Guideline

Roof Insulation

Southern California Gas Company

New Buildings Institute

Advanced Design Guideline Series

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CHAPTER 1: PREFACE

These Advanced Design Guidelines have been developed by the New Buildings Institute in cooperation with Southern California Gas Company to assist designers, program planners, and evaluators to make informed decision on the cost-effectiveness of energy saving measures. This Guideline deals specifically with roof insulation.

This Advanced Design Guideline is based on careful evaluation and analysis of various roof insulation levels to the most cost-effective option. These Guidelines describe efficiency measures that are more advanced than standard practice, yet still cost effective in all, or select markets. Design Guidelines are used by individuals and organizations interested in making buildings more energy efficient. They provide the technical basis for defining efficiency measures used in individual building projects, in voluntary energy efficiency programs, and in market transformation programs.

It should be remembered that this Guideline document deals primarily with the comparison of a single efficiency measure and its baseline. This means that the analysis assumes that all other features of the building are fixed. This is done primarily for clarity of the analysis, and allows one to focus on the advantages and economics of the single measure.

In reality, most new building design situations involve multiple energy efficiency options. The cost effectiveness of one measure is often influenced by other measures. For example, increases in building envelope insulation can often reduce HVAC loads enough to reduce the sizing requirements for the heating and cooling equipment. It is not uncommon for the cost savings from smaller equipment to offset increased insulation costs.

It is beyond the scope of this Guideline to attempt to address the interactions between measures, especially because these interactions can cover a huge range of options depending on the climate, the local energy costs, the building, and its systems. Nevertheless, the New Buildings Institute recommends that building designers give careful consideration to measure interactions and to integrated systems design. This Guideline can provide the starting point by providing insight into the performance of one measure.

CHAPTER 2: DESCRIPTION

Thermal insulation is material that is used to inhibit the flow of heat energy by conductive, connective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing the heat loss or gain of a structure. An important characteristic of insulating materials is the thermal resistance or R-value. A material with a high R-value is an effective insulator. Thermal resistance is the reciprocal of thermal conductance, which is a measure of heat flow through a material.

A. Types of Insulation

This Guideline is concerned with insulation for building roof applications. There is a wide variety of structural systems and roofing materials, with a correspondingly wide range of roof insulation materials and methods of application.

Basic Forms of Thermal Insulation

There are five basic forms of thermal insulation used for roofs: blankets, blown-in, foamed-in-place, rigid insulation, and reflective insulation systems.

- **Blankets**, in the form of batts or rolls, are flexible products, usually made from mineral fibers. They are available in widths suited to standard spacings of wall studs and attic or floor joists. Continuous rolls can be hand-cut and trimmed to fit. They are available with or without vapor retardant and reflective facings.
- **Blown-In** loose-fill insulation includes loose fibers or fiber pellets that are blown into building cavities or attics using special pneumatic equipment. Another form includes fibers that are co-sprayed with an adhesive to make them resistant to settling. The blown-in material can provide additional resistance to air infiltration if the insulation is sufficiently dense.
- **Foamed-In-Place** polyurethane foam insulation can be applied by a professional applicator using special equipment to meter, mix, and spray the material into place. Polyurethane foam can also help to reduce air leaks because it forms a continuous layer of material.
- **Rigid Insulation** is made from fibrous materials or plastic foams, and is pressed into board-like forms. These provide thermal and acoustical insulation, strength with low weight, and coverage with few heat loss paths. These boards may be faced with a reflective foil that reduces heat flow when next to an air space, and retards vapor penetration.
- **Reflective Insulation Systems** are fabricated from aluminum foils with a variety of backings such as kraft paper, plastic film, polyethylene bubbles, or cardboard. The resistance to heat flow depends on the heat flow direction (vertical, horizontal, etc.). This type of insulation is most effective in reducing downward heat flow. Reflective systems are typically located between roof rafters or floor joists. If a single reflective surface is used alone and faces an open space, such as an attic, it is called a radiant barrier. Radiant barriers are sometimes used in buildings to reduce summer heat gain and winter heat loss. They are more effective in hot climates than in cool climates. All radiant barriers must have a low emittance (0.1 or less) and high reflectance (0.9 or more).

Thermal Insulation Materials

The three most common types of building insulation are cellulose, fiberglass and polymers.

- **Cellulose** insulation has an R-value of approximately R-3.8 per inch. It doesn't vary significantly over a range of densities. Cellulose insulation maintains its R-value under cold conditions. Wood, paper and other plant based products all are cellulosic materials. Cellulose insulation is typically made from recycled paper products and treated with boron-based chemicals to make it fire retardant.
- **Fiberglass** insulation has R-values ranging from R-2.2 to 4.0 per inch, depending on the density. Fiberglass typically comes in batts ranging in thickness from 3" to 12". Batts need to be installed in cavities that can accommodate their thickness since compressed batts lose some of their R-value.

- **Polymer** type insulation includes polystyrene, polyurethane and polyisocyanurate. Polyisocyanurate provides the best insulating value per inch, typically R-6.0 to 7.4. Most leading manufacturers include in their product line a vented foam insulation product for installation over unventilated roof decks and moisture control.

B. Applications

Thermal insulation is generally installed in building envelope components to reduce space heating and space cooling, energy use and costs. Additional benefits include increased occupant comfort, reduced requirements for heating and cooling system capacity, and elimination of condensation on roof surfaces in cold climates.

Application Conditions

As with any part of a roofing system, it is important that the insulation be properly installed. The effectiveness of thermal insulation is seriously impaired when it is installed incorrectly. Insulation must be installed dry and be kept dry for the expected life of the roofing system. Other factors, including vibration, temperature cycling, and other mechanical forces, can affect thermal performance by causing settling and other dimensional changes. Gaps at the edges of both board- and batt-type insulation can lower insulation effectiveness. Drainage of water off any roof membrane is recognized as being critical to the proper performance of the roofing system.[1]

Moisture Control

Moisture control is a major concern associated with installing thermal insulation. If moisture condenses in the insulation, it may reduce thermal resistance, and perhaps physically damage the system. The warm air inside a building contains water vapor. If this vapor passes into the insulation and condenses, it can cause significant loss of insulating value. If moisture becomes deposited in the building structure, it can cause mold growth, peeling paint, damage to ceiling systems and eventual rotting of structural wood. To guard against moisture problems, vapor retarders and adequate ventilation must be provided to the insulation layer.

Vapor retarders are special materials including treated papers, plastic sheets, and metallic foils that reduce the passage of water vapor. Vapor retarders should be used in most parts of the country. In colder climates, the vapor retarder is placed on the warm side of the surface to be insulated. This location prevents the moisture in the warm indoor air from reaching colder layers near the exterior of the insulation.

Batts and blankets can be purchased with a vapor retarder attached. However, if new material is being added to insulation already in place, batts or blankets that do not have an attached vapor retarder should be used. If this type is not available, the vapor retarder facing between layers of insulation should be removed to allow the pass through of any moisture that does get into the insulation.

For loose-fill insulation or for batts and blankets not having an attached vapor retarder, heavy-weight polyethylene plastic sheets are available in rolls of various widths for use as vapor retarders. In places where vapor retardant materials cannot be placed, such as in finished ceiling cavities being filled with blown-in insulation, the interior surface can be made vapor-resistant with a low-permeability paint, or with wall paper that has a plastic layer.

[1] Of course, there are exceptions to this. For example, evaporative roof cooling systems intentionally collect water on the roof and use the evaporation of the water to cool the building. Special provisions are made to prevent any leaks.

CHAPTER 3: HISTORY AND STATUS

At the turn of the century, the predominant available insulation material was wood, so insulation was balsa wool or balsa batt - sawdust encapsulated in a paper package. In the 1930's, rock metal slag, a byproduct from U.S. steel mills provided another insulation product. It was heated to a liquid state and fiberized, and the end product was rock wool insulation. The same process was used to create insulation from sand or silica resulting in fiberglass. In 1933, a glass fiber material thin enough to be used as a commercial fiber glass insulation was produced.

During the energy crisis of the 1970s, demand for insulation reached an all-time high and a resurgence of interest in cellulose insulation followed. The newer materials were more sophisticated variations of the old balsa products.

Rigid foams including polystyrene, polyurethane and polyisocyanurate were originally developed for military and aerospace applications. However, the following characteristics, along with others, have made rigid foams popular insulating material, particularly for roofs:

- Stable over a large temperature range (-100°F to +250°F) and can be used as a component in roof systems that use hot asphalt.
- Low density, good adhesion to facers, low water absorption and low vapor transmission.

