NRC Publications Archive
Archives des publications du CNRC

Estimating energy savings from reinsulating houses
Quirouette, R. L.; Scheuneman, E. C.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20386493
Building Practice Note, 1981-05-01

NRC Publications Record / Notice d'Archives des publications de CNRC:
https://nrc-publications.canada.ca/eng/view/object/?id=1d7f67b6-eec0-40aa-8cca-8e4d4d29f535
https://publications-cnrc.canada.ca/fra/voir/objet/?id=1d7f67b6-eec0-40aa-8cca-8e4d4d29f535

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada | Conseil national de recherches Canada

Ref
Ser
TH1
N21b8
no. 20
BLDG

ISSN 0701-5216

IRC PUB

BUILDING PRACTICE NOTE

09883

ESTIMATING ENERGY SAVINGS FROM REINSULATING HOUSES

by

R.L. Quirouette and E.C. Scheuneman

ANALYZED

Division of Building Research, National Research Council of Canada

Ottawa, May 1981

BLDG. RES.
LIBRARY
81- 07- 24
BIBLIOTHÈQUE
Rech. Bâtim.
CNRC - ICIST

Preface

This paper presents a method for estimating energy savings from reinsulating houses. The method uses the previous year's fuel bill and is aimed at existing houses; it is not intended for use in the design of new houses. As further information becomes available, some of the factors and tables may be revised. The Division of Building Research welcomes comments.

TABLE OF CONTENTS

ESTIMATING ENERGY SAVINGS FROM REINSULATING HOUSES

by

R.L. Quirouette and E.C. Scheuneman

INTRODUCTION

This Note presents a method of estimating the savings from adding more insulation (reinsulating) to an existing house as well as a means for determining the payback period of particular retrofit measures. It is a development of the methodology originated by R.L. Quirouette for the Division of Building Research 1978 Seminar/Workshop - Insulating Existing Houses.

The most common way to estimate energy savings due to reinsulation is termed the "degree-day (DD) method." It uses a single coefficient to account for the effect of occupancy-generated heat gains, solar heat gains through windows, and thermal storage effect. Because the combined effects of these conditions can vary so widely even in identical houses, the prediction of energy consumption can and does vary widely from actual fuel records. Hence, savings predicted by this method are subject to important uncertainties.

The energy saved by reinsulating a particular house can be determined with greater confidence by using the previous year's fuel bill and an estimate of the "actual degree-days (ADD)" to calculate a range of energy savings by identifying the minimum and maximum values that may be obtained from particular retrofit measures. Since the actual savings will lie between the minimum and maximum limits, a further calculation termed "probable savings" is introduced to facilitate the economic analysis that follows.

The application of this method is explained in detail in this Note; the theory is left for another paper to be published as a DBR Building Research Note. A companion publication to this paper will provide the user with a computer program for hand-held computers.

EQUATIONS FOR DETERMINING MINIMUM (S_1) AND MAXIMUM (S_2) SAVINGS

The minimum and maximum savings are firm theoretical limits although the accuracy of the predictions depends on the accuracy of the information obtained. The following formulae apply to both metric SI and imperial units except as noted for maximum savings, S_2.

The following equation is used to calculate S_1, the minimum savings.

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{Total } Q_1} \qquad (1)$$

where S_1 = minimum savings in dollars per heating season for each upgraded building component

F_B = the previous year's fuel bill for space heating

Q_1 = original heat flow through each building component

Q_2 = new heat flow through each building component being upgraded

Total Q_1 = the sum of all the Q_1's

The following equation is used to calculate S_2, the maximum savings.

$$S_2 = 86{,}400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2) \quad \text{(metric SI units)} \qquad (2)$$

or

$$S_2 = 24 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2) \quad \text{(imperial units)} \qquad (3)$$

where S_2 = maximum savings in dollars per heating season

86,400 = number of seconds in a day to correspond to Joule/second

24 = number of hours in a day to correspond to Btu/hour

ADD = actual degree-days

K_1 = cost of fuel per unit at same price as used for fuel bill, F_B

K_2 = heat content of fuel per unit

K_3 = seasonal efficiency of heating plant

Q_1 = original heat flow through each building component

Q_2 = new heat flow through each building component being upgraded

EQUATIONS FOR DETERMINING PROBABLE SAVINGS (S_p)

For those users wanting an estimate of probable savings a further calculation is provided which is subject to two conditional equations. These equations estimate where the savings lie between the minimum and maximum limits. This technique is a new theoretical treatment and, therefore, may be subject to modification after further experience.

(a) Total $S_2 \le F_B$

When the total of the maximum savings (S_2's) is less than or equal to the previous year's fuel bill (F_B), use

$$S_p = S_1 + 0.75 (S_2 - S_1) \qquad (4)$$

to calculate the component probable savings (S_p's).

(b) Total $S_2 > F_B$

When the Total of the S_2's is greater than F_B, there are two ways to proceed:

(i) If all the retrofit options from this Total S_2 package are going to be done, use the formula

$$\text{Total } S_p = \text{Total } S_1 + 0.75 (F_B - \text{Total } S_1) \qquad (5)$$

and do not calculate the component S_p's which are not required since it is the savings of the entire retrofit package that is of interest.

(ii) If only certain retrofit options from this Total S_2 package are going to be done, calculate the new lower Total S_2 for these options and compare the Total S_2 to F_B.

If Total $S_2 \le F_B$, use procedure (a) above.

If Total $S_2 > F_B$, use procedure (b) (i) above.

Note: The condition of section (b), Total $S_2 > F_B$, will not occur often. However, it could happen when making major retrofits on buildings that have a high proportion of internal and free heat gains relative to their total heat loss. Highly insulated and passive-solar heated buildings could fall into this category. Further explanations will be given in the theoretical paper.

ENERGY SAVINGS CHART

The chart on the following two pages (charts 1A and 1B) has been developed to facilitate the presentation of the house characteristics and the analysis of the data and results for use in energy audit work. One is for metric SI units and the other for imperial units. The different parts of the S_1 and S_2 equations and this chart are discussed in general terms before an example calculation and analysis is carried out for a particular house. The calculations in this paper use metric SI units. For calculations in imperial units conversion tables are given in Appendix A.

F_B (Fuel Bill for Space Heating)

This cost should be determined from the previous year's fuel bills over a 12-month period, usually spring-to-spring or fall-to-fall. In cases where the same fuel is used for space heating and other uses such as appliances and water heating, it will be necessary to separate out the non-space heating costs. This is done by taking the average of the monthly fuel bills during the non-heating months (usually June through September), multiplying by 12, and subtracting this amount from the total twelve-month fuel bill.

Q's (Heat Flows)

This is the amount of heat per unit of time per degree of temperature difference that flows through a building component. It is defined and calculated by the equation

$$Q = \frac{A}{R}$$

where A = area of the component
R = thermal resistance of the component

Both of these quantities, A and R, must be measured and/or calculated first before Q can be calculated.

The heat flow (loss) due to air change is calculated by using the formula

$Q = 0.361 \times AC/h \times Vol$ ($Q = 0.0183 \times AC/h \times Vol$ for imperial units)

where AC/h (air change per hour) is explained in a following section; Vol is the volume of heated space in the house.

(i) A (area of component)

Areas are measured and calculated from the external house dimensions. Window and door opening areas are determined from the gross openings (the component plus its frame).

HART NO. 1A

ENERGY SAVINGS CHART

(metric SI units)

AME ______________________ TYPE OF HOUSE ______________________ INTERIOR TEMP. (T_i) ______________________

DDRESS ______________________ VOLUME OF HEATED SPACE ______________________ DEGREE-DAYS (DD) ______________________

HEATING SYSTEM ______________________ AIR CHANGE/h (No.) ______________________

ITY ______________ PROV ______________ HOT WATER HEATING ______________________

FUEL BILL, F_B = ______________________ K_2 = ______________________

K_1 = ______________________ K_3 = ______________________

		PREVIOUS YEAR			______ RETROFIT						
NO.	BUILDING COMPONENT	A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No.		No.						
12	TOTAL										

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

ADD = DD + (T_i − 18) x b = ______________________

$$S_2 = 86,400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= \_\_\_\_\_\_ \times (Q_1 - Q_2)$$

(a) TOTAL $S_2 \leq F_B$

$$S_p = S_1 + 0.75\ (S_2 - S_1)$$

(b) TOTAL $S_2 > F_B$

$$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\ (F_B - \text{TOTAL } S_1)$$

HART NO. 1B

ENERGY SAVINGS CHART

(imperial units)

AME ______________________

DDRESS ______________________

ITY ______________ PROV ______________

TYPE OF HOUSE ______________

VOLUME OF HEATED SPACE ______________

HEATING SYSTEM ______________

HOT WATER HEATING ______________

FUEL BILL, F_B = ______________

K_1 = ______________

INTERIOR TEMP. (T_i) ______________

DEGREE-DAYS (DD) ______________

AIR CHANGE/h (No.) ______________

K_2 = ______________

K_3 = ______________

		PREVIOUS YEAR			______ RETROFIT						
NO.	BUILDING COMPONENT	A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11	AIR CHANGE, Q = 0.0183 × Vol. × No.		No.		No.						
12	TOTAL										

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

ADD = DD + (T_i − 65) × b = ______________

$$S_2 = 24 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= \_\_\_\_\_\_ \times (Q_1 - Q_2)$$

(a) TOTAL $S_2 \leq F_B$

$$S_p = S_1 + 0.75\ (S_2 - S_1)$$

(b) TOTAL $S_2 > F_B$

$$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\ (F_B - \text{TOTAL } S_1)$$

(ii) R-values (Thermal Resistances)

To determine nominal R-values for building components such as walls, ceilings and windows, the individual R-values of the materials making up the building component (including the appropriate R-values for an interior and exterior air film) are added up. A list of thermal resistances, R-values, for building materials and air films/spaces is given in Table B-1 (Appendix B).

