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A study of energy use for homes built in Iowa: Evaluating changes in the Model Energy Code and investigating the potential savings of utilizing compact fluorescent bulbs in the home.

by

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CHAPTER 1. GENERAL INTRODUCTION

For many years energy suppliers encouraged the public to use as much energy as possible. Prior to the 1970s, energy was inexpensive and readily available. The general public regarded cheap sources of energy as a key to increasing the standard of living. The public used energy for any labor-saving device available, from electric can openers to larger cars. The public also used energy wastefully. At the time, energy was cheap so there was little incentive or effort to conserve it. If the cost of natural gas needed to heat a building was cheaper than the cost of adding additional insulation, it would seem financially economical for a building to have little insulation and to use a lot of natural gas for space heating.

The oil embargo of 1973 forced many homeowners to face the possibility of not having enough energy to heat their homes. Two major public responses arose from the growing recognition of the energy shortage. The initial response was to expand rapidly the country's sources of energy. The other response called for more energy conservation. Since new or additional sources of energy were not readily available on a cost effective basis, energy conservation was promoted as a viable solution to the energy supply problem. Many home owners started to conserve energy by adding insulation to their homes. However, their efforts to conserve energy were mainly in response to the increasing cost of heating oil rather than to the energy crisis. During this time, the rising cost of energy created a powerful incentive to conserve (Fowler, 1990, p2).

In 1977, the state of Iowa adopted the document known as the Model Energy Code (MEC) created by the Council of American Building Officials. The MEC lists regulations pertaining to the design and construction of new buildings in order to control future energy consumption. This code is revised every three years. The intent of the MEC is to regulate the design of building envelopes for adequate thermal resistance and low air leakage (MEC, 1977-

92, p1). The code also establishes requirements for the selection of mechanical, electrical, and illumination systems which will provide effective use of energy in new building construction.

The body of this research project involves two separate but related topics. The first topic is to evaluate the impact of changes in the regulations set forth by the Model Energy Code for an individual home owner and for the state of Iowa both in terms of energy savings and in dollar savings. This material is covered in chapters 1 to 4. The second topic is a study comparing the cost of using a variety of incandescent bulbs versus using energy saving compact fluorescent bulbs to accomplish the same lighting tasks This material is covered in chapters 5 to 8.

The provisions set forth by the MEC are intended to provide enough flexibility to encourage the development of innovative approaches to achieve effective energy use. The provisions of the code are structured to allow compliance with the code by any of the following design paths.

(1) A systems approach for the entire building and its energy subsystems which may utilize nondepletable sources of energy. (See chapter 4 of MEC)

(2) A component performance approach for various building elements and mechanical systems and components. (See chapter 5 of MEC)

(3) Specified acceptable practice. (See chapter 6 of MEC)

The third design path for compliance with the MEC requires that each separate section of a building must be built in accordance with the specifications set by the MEC. Thus all of the parts of a building envelope, i.e. the walls, roof/ceiling, and floor, must be constructed according to the specified methods.

The second design path for compliance with the MEC requires that each separate building component must comply with a performance guideline, usually expressed as a maximum allowed average U-value. This design path was chosen for my calculations on annual home heating usage and costs because it provided the simplest model. The MEC uses customary or "British" units rather than SI metric units, so the calculations will be carried out using the units used in the MEC.

The main focus of the research performed was to calculate the annual energy requirements and associated costs to heat a standard home that meets the minimum requirements for the thermal resistance of the building envelope and the efficiency of the heating device set forth by the MEC for the years 1977, 1983, 1986, 1989, and 1992. (A copy of the 1980 MEC was not available.)

The result of these calculations will be used to evaluate the impact of the changes in the MEC in terms of energy savings and environmental concerns, particularly in the release of carbon dioxide into the atmosphere. These results will be discussed in chapter 3 of this report.

Before proceeding with the calculations involved with this project, it would be useful to discuss several general aspects about heat loss and providing heat for a house. In addition to the home's primary heating system (i.e., the furnace or an electric heat pump), there are other sources of energy that contribute to heating the living space. Electricity used for lighting and electrical appliances is eventually converted to heat. Thermal energy radiated from people and the sun also contribute to heating the living space. These secondary energy sources can provide nearly 25% of the total energy required to heat a home. The amount of heat generated by these secondary sources is largely dependent on the personal habits of the members of the household but will tend to be approximately constant from year to year for any one particular household.

The amount of heat loss in a home will affect the comfort of the occupants and their finances. The human body at rest will emit 300 to 500 Btus of heat per hour when the air temperature is around 70 F°. The amount of energy that a body radiates is dependent on the temperature of its surroundings. Increasing the air temperature will reduce the amount of heat radiated by the body and thus makes us feel warmer. However, the air temperature alone is not a true guide to the comfort of the living space. The humidity, the air movements, and the amount of clothing, in addition to the temperature, will determine the comfort level of the living space.

The humidity of the air surrounding a body will partly determine its rates of evaporation and radiation. Humidity is a relative measure of the air's moisture content. High humidity decreases body radiation and evaporation which makes one feel warmer while low humidity increases body radiation and evaporation which makes one feel cooler. Therefore in winter, the excessively dry air will require higher air temperatures to make one feel warmer. This will increase heating costs as well as causing the throat and nasal passages to become dry. By increasing the air's humidity, these conditions may be alleviated.

The air movements inside a home will also affect an individual's comfort. Large air movements will increase the "draft" effect felt by a body. To compensate for this sensation, there will be an increase in the body's radiation, causing one to feel chilly. For proper comfort, the air in a room should not move faster than about 1/2 mile per hour. Higher velocity air movement is a reason why many people are dissatisfied with forced air heating.

For proper comfort, the air temperature inside a room and the temperature of the surroundings should be as close as possible. If the temperature of a wall is more than 10 F° below that of the room, the region near the wall will feel uncomfortable. If the walls of a building are very well-insulated compared to the glass in a window, areas near the window will seem much colder than areas around the walls because the body will radiate more heat to the cold window surface. This will make a person feel uncomfortable regardless of the air temperature in the rooms. Thus it is evident that air temperature is not an absolute index to measure the comfort of a living space.

CHAPTER 2. HEAT LOSS CALCULATIONS FOR A MODEL HOME

2.1 Methods of Heat Loss

A building will lose heat due to the three different physical processes of heat transfer: conduction, convection, and radiation.

Conduction is the process by which thermal energy is transferred through an object or between two objects as the result of molecular collisions. Heat conducts only if there is a temperature difference. The heat loss through the surfaces of the building envelope will be due to heat conduction.

Convection is the process whereby heat is transferred by the mass movement of molecules from one place to another. Whereas conduction involves molecules moving only over microscopic distances and colliding, convection involves the movement of molecules over macroscopic distances. The main sources of heat loss due to convection will arise from cold air infiltration and warm air exfiltration through the cracks and openings of a building structure.

The heat loss of an object through radiation is due to all objects radiating energy continuously in the form of electromagnetic waves. Buildings will lose energy by radiation through their windows. The amount of energy radiated by a body is proportional to the fourth power of the body's absolute temperature, T^4. Therefore, objects that are relatively cool will radiate much less energy than objects that are relatively hot. Windows will lose some heat by radiative processes.

2.2 Calculation of Annual Fuel Use and Cost

To calculate the annual fuel use for heating a home, it is necessary to know:

* the temperatures experienced at the home's location, generally expressed in terms of the average number of heating degree-days

* the heat loss from the house for the design temperatures (referred to as the specified internal and external temperatures)

* the rate of air infiltration/exfiltration, generally expressed in terms of the number of air changes per hour

2.2.1 Heating Degree Days

Heating degree days are defined as the number of degrees the average outdoor temperature deviates from a base temperature for each day during the heating season. For this project, as is customary among architects and engineers, the base temperature was taken to be 65 F°. For example, if the average outdoor temperature for a particular day was 10 F°, the number of degree days for that particular day would be 65 F° - 10 F° = 55 degree days. If the average outdoor temperature was higher than the base temperature, then the negative difference is counted as zero. Across Iowa, the annual average total of degree-days ranges from 6000 in southeast Iowa to 8000 in northern central Iowa. For a home in Ames, the average annual number of degree days is about 6800.

Heating degree days can be used to predict roughly a structure's heating costs for a specified period of time. The cost of fuel for a month divided by the number of heating degree days for that month provides the cost of heat per degree day. Using this number it is possible to estimate roughly the heating cost for any time period by multiplying the heating cost per degree days by the total number of degree days for that period.

2.2.2 Air Changes Per Hour

The number of air changes per hour will largely depend on the construction of the building. For reasonably well-built, insulated buildings without weatherstripping and without storm sash, approximately one air changes per hour occurs. For reasonably well-built, insulated buildings with weatherstripping and storm sash, approximately one-half an air change per hour occurs.

