Worksheet for Selection of Optimal Foundation Insulation

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ABSTRACT

A worksheet has been developed that can help a residential builder select the optimal level of foundation insulation for new or retrofit construction based on user-specified conditions. The worksheet solicits site-specific input from the user and supplementary look-up tables. The input is used in a series of simple mathematical equations leading to the identification of the most cost-effective solution from a list of user-specified options. The climate is specified by a heating degree-day base of 65°F and cooling degree-hour base of 74°F. The energy savings of various foundation insulation configurations are determined from heating and cooling load factors derived from linear regression analysis of the computer simulation data base described in the Building Foundation Design Handbook (Labs et al. 1988). Local energy prices are requested, and the user can choose from three different economic decision criteria: 20-year minimum life cycle cost (suggested for retrofit); 30-year minimum life cycle cost [used by ASHRAE (1989), BOCA (1989), and Labs et al. 1988)]; and second-year positive cash flow (suggested by the National Association of Home Builders National Research Center). A set of instructions guides the user step-by-step through the fill-in-the-blank worksheet. Eight reference tables minimize the input gathering effort.

INTRODUCTION

The 350-page Building Foundation Design Handbook was prepared under subcontract to a national laboratory in 1988 (Labs et al. 1988). This comprehensive handbook was targeted at the building designer and addresses not only how to design an energy-efficient foundation, but provides sufficient background information to convey why certain details should or should not be specified. A more condensed version of the handbook is under preparation, titled Builder's Foundation Handbook, which is targeted at the builder with an emphasis on specifically how to build an energy-efficient foundation. The worksheet described in this paper is for the Builder's Foundation Handbook and is in response to the request for a user-specified economic decision-making tool leading to an optimal foundation insulation strategy based on the user's definition of cost effectiveness.

The Building Foundation Design Handbook provides "optimal" foundation insulation strategies based on a 30-year minimum life cycle cost analysis and national average energy prices for natural gas and electricity. Although this handbook urges the reader to redo the analysis with site-specific inputs, the average builder would have a difficult time conducting the site-specific analysis. This worksheet is designed to allow a user, with minimal mathematical skills, to follow the fill-in-the-blank format leading to optimal foundation insulation strategy for a specific structure.

The worksheet and instructions are shown in Figures 1 and 2. Eight look-up tables (Tables 1 through 8) help the user fill in site-specific conditions and options for evaluation. The worksheet in Figure 1 has been condensed for this paper from its original size by removing added blank lines for each step and using a smaller font size. The

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worksheet instructions have also been abbreviated. The original set of instructions is very explicit about each step and as a result is longer than that shown in Figure 2. The look-up tables provide all of the inputs needed to complete the optimization worksheet, including representative insulation effective R-values and installation costs. However, two optional worksheets are provided which guide the user through estimations of insulation installation cost and determination of additional effective R-values not included in the tables. The cost worksheet is shown in Figure 3, and the effective R-value worksheet is shown in Figure 4.

WORKSHEET DEVELOPMENT

Approach

Heating and Cooling Load Factors. The first major step leading to the development of this worksheet was to generalize the Building Foundation Design Handbook load data base beyond the 13 cities and several insulation levels to all climates and all reasonable foundation insulation levels. This generalization had to be simple enough to permit easy calculation of expected annual energy load savings from foundation insulation, possibly with the aid of a hand calculator. The initial data base in the Handbook was developed by combining finite difference modeling with the whole building simulation model, DOE 2.1C (Labs et al. 1988).

An attempt was made to determine regression coefficients for an equation that predicted the total building heating and cooling loads with various foundation insulation levels. The resulting relatively small percentage errors in the prediction of the larger total load occasionally lead to large absolute errors when these regression equations were used to find the smaller delta loads due to adding foundation insulation. Delta load is defined as the annual whole building heating or cooling load change resulting from adding different foundation insulation levels to a building with an uninsulated foundation.

A second set of regression coefficients was therefore developed for a similar equation which estimated delta loads directly. Although this provided better results than when attempting to estimate the full loads, the R^2 values were worse. The R^2 value is a statistic that measures the proportion of total variation about the regression line. R^2 values can take values as high as 1 when the data can be reproduced exactly by the regression equation. Since the delta loads are necessary to estimate the energy cost savings of various insulation levels, the larger percentage error of a smaller value (delta load) actually produced less absolute error than when the regression equation for predicting total annual residential loads was used. A second benefit of using a regression equation for estimating delta loads instead of full loads is that the number of regression coefficients was reduced. This becomes particularly important in fulfilling the goal to develop a procedure that is easily performed without the aid of a personal computer. Hand calculating a regression equation with four or five coefficients, each with eight significant digits for each R-value of interest—one set for heating and another for cooling—can be a very tedious exercise for a builder anxious to saw boards and pound nails. Therefore, an even simpler procedure was pursued, which attempted to reduce the data down to two values needed for calculating the delta loads, one for heating and one for cooling.

Heating and cooling load factors were developed which, when used in Equation 1, simply estimate the delta loads (L_{hdelta} and L_{cdelta}). This equation is in steps G and H of the worksheet shown in Figure 1.

$$L_{hdelta} = U_{delta} \times HLF \times HDD65 \tag{1}$$

where

$U_{delta} = U_{uninsulated\ foundation} - U_{insulated\ foundation\ system}$

HLF = incremental energy savings divided by the HDD65 and U_{delta}

HDD65 = heating degree-day base 65°F.

A comparable cooling load factor CLF value is found for estimating cooling load impacts. The CLF is substituted in Equation 1 for HLF and CDH74 for HDD65. CDH74 is the climatic descriptor used for cooling, which is cooling degree hours base 74°F.

A similar procedure is proposed in ASHRAE 90.2P (1989) to trade off energy savings of various building components and still end up with an equivalent energy-efficient building to one complying with the recommended prescriptive portion of this standard.