Below-grade construction such as basements require special treatment. This is explained in Appendix B with Table B-2 providing R-values for typical constructions.

For improved accuracy of R-value calculations, the "thermal bridging effect" described in Appendix C should be taken into account.

ADD (Actual Degree-Days)

This method uses ADD (actual degree-days) to calculate savings. ADD is a measure of the actual temperature difference between the interior house temperature (T_i) and the outdoor temperature. This is different from standard DD (degree-days) which are computed from a base interior temperature of 18°C (65°F). The concept and calculation of ADD are given in Appendix D.

Heating System Factors

The determination of maximum savings, S_2, requires certain heating system factors. These factors which characterize the performance of the heating system are the cost of fuel (K_1), the heat content of fuel (K_2), and the seasonal efficiency (K_3).

(i) K_1 (Cost per Unit of Fuel)

This constant is the price in dollars per unit of fuel used. The price used should be the same as that used for the fuel bill. The normal units would be as follows:

Fuel oil (domestic)	\$/litre	(\$/gal)
Natural gas	\$/m^3	(\$/ft^3)
Electricity	\$/kW·h	(\$/kW·h)

(ii) K_2 (Heat Content per Unit of Fuel)

These values of the heat content for different fuels are given in Table 1. It should be noted that the same fuel unit must be used for both K_1 and K_2. For example, if \$/litre is used in K_1, then J/litre must be used for K_2.

TABLE 1. HEATING VALUE OF SOME COMMON HEATING FUELS

Fuel	SI (Joule)	Imperial (Btu)
Fuel oil (domestic)	38 757 000 per litre	167 000 per gal
Natural gas	37 300 000 per m^3	1 000 per ft^3
Electricity	3 600 000 per kW·h	3 413 per kW·h

(iii) K_3 (Seasonal Efficiency of Heating System)

This is the factor that determines the useful heat delivered to the house from the potential amount of heat in the fuel used during the heating season. A further explanation will be found in Appendix E.

Air Change Rate (air change/hour, AC/h)

Estimating the air leakage rate is a complicated task that involves an analysis of the effect of wind conditions and the stack effect pressures on the leakage openings of a house. Even then the results of this analysis are often too simplistic since the actual air leakage patterns and rates are altered by operational characteristics such as the opening and closing of windows and doors, and the operation of fireplaces, fuel-burning appliances, and exhaust fans.

It is generally accepted that there is a relationship between the indoor relative humidity during the heating season and the air leakage rate of a small house if it is occupied and no mechanical humidification is used. If the information in the paragraph that follows is not available, the value 1.00 air change/hour may be used as a "default" or "best guess" value.

The January and February indoor relative humidity (R.H.) can be approximately correlated to air change rates as follows:

- 15 to 25% R.H. as measured or indicated by dryness in the occupant's nose and throat or "shocks" from static electricity would suggest an air change rate of 1.50/h or higher.

- 25 to 35% R.H. as measured or indicated by slight condensation on double-glazed windows would suggest an air change rate of 0.75/h.

- 35% and higher R.H. as measured or indicated by frost on windows for long periods and mildew/fungus growth on organic materials would suggest an air change rate of 0.25/h or less. (This may occur in some electrically-heated homes because the absence of chimneys makes them generally tighter than houses with fuel-fired heating systems.)

Since there is uncertainty in estimating an air change rate, it may be preferable to estimate a high and low rate to give a range of values. This range is calculated by adding to and subtracting 50% from the value selected above. This provides a reasonable margin of error and can be used to illustrate the influence of air change rates on the predicted savings.

Applying the high/low range to these values would yield the following:

- 1.00/h transforms to 1.50 and 0.50
- 1.50/h transforms to 2.25 and 0.75
- 0.75/h transforms to 1.13 and 0.38
- 0.25/h transforms to 0.38 and 0.13

Cost and Payback

The cost for each retrofit action may vary considerably depending on who is doing the work (homeowner or contractor). Also, some material costs may be significantly reduced by government grant programs.

This simplified payback calculation,

$$\text{Payback} = \frac{\text{Costs}}{\text{Savings}} = \frac{C}{S} \text{ (years)}$$

assumes that the fuel price escalation is approximately the same as the interest rate on savings. Any significant cost reductions, as in the preceding paragraph, would provide shorter payback periods.

EXAMPLE 1. - BASIC DATA CALCULATIONS AND #1 RETROFIT

Location:	Ottawa
Type of House:	two-storey, detached
Volume of Heated Space:	481.4 m^3
Heating System:	oil-fired, forced warm air
Hot Water Heating:	electric
Fuel Bill, F_B =	\$1239 (for 5682 litre)
Cost per Unit of Fuel, K_1 =	\$0.218/litre

Step 1 - Basic House Data

- The basic data from above is entered on to the top of chart 2 (next page).

Step 2 - Climate and Air Change

- The climate and air change section at the top of chart 2 is filled in as follows:

- T_i is 21^oC.
- DD for Ottawa is 4674
- Air change/hour was chosen to be the default value of 1.00/h since we had no further information
- K_2 for oil from Table 1 is 38 757 000
- K_3 is chosen to be the default value of 0.55 (from Appendix E)

CHART NO. 2

ENERGY SAVINGS CHART

(metric SI units)

NAME ______________________

ADDRESS ______________________

CITY OTTAWA PROV ONT.

TYPE OF HOUSE 2-storey, detached

VOLUME OF HEATED SPACE 481.4 m^3

HEATING SYSTEM oil-fired forced air

HOT WATER HEATING electric

FUEL BILL, F_B = $1239

K_1 = $ 0.218/litre

INTERIOR TEMP. (T_i) 21 °C

DEGREE-DAYS (DD) 4674

AIR CHANGE/h (No.) 1.00

K_2 = 38,757,000

K_3 = 0.55

		PREVIOUS YEAR			#1 RETROFIT						
NO.	BUILDING COMPONENT	A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1	Ceiling	65.0	2.11	31	5.64	12	46	87	77	280	3.6
2	Frame walls	143.1	1.76	81	2.29	62	46	87	77	1100	14.3
3	Header joists	14.8	0.60	25							
4	Basement walls, A.G.	19.5	0.26	75	2.47	8	163	305	270	900	2.0
5	Basement walls, B.G.	49.2	0.8	62	3.2	15	115	214	189		
6	Basement floor	65.0	4.6	14							
7	Windows	13.9	0.35	40							
8	Doors	3.7	0.70	5							
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No. 1.00	174	No.						
12	TOTAL			507			370	693	613	2280	3.7

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

ADD = DD + (T_i − 18) x b = 4674 + (21 − 18) x 161 = 5157

$$S_2 = 86,400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= 4.557 \times (Q_1 - Q_2)$$

(a) TOTAL $S_2 \leq F_B$

$$S_p = S_1 + 0.75\,(S_2 - S_1)$$

(b) TOTAL $S_2 > F_B$

$$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\,(F_B - \text{TOTAL } S_1)$$

BR 6085-1

Step 3 - Building Components and Areas

- List all the building components that make up the building envelope, e.g. ceiling, frame walls, header joists, basement walls above grade (A.G.) and below grade (B.G.), basement floor, windows, exterior doors.

- The area of each component is entered in column A of Chart 2. Note that the areas of the windows and doors should be subtracted from the appropriate gross wall areas to give the net wall areas.

Step 4 - R_1 Values

- Each building component has an R-value. Calculate the R-values of materials from Table B-1 (Appendix B) and then sum these up for the component R-value.

- For the basement walls below grade and basement floor one uses Table B-2 (Appendix B).