2.2.3 Calculating Heat Loss

2.2.3.1 Insulation, U-values and R-values

Any material used in the construction of a building will have some insulation value. However, a building's insulation materials are much more effective at resisting heat flow than the denser materials used in its construction. The R-value of a material measures its resistance to the flow of heat. An R-value is the reciprocal of a material's thermal conductance U, (i.e., R = 1/U). In the "British" system, the units for R are (hour x ft^2 x degree F) / Btu. Higher numerical R-values indicate that the material will have a greater resistance to the flow of heat. This will also correspond to a low value for the thermal conductance, U.

For a composite slab consisting of several different materials, the total R-value of the slab will depend on the orientation of the materials. If the heat transfer is directed through one layer of material at a time (i.e., the materials are placed in series), the total R-value of the slab will be the sum of the individual R-values of the various materials.

$$R_{total} = R_1 + R_2 + R_3 + \ldots \quad \text{(series)}$$

If the heat flow is directed through all of the materials simultaneously, then the total R-value can be found using the expression:

$$1/R_{total} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots \quad \text{(parallel)}$$

In terms of the thermal conductivity U, (R = 1/U)

$$U_{total} = U_1 + U_2 + U_3 + \ldots$$

R-values and U-values for many building materials are listed in many books. The most extensive list of these values can be found in the ASHRAE Handbook of Fundamentals.

2.2.3.2 Heat Loss Calculations

The standard home chosen for modelling the heat loss calculations is shown in Figure 2.1. The R-values for the elements of the building were chosen in accordance with the minimum requirements set forth by the MEC. These values for the appropriate year of the MEC are listed in the appendix of this report.

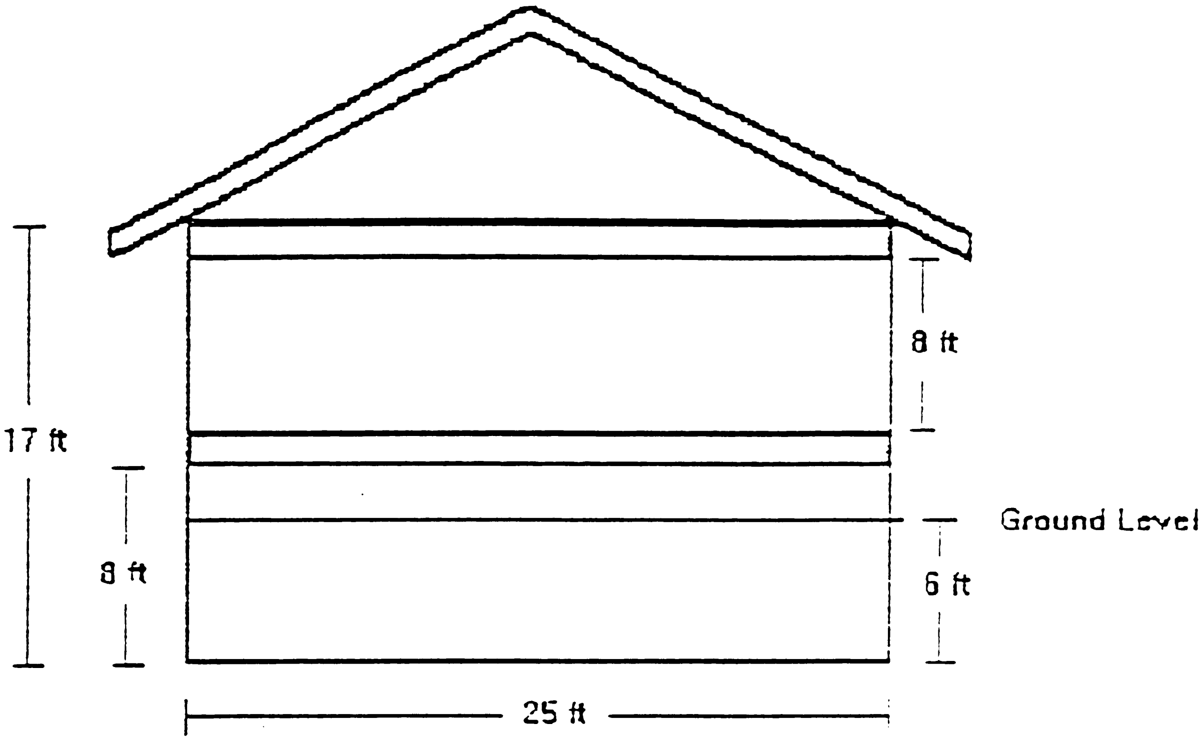
By calculating the amount of heat loss for the separate elements of the building envelope, it is possible to determine a heat-loss coefficient for each element with units of Btu/degree-day. The total heat-loss coefficient for a building will be the sum of all the coefficients for different building elements. For a simple estimate of a building's heat loss coefficient, four separate sources of heat loss will be considered. These sources are:

A. Heat losses through above-ground walls, windows, and doors
B. Heat losses through the roof/ceiling
C. Underground heat losses
D. Heat loss due to air infiltration and exfiltration

Sources A, B, and C represent the building's heat losses due to conduction and partly radiation. The convective heat losses will be due to cold air infiltration and warm air exfiltration through cracks and openings in the building's structure. The MEC only has requirements pertaining to the heat loss through the above ground walls, roof, and underground walls. There are no set requirements pertaining to air infiltration. All of the heat loss calculations were performed using the worksheet titled HHICODE, (Home Heating Index Code). A hard copy of the worksheet can be found in the appendix of this report.

A. Heat Losses Through Exterior Walls

The exterior wall surface is composed of the walls, doors, and windows. The MEC requires that the overall thermal conductivity of the exterior wall surface can not exceed the set standard of U_0 for the year in which the home was built. For example, the maximum allowed



Building Volume	21250	cu. ft.
Area per Level	1250	sq. ft.
Total Floor Area	2500	
Ceiling Surface Area	1250	
Through Insulation	1125	
Through Rim Joist	125	
Upper Level		
Wall Surface Area	2700	
Wall Area	2106	
Window Area	240	
Door Area	54	
Rim Joist Area	300	
Lower Level (Basement)		
Wall Area Above Ground	300	
Wall Area Below Ground	900	

Figure 2.1 Design outline and characteristics of standard home model

U-value for an exterior wall for single family homes built in 1977 was $U_o = 0.260$ (Btu/ hr x ft^2 x F). Thus any combination of U-values for the components of the walls, doors, and windows that gives an overall U-value less than or equal to the specified U_o will allow that building element to meet the requirements of the code.

To calculate the heat loss coefficient for the different components of the exterior wall, multiply the area of the component in ft^2 by 24 (the number of hours in one day) and then multiply by the component's U-value. If the R-value is known instead of the U-value, divide the product of the area and hours per day by the R-value. For each separate component of the outer wall (the walls, doors, and windows) it will be necessary to determine individual heat loss coefficients and find the total for all of the components.

Example: Calculating effective U-values for a composite wall.

A structure's exterior walls are composed of several materials, each providing a different amount of insulation as shown in Figure 2.1a on the following page. Single-pane windows (U = 1.1) cover 15% of the exterior wall surface. The R-value of the exterior surface, the brick veneer and insulated frame, will be the sum of materials' R-values, providing an effective value of R = 14.8. The effective U-value of brick and insulating frame will be the reciprocal of the R-value (U= 0.067). To calculate the total effective U-value of the exterior wall, it is necessary to account for the windows covering 15% of the exposed surface area. The heat flow will be directed through the walls and windows simultaneously, thus the total effective U-value can be determined from the following expression for all of the components used to construct the outer wall,

$$U_{total} = \sum \text{(\% Surface Area) x (U-value)}$$

$$U_{total} = (85\%) \times (0.067) + (15\%) \times (1.1)$$

$$U_{total} = 0.222 \text{ Btu / hr ft}^2 \text{ F}^\circ$$

$$U_{total} = \sum \text{ (\% Surface Area) x (U-value)}$$

$$U_{total} = (85\%) \times (0.067) + (15\%) \times (1.1)$$

$$U_{total} = 0.222 \text{ Btu / hr ft}^2 \text{ F}^\circ$$

$$R_{total} = 1/\,U_{total} = 4.506 \text{ hr ft}^2 \text{ F}^\circ \text{ / Btu}$$

The single-pane windows greatly reduce the wall's resistance to heat flow. The total effective U-values and R-values for the same type of wall using single-pane windows (U=1.1), double-pane windows (U=0.5), and double-pane windows with a low emissivity coating (U=0.4) with the windows accounting for 0 to 20% of the external surface area are shown in Figures 2.2 and 2.3. Examining these figures, it is evident that for window area greater than 5%, the type of window used can greatly affect the overall thermal resistance of the exterior walls.