Using all 13 cities in the Building Foundation Design Handbook data base produced heating and cooling load factors with rather poor curve fits. Therefore, climates were divided into zones, as shown in Figure 5. It was found that the HLF could be derived from this data base relatively easily for those climates with more than 2500 HDD. Table 3 shows the HLF for each of the more typical foundation insulation techniques discussed in the Building Foundation Design Handbook.

The R^2s are also shown and are relatively good (0.92 to 0.99). The percent error in the prediction of the nine-climate data base was always within 10%. The HLF [Btu ÷ (HDD65 x U_{delta})] for climates with more than 2500 HDD was derived by using all the data from the nine climates with more than 2500 HDD: Bismarck; Minneapolis; Chicago; Denver; Boston; Seattle; Kansas City; Washington, DC; and Atlanta. Equation 1 was used to calculate individual HLF for each data point. An initial estimated R-value was used for the uninsulated foundation system. This value is listed in Table 5 under the column labeled R_{ui}. The total R-value of the foundation construction and soil was thought to be higher; therefore, additional resistance was added. This value is listed in Table 5 under the column labeled R_{soil}. The value was determined by minimizing the standard deviation between the individual HLFs derived for each data point and the average HLF.

Linear regression analysis was then used to derive a single HLF for each foundation system using Equation 1. The R^2s are all extremely high, all but one above 0.98. This is important and ensures good reproduction of the estimated optimal foundation insulation levels listed in the Building Foundation Design Handbook. The handbook data indicate that the heating season energy savings is the predominant determinant of the amount of cost-effective foundation insulation.

A more simplified worksheet could have stopped here and ignored the cooling effects and written off those climates with less than 2500 HDD. Although this has not been quantified, one would speculate that this simplifying assumption would lead to reasonable recommended insulation levels. The quality of the reproduction of the base data is so high that a table of HLF for climates >2500 HDD should be considered for chapter 28 of the 1993 edition of the ASHRAE Handbook of Fundamentals.

Most of the effort in simplifying the delta loads data base in the handbook for this worksheet was spent on deriving a method to estimate HLF for those climates with less than 2500 HDD65 and CLF for all climates. Using Equation 1 directly produced poor curve fits for these cases.

To estimate the HLF in climates with less than 2500 HDD (Los Angeles, Miami, Fort Worth, and Phoenix), a slightly more complex procedure was required. The form of the equation used to derive HLF is shown below:

$$HLF = HLF_i + HLF_s \times HDD65 \tag{2}$$

where

HLF_i, HLF_s = regression coefficients.

Table 3 shows the coefficients derived for this equation for all foundation systems considered. The R^2s are not as good as for climates greater than 2500 HDD (0.51 to 0.85). However, the heating savings are considerably smaller in these regions, which make small absolute differences between the prediction and data seem more significant than they really are and lead to low R^2s.

To estimate the CLF also required first fitting the data to an equation similar to that used to estimate the HLF for climates with <2500 HDD.

$$CLF = CLF_i + CLF_s \times CDH74 \tag{3}$$

where

CLF_i and CLF_s are regression coefficients.

A single set of coefficients for all climates precipitated poor curve fits for the entire data base. Therefore, a series of plots of CLF vs. CDH74 revealed a repeated pattern, as shown in Figure 6. This led to the suggestion that there are four distinct climate types: (1) high heating, low cooling; (2) high cooling, high heating; (3) higher cooling, modest heating; and (4) very high cooling, no heating.

The entire U.S. climate range could be divided into three cooling zones—less than 15,000 CDH74, between 15,000 and 30,000 CDH74, and more than 30,000 CDH74. The distinct climate types were used as transition points from one region to the next.

A set of coefficients was developed for these three cooling zones. The fits are better for the hotter climates with larger cooling loads with most R^2s between 0.85 to 0.95, as shown in Table 4. The low R^2s for climates with less than 15,000 CDH74 are not as significant as for climates that require considerable cooling because the heating season benefits generally outweigh the cooling season penalties in this zone. Secondly, the delta cooling loads are smaller and therefore small absolute errors have a minimal impact on the cost-effectiveness calculation for determining "optimal" foundation insulation levels.

The first 7 of the 10 steps of the optimization worksheet, and Tables 1 through 5, guide the user through the estimate of heating and cooling load changes (L_{hdelta} and L_{cdelta}) resulting from several foundation insulation options chosen by the user. The user also inputs site-specific HDD base 65°F and CHD base 74°F. Table 2 provides the list of foundation types and insulation configurations covered by the worksheet. The user can specify any reasonable R-value of which the effective R-value is known and installed costs are available. Numerous examples with national average installed costs for new construction are provided in Table 2 (Christian and Strzepek 1987). This step familiarizes the user with the nomenclature used to retrieve the additional inputs from Tables 3 through 5 for Equation 1. The user should estimate local first costs (COST). The worksheet shown in Figure 3 helps guide this estimate. If a level of insulation considered is not provided in Table 2, an optional worksheet—shown in Figure 4—is provided to help estimate the effective R-value (R_i) needed to complete the optimization worksheet.

Energy Savings. With the delta loads derived for each option, the energy savings is estimated using steps I and J. It is in the selection of the present worth scalar ratios (HUPW and CUPW) that the user defines the economic decision criteria. Table 8 provides 63 scalar ratios derived using three different economic decision criteria: second-year positive cash flow, 20-year life cycle cost, 30-year life cycle cost, seven different fuel escalation rates for 0% to 6% (including inflation), and three mortgage rates: 10%, 11%, and 12%.

The scalar ratio is the ratio of the present worth factor for energy savings divided by the present worth factor of mortgage payments for the added foundation insulation cost. The present worth factor for the mortgage payments adjusts for income tax savings and accounts for points paid at the beginning of occupancy as a loan placement fee. It is based on no additional down payment, 1% loan placement fee "points," 10% after-tax equivalent discount rate, and 30% income tax (state and federal combined).