- Exterior doors constructed of solid-core wood with a storm door have an R of 0.70.

- R-values are written in the R_1 column of chart 2.
- AC/h (No.) is written in the R_1 column of row 11.

Step 5 - Heat Flow, Q_1

- The Q_1 column of chart 2 is filled by dividing each A by its respective R_1.
- The Q_1 for air change is calculated by using the formula

$$Q_1 = 0.361 \times AC/h \times Vol$$

- Q_1 values are rounded to the nearest unit.
- The total Q_1 is calculated by adding up the individual Q_1's. This result is entered in the Total row of the Q_1 column.

Step 6 - Selection of Retrofit Options

By examining the figures in column Q_1, one notes the relative importance of each building component regarding heat loss (Q_1). The larger the number, the greater the heat loss. In this case, air change contributes the greatest heat loss followed by frame walls, basement walls above grade, basement walls below grade, windows, ceiling, header joists, basement floor, and doors. One usually concentrates on the areas or components of greatest heat loss since these present the greatest potential for overall savings. Sometimes the areas of smaller heat loss will be the easiest and cheapest to retrofit. There are other factors to consider including the physical feasibility of each retrofit action.

As the purpose of this paper is to assist one in estimating the savings and payback for different retrofit options, the following retrofit actions have been evaluated:

Ceiling, from $R_1 = 2.11$ to $R_2 = 5.64$, Cost (C) = \$280
Frame walls, from $R_1 = 1.76$ to $R_2 = 2.29$, Cost (C) = \$1100
Basement walls A.G., from $R_1 = 0.26$ to $R_2 = 2.47$ Cost (C) = \$900
Basement walls B.G., from $R_1 = 0.8$ to $R_2 = 3.2$

Step 7 - R_2 Values and Cost (C)

- The R_2's from Step 6 are the combined R-value of the original R plus the added insulation and are written in the appropriate rows in the R_2 column of chart 2 while leaving the remaining rows blank. This section should be labelled #1 Retrofit to avoid confusion with different calculations that may be done later for the same house.

- The C's from Step 7 are written in the appropriate rows in the C column of the #1 Retrofit section, and added up to give the Total C.

Step 8 - Q_2's

- The Q_2 for each R_2 of chart 2 is calculated by dividing each A by its R_2 and rounding to the nearest unit.

Step 9 - Calculation of Minimum Savings, S_1

- The S_1's are calculated for each upgraded component of chart 2 by using the formula:

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{Total } Q_1}$$

- The S_1's are added and the result entered in the Total row.

Step 10 - Calculation of Maximum Savings, S_2

- The S_2's are calculated for each upgraded component of chart 2 by using the formula

$$S_2 = 86\ 400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

We know all the values in the S_2 equation except for ADD. The value for ADD is calculated as

ADD = 4674 + (21 - 18) x 161 = 5157 where b = 161 from Figure D-1 (app. D),

and entered on to chart 2 (bottom left).

- Since $86\ 400 \times ADD \times \frac{K_1}{K_2 \times K_3}$ remains the same for each particular house if no change occurs to the heating system, it is convenient to calculate this constant once as follows

$$86\ 400 \times 5157 \times \frac{0.218}{38\ 757\ 000 \times 0.55} = 4.557$$

and write it into the blank of the S_2 equation on chart 2 (bottom left).

This simplified form, $S_2 = 4.557 \times (Q_1 - Q_2)$, can be used to calculate all the various S_2's.

- the S_2's are calculated for the upgraded Q_2's.
- the S_2's are added and the result entered in the Total row.

Step 11 - Calculation of Probable Savings, S_p

Since the total S_2 of chart 2 is \$693 which is less than the F_B of \$1239, Total $S_2 < F_B$, the (a) formula is used to calculate the individual S_p's, that is,

$$S_p = S_1 + 0.75\ (S_2 - S_1)$$

- Calculate the S_p's for the appropriate Q_2's.
- Add up the S_p's to get Total S_p.

Step 12 - Calculation of Payback, C/S

Depending on whether the minimum/maximum limits of payback or the probable payback is desired, one can use any or all of S_1, S_2, and S_p to calculate the payback time period(s). For this example of chart 2 we will use S_p.

The paybacks are calculated for each upgrading measure by dividing the upgrading cost (C) by each S_p (C/S_p). Note that there is a combined payback for basement walls above and below grade because the price quotation of \$900 covers the entire basement wall area.

- The total payback is calculated by dividing total C by total S_p.

Step 13 - Calculation of Minimum/Maximum Payback

To further illustrate this method, the minimum and maximum payback is calculated below for each Q_2 (R_2).

	Minimum Payback (C/S_2), years	Maximum Payback (C/S_1), years
Ceiling	$\frac{280}{87} = 3.2$	$\frac{280}{46} = 6.1$
Frame Walls	$\frac{1100}{87} = 12.6$	$\frac{1100}{46} = 23.9$
Basement Walls A.G. & B.G.	$\frac{900}{519} = 1.7$	$\frac{900}{278} = 3.2$
Total	$\frac{2280}{693} = 3.3$	$\frac{2280}{370} = 6.2$

Example 2. - #2 Retrofit

This example illustrates the estimated savings and paybacks resulting from going to higher insulation levels for the following components. Frame walls have been left out because the #1 retrofit filled the remainder (36 mm) of the cavity (100 mm total) and so higher R-values cannot be achieved from the cavity since additional insulation cannot be added.

Ceiling, from $R_1 = 2.11$ to $R_2 = 10.57$, Cost (C) = \$700

Basement Walls A.G., from $R_1 = 0.26$ to $R_2 = 3.70$
Basement Walls B.G., from $R_1 = 0.8$ to $R_2 = 3.9$ Cost (C) = \$1100

Step 1 - R_2's and C's

The R_2's and C's are entered into the appropriate rows and columns in the Retrofit section which is labelled #2 Retrofit. (See chart 3.)

Step 2 - Calculations of Q_2, S_1, S_2, S_p

- The calculations are carried out for Q_2, S_1, S_2, and S_p and the quantities entered in the appropriate boxes in the #2 Retrofit section of chart 3.

Step 3 - Payback, C/S

- The desired savings from S_1, S_2, and S_p are chosen to calculate the payback. For this example we will again choose S_p which gives a payback of 6.9 years for the ceiling, 2.3 years for the basement walls, and 3.1 years total for both. (See chart 3.) These payback periods are reasonably short.

These results can be compared with the #1 Retrofit (chart 2) results to aid in choosing levels of insulation.

HART NO. 3

ENERGY SAVINGS CHART

(metric SI units)

AME ______

DDRESS ______

ITY OTTAWA PROV ONT.

TYPE OF HOUSE 2-storey, detached

VOLUME OF HEATED SPACE 481.4 m^3

HEATING SYSTEM oil-fired, forced air

HOT WATER HEATING electric

FUEL BILL, F_B = $1239

K_1 = $ 0.218/litre

INTERIOR TEMP. (T_i) 21 °C

DEGREE-DAYS (DD) 4674

AIR CHANGE/h (No.) 1.00

K_2 = 38,757,000

K_3 = 0.55

		PREVIOUS YEAR			#2 RETROFIT						
NO.	BUILDING COMPONENT	A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1	Ceiling	65.0	2.11	31	10.57	6	61	114	101	700	6.9
2	Frame Walls	143.1	1.76	81							
3	Header joists	14.8	0.60	25							
4	Basement walls, A.G.	19.5	0.26	75	3.70	5	171	319	282 }	1100	2.3
5	Basement walls, B.G.	49.2	0.8	62	3.9	13	120	223	197 }		
6	Basement floor	65.0	4.6	14							
7	Windows	13.9	0.35	40							
8	Doors	3.7	0.70	5							
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No. 1.00	174	No.						
12	TOTAL			507			352	656	580	1800	3.1

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

$ADD = DD + (T_i - 18) \times b$ = 4674 + (21-18) x 161 = 5157

$$S_2 = 86{,}400 \times ADD \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= 4.557 \times (Q_1 - Q_2)$$

(a) TOTAL $S_2 \leq F_B$

$S_p = S_1 + 0.75\ (S_2 - S_1)$

(b) TOTAL $S_2 > F_B$

TOTAL S_p = TOTAL $S_1 + 0.75\ (F_B - \text{TOTAL } S_1)$

BR 6085-1

EXAMPLE 3 - EFFECTS OF HIGH/LOW AIR CHANGE RATES

The same house from Example 1 is used to show the effects of varying the air change rate. The value of 1.00 AC/h used in Example 1 is increased and decreased by 50% to give the high/low range of 1.50 to 0.50. The same basic data and the same #1 Retrofit R_2 from chart 2 values are used to carry out two sets of calculations using the high (chart 4) and low (chart 5) air change rate.