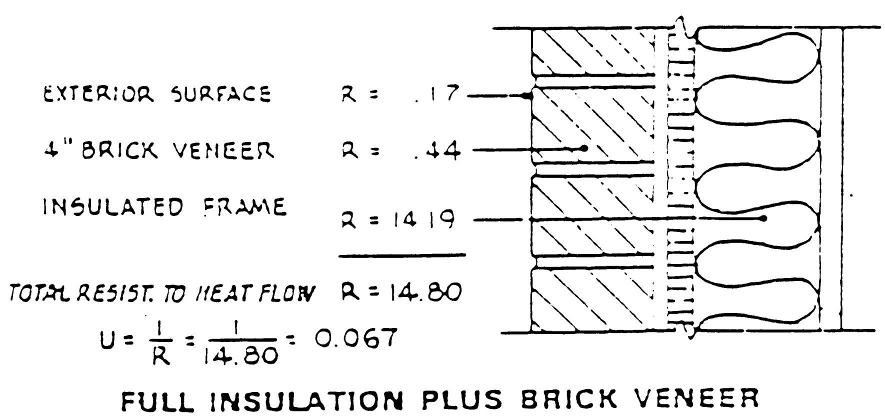
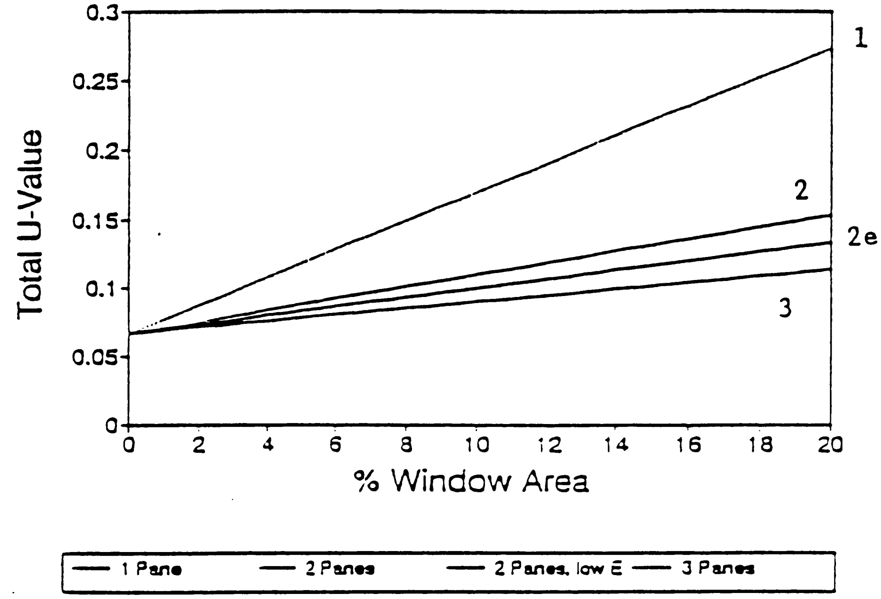


Figure 2.2 Example wall surface



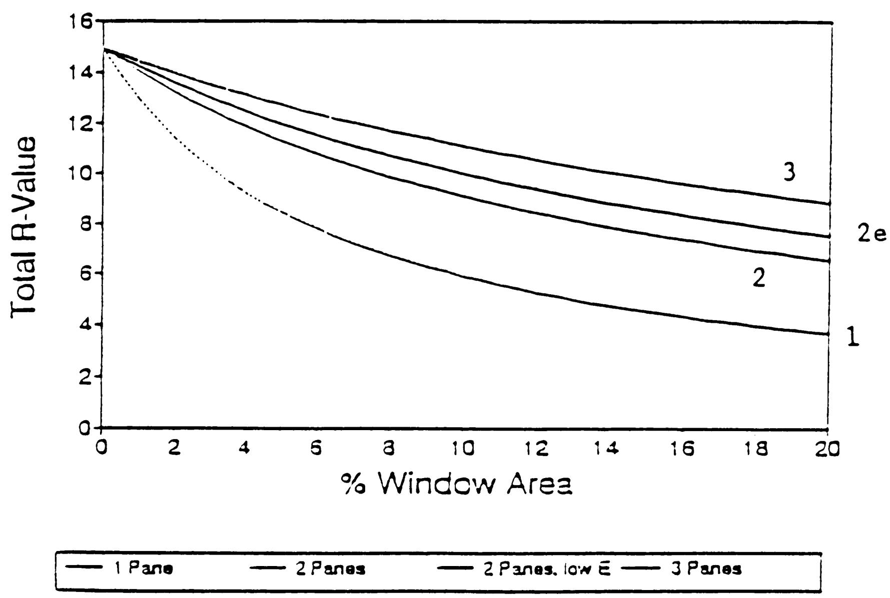


Figure 2.3 a) Total U-value and b) Total R-value of example exterior wall st

B. Heat Loss Through Roof or Ceiling

To calculate the heat loss coefficient for the roof or ceiling of a structure, use the same method as described for the exterior walls. Again, one must find separate coefficients through the insulation and through the attic joist. If the home has a sky light, the thermal conductivity of the sky lights must be included in a similar fashion as the windows on the exterior walls treated in part A.

C. Underground Heat Loss

The heat loss for the envelope of the building underground is more complicated than the roof and wall calculations. A reasonable method for these heat loss calculations is to use a modified R-value for the underground walls. The modified R-value equals the R-value of the wall insulation plus twice the average depth of the underground portion of the wall measured in feet. For a wall that extends 8 ft. underground, the average depth of the wall will be 4 ft., so one would the add 2 x 4 = 8 to the R-value.

D. Heat Loss Due to Air Infiltration/Exfiltration

The heat loss due to air infiltration/exfiltration is difficult to calculate accurately because it is difficult to make a precise measurement of the air infiltration rate. This rate will largely depend on the construction quality of a structure. This will make the heat loss due to air infiltration the largest source of uncertainty in determining a building's heat loss. A simple method for calculating the heat loss from air infiltration is given by the formula,

$$\text{Heat loss} = 0.018 \times (\text{Number of air changes per hour}) \times 24 \times (\text{Volume of indoor air in ft}^3).$$

The constant 0.018 is the heat capacity of air in Btu/(degree x ft^3).

The total heat loss of a building during a specified time period can be found by multiplying the heat loss coefficient (in Btu/DD) by the number of heating degree-days in that time period. If a home had a heat loss coefficient of 26,000 Btu/DD and there were 7,000 DD in the annual heating season, the total heat loss for that heating season will be,

(26,000 Btu/DD x 7,000 DD) = 182 million Btu.

2.2.4 Calculating Expected Fuel Consumption and Cost for a Heating Season

The amount of heat needed to keep the home warm will not equal the amount of energy that must be supplied by the furnace. Part of the energy required to heat the home will be supplied by internal heat generation from lights, appliances, and other electrical equipment. This will amount to about 100,000 Btu/day. Also, the heating system will have an efficiency less than 100%, so only some of the energy used by the heating system will contribute to heating the home.

To determine the expected fuel consumption for a non-solar home during a specified time period, subtract the total amount of heat from internal generation (# days in period x 100,000 Btu/day, or whatever value is assumed) from the calculated heat loss determined by the method described in Section 2.2.3. The resulting heat loss will equal the required amount of heat to be provided by an auxiliary heating system. The expected fuel consumption can be determined by dividing the remaining heat loss by the efficiency of the fuel and heating system.

Fuel consumption = Auxiliary heat loss / (Fuel Btu content x Heating efficiency)

The expected fuel cost can now be determined from the price of the fuel and the fuel consumption.

Expected Heating Cost = (Fuel consumption) x (fuel price per unit measure)

<u>Example</u>: Let's assume that the total Btu loss for a home during the heating season is estimated to be 100 million Btu after accounting for internal heat generation. If the home uses

a natural gas furnace with a 60% efficiency releasing 100,000 Btu per ccf, the expected fuel consumption will be 1833 ccf of natural gas.

(110,000,000 Btu) / (100,000 Btu per ccf x 0.60) = 1833 ccf of natural gas

If the cost of natural gas is $0.55 per ccf, the expected fuel cost for the heating season will be $1,008.

All of the calculations performed in estimating a home's heat loss coefficient, total heat loss, auxiliary heat loss, expected fuel consumption, and expected cost were calculated for the standard home just meeting the MEC requirements for the years 1977, 1983, 1986, 1989, and 1992 by use of computer worksheet. A printed copy of the worksheet is shown in the appendix of this report.