The values are derived from two computer programs. These programs perform a mortgage cash flow analysis and an energy savings cash flow analysis over the life of the study period. The 20- and 30-year life cycle cost analyses of energy savings assume a 10% (nominal, after tax) discount rate. The higher the scalar ratio, the greater the present worth of the energy savings, which leads to higher recommended insulation levels.

The last step in the worksheet derives the net dollar savings of each foundation insulation option. A host of sample installed costs are presented in Table 2 (Christian and Strzepek 1987). These costs are for new construction; however, the user is urged to estimate local costs, using the cost worksheet shown in Figure 3. The selection of a 20-year life cycle cost scalar ratio and retrofit installed cost estimates will extend this worksheet to existing buildings. The option with the highest positive net savings value in step K is the most cost-effective option. One positive side effect of this worksheet is that the builder sees that the net dollar savings of several options might actually be very similar, allowing more flexibility than may result by just showing one final "optimal" insulation configuration level.

Validation

The objective of this worksheet is to lead a builder to the most cost-effective foundation insulation level based on user-specified economic and HVAC performance characteristics. To test the procedure, the same set of economic assumptions was used in the worksheet to attempt to reproduce the optimal insulation configuration tables in the Building Foundation Design Handbook. More than 200 cases were run, and the worksheet recommended the same configuration more than 80% of the time. Most of the cases that were different resulted from the relatively similar net savings values from a number of different configurations. Those net savings differences between the Handbook and the worksheet "optimal" may have only been a couple of cents/ft of perimeter over a 30-year period.

Slab. The Handbook results, Table 4-3, Optimal Insulation Configuration for Slab-on-Grade Foundations, were reproduced exactly for 31 out of 39 cases. This covered 13 different climates and 3 different fuel prices. Six of the misses are suggested by the worksheet to insulate a few northern slabs to R-10 instead of R-5, as called for in the Handbook. Two misses are in Phoenix, where the worksheet suggested no insulation for the low- and medium-priced cases where the Handbook called for R-5.

Crawl Space. The Handbook results, Table 3-3, Unvented Crawl Spaces, 2-ft-high concrete or masonry wall were reproduced by the worksheet in 35 of the 39 cases. The worksheet suggested R-10 instead of R-5 for the high-fuel case in Seattle and Kansas City. The other two misses were for Los Angeles for the medium and high fuel prices for which R-5 was suggested by the worksheet and none in the Handbook.

For the unvented crawl space with 2-ft-high wood walls, 28 out of 39 recommendations were identical. Ten of the misses amount to the worksheet recommending R-11 instead of R-19, as in the Handbook. The remaining difference was in Forth Worth for the high fuel prices, in which the worksheet suggested no insulation, and the Handbook R-11.

For the Handbook, Table 3-4, Optimal Insulation Configuration for Vented Crawl Spaces, in which insulation is placed in the ceiling, the Handbook and worksheet match almost perfectly. The few differences resulted from very small differences in net dollar savings.

Deep Conditioned Basement. The Handbook results, Table 2-2, Optimal Insulation Configuration for Deep, Fully Conditioned Basements, where insulation is on the exterior of concrete or masonry wall, were reproduced by the worksheet exactly for 32 of 39 cases. Most of the differences were in southern climates due to errors in the cooling regressions, with one method recommending full 8-ft R-5, the other half wall insulation 4-ft R-5. Neither method consistantly recommended higher levels than the other when differences occurred. Nevertheless, the energy consequences of these differences are quite small.

The wood basement wall portion of the Handbook, Table 2-2, is reproduced almost completely. The only exception was in Phoenix, where the worksheet calls for R-11 rather than R-19 for the low and medium fuel price cases.

Deep Unconditioned Basement. The Handbook results, Table 2-5, Optimal Insulation Configuration for Deep, Unconditioned Basements with insulation on concrete or masonry walls, are reproduced in 35 of 39 cases by the worksheet. The four exceptions are the worksheet calling for slightly less insulation than the Handbook.

The table with the most misses is for the ceiling insulation above the unconditioned basement. The Handbook calls for R-30 in most northern climates, the worksheet R-19. The regression fit of these data was very poor. The Handbook data seemed to show an exceptionally large amount of energy savings for R-30, leading to much higher HLF than those for the R-11 and R-19 cases and, therefore, the R-30 data were not used to develop the HLF for this case. However, the net energy impact of these differences is still probably quite insignificant. A general observation is that neither method consistently recommends higher or lower levels than the other across all foundation types and configurations.

CONCLUSIONS

A simple worksheet has been developed to help a builder decide the foundation insulation configuration and level based on user-specified conditions, heating degree days, cooling degree hours, fuel cost, fuel escalation, HVAC efficiency, duct efficiency, mortgage rate, installed cost of insulation, and economic decision criteria: 30-year life cycle cost, 20-year life cycle cost, or 2-year positive cash flow. The worksheet is applicable to both new and retrofit conditions. The worksheet was validated by making more than 200 comparisons to the recommendations in the Building Foundation Design Handbook. The heating load factors derived for the worksheet should be considered for updating the foundation performance data in chapter 28 of the 1993 ASHRAE Handbook of Fundamentals.

REFERENCES

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Table 1 Weather Parameters for Selected Cities

City	State	HDD65	CDH74
Bismarck	ND	9080	1966
Minneapolis	MN	8010	3038
Chicago	IL	6183	5419
Denver	CO	6023	2692
Boston	MA	5596	2429
Seattle	WA	5122	0
Kansas City	MO	4814	14865
Washington	DC	4125	9034
Atlanta	GA	3025	12053
Fort Worth	TX	2420	30331
Phoenix	AZ	1444	48302
Los Angeles	CA	1595	1414
Miami	Fl	198	35861

Table 2 Foundation types, insulation configurations, effective and nominal R-value, and cost