A comparison of the results from charts 4 and 5 shows the following range of savings for the #1 Retrofit actions:

Air change/hour	S_1	S_2	S_p
	(1.50 → 0.50)	(1.50 → 0.50)	(1.50 → 0.50)
Ceiling	\$ 40 → \$ 56	\$ 87 → \$ 87	\$ 75 → \$ 79
Frame walls	\$ 40 → \$ 56	\$ 87 → \$ 87	\$ 75 → \$ 79
Basement walls A.G.	\$140 → \$197	\$305 → \$305	\$264 → \$278
Basement walls B.G.	\$ 98 → \$139	\$214 → 214	\$185 → \$195
Total	\$318 → \$448	\$693 → \$693	\$599 → \$631

These results show that the high/low range of air change/hour produces a 41% range for S_1 values; however it should be noted that it makes no difference to S_2 but does affect the S_p's by 5%. An analysis of the effects on the #2 Retrofit actions of Example 2 from chart 3 would show the same per cent ranges.

EXAMPLE 4 - AIR CHANGE REDUCTION BY RETROFITTING

Often the most cost-effective retrofit action is the tightening up of a house by weatherstripping, caulking, or using other means to reduce air leakage and the air change rate. It is difficult, however, to measure or determine the initial and final air change rates for a house. Hence, the following example is an illustration rather than a guarantee of possible savings.

For a "leaky" house with an air change of 1.50/h it is possible to effect a 50% reduction by thorough, careful tightening of the house.

The same house as in Example 1 (chart 2) will be assumed except that the original (R_1) AC/h is 1.50 and the new (R_2) AC/h is 0.75.

Chart 6 shows the data and calculation giving values of

$$S_1 = \$273$$
$$S_2 = \$597$$
$$S_p = \$516$$

from this retrofit action. This suggests a large savings that should be very cost-effective.

HART NO. 4

ENERGY SAVINGS CHART

(metric SI units)

AME ____________

DDRESS ____________

TY OTTAWA PROV ONT.

TYPE OF HOUSE 2-storey, detached

VOLUME OF HEATED SPACE 481.4 m^3

HEATING SYSTEM oil-fired, forced air

HOT WATER HEATING electric

FUEL BILL, F_B = $ 1239

K_1 = $ 0.218/litre

INTERIOR TEMP. (T_i) 21°C

DEGREE-DAYS (DD) 4674

AIR CHANGE/h (No.) 1.50

K_2 = 38,757,000

K_3 = 0.55

NO.	BUILDING COMPONENT	PREVIOUS YEAR: A	R_1	$Q_1 = \frac{A}{R_1}$	HIGH AC/h = 1.50 #1 RETROFIT: R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1	Ceiling	65.0	2.11	31	5.64	12	40	87	75		
2	Frame Walls	143.1	1.76	81	2.29	62	40	87	75		
3	Header joists	14.8	0.60	25							
4	Basement walls, A.G.	19.5	0.26	75	2.47	8	140	305	264		
5	Basement walls, B.G.	49.2	0.8	62	3.2	15	98	214	185		
6	Basement floor	65.0	4.6	14							
7	Windows	13.9	0.35	40							
8	Doors	3.7	0.70	5							
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No. 1.50	261	No.						
12	TOTAL			594			318	693	599		

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

$$ADD = DD + (T_i - 18) \times b = 4674 + (21-18) \times 161 = 5157$$

$$S_2 = 86{,}400 \times ADD \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= 4.557 \times (Q_1 - Q_2)$$

(a) $\text{TOTAL } S_2 \leq F_B$

$$S_p = S_1 + 0.75\,(S_2 - S_1)$$

(b) $\text{TOTAL } S_2 > F_B$

$$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\,(F_B - \text{TOTAL } S_1)$$

HART NO. 5

ENERGY SAVINGS CHART

(metric SI units)

AME ____________

DDRESS ____________

ITY OTTAWA PROV ONT

TYPE OF HOUSE 2-storey, detached

VOLUME OF HEATED SPACE 481.4 m^3

HEATING SYSTEM oil-fired, forced air

HOT WATER HEATING electric

FUEL BILL, F_B = $1239

K_1 = $ 0.218 / litre

INTERIOR TEMP. (T_i) 21 °C

DEGREE-DAYS (DD) 4674

AIR CHANGE/h (No.) 0.50

K_2 = 38,757,000

K_3 = 0.55

NO.	BUILDING COMPONENT	PREVIOUS YEAR			Low AC/h = 0.50, #1 RETROFIT						
		A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1	Ceiling	65.0	2.11	31	5.64	12	56	87	79		
2	Frame walls	143.1	1.76	81	2.29	62	56	87	79		
3	Header joists	14.8	0.60	25							
4	Basement walls, A.G.	19.5	0.26	75	2.47	8	197	305	278		
5	Basement walls, B.G.	49.2	0.8	62	3.2	15	139	214	195		
6	Basement floor	65.0	4.6	14							
7	Windows	13.9	0.35	40							
8	Doors	3.7	0.70	5							
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No. 0.50	87	No.						
12	TOTAL			420			448	693	631		

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

ADD = DD + (T_i − 18) x b = 4674 + (21−18) x 161 = 5157

$$S_2 = 86,400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$= 4.557 \times (Q_1 - Q_2)$

(a) $\text{TOTAL } S_2 \leq F_B$

$S_p = S_1 + 0.75\ (S_2 - S_1)$

(b) $\text{TOTAL } S_2 > F_B$

$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\ (F_B - \text{TOTAL } S_1)$

HART NO. 6

ENERGY SAVINGS CHART

(metric SI units)

AME ____________

DDRESS ____________

TY OTTAWA PROV ONT.

TYPE OF HOUSE 2-storey, detached

VOLUME OF HEATED SPACE 481.4 m^3

HEATING SYSTEM oil-fired, forced air

HOT WATER HEATING electric

FUEL BILL, F_B = $ 1239

K_1 = $ 0.218/litre

INTERIOR TEMP. (T_i) 21 °C

DEGREE-DAYS (DD) 4674

AIR CHANGE/h (No.) 1.50

K_2 = 38,757,000

K_3 = 0.55

		PREVIOUS YEAR			AIR CHANGE REDUCTION RETROFIT						
NO.	BUILDING COMPONENT	A	R_1	$Q_1 = \frac{A}{R_1}$	R_2	$Q_2 = \frac{A}{R_2}$	S_1	S_2	S_p	C	C/S
1	Ceiling	65.0	2.11	31							
2	Frame walls	143.1	1.76	81							
3	Header joists	14.8	0.60	25							
4	Basement walls, A.G.	19.5	0.26	75							
5	Basement walls, B.G.	49.2	0.8	62							
6	Basement floor	65.0	4.6	14							
7	Windows	13.9	0.35	40							
8	Doors	3.7	0.70	5							
9											
10											
11	AIR CHANGE, Q = 0.361 x Vol. x No.		No. 1.50	261	No. 0.75	130	273	597	516		
12	TOTAL			594							

$$S_1 = F_B \times \frac{(Q_1 - Q_2)}{\text{TOTAL } Q_1}$$

ADD = DD + (T_i − 18) × b = 4674 + (21−18) × 161 = 5157

$$S_2 = 86,400 \times \text{ADD} \times \frac{K_1}{K_2 \times K_3} \times (Q_1 - Q_2)$$

$$= 4.557 \times (Q_1 - Q_2)$$

(a) $\text{TOTAL } S_2 \leq F_B$

$S_p = S_1 + 0.75\ (S_2 - S_1)$

(b) $\text{TOTAL } S_2 > F_B$

$\text{TOTAL } S_p = \text{TOTAL } S_1 + 0.75\ (F_B - \text{TOTAL } S_1)$

CONCLUDING REMARKS

This paper has presented a methodology to estimate heating-season energy savings from reinsulation of houses. Further savings would be achieved if a house had a cooling or air-conditioning system. Although the minimum (S_1) and maximum (S_2) savings are theoretically correct, the actual results can vary considerably since S_1 depends on the values selected for Q_1 (or R_1) and Q_2 (or R_2) while S_2 additionally depends on ADD (or T_i) and K_3.

Some factors influencing these parameters are as follows:

Q_1 and Q_2 (R_1 and R_2). - Failure to include thermal bridging effects in the calculation of R-values can result in the predicted S_1, S_2, and S_p being considerably higher than actual.

ADD (or T_i). - The S_2 calculations are affected by the accuracy of ADD which is dependent on the variable factor, T_i. Some houses, especially older ones, may have lower interior temperatures (T_i's) than realized (and used in calculations) because of high heat loss rates and non-uniform heating. This would result in the calculations predicting greater-than-actual S_2 and S_p values.

K_3. - The S_2 calculations depend on the seasonal efficiency of the heating system and assume that it is constant before and after reinsulation.