CHAPTER 3. RESULTS OF MEC STUDY

The results of the calculations described in chapter 2 of this report have been assembled into a series of graphs in order to evaluate the impact of any changes in the regulations set forth by the MEC during the years 1977 to 1992. The changes in the MEC regulations have contributed to energy savings, dollar savings and environmental conservation for the individual home owner. In this section, four significant changes in the MEC regarding the building envelope and the heating system will be evaluated.

3.1 Changes in the MEC for the Building Envelope and Heating System

The maximum allowed values for the thermal conductance U_0 for a home's exterior walls, roof/ceiling, and basement walls are shown in Figures 3.1 and 3.2 along with their corresponding R-values. Before 1989, there were no requirements on the basement walls, so a thermal conductive value of U = 0.5 (corresponding to a typical concrete wall) is shown. All of the maximum allowed values for the thermal conductance depend on the number of heating degree days at the home's location, so they vary from one part of Iowa to another. The U-values and the R-values for this study are based upon an annual average of 6800 degree days corresponding to central Iowa, but the figures also show their values for the extremes of 5600 degree-days in southeast Iowa and 8000 degree-days in northcentral Iowa.

One of the most significant developments in the MEC building envelope regulations occurred in 1989. Before this year, there was no set minimum standard for the thermal resistance of the basement walls, (the common average was R = 2 or U = 0.5). In 1989 the MEC set the standard for basement walls to have a maximum value of U = 0.094. This reduced a home's heat loss through the basement walls by almost 70% compared homes built before this year. This increase in a home's basement insulation would approximately reduce the annual heat loss by 30 million Btu per year and saving about $250 to $450 a year in

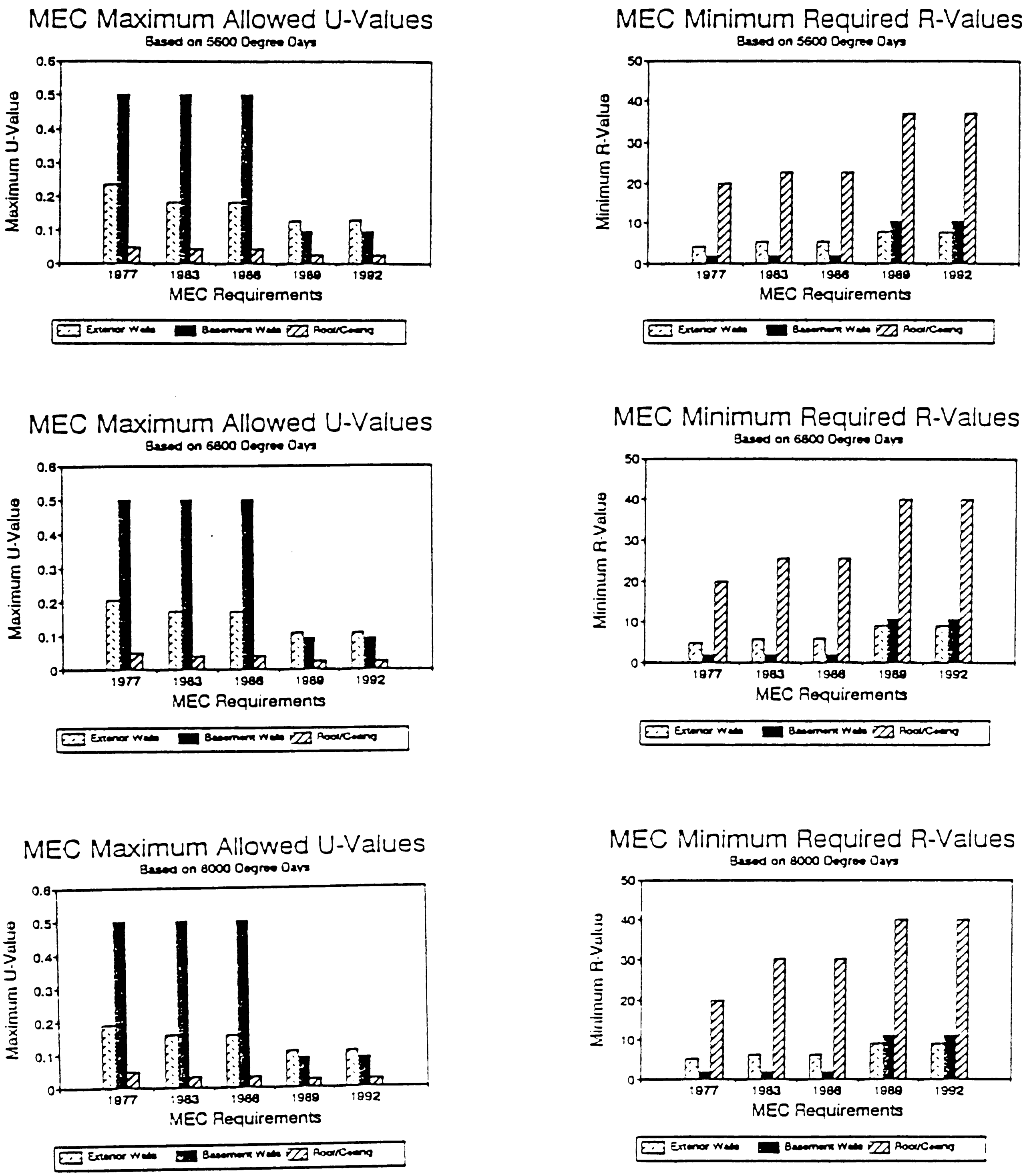


Figure 3.1 MEC requirements for U-value and R-value of building envelope based on 5600, 6800, and 8000 annual degree days

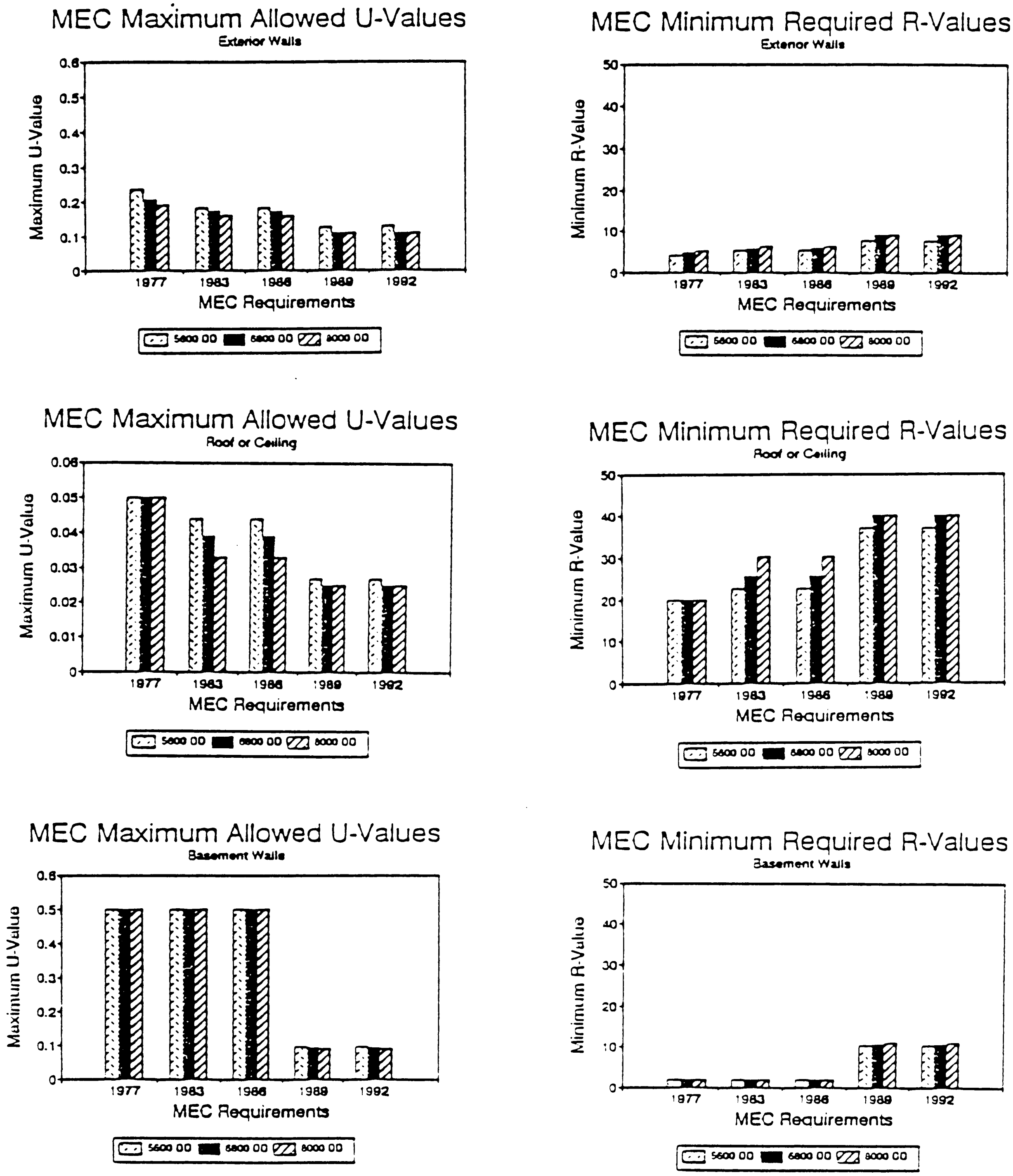


Figure 3.2 MEC requirements for U-value and R-value of building envelope based on 5600, 6800, and 8000 annual degree days

heating costs depending on the fuel source and furnace efficiency.