FOUNDATION SYSTEM Type	Insulation Configuration	Effective R-value R_i (°F ft^2 h/Btu)	Nominal R-value (°F ft^2 h/Btu)	Installed cost COST ($/ft)
Slab	2 ft fdn ext	5	4	$2.04
		6	5	2.25
		9	8	2.64
		11	10	3.50
		12	11	4.02
		15	14	4.58
	2 ft fdn int/R-5 rtg	6	5	1.30
		11	10	2.19
	2 ft fdn per/R-5 rtg	6	5	1.65
		11	10	2.80
	2 ft fdn 2 ft hor. ext	6	5	3.53
		11	10	5.70
	2 ft fdn 4 ft hor. ext	6	5	4.53
		11	10	7.90
	4 ft fdn ext	5	4	3.13
		6	5	3.53
		9	8	4.41
		11	10	5.70
		13	12	6.66
		16	15	7.69
		21	20	9.68
	4 fdn int/R-5 rtg	6	5	2.59
		11	10	4.40
		16	15	6.23
		21	20	8.06
	4 fdn per/R-5 rtg	6	5	2.69
		11	10	4.52

Table 2 Continued

FOUNDATION SYSTEM		Effective R-value	Nominal R-value	Installed cost
Type	Insulation Configuration	R_i (°F ft² h/Btu)	(°F ft² h/Btu)	COST ($/ft)
Crawl Space Wall (Concrete and Masonry)	2 ft ext	6	5	$2.00
		11	10	2.97
	2 ft int	6[2]	5	1.15
		11[2]	10	2.12
		12[3]	11	1.92
		14[3]	13	2.13
		20[3]	19	2.57
Crawl Space Wall (Wood)	2 ft wood	11.8	11	1.32
		13.5	13	1.48
		18.5	19	1.76
		27.9	30	2.32
Deep Basement (Concrete and Masonry)	4 ft ext	5	4	4.04
		6	5	4.44
		9	8	5.32
		11	10	6.54
		13	12	7.52
		16	15	8.47
Deep Basement (Concrete and Masonry)	8 ft ext	5	4	6.20
		6	5	7.01
		9	8	8.77
		11	10	10.87
		13	12	12.71
		16	15	14.55
		21	20	18.35
Deep Basement (Wood)	8 ft wood	11.8	11	8.52[4]
		13.5	13	9.19[4]
		18.5	19	9.87[4]
		27.9	30	15.78[4]
Floor[1]	Wood	13	11	0.34[5]
		14	13	0.41[5]
		19	19	0.52[5]
		27.3	30	0.86[5]

1. over basement or crawl space 2. foam boards 3. batts 4. cost includes $6.08/ft for drywall covering
5. cost in $/ft²

Table 3 Heating load factors, heating load factor coefficients and R^2 from regression analysis

FOUNDATION SYSTEM	CLIMATE: MORE THAN 2500 HDD65 HLF	R^2	LESS THAN 2500 HDD65 HLF	HLF_i	HLF_s	R^2
Slab						
2ft fdn ext	19.38	.99		-4.40399	0.011695	.82
2ft fdn int/R-5 rtg	18.77	.99		-4.14849	0.00996	.79
2ft fdn per/R-5 rtg	19.42	.99		-3.95460	0.00990	.80
2ft fdn 2ft hor.ext.	23.98	.98		-5.21022	0.01154	.51
2ft fdn 4ft hor.ext.	25.34	.98		-6.08104	0.01272	.56
4ft fdn ext	24.30	.99		-6.13994	0.01571	.81
4ft fdn int/R-5 rtg	24.20	.99		-6.13994	0.01571	.81
4ft fdn per/R-5 rtg	25.26	.99		-6.33494	0.01381	.82
Unvented Crawl Space						
2 ft. ext	19.06	.98		2.56965	0.00901	.66
2 ft. int	19.34	.98		4.07627	0.00861	.61
2 ft. wood	17.40	.92		-1.54462	0.00946	.55
Vented Crawl Space						
Floor	21.435	.99	21.435	NA	NA	
Deep Basement (Conditioned)						
4 ft. ext	80.40	.99		-5.63157	0.05430	.82
8 ft. ext or 8 ft. int	155.06	.99		-16.53665	0.09895	.85
8 ft. wood	186.07	.98		-24.93757	0.11622	.84
Deep Basement (Unconditioned)						
4 ft. ext	25.07	.98		0.39093	0.01225	.64
8 ft. ext or 8 ft. int	59.10	.99		-6.14049	0.02758	.64
8 ft. wood	33.34	.99		-0.82326	0.01519	.49
Floor	14.81	.98		-17.44417	0.01866	.67

Table 4 Cooling load factor coefficients and R^2 from regression analysis

FOUNDATION SYSTEM	CLIMATE: LESS THAN 15000 CDH74 CLF_i	CLF_s	R^2	MORE THAN 15000 CDH74 AND LESS THAN 30000 CDH74 CLF_i	CLF_s	R^2	MORE THAN 30000 CDH74 CLF_i	CLF_s	R^2
Slab									
2ft fdn ext	-1.89761	0.00015	.75	1.02787	-0.00005	.99	-1.93544	0.00005	.99
2ft fdn int/R-5 rtg	-2.45376	0.00017	.76	0.31361	-0.00003	.84	-1.78118	0.000044	.95
2ft fdn per/R-5 rtg	-3.02223	0.00019	.69	-0.33245	-0.00001	.27	-1.89340	0.000045	.91
4ft fdn ext	-3.18708	0.00024	.73	1.25057	-0.00007	.98	-2.81319	0.00007	.95
4ft fdn int/R-5 rtg	-2.43021	0.00016	.72	0.31361	-0.00003	.84	-1.78118	0.00004	.95
4ft fdn per/R-5 rtg	-5.58028	0.00033	.65	-1.97537	0.00002	.82	-3.32060	0.00007	.79
Unvented Crawl Space									
2 ft. ext	-1.43093	0.00012	.69	1.07080	-0.00005	1.0	-1.92333	0.00005	.95
2 ft. int	-2.37578	0.00017	.47	-1.23231	0.00003	.71	-1.23231	0.00003	.71
2 ft. wood	-2.16409	0.00016	.47	1.42995	-0.00007	.7	-2.50404	0.00006	.93
Vented Crawl Space									
Floor	-1.78237	0.000095	.38	-1.07055	-0.00003	.98	-1.16166	0.00003	.79
Deep Basement (Conditioned)									
4 ft. ext	0.20910	0.00006	.39	2.51623	-0.00008	.98	-3.04576	0.00010	1.0
8 ft. ext or 8 ft. int	-0.09706	0.00010	.27	4.73889	-0.00018	.96	-6.98257	0.00020	.95
8 ft. wood	-0.25473	0.00009	.17	4.93520	-0.00021	.89	-8.92914	0.00025	.98
Deep Basement (Unconditioned)									
4 ft. ext	-3.45221	0.00022	.50	0.70912	-0.00005	.82	-3.10899	0.00008	.86
8 ft. ext or 8 ft. int	-10.68317	0.00058	.43	-1.34275	-0.00006	.37	-8.91748	0.00021	.83
8 ft. wood	-6.64161	0.00033	.22	-0.73835	-0.00005	.54	-6.25373	0.00015	.75
Floor	-3.84203	0.00020	.47	-1.53760	0.00002	.86	-2.118515	0.000045	.85

