require large computing systems and detailed information on home construction. The second decision was to restrict the performance analysis to the heating season only. The purpose here was to avoid dealing with the more complex factors associated with the cooling season. The method was structured such that cooling analysis could be added in the future.

The next step in the development was to define energy efficient construction standards. The Guide To Constructing An Energy Efficient Home (EEH) was selected as a starting point (5). The EEH guide sets prescriptive standards for ceiling, wall, and floor insulation by climatic zone. Window type and area are also prescribed by degree days. These prescriptive standards were used as a bench mark against which the thermal envelope characteristics of any home could be compared. Air infiltration rates are not prescribed by EEH. The Updated Project Conserve Home Energy Audit System (HEAS) documentation was used to establish a measuring range for air infiltration. A home built to EEH standards was assumed to have tight air infiltration characteristics.

The third step involved developing a method of normalizing annual heat loss to a common denominator such as square footage of living area. The primary need for normalization was to permit different house configurations to be compared on a common basis. A secondary need was to not penalize a home simply because of its size. Two homes with similar envelope characteristics but different floor areas would obtain a similar efficiency rating.

The fourth step required quantifying the energy performance of a home so that a comparison to an EEH standard could be made. Conceptually, a system was desired such that a home would be awarded points for discrete energy conserving features. The points awarded for each envelope element would be summed and compared to a standard EEH point total for that type of construction similar to the Edison Electric Institute National Energy Watch (NEW) program (6). The percentage of points awarded to a house relative to those obtained by the EEH standard would be computed. To accomplish this, the thermal transmittances, or U-values of all envelope components were area weighted. Weighting factors for ceilings and floors were established for common house styles.

The final step involved selecting a calculational method of predicting the seasonal thermal performance of envelop elements. The Degree Day methodology was adopted primarily due to its simplicity and widespread use in determining heating requirements for residences (7).

The seasonal heat loss through a particular envelope component such as a ceiling is proportional to the product of the U-value, area and temperature differential across that component. The basic Degree Day equation is

$$HL = (U_c) \quad (A_c) \ (DD) \ (24) \qquad (1)$$

where:

U_c = Component thermal transmittance

A_c = Component area

DD = Number of Degree Days

HL = Seasonal heat loss

The seasonal heat loss for a component is normalized to square footage of living area by

$$HL = (U_cA) \ (DD) \ (24) \qquad (2)$$

where:

$A = A_c/A_t$ Normalized area

A = Total living area

The purpose of normalizing the component area was so that a component thermal transmittance could be combined with the area term and compared directly to those of other components in the house envelope. The comparisons are used to identify those envelope elements that are inefficient from a heat loss standpoint relative to the other components. For the purpose of this analysis it was necessary to define the ratios of component area to living area for various styles of construction. Three basic types of houses included in the analysis were ranch, split-level, and two-story construction. Component to living space area ratios for ceilings and floors were taken from the Updated Project Conserve program (4). Total wall areas ratios were taken as unity. Table 1 lists area ratios used for ceilings, gross walls and floors for the three house constructions.

Envelope components included in the analysis were roofs, opaque walls, windows, floors, and air infiltration. These components are individually discussed below.

Roof Systems

The steady-state performance of a roof system may be illustrated by the thermal circuit in Fig. 1. Heat flows through the finished ceiling, through insulation and studs, and finally, dissipates through the roof, endwalls, and air vents. The thermal circuit was analyzed for the roof construction in the National Association of Home Builders' Insulation Manual (8). The roof construction was asphalt shingles over a plywood deck at a four in twelve pitch. Truss framing was on sixteen inch centers. The interior ceiling finish was gypsum board. Ventilation was provided by a combined soffit and gable vent system at an assumed rate of 0.1 cubic feet per minute per unit attic floor area. The thermal transmittance or U-value of the pitched roof system is

$$U_r = \frac{0.944 + 0.010 \cdot R}{3.195 + 1.027 \cdot R} \qquad (3)$$

where:

U_r = Roof system thermal transmittance

R = Insulation thermal resistance

It must be emphasized at this point that the thermal transmittances or U-values are system values and not ceiling U-values. This concept is a departure from the Degree Day method where an intermediate attic temperature must be calculated. The system approach allows indoor to outdoor temperature differences to be used without having to calculate intermediate attic temperatures. The system approach does require that the attic geometry be fixed.