In 1983 the MEC established the minimum required R-value for a home's roof/ceiling to be R = 25.6 for 6800 degree days. Before this year, there was no minimum required R-value for the roof of a home; a typical value used by many builders was R = 20. This reduced the heat loss through the roof/ceiling by 22%, thus saving about 2.3 million Btu per year. In 1989 the standard for the thermal resistance of the roof/ceiling was increased to R = 40. This increase reduces the annual heat loss through the roof/ceiling by 2.8 million Btu per year compared to homes built during 1983-1988 and saving 5.1 million Btu per year compared to homes built before 1983.

In 1983 the MEC increased the minimum required R-value for a home's exterior walls from R = 3.8 to R= 5.8. This increase approximately reduced the annual heat loss through the exterior walls by 38 million Btu and thus results in saving approximately $950 to $1750 per year in heating costs depending on the fuel source and furnace efficiency. In 1989 the required R-value was raised to R = 9.1. This increase reduced the heat loss through the walls by 27 million Btu per year (saving $375 to $675) compared to homes built during 1983-1988 and reduced the heat loss through the walls by 66 million Btu per year (saving $900 to $1650) compared to homes built before 1983.

From these results, the most significant changes in the MEC requirements for the building envelope have been the adoption of a minimum required R-value for the basement walls in 1989 and increasing the required R-values for a home's exterior walls in 1983 and 1989. In 1983 the MEC also raised the minimum required seasonal operating efficiency of a home's furnace system from 40% to 74%. This increase greatly contributes to the energy savings during the heating season. The results of the changes in the MEC have been assembled into a series of figures listed on the next page. These figures signify the results of changes in the building envelope and the efficiency of the building's heating system in terms of energy use, energy savings and monetary savings.

Figure 3.3	Annual Auxiliary Heat Requirements
Figure 3.4	Annual Energy Use by Heating System
Figures 3.5 - 3.7	Annual Heating Cost for various fuel types
Figure 3.8	Annual Savings for MEC Specifications
Figures 3.9 - 3.11	Annual Savings for various fuel types

By examining Figure 3.8, it is evident that the revisions in the MEC have produced an annual savings of $1200 to $1500 (at today's energy prices) for homes built during 1983-1988 and an annual savings of $1500 to $2100 for homes built during or after 1989 when compared with a home built according to the minimum MEC specifications before 1983. These reults are for the model home and would be less for smaller homes but more for larger homes. Since the annual heat loss for a home has decreased over the years due to changes in the MEC, the necessary heating capacity of the home's heating system could also be reduced. This would provide a significant dollar savings during the construction of a home if the proper furnace size is chosen.

Further energy and dollar savings would also result from the cooling of the living space during warmer periods as a result of the increased insulation required by the MEC. This will reduce the flow of heat from the outdoors and thus cut down on the amount of cooling to be performed by a home's air conditioning system.

3.2 Comparison with a State of the Art Home

The previous calculations and results were done for a home built according to the *minimum* requirements set forth by the MEC. During a 30 to 40 year ownership period, the total cost of energy consumed in the home is comparable to to the purchase price of the home. Therefore, many homeowners will design and/or retrofit their homes to reduce future energy consumption and expense thereby increasing the value of the home.