Table 5 Initial effective R-values for uninsulated foundation system and adjacent soil

FOUNDATION SYSTEM		R_{ui}	R_{soil}
Slab	2ft fdn ext	1.0	1.25
	2ft fdn int/R-5 rtg	1.0	1.25
	2ft fdn per/R-5 rtg	1.0	1.25
	2ft fdn 2ft hor.ext.	1.0	1.25
	2ft fdn 4ft hor.ext.	1.0	1.25
	4ft fdn ext	1.0	1.25
	4ft fdn int/R-5 rtg	1.0	1.25
	4ft fdn per/R-5 rtg	1.0	1.25
Unvented Crawl Space	2 ft. ext	1.0	1.25
	2 ft. int	1.0	1.25
	2 ft. wood	2.5	2.1
Vented Crawl Space	Floor	4.8	0
Deep Basement	4 ft. ext	1.0	1.1
(Conditioned)	8 ft. ext or 8 ft. int	1.0	1.8
	8 ft. wood	2.5	4.3
Deep Basement	4 ft. ext	1.0	1.7
(Unconditioned)	8 ft. ext or 8 ft. int	1.0	3.2
	8 ft. wood	2.5	0
	Floor	4.8	1.4

Table 6 Heating and Cooling equipment seasonal efficiencies

HEEF	Low	Medium	High	Very High
gas furnace	0.50	0.65	0.80	0.90
oil furnace	0.50	0.65	0.80	0.90
heat pump (HSCOP)	1.6	1.9	2.2	2.5
electric furnace	1.0	1.0	1.0	1.0
electric baseboard	1.0	1.0	1.0	1.0
CEEF				
heat pump (SEER)	7.25	8.75	10.25	11.75
air conditioner	6.0	8.0	10.0	12.0

Table 7 Typical energy prices (HP and CP) and conversion factors to go from pricing unit to $/MBtu

ENERGY	SAMPLE PRICE (typical units)	$/MBtu (HP)	Conversion factor (CONFT)
ELECTRICITY	8 CENTS/KWH	23.45	2.93
NATURAL GAS	60 CENTS/THERM	6.00	0.10
FUEL OIL	85 CENTS/GAL	6.07	0.07
PROPANE	95 CENTS/GAL	10.33	0.11

Table 8 Scalar ratios (HUPW and CUPW) for various economic criteria

MORTGAGE (PERCENT)	FUEL ESCALATION (PERCENT)	SCALER RATIO 2 YR CROSS OVER	20 YR LIFE CYCLE[1]	30 YR LIFE CYCLE[1]
10	0	13.25	10.07	11.69
10	1	13.51	10.88	12.84
10	2	13.78	11.75	14.16
10	3	14.05	12.73	15.7
10	4	14.31	13.83	17.48
10	5	14.58	15.05	19.58
10	6	14.84	16.41	22.03
11	0	12.28	9.52	10.84
11	1	12.53	10.28	11.91
11	2	12.78	11.11	13.14
11	3	13.02	12.06	14.56
11	4	13.27	13.08	16.22
11	5	13.51	14.23	18.16
11	6	13.76	15.51	20.44
12	0	11.5	9.0	10.14
12	1	11.72	9.72	11.14
12	2	11.95	10.51	12.29
12	3	12.18	11.39	13.62
12	4	12.41	12.37	15.17
12	5	12.64	13.46	16.99
12	6	12.87	14.68	19.12

1. based on 10% real after tax discount rate

Step A: CLIMATE. Determine weather parameters, HDD base 65°F (HDD65) and CDH base 74°F (CDH74).

Heating Degree Days @65 °F: HDD65 (Table 1) ________

Cooling Degree Hours @74 °F: CDH74 (Table 1) ________

Step B: OPTIONS. Select foundation type, configuration and nominal R-value options of interest. See Table 2.

Options	Type (example: slab)	Configuration (example: 2ft fdn ext)	Nominal R-value (example: R-5)	Effective R-value	COST ($/ft)*
1)	____	____	____	____	____
2)	____	____	____	____	____

Step C: PERFORMANCE. Determine heat & cool load factors (HLF & CLF), if HDD65 > 2500, enter HLF directly.

	HLF_i (Table 3)	+	(HLF_s (Table 3)	x	HDD65) (Step A)	=	HLF [Btu/(HDD65 x U_{delta})]
1)	____	+	(____	x	____)	=	____
2)	____	+	(____	x	____)	=	____

	CLF_i (Table 3)	+	(CLF_s (Table 3)	x	CDH74) (Step A)	=	CLF [Btu/(CDH74 x U_{delta})]
1)	____	+	(____	x	____)	=	____
2)	____	+	(____	x	____)	=	____

Step D: PERFORMANCE. Calculate effective U-value of uninsulated foundation system (U_{ui}) under consideration.