The seasonal energy requirements for an envelope component are proportional to the system U-value as illustrated in Eq. 1. A more convenient way to present the system thermal characteristics of various insulation levels is to remove the decimal point from the U-value. The U-value to three places without the decimal point will be subsequently referred to as U-points. U-points are used later in rating an envelope to a selected standard.

Table 2 lists common insulation levels, installed R-value accounting for compression at the eaves, system U-values and U-points for apitched roof construction.

A similar analysis was possible for catherdral and flat roof constructions. The U-value of a flat or cathedral roof is given by

$$U_r = \frac{0.956 + 0.005 \cdot R}{3.590 + 1.000 \cdot R} \tag{4}$$

Table 3 lists system U-values and U-points of nominal insulation levels for flat and cathedral ceilings. The area weighing factor for a ranch type construction with flat ceilings is 1.0 whereas that for a cathedral ceiling is 1.08 based on a four in twelve (4/12) roof pitch. The joists were assumed to be two by eights on twenty-four inch centers for both constructions. A ventilation rate of 0.1 cubic feet per minute per unit ceiling area was again assumed.

Sidewall Systems

The steady-state performance of an opaque wall system may be illustrated by the thermal circuit in Fig. 2. Heat flows through the finished surface, splits through the cavity and stud, and finally through the exterior sheathing and siding. The thermal circuit was analyzed based again on the NAHB Insulation Manual house. Framing members were assumed to account for twenty percent of the total opaque wall area. The thermal U-value of the opaque wall system is given by

$$U_w = \frac{0.914 + 0.026 \cdot R}{4.420 + 1.000 \cdot R} \tag{5}$$

where:

U_w = Wall thermal transmittance

for R-values of 0 and 7.

The U-value for R-values of 11 and 13 is

$$U_w = \frac{0.888 + 0.026 \cdot R}{3.410 + 1.000 \cdot R} \tag{6}$$

The U-value equation changes when the wall cavity is completely filled with insulation to account for the loss of R-value attributed to a still air space. The final U-value equation for R-19 is

$$U_w = \frac{0.866 + 0.019 \cdot R}{3.410 + 1.000 \cdot R} \tag{7}$$

This equation is based on two by six wall studs on sixteen inch centers. Table 4 lists system U-values and U-points of wall with nominal levels of insulation.

Floor Systems

The thermal circuit analogous to steady-state heat loss through a floor system is illustrated in Fig. 3. Heat flows through the living space floor into the crawl space or basement and is dissipated through the foundation wall, floor, and by ventilation.

Four types of foundations analyzed were vented crawl space, non-vented crawl space, basement, and slab floor. Heat loss through below-grade walls and floors were simulated using the ASHRAE arc procedure (9).

The first type of foundation analyzed was a vented crawl space. A crawl space depth of four feet with one foot above grade was assumed. The ventilation rate used was 0.1 cubic feet per minute per square foot floor area. The U-value of the vented crawl space system is given by

$$U_f = \frac{0.935 + 0.003 \cdot R}{7.209 + 1.022 \cdot R} \qquad (8)$$

where:

U_f = Floor system thermal transmittance

Table 5 lists the system U-values and U-points of a vented crawl space for nominal insulation levels.

Non-vented crawl spaces perform somewhat differently than vented ones. Insulation is applied to the foundation walls in lieu of the floor to maintain a reasonable temperature within the crawl space. Fig. 4 illustrates the thermal circuit analogues to a non-vented crawl space. The U-value of a non-vented crawl space system is realted to the level of insulation by

$$U_f = \frac{0.585 + 0.030 \cdot R}{5.472 + 1.135 \cdot R} \qquad (9)$$

Table 6 lists the system U-values and U-points.