These factors, teamed with the oil embargo of the 1970s that caused a dramatic demand for energy-conserving technologies, resulted in the success of rigid foam in the marketplace. Polyisocyanurate insulation, developed in the late 1970s, has evolved into one of the most energy-efficient and cost-effective insulation applications.

A. Standards and Rating

Unlike the national equipment or lighting efficiency standards, envelope insulation standards are quite local. Federal, state and local energy codes establish the required roof insulation levels to reflect climate differences, energy costs, local practice, and other factors. While different government agencies use various methods for determining the appropriate level of insulation, many of them utilize the procedures and recommendations developed for the ASHRAE Standard 90.1 energy efficiency standards. These are procedures used in this Guideline. They are explained in Chapter 4.

CHAPTER 4: ANALYSIS

This chapter discusses the method for analyzing the economics of roof insulation.

A. Cost Effectiveness

The economically optimal insulation thickness in an envelope component minimizes the total o the installation and life-cycle space heating and cooling costs attributable to that component. Typically, as the thermal resistance of the insulation is increased, insulation costs increase and space heating costs decrease. As long as the incremental savings in heating and cooling costs caused by the increase in insulation thickness exceed the incremental insulation material and installation cost, the measure is cost-effective. Beyond a certain level, incremental costs will exceed incremental savings, and additional insulation is not cost effective.

B. Analysis Tool

The analysis tool used to develop the cost effectiveness graphs presented in the following chapter is similar to the tool used to develop the ASHRAE Standard 90.1 criteria. The analysis tool, named *NBI Criteria* for this analysis, is used to develop cost-effectiveness criteria for various insulation levels. The tool enables users seeking optimum insulation levels to take account of energy costs, the value of future energy savings, climate effects and construction costs.

The software consists of three components: a main program, a database and an analysis engine. The main program provides the user interface, where the input parameters and criteria sets are defined. The engine is an ActiveX DLL file that provides analysis functionality to the main program. As an ActiveX DLL, the functionality can easily be provided to other applications. It can be referenced by an Excel spreadsheet or an Access database. The database component is a Microsoft Access formatted database and contains the building envelope assemblies to be analyzed by the engine. It also contains energy use coefficients and other information that is needed by the engine. The database can be edited with Microsoft Access or a compatible database program.

The software tool uses a few key inputs - climate information, economic criteria (analysis period, fuel costs, discount rate, etc.) and construction costs - to produce lists of economically optimum envelope criteria.

This methodology is consistent with the methodology used by the ASHRAE Std. 90.1[1] envelope subcommittee.

C. Technical Basis

This section describes the methodology for developing the energy model.

Space Categories

The coefficients to the energy model are calculated separately for three categories of building use, which are referred to as space categories.

- Nonresidential. The nonresidential space category covers offices, retail, schools, etc. The assumption is that the building is operated for 16 hours/day during the week and a 12 hours/day on Saturday. The space is assumed to be both heated and cooled.
- Residential. The residential space category includes hotel/motel guest rooms, patient rooms in hospitals, nursing homes, high-rise residential, fraternity houses, etc. The assumption is that the space is both heated and cooled on a continuous basis (24 hours/day, 7 days/week). For this analysis, single family residential construction is not included.
- Semi-heated. The semi-heated space category includes warehouses and other buildings that are heated only. The heating set-point is assumed to be only 50°F, primarily to prevent freezing.

Classes of Construction

The concept of construction classes is used in determining the criteria or recommended construction. Opaque constructions are first divided into types: roofs, walls, floors, slabs and doors. Each opaque type is further divided into classes. For roofs, there are three classes as described below. These classes are consistent with ASHRAE Standard 90.1-1989R.

[1] The ASHRAE Standard 90.1 Committee develops the national model energy code for nonresidential buildings.

- *Metal Building*. Metal buildings are generally insulated with batt insulation draped over the purlins and then covered by the metal deck. The insulation is compressed at the connection. Continuous rigid insulation can also be added.
- *Insulation Entirely Above Deck*. This class of construction includes cases where the insulation is installed above the structural deck. Examples include metal decks, concrete slabs, etc.
- *Attic and Other*. This class of construction covers all roof constructions that do not qualify for one of the other two classes.

Figure 1 shows the roof construction data used for the analysis for each class. These data are consistent with the constructions used in the development of ASHRAE Standard 90.1-1989R. The constructions shown in these tables are the only ones that survived a preliminary screening[1].

Energy Model

A simplified energy model was developed for predicting annual energy use related to varying levels of insulation. The model has the form shown in equations (1) and (2). The equation for life-cycle cost is shown as (3). The scalar, or scalar ratio, is a mathematical simplification of a life-cycle cost analysis. In technical terms, the scalar ratio represents the series present worth multiplier. The boundary between subsequent insulation levels occurs when the life-cycle cost of the subsequent constructions is equal. Skipping a few intermediate steps, equations (4) and (5) give the intercepts for the boundary lines.

$$kWh_i = e_0 + e_1 \cdot A \cdot U_i \cdot CDD_{50} \quad (1)$$

$$Therms_i = f_0 + f_1 \cdot A \cdot U_i \cdot HDD_{65} \quad (2)$$

$$LCC_i = C_i + Scalar \cdot (kWh_i \cdot P_E + Therms_i \cdot P_F) \quad (3)$$

$$\Delta C = Scalar \cdot P_E \cdot e_1 \cdot \Delta U \cdot CDD_{50} \quad (4)$$

or

$$Scalar \cdot P_E \cdot CDD_{50} = \frac{\Delta C}{e_1 \cdot \Delta U}$$

$$\Delta C = Scalar \cdot P_F \cdot f_1 \cdot \Delta U \cdot HDD_{65} \quad (5)$$

or

$$Scalar \cdot P_F \cdot HDD_{65} = \frac{\Delta C}{f_1 \cdot \Delta U}$$

Where:

P_E = price of electricity

P_F = price of fuel (gas)

e_1 = cooling coefficient

f_1 = heating coefficient

ΔC = change in cost

ΔU = change in U-factor

CDD_{50} = cooling degree days, base 50°F

HDD_{65} = cooling degree days, base 65°F

Further discussion of the scalar is provided in the Appendix.

Coefficients

The cooling coefficient, e_1, and the heating coefficient, f_1, are provided in Figure 2 by space category and construction class.

[1] The screening eliminated many constructions that will never be cost effective. For instance, if two constructions have the same performance, it is only necessary to consider the one with the least first cost. Likewise, if two constructions have the same cost, it is only necessary to consider the one that performs better.

Class	Name	Cost	U-Factor
Metal Building	R-0.0	0.00	1.280
	R-6.0	0.37	0.167
	R-10.0	0.44	0.097
	R-13.0	0.50	0.083
	R-16.0	0.56	0.072
	R-19.0	0.62	0.065
	R-13.0 + R-13.0	0.80	0.055
	R-13.0 + R-19.0	0.92	0.049
	R-16.0 + R-19.0	0.98	0.047
	R-19.0 + R-19.0	1.04	0.046
	R4/R19/R10	2.00	0.033
	R5.6/R19/R10	2.21	0.031
Insulation Entirely Above Deck	R-0.0	0.00	1.282
	R-3.8	0.34	0.218
	R-5.0	0.43	0.173
	R-7.6	0.66	0.119
	R-10.0	0.80	0.093
	R-15.0	1.08	0.063
	R-20	1.36	0.048
	R-25	1.64	0.039
	R-30	1.92	0.032
	R-39.2	2.62	0.025
	R-44.8	2.93	0.022
	R-50.4	3.23	0.020
	R-56.0	3.53	0.018
	R-61.6	3.84	0.016
	R-67.2	4.14	0.015
Attic and Other	R-0.0	0.00	0.613
	R-13.0	0.23	0.081
	R-19.0	0.29	0.053
	R-30.0	0.40	0.034
	R-38.0	0.50	0.027
	R-49.0	0.66	0.021
	R-60.0	0.77	0.017
	R-71.0	0.90	0.015
	R-82.0	1.03	0.013
	R-93.0	1.16	0.011
	R-104.0	1.29	0.010
	R-115.0	1.42	0.009
	R-126.0	1.54	0.008
	R-137.0	1.67	0.008
	R-148.0	1.80	0.007

Figure 1 - Roof Constructions

Space Category	Class	CoefHeat (*f1*)	CoefCool (*e1*)
Nonresidential	Metal Building	0.000229	0.000256
	Insulation Entirely Above Deck	0.000228	0.001150
	Attic and Other	0.000228	0.001150
Residential	Metal Building	0.000335	0.00068
	Insulation Entirely Above Deck	0.000195	0.00166
	Attic and Other	0.000195	0.00166
Semi-heated	Metal Building	0.000078513	0
	Insulation Entirely Above Deck	0.0000808	0
	Attic and Other	0.0000808	0

Figure 2 - Energy Use Coefficients for Various Roof Types

CHAPTER 5: DESIGN ANALYSIS GRAPHS

This section presents guidelines for selecting cost-effective roof insulation. The guidelines are based on procedures used as part of the development process for ASHRAE Standard 90.1-1989R. These procedures use life-cycle cost analysis to determine the most cost effective insulation level for various building types and classes of construction, as described in Chapter 4.