	1	÷	(R_{ui} (Table 5)	+	R_{soil}) (Table 5)	=	U_{ui} [Btu/°F ft^2 h]
1)	1	÷	(____	+	____)	=	____
2)	1	÷	(____	+	____)	=	____

Step E: PERFORMANCE. Calculate effective U-value of foundation at insulation levels (U_{tot}) under consideration.

	1	÷	(R_i (Table 2)	+	R_{soil}) (Table 5)	=	U_{tot} [Btu/°F ft^2 h]
1)	1	÷	(____	+	____)	=	____
2)	1	÷	(____	+	____)	=	____

Step F: PERFORMANCE. Calculate delta U-value (U_{delta}), difference between insulated and uninsulated options.

	U_{ui} (Step D)	-	U_{tot} (Step E)	=	U_{delta} [Btu/°F ft^2 h]
1)	____	-	____	=	____
2)	____	-	____	=	____

Step G: PERFORMANCE. Calculate heating load savings (L_{hdelta}) of each option.

	U_{delta} (Step F)	x	HLF (Step C)	x	HDD65 (Step A)	÷	1,000,000	=	L_{hdelta} [MBtu/ft]*
1)	____	x	____	x	____	÷	1,000,000	=	____
2)	____	x	____	x	____	÷	1,000,000	=	____

Step H: PERFORMANCE. Calculate cooling load savings (L_{cdelta}) of each option.

	U_{delta} (Step F)	x	CLF (Step C)	x	CDH74 (Step A)	÷	1,000	=	L_{cdelta} [KBtu/ft]*
1)	____	x	____	x	____	÷	1,000	=	____
2)	____	x	____	x	____	÷	1,000	=	____

Step I: ENERGY SAVINGS. Calculate heating energy dollar savings (HESAV) of each option.

	[L_{hdelta} (Step G)	÷	(HEEF x DTE)] (table 6)	x	HP (Table 7, $/MBtu)	x	HUPW (table 8)	=	HESAV [$/ft]*
1)	(____	÷	____)	x	____	x	____	=	____
2)	(____	÷	____)	x	____	x	____	=	____

Step J: ENERGY SAVINGS. Calculate cooling energy dollar savings (COSAV) of each option.

	[L_{cdelta} (Step H)	÷	(CEEF x DTE)] (table 6)	x	CP (table 7, $/kWh)	x	CUPW (table 8)	=	COSAV [$/ft]*
1)	(____	÷	____)	x	____	x	____	=	____
2)	(____	÷	____)	x	____	x	____	=	____

Step K: NET DOLLAR SAVINGS. Calculate net $ savings (NETSA). Option with largest NETSA is optimal.

	HESAV (Step I)	+	COSAV (Step J)	-	COST (Table 2 or Fig. 3)	=	NETSA [$/ft]*
1)	____	+	____	-	____	=	____
2)	____	+	____	-	____	=	____

* If options are floor insulation than units are per ft^2 of floor area instead of perimeter ft.

Figure 1. Worksheet for selection of optimal foundation insulation

Work Sheet Instructions

Step B. Foundation types are in Table 2, first column, choose one. Select the insulation configuration from Table 2, second column for the foundation type chosen. You may choose different insulation configurations from Table 2, under the chosen foundation type. You are not limited to the R-values in Table 2, but you will need installed costs (see Fig. 3) and the effective R-value (see Fig. 4) for each option.

Step C. For climates with more than 2500 HDD65 the HLF is given in Table 3 and does not have to be calculated, enter directly at the end of lines 1-4. For determining the HLF in those climates with less than 2500 HDD65 and for the CLF in all climates obtain coefficients (HLF_i, HLF_s, CLF_i, and CLF_s) from Tables 3 and 4 for climate and foundation system.

Step D. Use Table 5 to obtain the effective R-value of the uninsulated foundation construction (R_{ui}) and the effective R-value of the adjacent soil (R_{soil}). These are not actual R-values, rather values which produce the best reproduction of the annual heating and cooling load savings data base from which this work sheet is based. These values should not be varied from those shown for each system in Table 5.

Step E. A list of effective R-values (R_i) are provided in Table 2. R_i is a value which includes the structural components and insulation of the foundation system. You can select other insulation levels than those shown in Table 2, use the optional effective R-value work sheet shown in Figure 4. The R_{soil} is found in Table 5 and should be the same as used in step D.

Step I. HEEF is the heating equipment efficiency, suggested values are listed in Table 6. DTE is the HVAC duct efficiency. The data base of which the simplified approach is based, used 0.9 when ducts were in unconditional spaces like attics and crawl spaces. Some duct efficiencies, even in energy efficient homes have been found to be much lower. ASHRAE 90.2P used a heating duct efficiency of 0.75. When ducts are located within the conditioned space HTE should be between 0.9 and 1.0. HP is the current years heating energy price. Some near national average prices are shown in Table 7, but your local energy supplier should provide current rates. The value to be entered for HP must be in ($/MBtu). To convert the typical pricing units shown in Table 7 to ($/MBtu) multiply the quoted rate in units shown in Table 7 by the conversion factor (CONFT) in Table 7. HUPW is a scalar ratio used to determine the present worth of the foundation insulation heating energy savings. Table 8 provides a variety of scalar ratios calculated with different mortgage rates, fuel escalation rates and three different economic decision criteria; second year positive cash flow, 20 and 30 year minimum life cycle cost analysis. The second year positive cashflow criteria requires that after the 2nd year the additional mortgage payment for the foundation insulation be less than the resulting annual energy savings. The Design Handbook[1], ASHRAE Standard 90.2P[2] and the Model Energy Code[3] are all based on a scaler ratio around 18. To be consistent with these codes and standards, use 18.