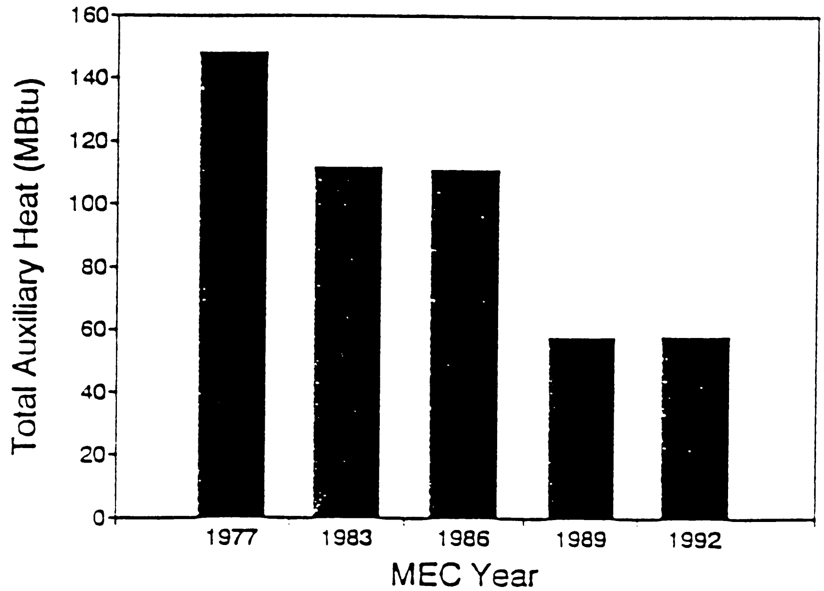


Figure 3.3 Annual auxiliary heat requirements

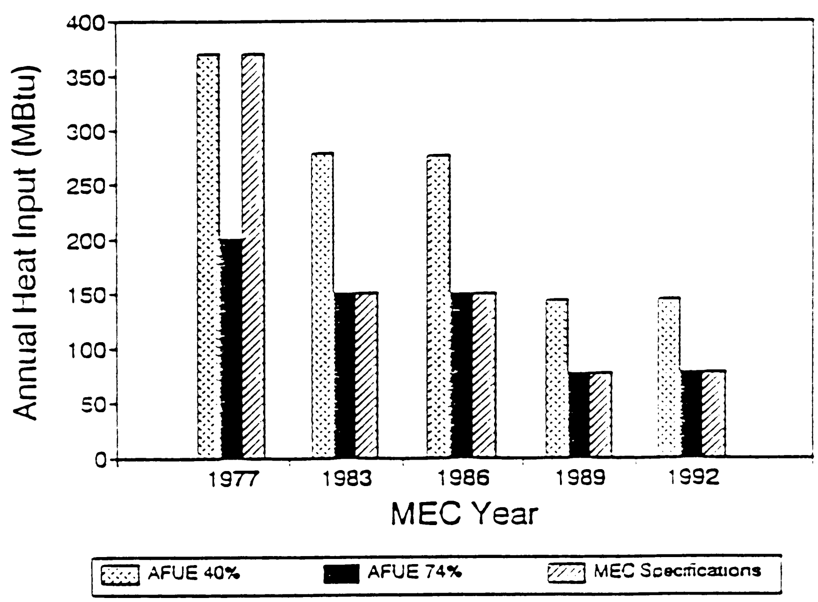


Figure 3.4 Annual energy use by heating system

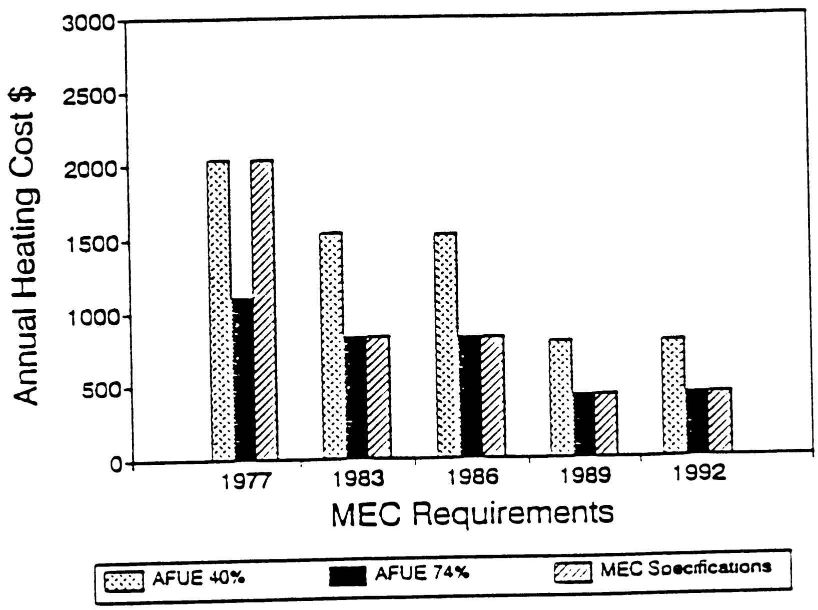


Figure 3.5 Annual heating cost using natural gas

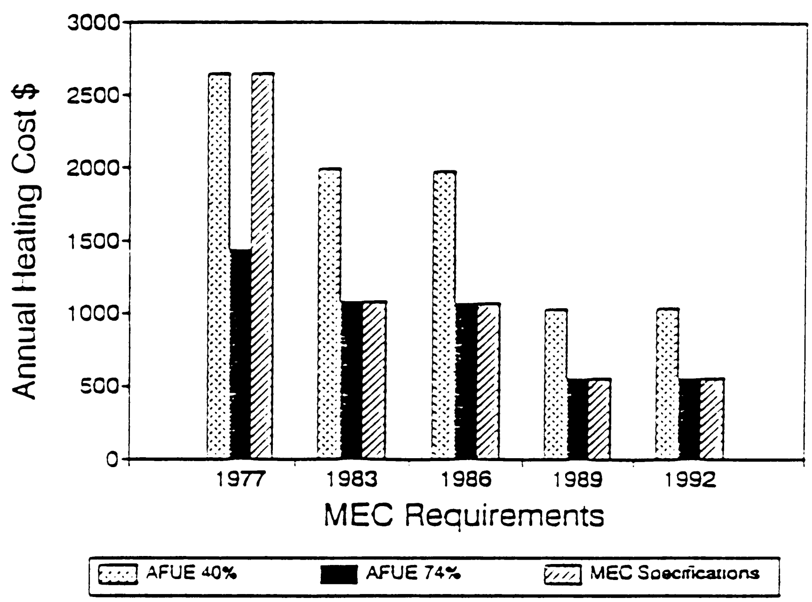


Figure 3.6 Annual heating cost using propane

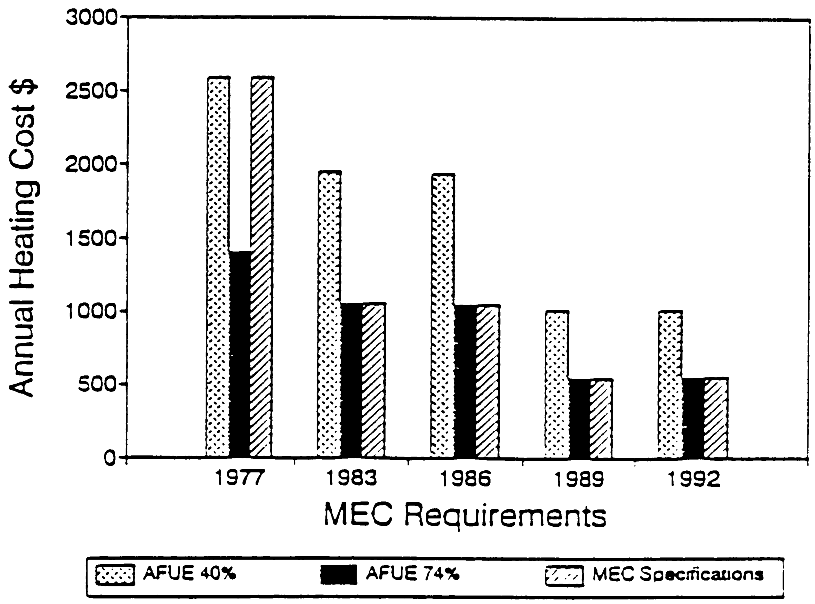


Figure 3.7 Annual heating cost using heating oil

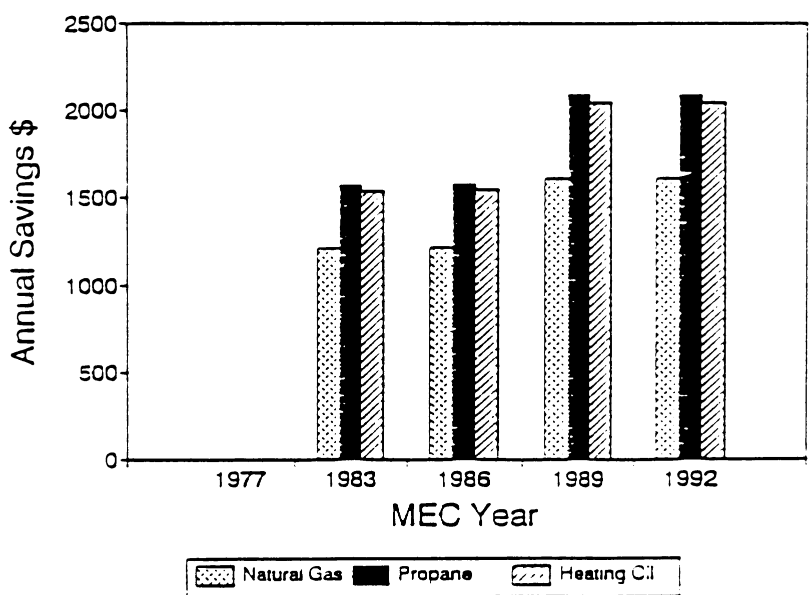


Figure 3.8 Annual savings for MEC specifications compared to MEC

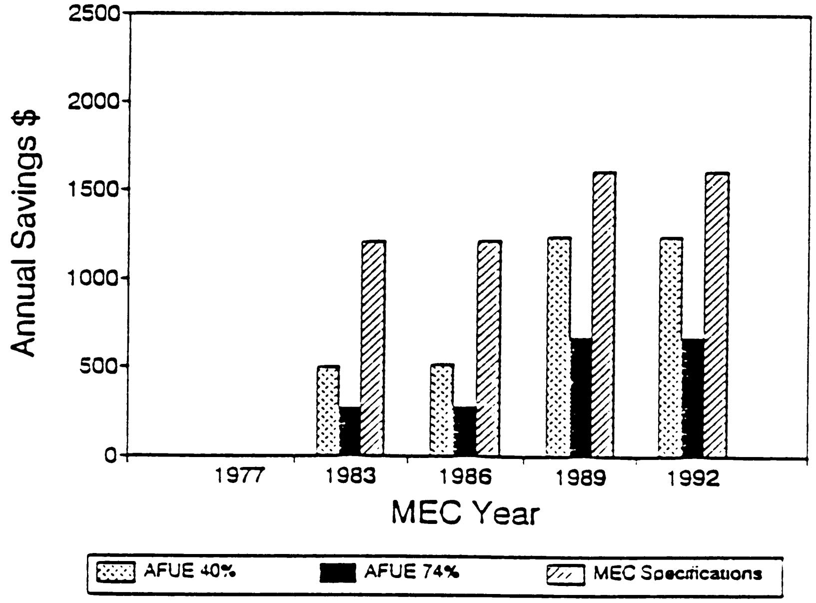


Figure 3.9 Annual savings using natural gas compared to MEC 1977

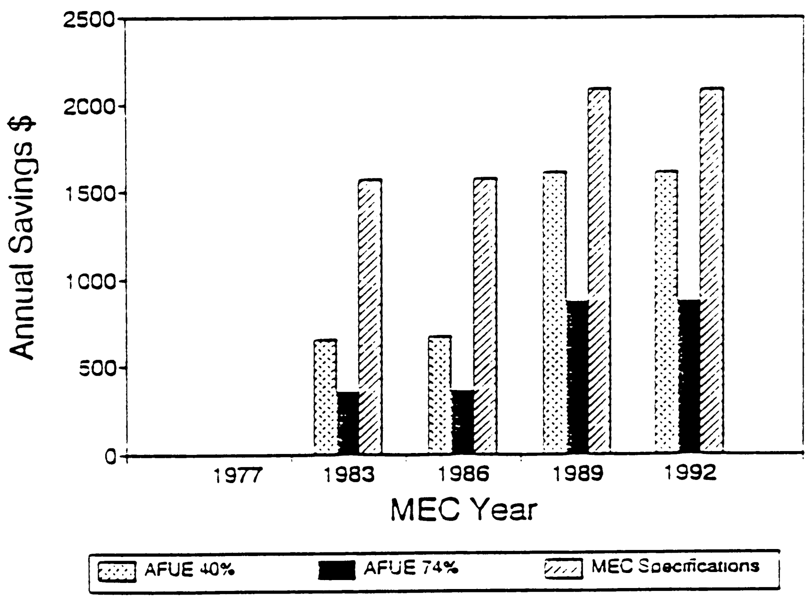


Figure 3.10 Annual savings using propane compared to MEC 1977

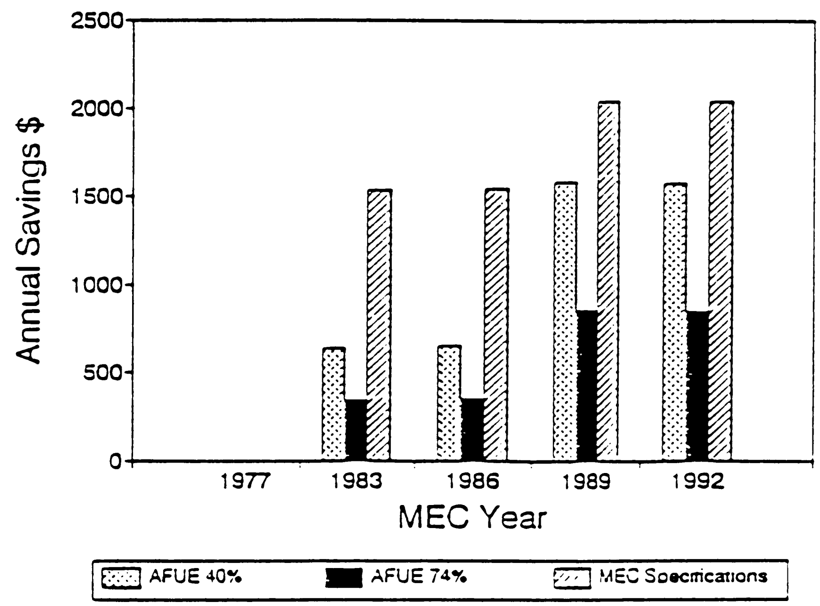


Figure 3.11 Annual savings using heating oil compared to MEC 1977

The R-values of a home's exterior walls, basement walls, roof/ceiling and other characteristics built to according to minimum MEC specifications (based on 6800 DD) are listed along with the corresponding values for a non-solar energy efficient home are shown in Table 3.1. The results of the calculations for annual auxiliary heat requirements (the heat supplied by the home's heating system) and the annual heating costs for homes built according to these values are shown in Figures 3.12 and 3.13 on the next page. A well-built insulated home with a reduced rate of air-infiltration will use approximately 10% as much of the energy for space-heating as will a home built in 1977 complying to the minimum MEC requirements.

Table 3.1 MEC minimum allowed thermal resistance, R-values of building envelope for MEC regulations and an advanced home based on 6800 degree-days

Year	Ext Walls	Basement	Roof/Ceiling	AFUE %
1977	4.9	2.0	20.0	40
1983	5.8	2.0	25.6	74
1986	5.8	2.0	25.6	74
1989	9.1	10.6	40.0	74
1992	9.1	10.6	40.0	74
Adv. Home	14.7	14.9	50.0	90

The advanced energy conserving home also uses windows with a low emissivity coating to reduce radiative heat transfer.

AFUE % - Seasonal operating efficiency of furnace system.

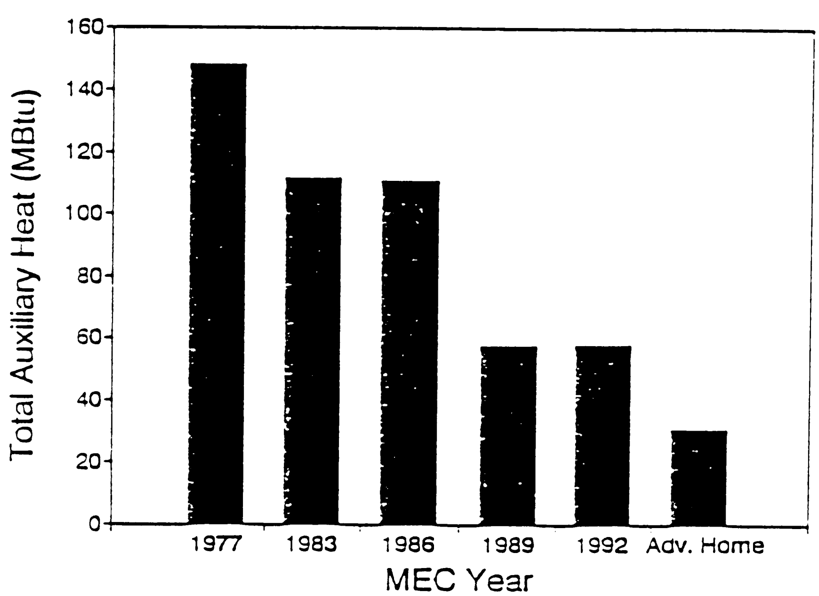


Figure 3.12 Annual auxiliary heat requirements (Advanced energy efficient home)

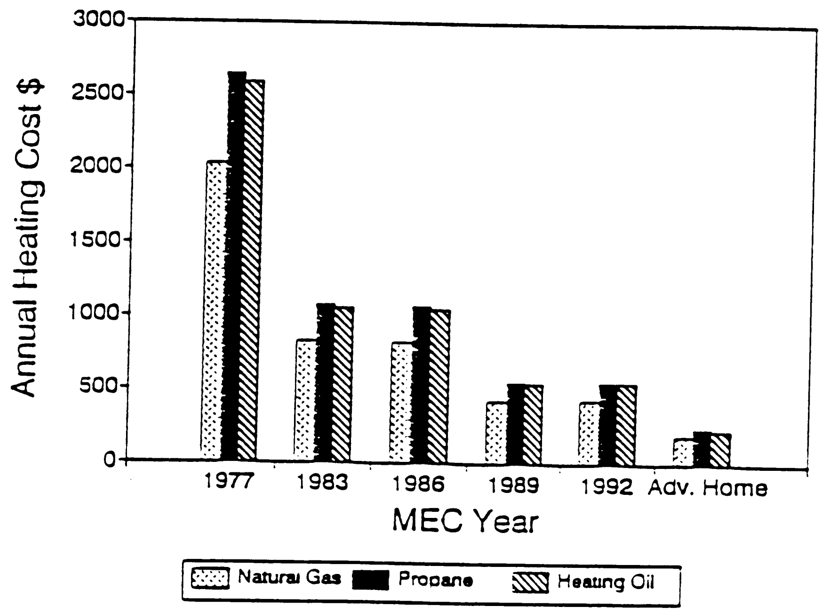


Figure 3.13 Annual heating cost (MEC specifications and an energy efficient home)