The building types are defined as:

- Nonresidential,
- Residential, and
- Semi-Heated

The classes of construction are:

- Insulation above roof deck,
- Metal building, and
- Attic and Other

The independent variables to the analysis are

- the price of electricity and fuel,
- climate as represented by heating and cooling degree days, and
- the value placed on future energy savings as represented by a scalar ratio[1].

Alternative insulation methods are identified for each class of construction, and for each, the U-factor and cost premium are calculated.

A. Graphic Presentation of Results

For each set of conditions (energy prices, space category, scalar and class of construction), the results of the analysis are presented graphically. There are a number of ways the results can be presented. **Error! Reference source not found.** shows the boundary conditions between subsequent insulation levels for a specific set of energy prices, scalar ratio, construction class and space category. Heating degree days (base 65°F) extend along the horizontal axis, and cooling degree days (base 50°F) on the vertical axis. The lines on the graph represent the "break-even" cost-effectiveness for various insulation levels.

Climate locations may be represented as points on the graph, as illustrated by the squares in **Error! Reference source not found.**. The data points are centered around the R-10 line. Points on the line and to the left of the line indicate that R-10 is the cost-effective option for those locations. Points to the right of the line indicate the next level of insulation, R-15, is the cost-effective choice. Cost-effectiveness is defined as the point where construction costs and life cycle costs savings are equal; in other words, where the total costs are minimized.

The presentation in **Error! Reference source not found.** is appropriate for determining the criteria for a variety of climates. When determining the insulation level for a particular climate, construction class and space category, a presentation similar to **Error! Reference source not found.** is more appropriate. With this presentation, the space category and construction class are fixed, but climate, energy prices and scalar ratio are variables. The horizontal axis has the product of the scalar ratio, fuel price and heating degree days (the heating term). The vertical axis has the product of the scalar ratio, electricity price, and cooling degree days (the cooling term).

The slopes of the lines representing boundary conditions indicate the extent to which heating and cooling factors impact the recommended insulation level. Vertical lines indicate that the criterion is driven entirely by heating. Flat lines indicate that the criterion is driven by cooling. Sloped lines denote that both the factors impact the recommended insulation level.

These graphs can be used to determine the appropriate insulation level. First, decide on the appropriate scalar for the analysis, find the correct fuel prices are determine. the right heating and cooling degree days for the location under consideration. From these, the heating and cooling terms are calculated. These values determine a point on the graph, which indicates the cost-effective R-value of roof insulation.

Examples for using these graphs are provided in the following section, "City Specific Data."

[1] The scalar ratio can be viewed as the series present worth factor (SPWF), which takes account of the building study period (life), the discount rate, and other factors.

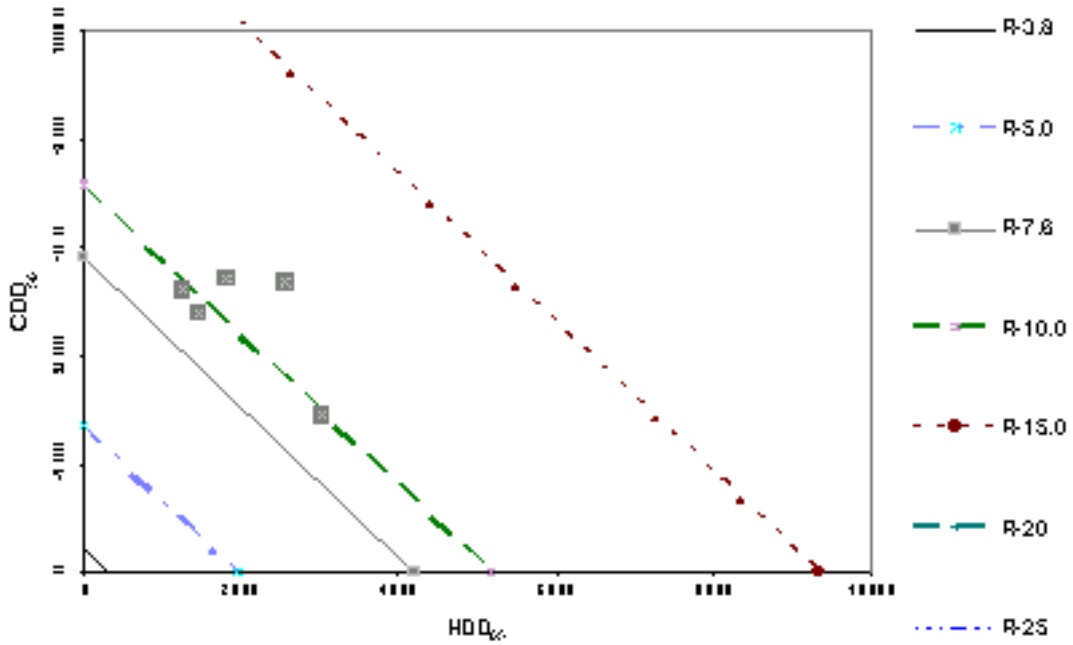

Figure 3 : Example Graph for a Specific Energy Price, Construction Class, Space Category and Scalar

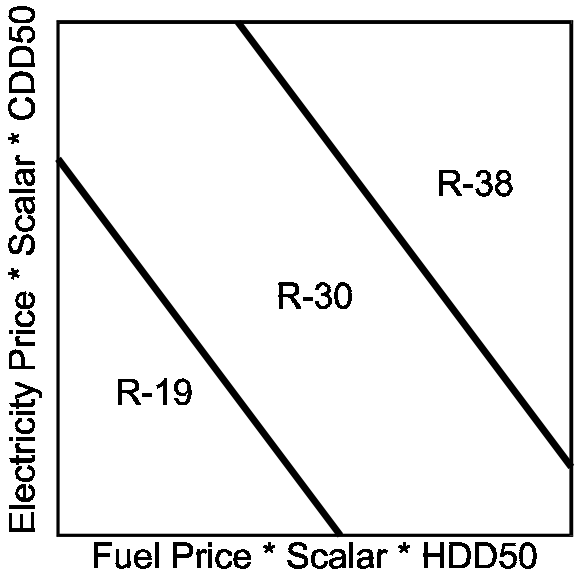

Figure 4 : Example Graphic Presentation for a Space Category and Construction Class

Nonresidential Buildings

The following graphs in Figure 5 through Figure 7, present the results for each construction class for nonresidential buildings. Three different x-axes are provided one for gas heating, one for heat pump heating and one for electric resistance heating. PF on the Fuel Heating axis, stands for Price of Fuel in $/therm. PE on the Heat Pump and Electric Resistance axis, and on the y-axis stands for Price of Electricity in $/kWh. Note that there may be different heating and cooling electric prices for a particular location.