Step J. Suggested values for the cooling equipment efficiency (CEEF) are shown in Table 6. DTE is the HVAC duct efficiency. The Foundation Design Handbook assumed 0.9 for cooling duct efficiency same as for heating. ASHRAE 90.2p used 0.8 for cooling duct efficiency, when ducts are in unconditioned spaces. CP is the current years cooling energy price. Consult your local energy suppliers. Table 7 contains near national average residential energy prices. The value to be entered for CP must be in ($/Kwh). CUPW is the scaler ratio used to estimate the present worth of the cooling energy savings resulting from foundation insulation. Table 8 provides a variety of scaler ratios based on different economic criteria, mortgage rates and real fuel escalation rates. The handbook, ASHRAE 90.2 and the MEC are all based on around 18.

Step K. The option with the largest positive (NETSA) is the most cost effective option. This step subtracts the first cost of each insulation level under consideration from the corresponding present worth value of the energy savings. Some typical values for NEW construction COST are shown in Table 2[4]. They were 1987 national average values but you should use the cost work sheet in figure 3 to obtain current costs. If all the net savings values are negative this indicates none of the options meet your cost effectiveness criteria. Select a set of options which have lower installed costs and repeat the work sheet. If still none exist, foundation insulation may not be a good investment for this project.

Figure 2. Worksheet instructions

Step A: Material Cost. Estimate material costs.

Option	INSULATION $	+	FASTENERS $	+	COVER $	=	MATERIAL $
1)	______	+	______	+	______	=	______
2)	______	+	______	+	______	=	______

Step B: Labor Cost. Estimate labor costs.

	SITE PREPARATION $	+	INSTALL INSULATION $	+	INSTALL COVER $	=	LABOR $
1)	______	+	______	+	______	=	______
2)	______	+	______	+	______	=	______

Step C: Total Installed Cost. Calculate the total cost of foundation insulation

	(MATERIAL (Step A)	+	LABOR) (Step B)	x	SUB MARKUP (Example: 1.3)	x	BUILDER MARKUP (Example: 1.3)	= TOTAL $
1)	(______	+	______)	x	______	x	______	= ______
2)	(______	+	______)	x	______	x	______	= ______

Step D: Total Installed Cost. Convert the total installed cost into cost per foundation perimeter foot.

	TOTAL (Step C)	÷	PERIMETER (ft)	=	COST ($/ft)
1)	______	÷	______	=	______
2)	______	÷	______	=	______

Instructions

Step A. Material costs should be for the entire job. INSULATION represents the material costs for the entire area to be covered. FASTENERS includes the insulation attachment materials, examples are fasteners for exterior systems and framing for interior systems. COVER includes the above grade protection needed for exterior insulation or flame spread protection for interior applications. If the covering provides other amenities such as aesthetics (basement finishing needed anyway) than this cost should be zero.

Step B. SITE PREPARATION includes surface preparation that may be needed such as cleaning prior to liquid adhesive application. In retrofit installations the cost of excavation for exterior systems and interior wall fixture relocation for interior systems should be entered. INSTALL INSULATION covers total labor cost of attaching the insulation. INSTALL COVER includes the labor for applying either the exterior above grade covering or flame spread protection covering on the interior if done only to meet safety standards.

Step C. The total installed cost may include subcontractor (SUB MARKUP) and builder (BUILDER MARKUP) markup. These markups account for indirect charges, overhead, and profit. The costs for new construction foundation insulation in Table 2 includes 30 percent for both markups. For retrofit, BUILDER MARKUP should be 1.0. For homeowner retrofit the SUB MARKUP should also be 1.0.

Step D. This last step converts the total cost into dollars per foundation perimeter foot (COST), for use in Step K of the work sheet for selection of optimal foundation insulation shown in Figure 1.

Figure 3. Optional worksheet for estimating foundation insulation installation cost (COST)

Step A: Calculate the U-value of the insulation layer, which may have fasteners or framing.

Option	(f_1	÷	R_1)	+	(f_2	÷	R_2)	+ ... +	(f_N	÷	R_N)	= U_i [Btu/°F ft² h]
1)	(___	÷	___)	+	(___	÷	___)	+ ... +	(___	÷	___)	= ___
2)	(___	÷	___)	+	(___	÷	___)	+ ... +	(___	÷	___)	= ___

Step B: Calculate the effective R-value (R_i) for use in Step E. of the work sheet for selecting optimal foundation insulation shown in figure 1.

Option	R_{ui} (Table 5)	+	(1	÷	U_i) (Step A)	=	R_i [°F ft² h/Btu]
1)	________	+	(1	÷	________)	=	______
2)	________	+	(1	÷	________)	=	______

Instructions

Step A. The U-value of just the insulation layer for concrete or masonry walls can be calculated by assuming parallel heat flow paths through areas with different thermal resistances. f_1, f_2 and f_N are fraction of total area transverse to heat flow representing material 1,2, ...N. For stud walls 16in. on center, the fraction of framing is usually assumed to be approximately 0.15; for studs 24 in. on center, approximately 0.12. R_1, R_2 and R_N are the R-values of materials contained in the insulation layer. For example an insulated stud wall will have wood and mineral batts.

Step B. R_{ui} must be selected from Table 5 it represents the system that was modeled and can not be varied in this work sheet. If the fasteners are to be ignored for board insulations as was done in table 2, the nominal R-value can be added to R_{ui} to obtain R_i.