The MEC has no requirements pertaining to the rate of air-infiltration (number of air changes per hour) of a home because of the difficulty in measuring this property. The cold air-infiltration rate is not only dependent on the materials used in the home's construction but is also largely dependent on the quality of the craftsmanship of the construction. A well-built home without weatherstripping or storm sash will have an air-infiltration rate approximately one air change per hour. A well-built home with weatherstripping and storm sash will have have approximately one-half of an air change per hour. A minimum air-infiltration rate of one-half air changes per hour is necessary for proper ventilation of odors and germs.

A home can be built to have a natural air-infiltration rate less than one-half air changes per hour but then use an external exhaust system for proper ventilation when desired. To reduce the heat loss by the external exhaust system, a heat exchanger can be used to recover some of this lost heat. A common air-to-air heat exchanger will use streams of air separated by a thin sheet of metal or plastic. Each stream of air is forced by an electrical fan or blower. The warm outgoing air will transfer some of its heat to the incoming cold air by conduction through the thin metal or plastic wall. By the time the warm air is vented outdoors, it has transfered 60 to 80% of its heat to the incoming air. The recovery of this heat results in an effective air-infiltration rate somewhere between the natural rate and the necessary rate for proper ventilation.

3.3 Changes in the MEC: Environmental Impact

As newer editions of the MEC were adopted over the years, the annual amount of energy needed for conditioning the living space has been greatly reduced. This reduction in energy consumption has resulted in reducing the annual amount of pollution produced by a home's heating system. The annual amount of carbon in carbon-dioxide produced by a home's heating system was calculated for three different fuel sources: natural gas, propane and heating oil (Howles, 1990, p 48). To calculate the amount of carbon in carbon-dioxide released by a heating system, it is necessary to know the following:

(1) the carbon content of the fuel source
(2) the percentage of carbon in the fuel that chemically reacts with O_2 to become CO_2
(3) the energy content of the fuel
(4) the total amount of energy used by the heating system.

<u>Example</u>: A natural gas (methane CH_4) furnace uses 200 million Btu of energy during the heating season. The amount of carbon released as CO_2 can be calculated using the following method.