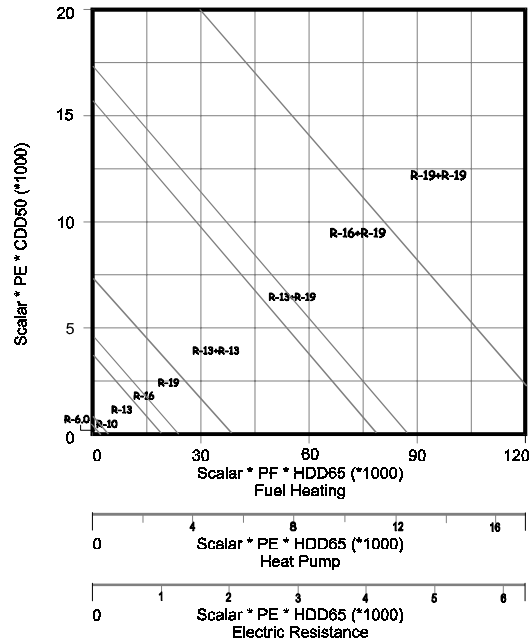

Figure 6 - Recommended Roof Insulation, Metal Building, Nonresidential

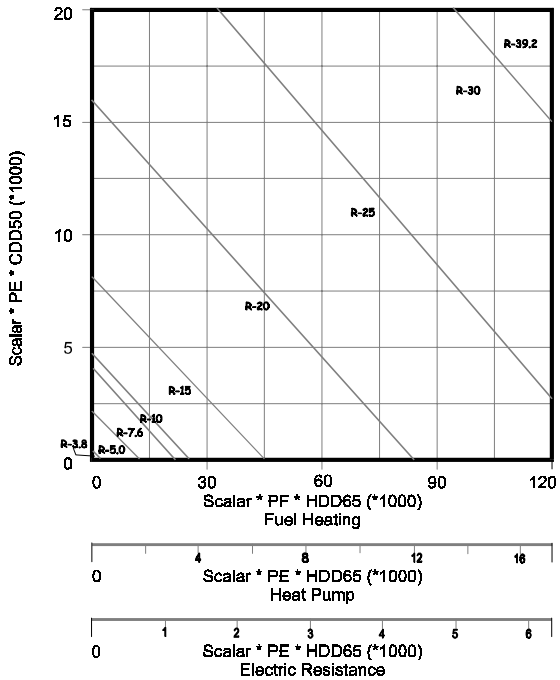

Figure 5 - Recommended Roof Insulation, Insulation Above Deck, Nonresidential

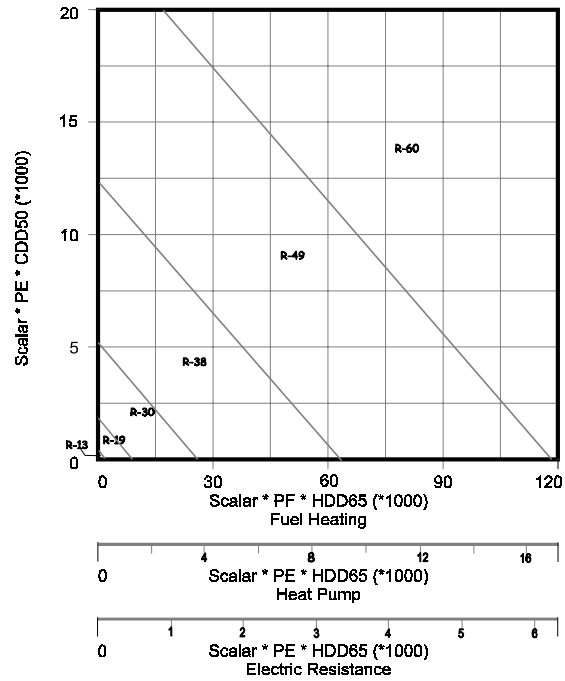

Figure 7 - Recommended Roof Insulation, Attic and Other, Nonresidential

Residential Buildings

The following graphs in Figures 8 through 10, present the results for each construction class for residential buildings, including hotel/motel guest rooms, nursing homes and dormitories. Three different x-axes are provided, one for gas heating, one for heat pump heating and one for electric resistance heating. PF on the Fuel Heating axis, stands for Price of Fuel in $/therm. PE on the Heat Pump and Electric Resistance axis, and on the y-axis stands for Price of Electricity in $/kWh. Note that there may be different heating and cooling electric prices for a particular location.

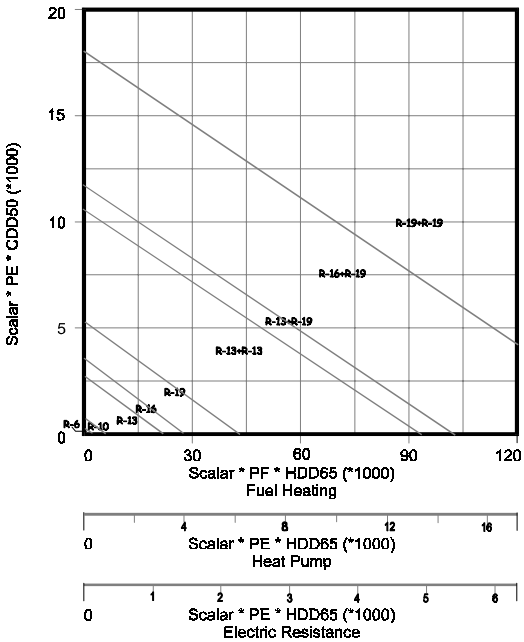

Figure 9 - Recommended Roof Insulation, Metal Building, Residential

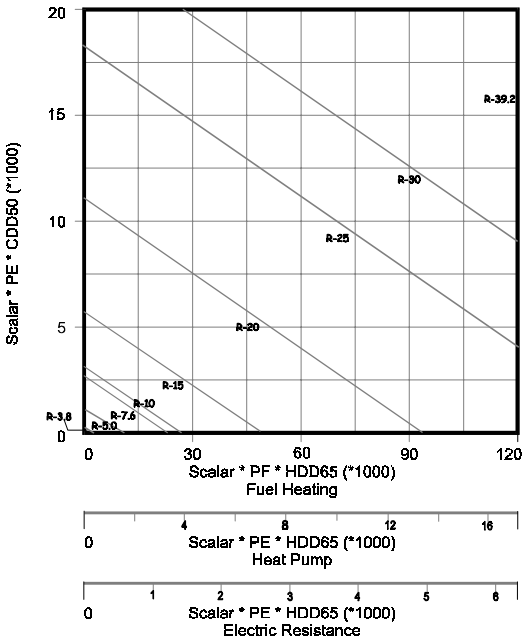

Figure 8 - Recommended Roof Insulation, Insulation Above Deck, Residential

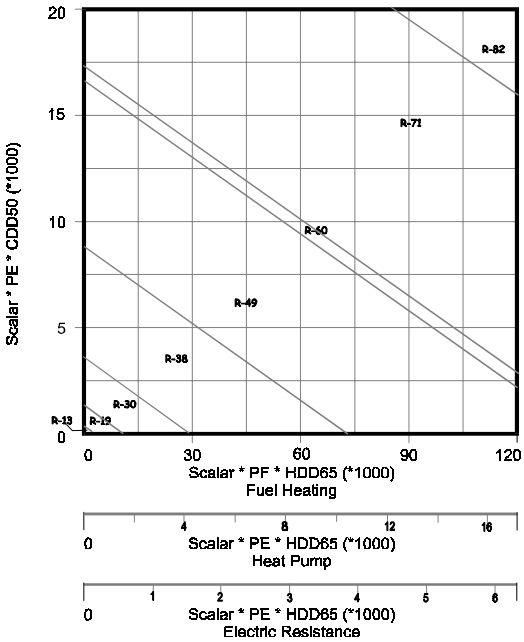

Figure 10 - Recommended Roof Insulation, Attic and Other, Residential

Semi-heated Buildings

The following graphs in Figures 11 through 13, present the results for each construction class for semi-heated buildings, including warehouses and industrial facilities. Three different x-axes are provided, one for gas heating, one for heat pump heating and one for electric resistance heating. PF on the Fuel Heating axis, stands for Price of Fuel in $/therm. PE on the Heat Pump and Electric Resistance axis, and on the y-axis stands for Price of Electricity in $/kWh. Note that electricity costs for cooling are irrelevant because this type of building has no air conditioning.