The thermal performance of unheated basement systems is similar to that of unheated crawl spaces with the exception of ventilation. Though some ventilation air reaches the basement, it was assumed to be minimal for this analysis. A seven foot deep basement with one foot above grade was analyzed. The system U-value is given by

$$U_f = \frac{0.935 + 0.007 \cdot R}{8.144 + 1.029 \cdot R} \qquad (10)$$

System U-values for nominal levels of insulation in the floor are listed in Table 7.

The final foundation system characterized was slab-on-grade. The U-value of this system is dependent on the perimeter of exposed edge. The U-values for two levels of perimeter insulation based on a twenty-four by forty-eight foot floor are listed in Table 8.

Window Systems

Window system U-values were taken from ASHRAE (7). Table 9 lists system U-values and associated U-points for common residential window units. Area weighting factors for windows were set at ten, fifteen and twenty percent of the gross wall area.

Air Infiltration

The final envelope characteristic studied which influences heat loss was air infiltration. Air infiltration is admittedly a very complex phenomena (10). The Updated Project Conserve program was used as a reference for typical infiltration rates found in residences (4). Air infiltration is expressed in U-value terms by

$$U_i = \frac{(1.08)\ (INF)}{7.5} \qquad (11)$$

where

U_i = Infiltration thermal transmittance

INF= Infiltration air changes per hour

The U-value given by Eq. 11 was based on an eight foot ceiling height. Table 10 lists air change values, equivalent U-vales, and U-points for four levels of house tightness.

Area-Weighting and Point System

The thermal characteristic of a total house envelope is determined by summing the area-weighted U-points of the individual envelope components. The relationship is expressed by

$$q_e = \sum (U_c \cdot A) \qquad (12)$$

where:

q_e = Envelope thermal index

The index characterizes the thermal performance envelope. In essence the index is an equivalent U-value for the entire envelope. The total heat loss through the envelope is equal to the product of the index, living space area and indoor-outdoor temperature differential.

The index is useful for comparing the thermal characteristics of a house envelope to known standards. For comparison purposes, the thermal indexes for an uninsulated house and one insulated to EEH construction standards were established for six climatic zones. The reference house selected was the NAHB Insulation Manual house. The house is ranch style over a crawl space. The roof system was an enclosed attic. The window area for the uninsulated house was twenty percent of the gross wall area as compared to fifteen percent for the EEH house. The thermal treatment of the EEH envelope is specified in Table 11 for the six climatic zones. Thermal index point totals for the uninsulated house are listed in Table 12 for ranch, split-level, and two-story construction. Similar index points for EEH construction are listed in Table 13. The six climatic zones were established from a data base of 256 cities across the continental United States. Table 14 lists the average number of degree days associated with each climatic zone. Zone six is the western coast.

The differences in point totals between the uninsulated reference case and the EEH specification are listed in Table 15. This difference forms the basis for determining the relative rating for a given house. The thermal rating is given by

$$\text{Rating} = \frac{(U \cdot A)_{ref} - (U \cdot A)}{(U \cdot A)_{ref} - (U \cdot A)_{eeh}} \cdot (100) \qquad (13)$$

where:

$(U \cdot A)$ = House index point total

$(U \cdot A)_{eeh}$ = EEH Standard index point total

$(U \cdot A)_{ref}$ = Uninsulated index point total

Application

An appraisal form was developed for recording appropriate construction data on a walk-through audit. The appraisal form is used in conjunction with a scorecard where index point totals are recorded for each envelope component, EEH point totals are summarized and the relative ranking is calculated. An example walk-through appraisal and ranking analysis is illustrated in Fig. 5. The rating for the house described is 59.7 percent.

Figure 6 illustrates a retrofit appraisal based on the example house. The cost point ratio is simply the cost premium to upgrade the envelope divided by the additional U-points achieved. The retrofit items with the low cost point ratios should be performed first. The total additional points for the retrofit items listed totals 235 and would raise the efficiency rating from 59.7 to 91.3 percent.