If the ratio of furnace rated output to building heat loss is increased by reinsulating (K_3 becomes smaller), the actual savings can decrease or even disappear. It is very important, therefore, to downsize the furnace where required.

ACKNOWLEDGEMENT

The authors wish to thank C. J. Shirtliffe for the numerous ideas and constructive discussion during the conceptual development of this method.

APPENDIX A

CONVERSIONS FROM AND TO SI

TABLE A1 - CONVERSIONS FROM METRIC (SI) TO IMPERIAL

(Multiply the metric (SI) unit by the factor given in the equation to convert to imperial.)

Length	1 m = 3.281 ft
	1 mm = 0.0394 in.
Area	$1\ m^2 = 10.76\ ft^2$
Volume	$1\ m^3 = 1000$ litre
	$= 35.31\ ft^3$
	1 litre = 0.220 gallon
Mass	1 kg = 2.205 lb
Density	$1\ kg/m^3 = 0.0624\ lb/ft^3$
Temperature	9/5 °C + 32 = °F
Energy	$1\ J = 9.48 \times 10^{-4}$ Btu
	1 kJ = 0.948 Btu
Power	1 W = 1 J/s
	= 3.412 Btu/hr
R-Value	$1\ m^2$ °C/W = 5.678 hr ft^2 °F/Btu
R/unit thickness	1 RSI/mm = 144.2 R/in.

TABLE A2 - IMPERIAL TO METRIC (SI) CONVERSIONS

(Multiply the imperial unit by the factor given in the equation to convert to metric (SI).)

Length	1 ft = 0.3048 m
	1 in. = 25.4 mm
Area	1 ft^2 = 0.0929 m^2
Volume	1 litre = 0.001 m^3
	1 gallon = 4.55 litre
	1 ft^3 = 0.0283 m^3
Mass	1 lb = 0.454 kg
Density	1 lb/ft^3 = 16.03 kg/m^3
Temperature	5/9 (°F - 32) = °C
Energy	1 Btu = 1.05×10^3 J
	1 Btu = 1.05 kJ
Power	1 J/s = 1 W
	1 Btu = 0.293 W
R-Value	1 hr ft^2 °F/Btu = 0.1761 m^2 °C/W
R/unit thickness	1 R/in. = 0.00693 RSI/mm

APPENDIX B

THERMAL RESISTANCES

TABLE B1 - THERMAL RESISTANCE OF SOME COMMON BUILDING MATERIALS *

Building Material or Component	Thermal Resistance S.I. R/mm	S.I. For Thickness Listed	imperial R/in.	imperial For Thickness Listed
Insulation				
Fibreglass Batt	0.022	---	3.17	---
Rockwool Batt	0.023	---	3.32	---
Fibreglass Loose Fill (Blown-In)	0.015	---	2.16	---
Fibreglass Loose Fill (Poured)	0.021	---	3.03	---
Rockwool Loose Fill (Blown-In)	0.019	---	2.74	---
Rockwool Loose Fill (Poured)	0.021	---	3.03	---
Cellulose Fibre (Blown)	0.025	---	3.61	---
Cellulose Fibre (Poured)	0.024	---	3.46	---
Expanded Mica (Vermiculite, Zonolite, etc.)	0.016	---	2.31	---
Polystyrene Loose Fill	0.020	---	2.88	---
Expanded Polystyrene (Rigid)	0.027	---	3.89	---
Extruded Polystyrene (Rigid)	0.035	---	5.05	---
Polyurethane (Rigid)	0.042	---	6.06	---
Polyurethane (Foamed in Place)	0.042	---	6.06	---
Fibreglass Sheathing	0.031	---	4.47	---
Urea Formaldehyde (Foamed in Place, After Curing)	0.018	---	2.60	---
Wood Fibre	0.023	---	3.32	---
Wood Shavings	0.017	---	2.45	---
Cork	0.026	---	3.75	---
Glass Fibre Roof Board	0.028	---	4.04	---
Mineral Aggregate Board	0.018	---	2.60	---
Compressed Straw Board	0.014	---	2.02	---
Fibreboard	0.019	---	2.74	---
Structural Materials				
Softwood Lumber (except Cedar)	0.0087	---	1.25	---
Cedar Logs and Lumber	0.0092	---	1.33	---
Concrete 2400 kg/m^3 (150 lb/ft^3)	0.00045	---	0.06	---
Concrete 1760 kg/m^3 (110 lb/ft^3)	0.0013	---	0.19	---
Concrete 480 kg/m^3 (30 lb/ft^3)	0.0069	---	1.00	---

* Handbook on Insulating Homes for Energy Conservation, E. Scheuneman, S. Moffatt and M. Adelaar, Canadian General Standards Board, CGSB 51-GP-42MP, Ottawa, July 1980.

TABLE B1 - THERMAL RESISTANCE OF SOME COMMON BUILDING MATERIALS (Cont'd)

Building Material or Component	Thermal Resistance S.I. R/mm	S.I. For Thickness Listed	imperial R/in.	imperial For Thickness Listed
Structural Materials (Cont'd)				
Concrete Block (3 Oval Core)				
Sand and Gravel Aggregate				
100 mm (4")	---	0.12	---	0.68
200 mm (8")	---	0.20	---	1.14
300 mm (12")	---	0.22	---	1.25
Cinder Aggregate				
100 mm (4")	---	0.20	---	1.14
200 mm (8")	---	0.30	---	1.70
300 mm (12")	---	0.33	---	1.87
Lightweight Aggregate				
100 mm (4")	---	0.26	---	1.48
200 mm (8")	---	0.35	---	1.99
300 mm (12")	---	0.40	---	2.27
Common Brick, Clay, 100 mm (4")	---	0.07	---	0.40
Common Brick, Concrete, 100 mm (4")	---	0.05	---	0.28
Stone (Lime or Sand)	0.00060	---	0.09	---
Steel	0.000022	---	0.0032	---
Aluminum	0.0000049	---	0.0007	---
Glass (No Air Films) 3 - 6 mm (1/8" - 1/4")	---	0.01	---	0.06
Air				
Enclosed Air Space (Non-Reflective)				
Heat Flow Up, 25 - 100 mm (1" - 4")	---	0.15	---	0.85
Heat Flow Down, 25 - 100 mm (1" - 4")	---	0.18	---	1.02
Heat Flow Horizontal, 25 - 100 mm (1" - 4")	---	0.17	---	0.97
Air Surface Films				
Outside Air Film (Moving Air)	---	0.03	---	0.17
Inside Air Film (Still Air)				
Horizontal, Heat Flow Up	---	0.11	---	0.62
Sloping 45°, Heat Flow Up	---	0.11	---	0.62
Vertical, Heat Flow Horizontal	---	0.12	---	0.68
Horizontal, Heat Flow Down	---	0.16	---	0.91
Attic Air Film	---	0.08	---	0.45

TABLE B1 - THERMAL RESISTANCE OF SOME COMMON BUILDING MATERIALS (Cont'd)

Building Material or Component	Thermal Resistance S.I. R/mm	S.I. For Thickness Listed	imperial R/in.	imperial For Thickness Listed
Roofing				
Asphalt Roll Roofing	---	0.03	---	0.17
Asphalt Shingles	---	0.08	---	0.45
Wood Shingles (Cedar Shakes)	---	0.17	---	0.97
Built-Up Membrane (Hot Mopped)	---	0.06	---	0.34
Crushed Stone (Not Dried)	0.00055	---	0.08	---
Sheathing Materials				
Softwood Plywood	0.0087	---	1.25	---
Mat-Formed Particle Board	0.0087	---	1.25	---
Insulating Fibreboard Sheathing	0.017	---	2.45	---
Gypsum Sheathing	0.0062	---	0.89	---
Sheathing Paper	0.00040	---	0.06	---
Asphalt-Coated Kraft Paper	Negli.	---	Negli.	---
Polyethylene Vapour Barrier	Negli.	---	Negli.	---
Cladding Materials				
Fibreboard Siding				
Medium Density Hardboard, 11 mm (7/16")	---	0.10	---	0.57
High Density Hardboard, 11 mm (7/16")	---	0.08	---	0.45
Softwood Siding (Lapped)				
Drop, 18 × 184 mm (3/4" × 7 1/4")	---	0.14	---	0.79
Bevel, 12 × 184 mm (1/2" × 7 1/4")	---	0.14	---	0.79
Bevel, 18 × 235 mm (3/4" × 9 1/4")	---	0.18	---	1.02
Plywood, 9 mm (3/8")	---	0.10	---	0.57
Wood Shingles	---	0.17	---	0.97
Brick (Clay or Shale) 100 mm (4")	---	0.08	---	0.45
Brick (Concrete, Sand-Lime) 100 mm (4")	---	0.05	---	0.28
Stucco, 25 mm (1")	0.0014	0.03	0.20	0.17