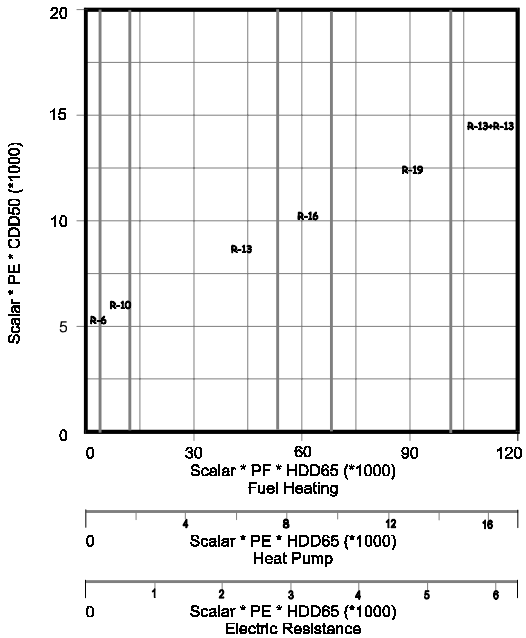

Figure 12 - Recommended Roof Insulation, Metal Building, Semi-Heated

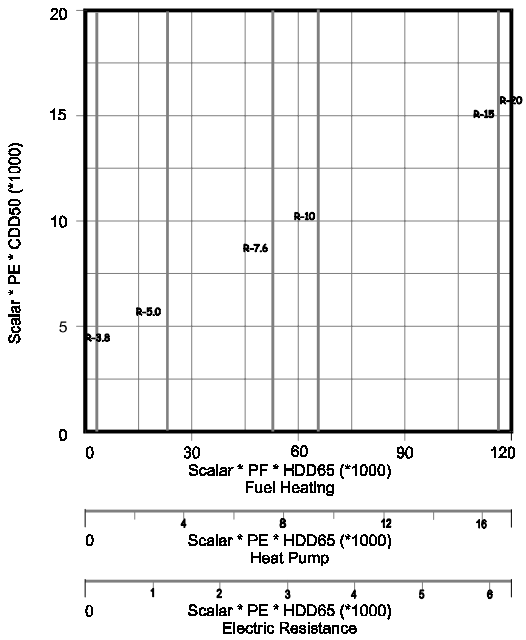

Figure 11 - Recommended Roof Insulation, Insulation Above Deck, Semi-Heated

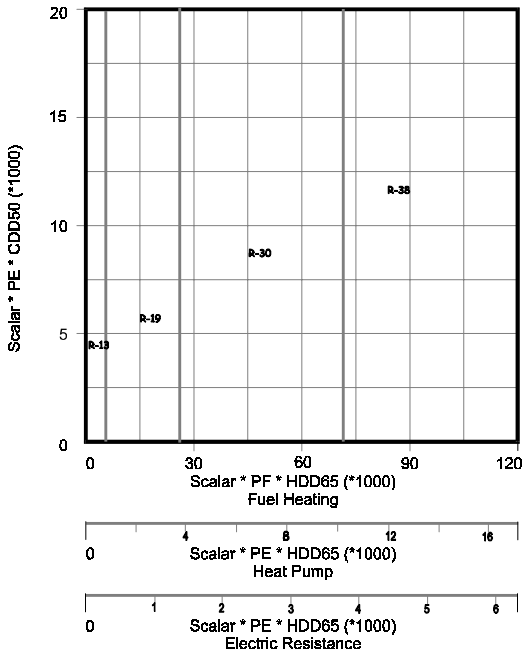

Figure 13 - Recommended Roof Insulation, Attic and Other, Semi-Heated

B. City Specific Data

The table in Figure 14 gives climate data, and average electricity and fuel prices for representative cities in the United States. To ease the process of using graphs 5 through 13, the heating and cooling factors are calculated for these typical conditions. The table in Figure 15 shows the cost-effective insulation levels for each city based on the two scalars and construction type, assuming gas heating. The following graphs, in Figure 16 through Figure 25, provide the graphical results for Insulation Above Deck .

Varying the gas price moves the result back and forth across the x-axis. Varying the electric price moves the result up and down the y-axis. For areas with low cooling loads, the result will not be strongly influenced by a variation in the cooling term resulting from changes in electric rates. Similarly, results for areas with low heating rates will not be strongly affected by variations in gas rates.

Note that the line spacing increases as the insulation levels increase. This is because the cost-effectiveness of adding additional insulation decreases as the thickness or R-value of the insulation increases. That is, for each additional increment of insulation there is less of an incremental benefit. At a certain level increased insulation will not have any noticeable affect.

These graphs may be used to solve for the gas, PF, or electric price, or PE, for any given insulation level. This will provide an estimate of the fuel rates at which the next level of insulation, increase or decrease, becomes cost-effective. For example, we can determine the gas price at which R-20 insulation becomes cost-effective for Chicago, Scalar 8 as follows (refer to Figure 17):

$$\text{Heating term} = \text{Scalar} \times \text{HDD} \times \text{PF}$$

$$= 30{,}000 = 8 \times 6536 \times \text{PF}$$

$$\text{PF} = \frac{30{,}000}{52{,}288}$$

$$= \$0.58/\text{therm}$$

Lowering the gas rate to $0.22/therm will lower the requirement to R-10. Using the same approach for a scalar of 18, increasing the electric rate from $0.11/kWh to $0.13/kWh increases the level to R-25. While the price increases may be exaggerated, this methodology provides a means for gauging the sensitivity of several different factors on the impact of insulation levels.

A comparison of the plots for Atlanta (Figure 16) and Chicago (Figure 17), shows how the results are affected by the climate data (HDD and CDD). The variation in the Atlanta results between a scalar of 8 and a scalar of 18 is more vertical, indicating the larger impact of cooling. The variation in the Chicago results for the two scalars is more horizontal, indicating a larger impact of heating. For both Atlanta and Chicago, the results are fairly close to the line. This suggests that a variation in fuel price, PF for heating and PE for cooling, may change the cost-effective option. For example, in Atlanta, the average electric rate is $0.11/kWh. If the rate were $0.10/kWh the multiplier would be 9,068 lowering the insulation requirement to R-20. Similarly, using a different gas rate for a scalar of 18 in Chicago, of $0.55/therm, raises the insulation requirement to R-25.

The insulation requirements for Fort Worth (Figure 18) are more influenced by the cooling term, due both to a relatively larger CDD than HDD and to low gas prices. The Scalar 18 requirements for both Fort Worth and Los Angeles (Figure 19), will increase from R-20 to R-25 from small changes in either the heating multiplier or the cooling term.

As with Fort Worth, the Miami requirements are affected primarily by the cooling term. Although Miami has high gas prices, a decrease in the gas price will not affect the insulation requirement, as indicated in Figure 20.

In Phoenix (Figure 21), where gas and electric prices are fairly average, the scalar 8 results are very cost sensitive. A slight decrease in the gas price will change the requirement to R-15 as will a slight decrease in the electric price.

The results for San Diego (Figure 23) are similar to the other cities with low heating load, with the cooling term having a larger effect than the heating product. Since San Diego has a mild climate, the results are primarily driven by energy prices. The high electric rate in San Diego, results in the relatively high insulation requirement.

The result for a scalar of 8 for San Francisco is on the R-10 line, as shown in Figure 24. Any increase in either the heating or cooling term, will change the result to R-15. Lowering either the gas rate or the electric rate could bring the requirement down to R- 7.6.

A similar result exists for the scalar 18 conditions in Washington D.C. The cost-effective requirement, as plotted in Figure 25, is R-25. Any decrease in either the heating or cooling term, will change the requirement to R-20.

City	Heating Values		Cooling Values		Scalar	Multiplier	
	HDD	Gas Rate	CDD	Elec Rate		Heating	Cooling
Atlanta	2991	$0.63	5038	$0.11	8	15,014	4,478
					18	33,781	10,075
Chicago	6536	$0.39	2941	$0.11	8	20,229	2,614
					18	45,514	5,881
Fort Worth	2304	$0.23	6557	$0.11	8	4,233	5,828
					18	9,524	13,113
Los Angeles	1458	$0.55	4777	$0.15	8	6,382	5,571
					18	14,359	12,535
Miami	200	$0.99	9474	$0.09	8	1,583	7,033
					18	3,562	15,825
Phoenix	1350	$0.71	8425	$0.11	8	7,655	7,084
					18	17,224	15,938
Riverside	1861	$0.54	5295	$0.12	8	8,040	4,978
					18	18,090	11,201
San Diego	1256	$0.68	5223	$0.17	8	6,830	6,957
					18	15,367	15,653
San Francisco	3016	$0.57	2883	$0.11	8	13,794	2,498
					18	31,036	5,620
Washingotn D.C.	4707	$0.84	3709	$0.12	8	31,780	3,676
					18	71,506	8,270

Figure 14 - Climate and Energy Price Data for Typical Cities

City	Scalar Ratio	Insulation Above Deck	Metal Building	Attic and Other
Atlanta	8	R-15	R-19	R-38
	18	R-25	R-13+R-19	R-49
Chicago	8	R-15	R-19	R-38
	18	R-20	R-13+R-13	R-49
Fort Worth	8	R-15	R-19	R-38
	18	R-20	R-13+R-13	R-49
Los Angeles	8	R-15	R-19	R-38
	18	R-20	R-13+R-13	R-49
Miami	8	R-15	R-19	R-38
	18	R-25	R-13+R-19	R-49
Phoenix	8	R-20	R-13+R-13	R-38
	18	R-25	R-16+R-19	R-49
Riverside	8	R-15	R-19	R-38
	18	R-20	R-13+R-13	R-49
San Diego	8	R-15	R-19	R-38
	18	R-25	R-16+R-19	R-49
San Francisco	8	R-10	R-19	R-30
	18	R-20	R-13+R-13	R-38
Washington D.C.	8	R-15	R-13+R-13	R-38
	18	R-25	R-16+R-19	R-49