The earned point totals for the example house pre-and post-retrofit may be converted to seasonal energy savings by

$$SS = \frac{(\Delta qe)}{1000} \quad (A_t) \quad (DD) \quad (24) \tag{14}$$

where:

Δqe = Change in envelope thermal index

SS = Seasonal energy savings, therms

The Btu savings are in turn converted to a fuel cost savings by

$$\text{Cost Savings} = \frac{(SS)\ (FC)}{(HV)\ (EFF)} \tag{15}$$

where:

FC = Fuel cost

HV = Fuel heating value

EFF = Fuel conversion efficiency

The intent of developing the rating method was to estimate the relative thermal efficiency of a home envelope. The positive aspects of the rating procedure are the ability to perform quick energy audits of house envelopes and identify the relative benefits of various energy conserving opportunities. The actual fuel cost savings that result from retrofit activities are dependent on many factors and may vary for houses of similar construction due to occupant life-styles.

Conclusions

The rating method developed has several benefits. First, it enables comparison of the thermal characteristics of a home envelope on a continuum. Fig. 7 illustrates a proposed format for such a continuum. Fuel sources are broken out separately in the continuum. House envelopes are ranked as good, fair, and poor. A good rating would imply the envelope thermal treatment is consistant with construction practices prescribed by current standards. A poor rating would indicate poor relative thermal treatment. Houses with poor ratings would be singled out as candidates for retrofit activities at the time of resale. Secondly, the method provides a means of recommending retrofit measures based on the cost-benefit relationship. A homeowner who owns a house requiring several retrofit measures, but has a limited budget, is directed to those measures which provide the highest return on his investment. And finally, the procedure is reducible to a scorecard and set of tables that a real estate appraiser or loan officer may complete without difficulty.

Nomenclature

A = Normalized area, ft^2

A_c = Component area, ft^2

A_t = Total living space area, ft^2

EFF = Fuel conversion efficiency, fraction

FC = Fuel cost, dollars per therm, gallon, kWh

HV = Fuel Heating Value, Btu per therm, gallon, kWh

INF = Infiltration rate, air changes per hour

q_e = Envelope thermal index, Btu/(hr-ft^2-°F)

R = Insulation thermal resistance, (hr-ft^2-°F)/Btu

SS = Seasonal energy savings, Btu's or therms

U_c = Component thermal transmittance, Btu/(hr-ft^2-°F)

U_f = Floor thermal transmittance, Btu/(hr-ft^2-°F)

U_i = Infiltration thermal transmittance, Btu/(hr-ft^2-°F)

U_r = Roof system thermal transmittance, Btu/(hr-ft^2-°F)

U_w = Wall system thermal transmittance, Btu/(hr-ft^2-°F)

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4. Updated Project Conserve Audit System, Applied Urbanetics, May, 1978.

5. Guide To Constructing An Energy Efficient Home, Owens Corning Fiberglas, July, 1977.

6. "National Energy Watch: Operating Manual And Promotion Catalog," Edison Electric Institute, 1977.

7. ASHRAE Guide And Data Book, 1977 Handbook Of Fundamentals, ASHRAE, 1977, Chapter 22.

8. "NAHB Insulation Manual: Homes And Apartments," NAHB Research Foundation, September, 1971, page 43.

9. Ibid (7), Chapter 24.

10. Ibid (2), Chapter 9.

Table 1 : Ceiling, Wall, and Floor Area Weighting Factors

Component	Ranch	Split-level	Two-story
Roof system			
Pitched	1.00	0.67	0.50
Flat	1.00	0.67	0.50
Cathedral	1.08	0.72	0.54
Wall system	1.00	1.00	1.00
Floor system	1.00	0.67	0.50

Table 2 : Roof System U-value Summary For Pitched Roofs

Nominal R-value	Adjusted R-value	Roof System U-value	Roof System U-points
0	0.0	0.295	295
11	11.0	0.073	73
19	18.8	0.050	50
26	25.2	0.041	41
30	28.6	0.038	38
33	31.1	0.036	36
38	35.0	0.033	33
44	39.2	0.031	31