TABLE B1 - THERMAL RESISTANCE OF SOME COMMON BUILDING MATERIALS (Cont'd)

Building Material or Component	Thermal Resistance S.I. R/mm	S.I. For Thickness Listed	imperial R/in.	imperial For Thickness Listed
Cladding Materials (Cont'd)				
Metal Siding				
Horizontal Clapboard Profile	---	0.12	---	0.68
Horizontal Clapboard with Backing	---	0.25	---	1.42
Vertical V-Groove Profile	---	0.12	---	0.68
Vertical Board and Batten Profile	---	Negli.	---	Negli.
Interior Finishes				
Gypsum Board, Gypsum Lath, Drywall, 13 mm (1/2")	0.0062	0.08	0.89	0.45
Gypsum Plaster				
Sand Aggregate, 13 mm (1/2")	0.0014	0.02	0.20	0.11
Lightweight Aggregate, 13 mm (1/2")	0.0044	0.06	0.63	0.34
Plywood, 7.5 mm (5/16")	0.0093	0.07	1.34	0.40
Hardboard, (Standard), 6 mm (1/4")	0.0053	0.03	0.76	0.17
Insulating Fibreboard, 25 mm (1")	0.017	0.42	2.45	2.38
Flooring				
Maple or Oak (hardwood), 19 mm (3/4")	0.0063	0.12	0.91	0.68
Pine or Fir (softwood), 19 mm (3/4")	0.0089	0.17	1.28	0.97
Plywood, 16 mm (5/8")	0.0088	0.14	1.27	0.79
Mat-formed Particle Board, 16 mm (5/8")	0.0088	0.14	1.27	0.79
Wood Fibre Tiles, 13 mm (1/2")	0.016	0.21	2.31	1.19
Linoleum, Tile (resilient), 3 mm (1/8")	---	0.01	---	0.06
Terrazzo, 25 mm (1")	0.00056	0.01	0.08	0.06
Carpet, Typical Thickness				
with Fibrous Underlay	---	0.37	---	2.10
with Rubber Underlay	---	0.23	---	1.31

TABLE B1 - THERMAL RESISTANCE OF SOME COMMON BUILDING MATERIALS (Cont'd)

Building Material or Component	Thermal Resistance S.I. R/mm	S.I. For Thickness Listed	imperial R/in.	imperial For Thickness Listed
Windows (including inside and outside air films)				
Single Glass	---	0.15	---	0.85
Insulated Glass (Double Pane)				
5 mm (3/16") Air Space	---	0.25	---	1.42
6 mm (1/4") Air Space	---	0.27	---	1.53
13 mm (1/2") Air Space	---	0.30	---	1.70
19 mm (3/4") Air Space	---	0.33	---	1.87
Insulated Glass (Triple Pane)				
6 mm (1/4") Air Space	---	0.38	---	2.16
13 mm (1/2") Air Space	---	0.49	---	2.78
19 mm (3/4") Air Space	---	0.50	---	2.84
Storm Windows				
Single Pane + 25 - 100 mm (1" - 4") Air Space	---	0.35	---	1.99
19 mm (3/4") Sealed Unit + 25 - 100 mm (1" - 4") Air Space	---	0.49	---	2.78

Thermal Resistance Values for Basements

The basement wall above grade and the basement wall and floor below grade are treated separately. The foundation wall above grade is exposed to outside air temperatures and behaves in much the same way as other above-grade construction. The below-grade portion requires special consideration, however, because other factors must be taken into account to obtain the thermal resistance values shown in Table B2. These values were obtained from measured results and will be revised as more information about below-grade heat losses becomes available.

If the desired insulation requirements do not exactly match those shown in Table B2, the one that most clearly approximates the desired value should be chosen. As the R-values for various construction types are not linear functions, they should not be interpolated from these values.

TABLE B-2 - PROVISIONAL THERMAL RESISTANCE VALUES FOR BELOW-GRADE CONSTRUCTION IN CANADA

For 200 mm (8 in.) concrete foundation wall

	Thermal Resistance	
	S.I.	(imperial)
Without insulation	0.8	(4.5)
With insulation 610 mm (24") below grade and 1220 mm (48") uninsulated		
R 0.70 (R4) insulation	0.9	(5.1)
R 1.41 (R8) insulation	1.1	(6.2)
R 2.11 (R12) insulation	1.2	(6.8)
R 3.52 (R20) insulation	1.3	(7.5)
With insulation down to footing		
R 0.70 (R4) insulation	1.8	(10)
R 1.41 (R8) insulation	2.5	(14)
R 2.11 (R12) insulation	3.2	(18)
R 3.52 (R20) insulation	3.9	(22)
Concrete floor	4.6	(26)

APPENDIX C

THERMAL BRIDGING IN WALLS AND CEILINGS

Thermal bridging refers to the effect of heat flowing at different rates through a building component due to different materials in the component. The most common example in housing is the presence of wall studs and ceiling joists which have a different heat flow or heat resistance (R-value) from the rest of the wall and ceiling area. Thermal bridging alters the nominal resistance (R) values of walls and ceilings and should be considered when calculating the thermal resistance of a building component, both before and after upgrading.

For example, in most houses the wall studs comprise about 20% of the net wall area and ceiling joists about 10% of the ceiling area. The formulae to calculate the R values for these houses would be:

$$R\ wall = 0.80\ R\ cavity + 0.20\ R\ stud$$

$$R\ ceiling = 0.90\ R\ cavity + 0.10\ R\ joist$$

This is referred to as a parallel heat flow calculation.

Example 1

The example of a wall, shown in Figure C-1, illustrates the effects on R-values and savings.

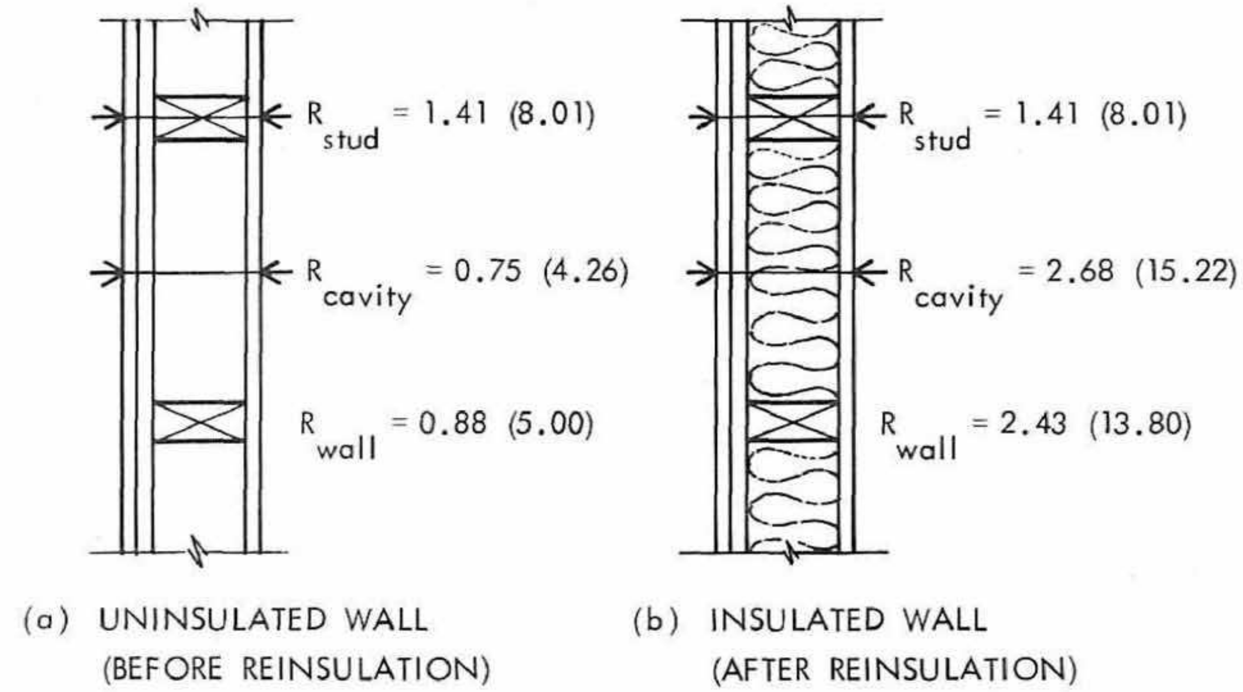

Fig. C-1 Thermal Bridging Effect of Wall Studs

It can be seen for: (a) that the thermal bridging increases the over-all R-value by 17%, (0.88 - 0.75) ÷ 0.75 × 100 and for (b) it decreases the over-all R-value by 9%, (2.68 - 2.43) ÷ 2.68 × 100.