Figure 15 - R-value Criteria for Select Cities and Scalar Ratios

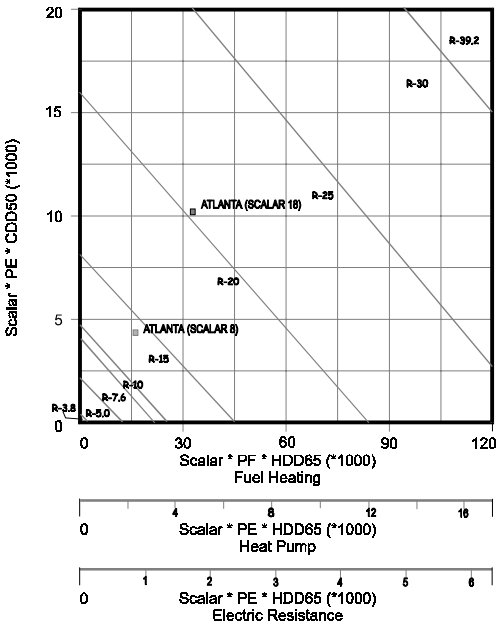

Figure 16 - Insulation above Deck Requirements for Atlanta, for Gas Heating

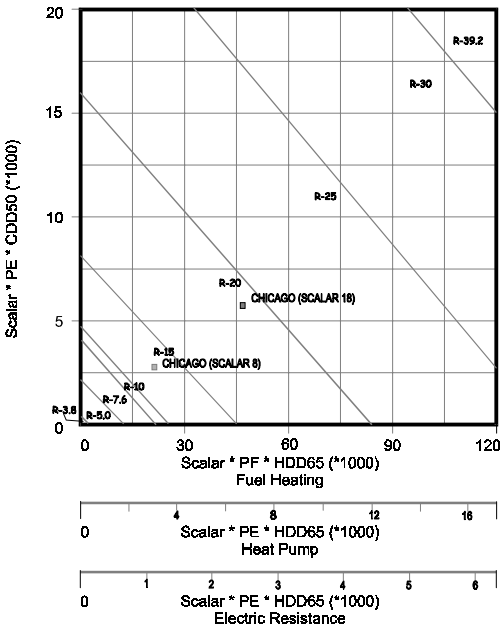

Figure 17 - Insulation above Deck Requirements for Chicago, for Gas Heating

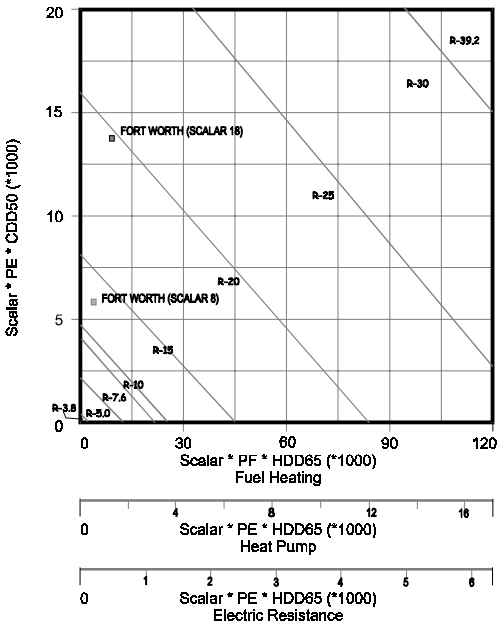

Figure 18 - Insulation above Deck Requirements for Forth Worth, for Gas Heating

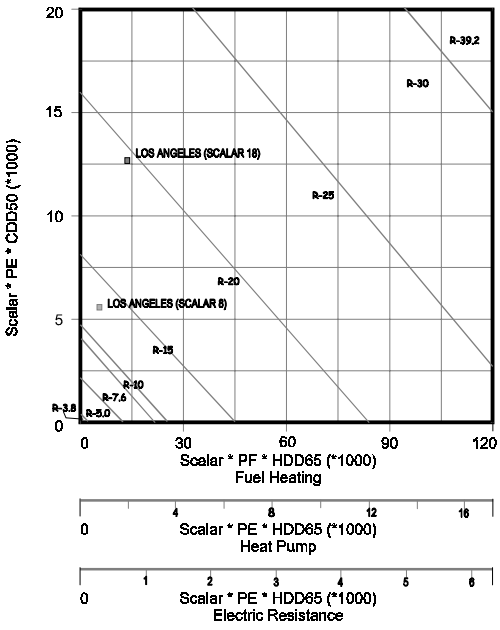

Figure 19 - Insulation above Deck Requirements for Los Angeles, for Gas Heating

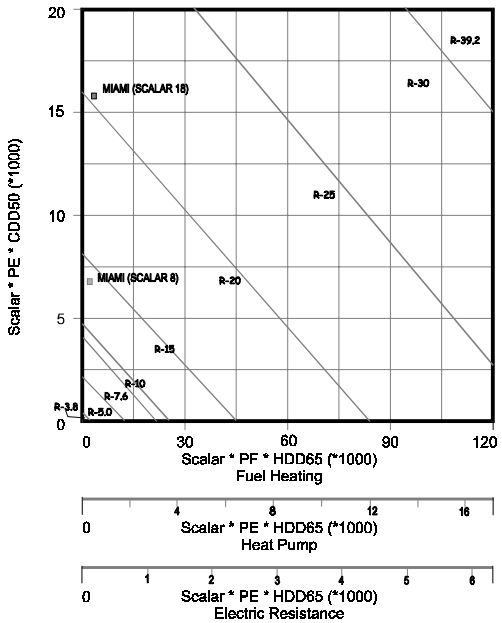

Figure 20 - Insulation above Deck Requirements for Miami, for Gas Heating

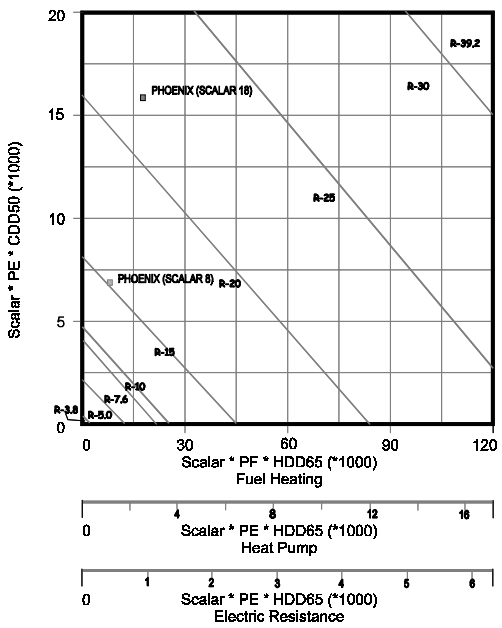

Figure 21 - Insulation above Deck Requirements for Phoenix, for Gas Heating

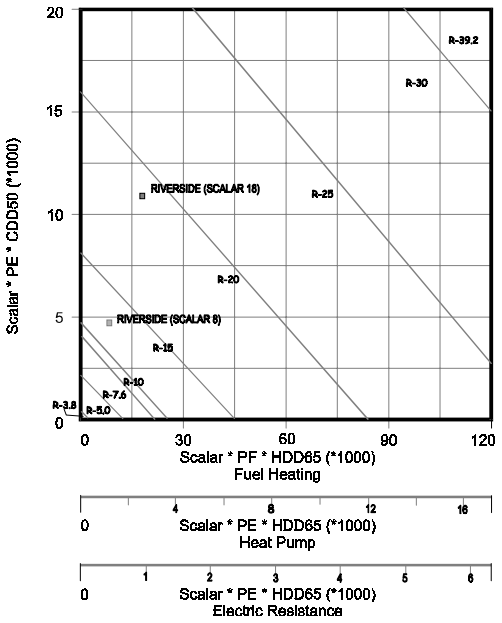

Figure 22 - Insulation above Deck Requirements for Riverside, for Gas Heating

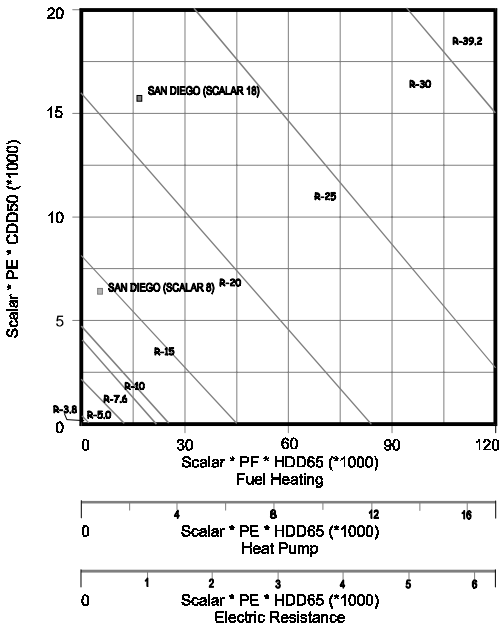

Figure 23 - Insulation above Deck Requirements for San Diego, for Gas Heating

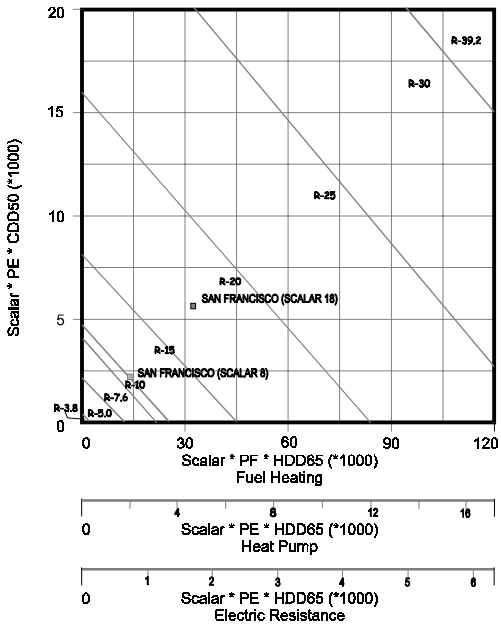

Figure 24 - Insulation above Deck Requirements for San Francisco, for Gas Heating

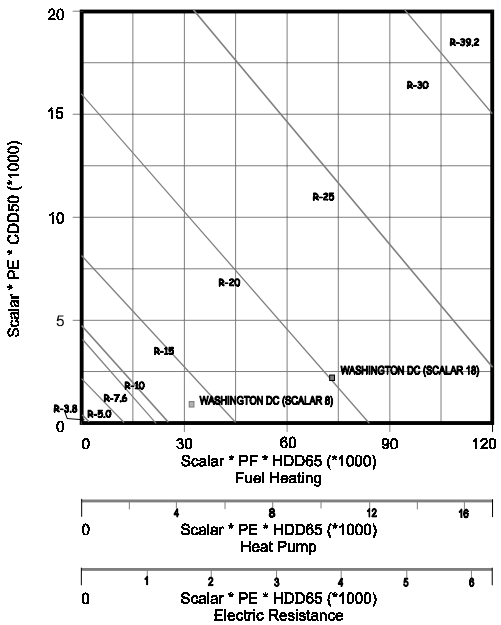

Figure 25 - Insulation above Deck Requirements for Washington D.C., for Gas Heating

C. Additional Examples

The following additional examples illustrate how the graphs can be used for values other than those provided in the tables above.

Gas Heat in Chicago

Consider a gas heated residential building in Chicago with average electricity and fuel prices from Figure 14. The building owner will accept a scalar ratio of 12. What is the recommended attic roof insulation level for these conditions?

Figure 14 lists the heating and cooling degree days for Chicago and the average electricity and fuel prices. The cooling and heating factors in Figure 14 are for scalars of 8 and 18. We must determine the factors for a scalar of 12. This calculation is shown below.

$$\text{HeatingFactor} = 20{,}229 \times 12/8 = 30{,}343$$

$$\text{CoolingFactor} = 2{,}614 \times 12/8 = 3{,}921$$

With the Heating Factor and Cooling Factor determined, the recommended roof insulation level is R-38 from Figure 10 for residential buildings with attics.

Electric Heat in Atlanta

Consider a nonresidential building in Atlanta with electric resistance heat. The price of electricity is $0.11/kWh. The building owner will accept a scalar ratio of 15. What is the recommended metal building roof insulation level for these conditions?

The Heating and Cooling Factors must be calculated for this case since the fuel price and scalar are different from the averages. We can, however, use the heating and cooling degree days. The Factors are calculated as shown below.

$$\text{HeatingFactor} = \text{Scalar} \times \text{PF} \times \text{HDD65} = 15 \times 0.11 \times 2{,}991 = 4{,}985$$

$$\text{CoolingFactor} = \text{Scalar} \times \text{PE} \times \text{CDD50} = 15 \times 0.11 \times 5{,}038 = 8{,}396$$

Refer to Figure 6 for metal roof insulation level for nonresidential buildings. On the x-axis of Figure 6, read the Heating Factor (4,985) from the scale that indicates the heating factors for electric resistance heat. On the y-axis read the Cooling Factor (8,396). The recommended metal roof insulation level is R-19+R-19.

CHAPTER 6: BIBLIOGRAPHY

ASHRAE *1997 Fundamentals Handbook*, Chapter 22.

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Insulation Fact Sheet , DOE/CE-0180, June 1997.

Plant Engineers and Managers Guide to Energy Conservation, Albert Thumann, Fairmont Press, Lilburn, GA 1989.