Table 3 : Flat and Cathedral Ceiling U-value Summary

Nominal R-value	Roof System U-value	Roof System U-points
0	0.266	266
11	0.069	69
19	0.047	47

Table 4 : Sidewall System U-value Summary

Nominal R-value	Wall System U-value	Wall System U-points
0	0.207	207
7	0.096	96
11	0.081	81
13	0.075	75
19	0.055	55

Table 5 : Vented Crawl Space U-value Summary

Nominal R-value	Floor System U-value	Floor System U-points
0	0.130	130
11	0.055	55
13	0.050	50
19	0.040	40
22	0.037	37

Table 6 : Non-vented Crawl Space U-value Summary

Nominal R-value	Floor System U-value	Floor System U-points
0	0.107	107
7	0.059	59
11	0.051	51
19	0.043	43

Table 7 : Unheated Basemant U-value Summary

Nominal R-value	Floor System U-value	Floor System U-points
0	0.115	115
11	0.052	52
19	0.039	39
22	0.035	35

Table 8 : Slab On Grade U-value Summary

Perimeter Insulation	Floor System U-value	Floor System U-points
none	0.101	101
1 inch	0.069	69
2 inch	0.063	63

Table 9 : Window System U-value Summary

Window Type	System U-value	System U-points
Metal Sash		
Single Pane	1.000	1000
Double Pane	0.744	744
Single Pane + Storm	0.600	600
Triple Pane	0.468	468
Wood Sash		
Single Pane	0.990	990
Double Pane	0.589	589
Single Pane + Storm	0.450	450
Triple Pane	0.371	371

Table 10 : Air Infiltration U-value Summary

Characteristic	Air Changes	U-value	U-points
Very Leaky	1.50	0.216	216
Leaky	1.00	0.144	144
Average	0.75	0.108	108
Tight	0.50	0.072	72

Table 11 : EEH Envelope Thermal Specifications

	Climatic Zone					
Component	1	2	3	4	5	6
Ceiling	R-38	R-33	R-30	R-26	R-26	R-19
Sidewall	R-19	R-19	R-19	R-19	R-13	R-11
Floor	R-22	R-22	R-19	R-13	R-11	R-11
Windows	T	D	D	S	S	D
Infiltration	--------		Tight	------------		

Note:
T - denotes triple glazing
D - denotes double glazing
S - denotes single glazing

Table 12 : Uninsulated House Thermal Index Point Summary

Construction Type	Weighting Factor	U-points	Index Points
Ranch			
Roof	1.0	295	295
Sidewall	0.8	207	166
Floor	1.0	130	130
Windows	0.2	1100	220
Infiltration	1.0	216	216
		Totals	1027
Split-level			
Roof	0.67	295	197
Sidewall	0.8	207	166
Floor	0.67	130	87
Windows	0.2	1100	220
Infiltration	1.0	216	216
			886
Two-story			
Roof	0.5	295	148
Sidewall	0.8	207	166
Floor	0.5	130	65
Windows	0.2	1100	220
Infiltration	1.0	216	216
			815

Table 13 : EEH Construction Thermal Index Point Summary

Construction	Climatic Zone 1	2	3	4	5	6
Ranch						
Roof	33	36	38	41	41	50
Sidewall	47	47	47	47	64	69
Floor	37	37	40	50	55	55
Windows	70	90	90	165	165	90
Infiltration	72	72	72	72	72	72
Totals	259	282	287	375	397	336
Split-level						
Roof	22	24	25	27	27	33
Sidewall	47	47	47	47	64	69
Floor	25	25	27	33	37	37
Windows	70	90	90	165	165	90
Infiltration	72	72	72	72	72	72
Totals	236	258	261	344	365	301
Two-story						
Roof	17	18	19	22	22	25
Sidewall	47	47	47	47	64	69
Floor	19	19	20	25	28	28
Windows	70	90	90	165	165	90
Infiltration	72	72	72	72	72	72
Totals	225	246	248	330	350	284