Using F_B = \$1239 and A = 143.1 values from the text example, we can examine the effects on the savings as follows:

(i) Using R-values without accounting for thermal bridging:
Total Q_1 = 511 + 191 - 81 = 621

(ii) Using R-values accounting for thermal bridging:
Total Q_1 = 511 + 163 - 81 = 593

		A	R_1	Q_1	R_2	Q_2	S_1	S_2	S_p
Walls	(i)	143.1	0.75	191	2.68	53	\$275	\$629	\$541
	(ii)	143.1	0.88	163	2.43	59	\$217	\$474	\$410

Case (i) gives results for S_1, S_2 and S_p that are high by 27%, 33%, and 32% respectively. This demonstrates the importance of accounting for thermal bridging effects.

The percent error will vary for different situations as shown by Example 2.

Example 2

Using the wall from the example in the main text (assuming these are nominal values only) and the R stud value from Figure C-1, one can use the parallel heat flow calculation to obtain corrected R-values as follows:

$$R_1 = 0.80\ (1.76) + 0.20\ (1.41) = 1.69$$
$$R_2 = 0.80\ (2.29) + 0.20\ (1.41) = 2.11$$

(i) Nominal calculation:
Total Q_1 = 511 + 81 - 81 = 511

(ii) Parallel heat flow calculation:
Total Q_1 = 511 + 85 - 81 = 515

		A	R_1	Q_1	R_2	Q_2	S_1	S_2	S_p
Walls	(i)	143.1	1.76	81	2.29	62	\$46	\$87	\$77
	(ii)	143.1	1.69	85	2.11	68	\$41	\$77	\$68

Case (i) again gives results for S_1, S_2 and S_p that are high by 12%, 13%, and 13% respectively.

APPENDIX D

DEGREE-DAYS (DD) AND ACTUAL DEGREE-DAYS (ADD)

Degree-Days (DD)

Heating degree-days is a measure used to estimate heating energy consumed. Past measurements revealed that the fuel consumed in small buildings was roughly proportional to the difference between an indoor temperature of 65°F (≈18°C) and the outdoor temperature; consequently degree days (DD) were tabulated using a base of 65°F (≈18°C). This empirical correlation has served well but, because of changes to insulation levels in buildings and particularly the increased use of electrical appliances, this relation is no longer adequate.

Actual Degree-Days (ADD)

Many houses today seem to require heating only when the outdoor temperature is below freezing. It was decided, therefore, that the actual indoor/outdoor temperature difference would provide a more useful measure for computation. The true thermal load on a house could be determined using actual degree-days (ADD); the contribution of the internal heat gains would be reconsidered in some other way.

Table D1 is a list of actual degree-day (ADD) values based on an indoor temperature (T_i) of 21°C (70°F). The values were computed using an approximation method and are believed to be within a 5% accuracy.

For values not listed in Table D1 or for an interior temperature, T_i, other than 21°C (70°F), the ADD may be computed from the following formula:

$$ADD = DD + (T_i - 18) \times b \qquad (\text{Imperial: } ADD = DD + (T_i - 65) \times b)$$

where DD = degree-days for location*
T_i = interior temperature
b = constant factor from location on map in Figure D-1

---

* This value can be obtained from the local weather office, CMHC office, electric utility office, library, The Supplement to the National Building Code of Canada, 1980, pp. 11-21, NRCC No. 17724 or Atmospheric Environmental Service, 4905 Dufferin Street, Downsview, Ontario, M3H 5T4, Phone: 416-667-4917.

The temperature, T_i, may be measured or approximated as the thermostat setting. For example, a house in Winnipeg has a constant thermostat setting of 22°C; hence, T_i = 22°C (72°F) and DD = 5887 (10679). From Figure D-1 the b for Winnipeg is 161 (290) which gives

$$ADD = 5887 + (22 - 18) \times 161 = 6531$$
$$(ADD = 10679 + (72 - 65) \times 290 = 12709)$$

Many occupants, however, are practicing thermostat setback, i.e., the thermostat setting is turned down at night or other times. For these situations the following formula can be used to estimate an average T_i:

$$T_i = \frac{h_1}{24} T_1 + \frac{h_2}{24} T_2$$

where h_1 = number of hours/day at temperature T_1
h_2 = number of hours/day at temperature T_2

For example, a house has thermostat settings as follows:

T_1 = 21°C (70°F) from 8 am to 10 pm (i.e., h_1 = 14)

T_2 = 16°C (61°F) from 10 pm to 8 am (i.e., h_2 = 10)

Therefore,

$$T_i = \frac{14}{24}(21) + \frac{10}{24}(16) = 19°C$$

$$(T_i = \frac{14}{24}(70) + \frac{10}{24}(61) = 66°F)$$

and hence for a house in Winnipeg

$$ADD = DD + (T_i - 18) \times b$$
$$= 5887 + (19 - 18) \times 161 = 6048$$
$$(ADD = 10679 + (66 - 65) \times 290 = 10969)$$

TABLE D1 - ACTUAL DEGREE-DAYS (ADD) BELOW 21°C (70°F)
FOR SELECTED LOCATIONS IN CANADA*

Location	°C (ADD)	(°F)
Northwest Territories		
Alert	13727	25313
Frobisher Bay	10453	19701
Yellowknife	9125	17234
Yukon		
Dawson	8806	16667
Whitehorse	7412	14075
Newfoundland		
St. John's	5336	10591
Grand Falls	5440	10877
Corner Brook	5312	10578
Prince Edward Island		
Charlottetown	5130	10011
Nova Scotia		
Halifax	4630	8886
Sydney	4966	9574
Yarmouth	4558	8940
New Brunswick		
Moncton	5214	10236
Edmundston	5767	11246
Fredericton	5182	10121
Saint John	5278	9978
Québec		
Montréal	4955	9653
Québec	5587	10462
Sept Iles	6703	13027
Gaspé	5906	11400
Drummondville	5161	10150
Schefferville	8761	16480
St. Jean	4997	10025
Trois Rivières	5436	10756

Location	°C (ADD)	(°F)
Ontario		
Toronto	4565	8277
Ottawa	5157	10143
Timmins	6695	12925
North Bay	5825	11202
Kenora	6413	12246
London	4541	8774
Sault Ste Marie	5596	11025
Thunder Bay	6251	11930
Manitoba		
Winnipeg	6370	12129
Thompson	8437	15425
Morden	6086	11518
Churchill	9781	18428
The Pas	7358	13806
Saskatchewan		
Saskatoon	6551	12281
Regina	6395	12231
Maple Creek	5408	10925
North Battleford	6549	12507
Alberta		
Calgary	5851	11228
Edmonton	6097	11793
Fort Vermilion	7584	14638
Lethbridge	5200	10094
British Columbia		
Vancouver	3539	7115
Victoria	3609	7179
Kamloops	4229	8224
Fort Nelson	7571	14302
Prince George	5894	11280

* These °C and °F values cannot be directly converted from one to the other, as 21°C is not exactly equal to 70°F