CHAPTER 7: APPENDIX - SCALAR RATIO & SIR

Throughout the Guidelines, the terms scalar ratio and SIR (savings to investment ratio) are used to describe the economic analysis of measures. A scalar ratio is a mathematical simplification of life cycle costing (LCC) analysis. An SIR compares the life cycle savings to the initial investment. An LCC analysis is preferable to a simple payback analysis, because it enables a more realistic assessment of all the costs and savings to be expected over the life of an investment. While LCC analysis can be quite complicated and difficult to understand, a scalar ratio and an SIR are relatively simple to use. This discussion explains their meaning and derivation, and provides some guidance on how to use them in better understanding the analysis graphs in these Guidelines.

Scalar Ratios Simplified

In technical terms, the scalar ratio represents the series present worth multiplier. This can be understood by assuming a simple situation: an initial investment in an energy efficiency measure, followed by a series of annual energy savings realized during the lifetime of the measure. The annual energy costs are assumed to escalate at a steady rate over the years and an annual maintenance cost, when included, is assumed to escalate at a different steady rate. Once the included costs and savings are laid out over the life of the investment, each year's net savings is discounted back to present dollars, and the resulting present worth values are summed to arrive at the life cycle energy savings. This number is then divided by the net savings for the first year, to obtain the scalar ratio. Once the scalar ratio is determined, it can be applied to other investment scenarios that share the same economic rates of energy cost and maintenance cost escalation. One simply calculates the first year's energy savings and multiplies it by the scalar ratio to obtain the net present worth of the savings.

The process of discounting these future dollars back to present dollars is a straightforward calculation (most spreadsheets have built-in present worth functions). The present worth of a future dollar earned (or saved) is a function of the number of years in the future that the dollar is earned, and of the discount rate. The discount rate may be thought of as the interest rate one would earn if the first cost dollars were put into a reliable investment, or as the minimum rate of return one demands from investments. If the investment is a good one, the present worth of the discounted savings will exceed the cost of the investment. If the present worth of savings does not exceed the investment cost, then the investment will not provide the minimum rate of return and could be better spent on another investment.

Of course, in the case where the net cost of the higher efficiency equipment is lower than that of the base case equipment, <u>any</u> positive present worth of energy savings indicates a sound investment. In some cases more efficient equipment allows downsizing of other equipment in the building, such as the electrical load center and service drop. These savings can be significant enough to offset the incremental cost of the more efficient equipment, resulting in a lower overall first cost. To be conservative, in the development of these Guidelines, we have ignored these potential related savings.

Likewise, maintenance costs were not included because there are too many variables and the additional complication would not have increased the clarity or accuracy of the analysis.