Table 14 : Degree Day Summary By Climatic Zone

Zone	Number Of Cities	Average Degree Days	Standard Deviation
1	22	8672	745
2	82	6641	724
3	66	4953	659
4	47	1546	580
5	24	1241	461
6	15	3845	1393

Table 15 : Thermal Index Point Total Difference Summary

Zone	Ranch	Two-story	Split-level
1	768	590	650
2	745	569	628
3	740	567	625
4	652	485	542
5	630	465	521
6	691	531	585

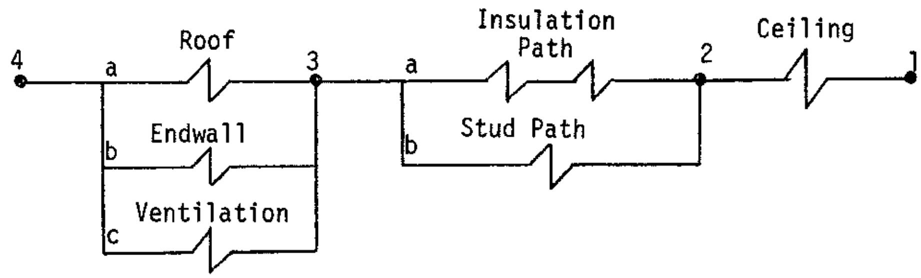

Fig. 1: Ceiling Thermal Circuit

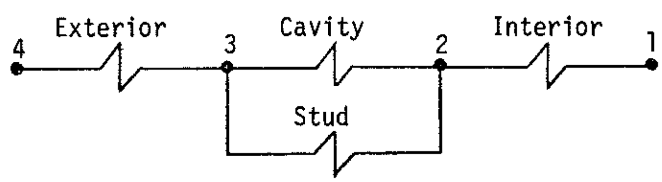

Fig. 2: Sidewall Thermal Circuit

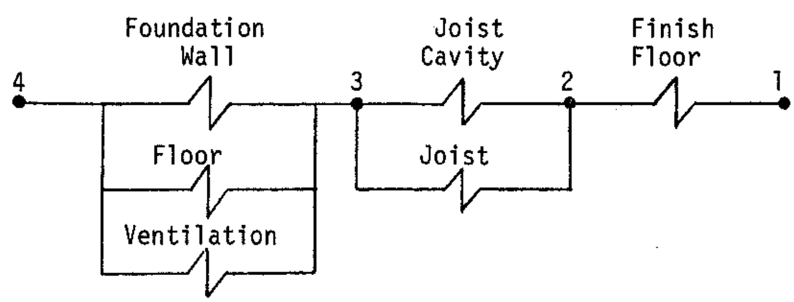

Fig. 3: Thermal Circuit For A Vented Crawl Space

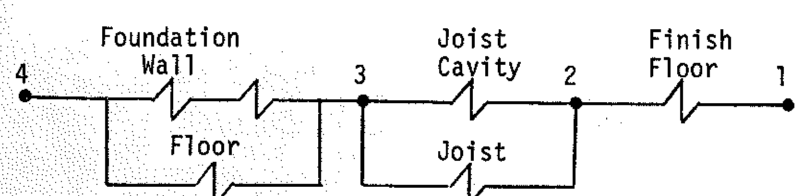

Fig. 4: Thermal Circuit For A Non-Vented Crawl Space

Walk Through Appraisal Form

Homeowner : ____________________

Address : ________________________

Living Area: _______

Map Zone 1 2 3 4 5 6

House Type : Ranch Two-Story Split-Level

Fuel Source : Gas Oil Electric Heat Pump Other

Ceiling Type : Attic Flat Cathedral

Foundation Type: Vented Crawl Non-Vented Crawl Basement Slab

Window Type : Single Double Triple Storm Metal

Percent Window Area : 10% 15% 20%

Infiltration : Leaky Average Tight

Insulation Level : Ceiling: None 11 19 30 38
Wall : None 7 11 13 19
Floor : None 11 19 30 38