Figure 4. Optional worksheet for estimating foundation insulation effective R-value (Ri) for concrete and masonry foundations

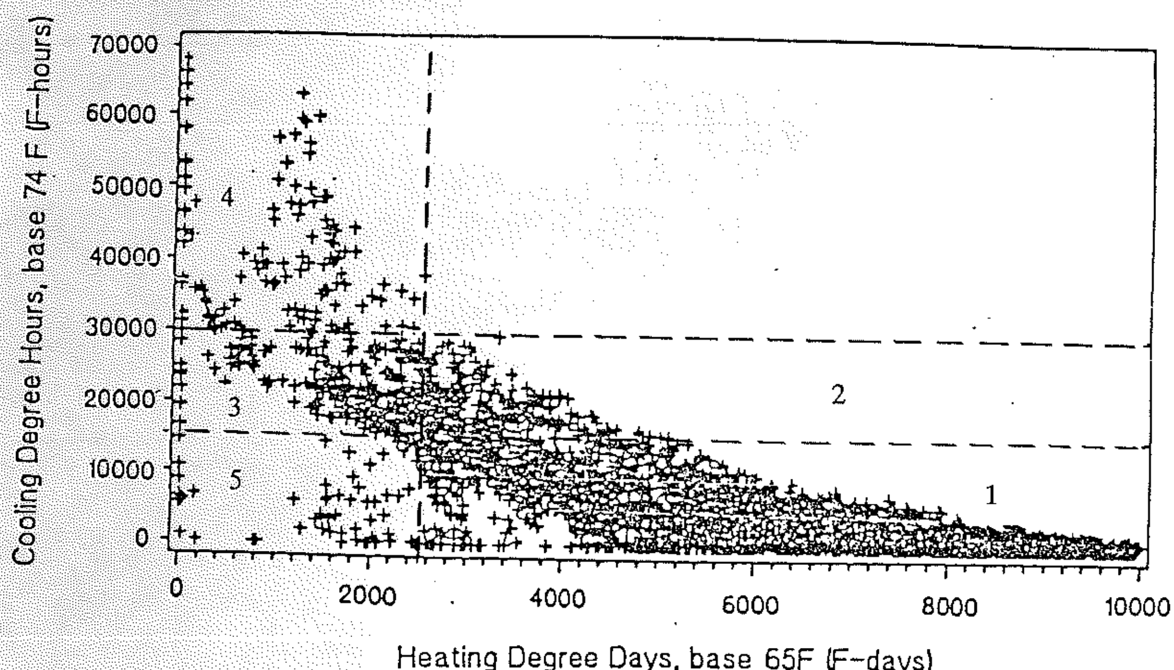

Figure 5. Five climatic zones used to develop heating and cooling load factors on plot of cooling degree hours, base 74°F, versus heating degree days, base 65°F, for 3,349 cities in the United States

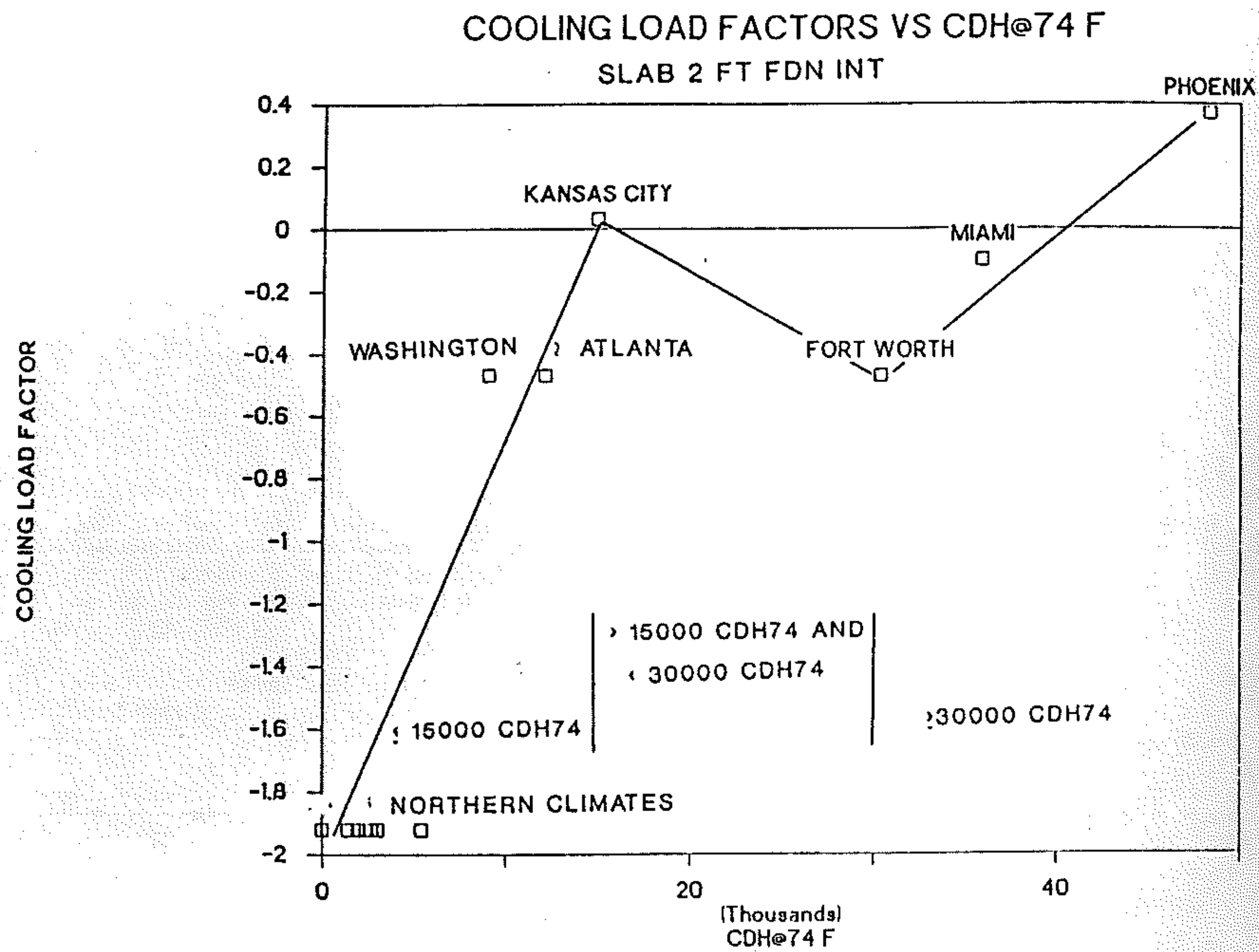

Figure 6. Example of CLF behavior as a function of CDH74