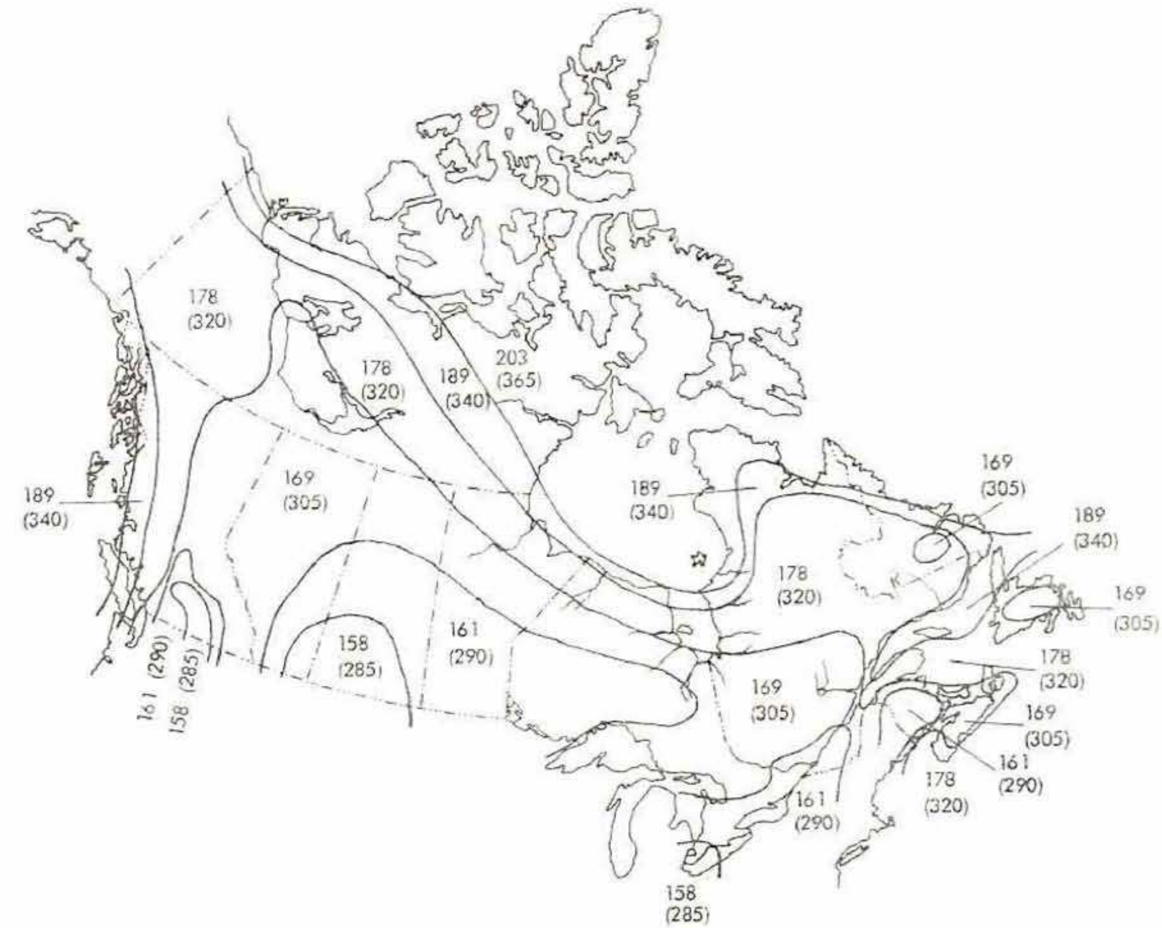

FIGURE D-1

APPROXIMATE DEGREE DAYS PER DEGREE FROM 18°C (65°F) TO 24°C (75°F)

APPENDIX E

SEASONAL EFFICIENCY OF HEATING SYSTEMS (K_3)

The steady-state efficiency of the heating system is the efficiency obtained when the system has reached its optimum operating conditions.

The seasonal efficiency, is the efficiency obtained over the heating season as the average of the efficiencies obtained when the system is operating under both optimum and during less than optimum conditions. Hence, the seasonal efficiency is usually lower, often considerably lower, than the steady-state efficiency. The amount of time spent in non-optimum operation relative to optimum operation determines the difference between steady-state and seasonal efficiencies.

This Appendix deals with the heating efficiency of only the following: electricity, gas, and oil. It also includes the numerical determination of seasonal efficiency, K_3. A system that is 100% seasonally efficient would have a K_3 of 1.00 whereas a system that is 70% seasonally efficient would have a K_3 of 0.70.

Electricity

It is generally accepted that both the seasonal and steady-state efficiencies of electric heating systems are 100%. Hence, for space heating by baseboard heaters or forced-air furnaces, the value of K_3 is 1.00.

Gas and Oil

The steady-state efficiencies of gas and oil furnace heating systems are considerably less (by 20-25%) than 100% because of the combustion process and other factors. Seasonal efficiencies are less than the steady-state efficiencies because gas and oil furnaces require 5-10 minutes after each start-up to reach optimum (steady-state) operating conditions. If a furnace is oversized relative to the house heating load, the furnace on-time of the furnace cycle is shorter. This results in a lower seasonal efficiency because of the higher ratio of non-optimum to optimum operation time. After reinsulating, the house heating load has been reduced and the furnace should be adjusted to reduce its output capacity to match the new reduced load.

Little can be done to reduce the capacity of gas furnaces except by replacing them. The capacity of an oil-fired furnace, however, can be reduced by replacing the oil burner nozzle. At present, the nozzle can only be reduced to one size lower than the CSA rating without voiding certification. If a retention head burner is retrofitted, further reduction is encouraged.

Determination of K_3 for Gas and Oil Furnaces

The following information and procedure apply to older furnaces and may not apply to newer gas and oil furnaces with features such as electronic ignition, retention head burner, and solenoid valve.

If it is not feasible to determine K_3 by the following technique, the value 0.55 may be used as a "default" or "best guess" value for both gas and oil furnaces.

The first step is to calculate the building heat loss using the following formula:

$$\text{building heat loss} = \text{Total } Q_1 \times (T_i - T_D)$$

where Total Q_1 = sum of Q_1's

- found in row 12 of Column Q_1 in the Energy Savings Chart. (For example, Total Q_1 = 511 from Chart 2.)

$(T_i - T_D)$ = design temperature difference

where T_i is the previously calculated interiour house temperature and T_D is the 2 1/2% January Design Temperature from Table E-1.

The second step is to find the furnace rated output which is usually called bonnet capacity and stamped on a plate on the casing of oil furnaces. For gas furnaces one takes the rated input shown on the furnace plate and multiplies it by 0.75 which yields the furnace rated output. (Remember to convert these values to metric if working with metric units.)

The third step is to calculate the furnace overfiring capacity by putting the foregoing two quantities into the following equation and carrying out the numerical calculation.

$$\text{furnace overfiring} = \frac{\text{furnace rated output} - \text{building heat loss}}{\text{building heat loss}} \times 100\%$$

The fourth step is to measure or calculate the steady-state efficiency of the furnace. This can be measured by having a furnace efficiency test carried out on oil and gas furnaces.* It may be calculated for oil, but not gas, furnaces using the following equation:

$$\text{steady-state efficiency} = \frac{\text{bonnet capacity}}{\text{firing rate} \times 140{,}000}$$

where

- bonnet capacity is read off furnace plate
- firing rate is read off furnace plate

---

* For details see The Billpayer's Guide to Furnace Servicing, EMR, 1975, pp. 40-43 and 59-61

TABLE E1 - JANUARY 2½% DESIGN TEMPERATURES FOR SELECTED LOCATIONS IN CANADA

Location	Design Temperature °C	(°F)
Northwest Territories		
Alert	-43	(-45)
Frobisher Bay	-40	(-40)
Yellowknife	-43	(-45)
Yukon		
Dawson	-50	(-58)
Whitehorse	-41	(-42)
Newfoundland		
St. John's	-14	(7)
Grand Falls	-21	(-6)
Corner Brook	-19	(-2)
Prince Edward Island		
Charlottetown	-20	(-4)
Nova Scotia		
Halifax	-16	(3)
Sydney	-16	(3)
Yarmouth	-13	(9)
New Brunswick		
Moncton	-22	(-8)
Edmundston	-27	(-17)
Fredericton	-24	(-11)
Saint John	-22	(-8)
Québec		
Montréal	-23	(-9)
Québec	-25	(-13)
Sept Iles	-30	(-22)
Gaspé	-23	(-9)
Drummondville	-25	(-13)
Schefferville	-28	(-36)
St. Jean	-24	(-11)
Trois Rivières	-25	(-13)

Location	Design Temperature °C	(°F)
Ontario		
Toronto	-18	(0)
Ottawa	-25	(-13)
Timmins	-34	(-29)
North Bay	-28	(-18)
Kenora	-33	(-27)
London	-18	(0)
Sault Ste Marie	-25	(-13)
Thunder Bay	-31	(-24)
Manitoba		
Winnipeg	-33	(-27)
Thompson	-42	(-44)
Morden	-31	(-24)
Churchill	-39	(-38)
The Pas	-36	(-33)
Saskatchewan		
Saskatoon	-35	(-31)
Regina	-34	(-29)
Maple Creek	-31	(-24)
North Battleford	-34	(-29)
Alberta		
Calgary	-31	(-24)
Edmonton	-32	(-26)
Fort Vermilion	-41	(-42)
Lethbridge	-30	(-22)
British Columbia		
Vancouver	-7	(19)
Victoria	-5	(23)
Kamloops	-25	(-13)
Fort Nelson	-40	(-40)
Prince George	-33	(-27)

For other Canadian locations see "The Supplement to the National Building Code of Canada, 1980," pp. 11-21, NRCC No. 17724. (Price: $7.30)

The final step is to use the overfiring capacity and steady-state efficiency with Table E2 to find the seasonal efficiency, K_3

TABLE E2 - APPARENT SEASONAL EFFICIENCY OF OIL- AND GAS-FIRED FURNACE (K_3)

Rated Steady State Efficiency of Furnace	Overfiring Capacity				
	0	20	40	60	80
0.80	0.67	0.64	0.62	0.59	0.57
0.75	0.63	0.60	0.58	0.56	0.54
0.70	0.58	0.56	0.54	0.52	0.50
0.65	0.54	0.52	0.50	0.48	0.46
0.60	0.50	0.48	0.46	0.44	0.43