Scorecard

Envelope Component	Points Earned	EEH Points	
Ceiling	222	259	Figure 5
Wall	-	119	6
Floor	15	93	7
Window	100	130	8
Infiltration	108	144	9
Totals	445	745	

Rating $\frac{445}{745} \times 100 = 59.7\%$

Fig. 5: Example Walk-Through Appraisal

Retrofit Appraisal Form

Retrofit Item	Additional Points	Cost	Cost Point Ratio
Caulk & Weatherstrip	36	$30	0.8
R-11 Floor Insulation	63	$180	2.9
R-11 Sidewall Insulation	101	$700	6.9
R-19 Ceiling Insulation	35	$300	8.6
Totals	235	$1210	

Original Point Total	445
Points Added	235
New Point Total	680
New Rating	$\frac{(680)}{745}\,100 = 91.3\%$

Fig. 6: Example Retrofit Appraisal Form

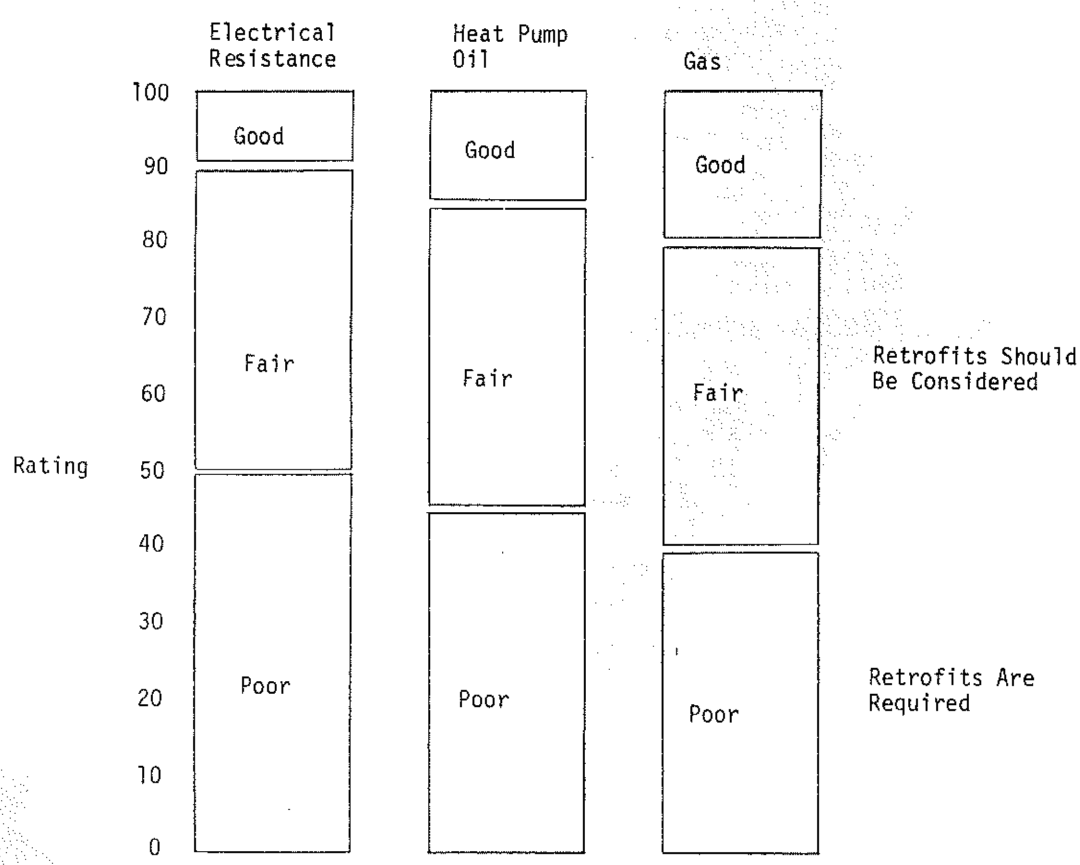

Fig. 7: Rating Scale