Figure 26 shows a simple spreadsheet illustrating how this basic scenario would be calculated. In the example, the first year's savings are $1,051. The annual energy savings escalate at 4% per year, and the annual maintenance costs escalate at 2% per year. If you simply add up these costs after five years, you will expect to save $5,734. The discounted present worth is calculated using the spreadsheet's net present value (NPV) function using the string of annual totals and the discount rate. If the discount rate is 15%, these savings have a present worth of $3,799, which is 3.6 times the first year's savings (scalar ratio = 3.6). If the initial investment to achieve these savings was less than $3,799, then it meets the investment criteria and will provide a rate of return greater than 15%. On the other hand, if the discount rate is 3%, the present worth of the savings is $5,239 and the scalar ratio is 5.0. Investors with high discount rates have higher expectations for their returns on investment, and are therefore less willing to invest in efficiency measures that have lower savings. On the other hand, public agencies and most individuals have lower discount rates and accept lower rates of return in exchange for reliable returns. A discount rate of 3% in this example yields a scalar ratio of 5.0 and indicates that a substantially higher initial investment of $5,239 could be justified.

Year:	1	2	3	4	5
Energy Savings (escalated 4%/yr);	$1,200	$1,248	$1,298	$1,350	$1,404
Maint. costs (escalated 2%/yr):	($150)	($153)	($156)	($159)	($162)
Annual totals:	$1,051	$1,097	$1,145	$1,195	$1,246
			(Sum of Annual totals:		$5,734)
Discounted Present Worth: (15% discount rate)	$3,799	/ $1,051 = Scalar:	3.6		
Discounted Present Worth: (3% discount rate)	$5,239	/ $1,051 = Scalar:	5.0		

Figure 26 - Example Present Worth Calculation

Selecting a Scalar Ratio

To use the cost-effectiveness analysis graphs in this Guideline, one must select a scalar ratio by deciding on the economic conditions for their efficiency investments. The example discussed here has been rather simplistic, and the five-year analysis period is quite short for most energy efficiency measures. In selecting a scalar, users should decide on at least the following:

- Period of Analysis - This is the number of years the energy efficiency investment is expected to provide savings. Some users will have a long-term perspective, and will choose a period of analysis that approaches the expected life of the measure. For long life measures, such as building insulation, the period of analysis may be thirty years or more. For mechanical system measures, the period may be fifteen years. Other users may choose a shorter analysis period because they are interested in their personal costs and benefits and are not expecting to hold the property for a long time. Public policy agencies setting energy codes may choose a societal perspective, based on the principle that building investments impinge on the environment and the economy for a longer period of time, and so may select a long period of analysis.
- Discount Rate - This is the real rate of return that would be expected from an assured investment. A rate of return offered by an investment instrument is the investment's nominal interest rate and must be adjusted, by the loss in real value that inflation causes, to arrive at the real interest rate. Nominal discount rates must likewise be adjusted for inflation to find the real discount rate. In order to simplify the analysis, we assumed a zero inflation rate, which then makes the nominal and real discount rates the same. As discussed in the example above, different kinds of people may have different expectations. A lower end interest rate (and discount rate) might be the rate of return expected from savings account or a money market fund (2% - 4%). An upper end might be the rate of return that an aggressive investor expects to produce with his money (10% - 20%), although it is difficult to argue that this represents an "assured investment." Another way to think of the real discount rate is the real rate of return that competing investments must provide in order to change the choice of investments that the organization makes.

The table in Figure 27 shows a range of typical scalars. It presents the resulting scalars for 8, 15 and 30-year study periods, discount rates ranging from 0% to 15% and escalation rates ranging from 0% to 6%.

Savings to Investment Ratios (SIRs)

An extension of the present worth and scalar concepts is the *Savings to Investment Ratio (SIR)*. As indicated above, one is interested in both the incremental first cost of an investment (how much more it costs than the base case) and in the present worth of its cost savings. The SIR provides a simple way to compare the two: divide the present worth of the savings by the incremental first cost (or its present worth if the investment extends over time). If this ratio is greater than one, then the discounted savings are greater than the first cost, and the return on investment will be greater than the discount rate. The cost-effectiveness analysis graphs presented in this Guideline use the SIR on the vertical axis. Thus any points on the curves that lie above an SIR value of one are deemed to be cost effective.

Advanced Economic Analysis

The economic analysis could be more elaborate than the examples discussed here, of course, and could account for more factors. For example, there could be other maintenance costs that recur every few years, the energy cost escalation factors could be non-linear, or the tax deductions for the operating and maintenance costs could be included. In addition, the first costs could be spread out over the years as loan payments and interest cost deductions. All of these costs would be discounted back to present dollar values and summed to arrive at the net present value, which compares the life cycle costs to the life cycle savings[1].

Analysis for different purposes will include both different types of inputs as well as varying levels for the input types chosen. For example, while a commercial building owner is likely to be interested in the economic impacts within a relatively short time frame, e.g., 8-10 years, a state energy office is likely to be more concerned with the societal economic impacts over a much longer term, like 30 years for residential energy codes. A business owner, who is looking at energy efficiency investments relative to other business uses of her capital, might also feel that a discount rate of 15% reflects her value for future energy savings. On the other hand, an energy efficiency program planner or energy code developer could justify a 0% discount rate as representative of the future value of resource savings.

The table in Figure 28 provides guidance on selecting between the range of potential scalars.

A more comprehensive economic analysis might also consider measure interactions and analyze the impacts of numerous building elements as a system. For example, increasing the level of roof insulation can lead to the ability to downsize the cooling equipment. Selection of a gas chiller could potentially allow the downsizing of the electric service drop and load center for the building. The analysis in this Guideline did not include such synergies because of the complication of identifying situations in which the additional savings could be expected.

Appendix section A described the base case buildings that were used in the analysis for these Guidelines. A more comprehensive, targeted analysis would begin with an examination of these building descriptions to determine whether they are representative of the location of interest. The building design can greatly increase or decrease the cost effectiveness of various measures. For example, a base case office building with effective daylighting, reducing internal gains from lighting systems, and high performance glazing on the south, east and west, may have a small enough cooling load that high efficiency equipment will be less cost effective.

Finally, it is assumed in this analysis that a decision about the cost effectiveness of options is being made at the time of new construction. For program designers focusing on retrofit applications of these technologies, additional first costs will need to be included. This is less of an issue when the change-out is due to equipment failure and replacement is required. In the case of replacements for equipment that is still functioning, the incremental first cost will be the full cost of the new equipment minus the salvage value of the equipment removed. Obviously, the energy savings must be of much greater value to justify replacing equipment before the end of its useful life.

As this discussion illustrates, a thorough economic analysis of energy efficiency investments can require considerable thought and calculation. The scalar and SIR approach used throughout these Guidelines provide a convenient method for simplifying the economic analysis task. For many purposes, this will be sufficient, provided the decision-makers who will be relying on this analysis understand its limitations.

[1] For a more in-depth description, see *Plant Engineers and Managers Guide to Energy Conservation*, by Albert Thumann, Fairmont Press, Lilburn, GA 1989.

	Scalars for 8 year period				Scalars for 15 year period				Scalars for 30 year period			
	Escalation rates				Escalation rates				Escalation rates			
Discount Rates	**0%**	**2%**	4%	**6%**	**0%**	**2%**	**4%**	**6%**	**0%**	**2%**	**4%**	**6%**
0%	8.0	8.8	9.6	10.5	15.0	17.6	20.8	24.7	30.0	41.4	58.3	83.8
3%	7.0	7.7	8.4	9.1	11.9	13.9	16.2	19.0	19.6	25.9	35.0	48.3
5%	6.5	7.0	7.7	8.4	10.4	12.0	13.9	16.2	15.4	19.8	26.0	34.9
7%	6.0	6.5	7.1	7.7	9.1	10.4	12.0	13.9	12.4	15.5	19.9	26.0
9%	5.5	6.0	6.5	7.1	8.1	9.2	10.5	12.1	10.3	12.6	15.7	20.0
11%	5.1	5.6	6.0	6.5	7.2	8.1	9.3	10.6	8.7	10.4	12.8	15.9
13%	4.8	5.2	5.6	6.1	6.5	7.3	8.2	9.3	7.5	8.8	10.6	12.9
15%	4.5	4.8	5.2	5.6	5.8	6.5	7.4	8.3	6.6	7.6	9.0	10.8

Figure 27 - Range of Typical Scalars

INPUT	IF INPUT:	THEN SCALAR TENDS TO:
Measure Life	Increases	Increase
Discount Rate	Increases	Decrease
Energy Cost Escalation Rate	Increases	Increase
Maintenance Escalation Rate	Increases	Decrease
Inflation Rate	Increases	Decrease
Mortgage Interest Rate	Increases	Decrease
Tax Advantage	Increases	Increase

Figure 28 - Variable Effects on Scalar