(1) Using the ideal gas law (PV=nRT) at the combustion conditions of 273 K and 1 atm, there will be 117.5 mol (1.41 kg) of carbon released for every ccf of methane burned. (Note: 1 ccf = 100 ft^3)

(2) Virtually all of the carbon in the methane chemically reacts with oxygen to form CO_2. (A small percentage of the carbon in methane will form carbon monoxide, CO.)

$$CH_4 + 2\,O_2 \longrightarrow CO_2 + 2\,H_2O$$

(3) Burning one ccf of natural gas releases 10^5 Btu of heat.

(4) The home's heating system uses 200 million Btu of heat during the season which must be supplied by 2000 ccf of natural gas.

At the rate of 1.41 kg of carbon per ccf of methane, the heating system will release approximately 2820 kg of carbon forming carbon-dioxide during the heating season. Table 3.2 lists the carbon-dioxide rates for different fuels. The variations in the emission rates results from impurities in the fuel type and imperfections in the combustion process.

These amounts of CO_2 produced are shown in Figure 3.14. The annual amount of carbon-dioxide emitted by a home's furnace has been reduced by almost 80% for homes built in 1989 compared with homes built in accordance with the 1977 edition of the MEC. When considering the process and potential impact of carbon-dioxide on global warming, this reduction in carbon-dioxide emissions is very significant.

Table 3.2 Carbon-dioxide emission rates for various fuels [kg of C in CO_2]

Fuel Type	kg C in CO2 per million BTU energy	Adopted Value
Natural Gas	14 - 15	14.5
Liquids fuels from crude oil	19 - 22	20.3
Bitmous coal	25	25.1
Shale oil	30 - 110	
Liquids from coal	32 - 54	
High BTU gas from coal	34 - 43	

Source: Carbon Dioxide Review, 1982, W. C. Clark, ed.

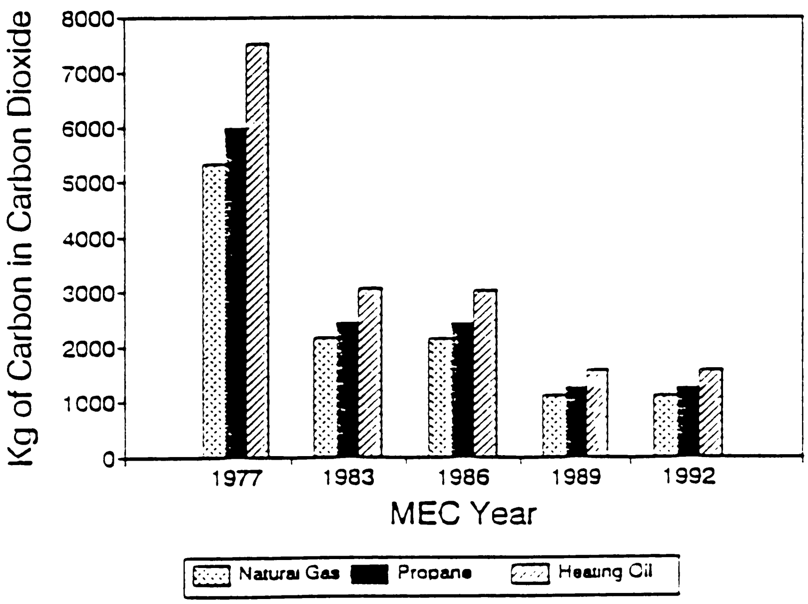


Figure 3.14 CO_2 emissions of various fuel types for MEC spec

CHAPTER 4. CONCLUSIONS OF MEC STUDY

The state of Iowa has continued to adopt the revisions of the Model Energy Code since its creation in 1977. Over the years, the requirements of the MEC have been updated in order to promote a more conservative use of energy in conditioning the living space of a home. The revisions in the MEC have resulted in an approximate $2000 annual energy savings for a 2500 ft^2 home built according to the 1989 and 1992 editions of the MEC compared to the same type of home built in accordance with the 1977 edition of the MEC. The major changes in the MEC responsible for this savings are: (1) the increase in the required R-value for a home's exterior walls in the 1983 and 1989 editions of the MEC, (2) the adoption of a minimum required R-value for the basement walls in the 1989 MEC edition, and (3) the increase in the minimum required seasonal operating efficiency of the home's heating system from 40 to 74 % in the 1983 MEC edition. These changes have not only helped the individual home owner save money, but have allowed the state of Iowa to direct some of the saved energy and monetary savings into other projects.

In order to offset any future rise in energy cost and any increased cost due to the possible implementation of an energy tax, the requirements set forth by the MEC concerning the thermal resistance of the building envelop should be increased. Updating the minimum required R-values of the exterior walls would be the best place to start. The MEC also could adopt some minimum standards regarding the rate of cold air-infiltration in order to reduce the energy loss to the outdoors.

How far should the state of Iowa go in requiring building's to be less energy-intensive depends on how high energy prices can be expected to go up and the availability of the present common sources of energy being used (i.e. natural gas, coal, oil....) in the future. One of the larger problems facing the state presently is the inability to respond quickly to higher energy prices either through improved efficiency or through increased regional supply. In order to reduce the impact of this problems, one priority of the state would be to retrofit existing buildings to some minimum level of energy efficiency. Currently, the MEC does not require existing buildings to under go any retrofit process to reduce energy consumption.

CHAPTER 5. INTRODUCTION TO LIGHTBULB COMPARISON STUDY

The average family uses between 60 and 100 kwh of electrical power each month for domestic lighting. The amount of energy used for lighting is about 8% of the total amount of energy consumed in the home. The traditional light source for providing illumination in the home has been the incandescent lamp. In the home, incandescent lamps have scarcely been challenged as the universal lighting source. While fluorescent and other discharge lamps have steadily been adopted in offices, factories, businesses, and public buildings, incandescent lamps seem to have an unlimited future of use in the home.

Recent technological developments have aided in the production of cheaper low-energy compact fluorescent bulbs that could directly replace the traditional incandescent bulbs while using the same lighting fixtures. The primary aim of this study is to compare the cost of using a variety of incandescent bulbs versus using energy saving compact fluorescent bulbs to accomplish the same lighting task. Additional consideration will be given to the environmental impact for using both bulb types.

5.1 How Light is Produced by Incandescent and Fluorescent Bulbs

The basic operation of an incandescent lightbulb is simple. Incandescent bulbs produce light as a result of the electricity flow through a thin metal filament inside the bulb. As the temperature of the filament is raised above 773 K, a very small amount of visible light is emitted in addition to the infra-red energy emitted at lower temperatures (a standard incandescent bulb will operate between 2000 to 5000 K). The incandescence of the filament is a result of its resistance to the flow of electric current through the wire. Tungsten is commonly used as a filament material because of its high melting point and relatively low rate of evaporation at high temperatures. No other substance presently used is as efficient in converting electrical energy into light on the basis of bulb life and cost.

The light emitted from the incandescent bulb filament is due to blackbody radiation. All physical objects at an absolute temperature T (usually measured in Kelvin units) will radiate thermal energy by electromagnetic waves at the rate described by the Stefan-Boltzman law, $Q/t = e \sigma A T^4$, where: Q is the thermal energy emitted; e is the emissivity of the body, which varies from 0 to 1; σ is the Stefan-Boltzman constant; A is the surface area of the body; T is the absolute temperature of the body; and t is time. An object that absorbs all of the radiation incident upon it is called a blackbody and has an emissivity of 1. A blackbody is a perfect absorber and emitter of thermal radiation.

The Stefan-Boltzman law only describes the amount of energy radiated by the body and nothing about the wavelengths of the emitted radiation. Max Planck developed a radiation law that describes the relative intensity of the emitted thermal radiation as a function of the radiating wavelength and the absolute temperature of the body.

$$\text{Relative Intensity} = \frac{2 \Pi c^2 h}{\lambda^5} \frac{1}{(e^{ch/\lambda kT} - 1)}$$

A plot of this equation showing the relative intensities of the wavelength spectrum for various temperatures is shown in Figure 5.1. A standard incandescent bulb will operate in the 2000 to 4500 K temperature range. For temperatures below this range, the relative intensity of emitted radiation in the visible spectrum (400 to 700 nm) is very small. The relative intensity of the emitted radiation in the visible spectrum increases as the absolute temperature of the body increases. Therefore, higher wattage bulbs operating at higher temperatures will emit more visible light than lower wattage bulbs operating at lower temperatures.

In fluorescent bulbs, an electric current passes through a gas containing a small quantity of mercury droplets. The electrical current flowing through the gas causes the mercury to vaporize at very low pressures. The collisions between the flowing electrons of the current and the mercury vapor atoms displace the bound electrons of the mercury from their normal positions. This causes the mercury atoms to radiate ultraviolet energy at 253.7 nm. This UV energy then excites the phosphor coating of the fluorescent bulb to produce visible light. The mixture of the phosphor coating on the bulb enclosure can be varied in order to produce a variety of colors for the emitted light.

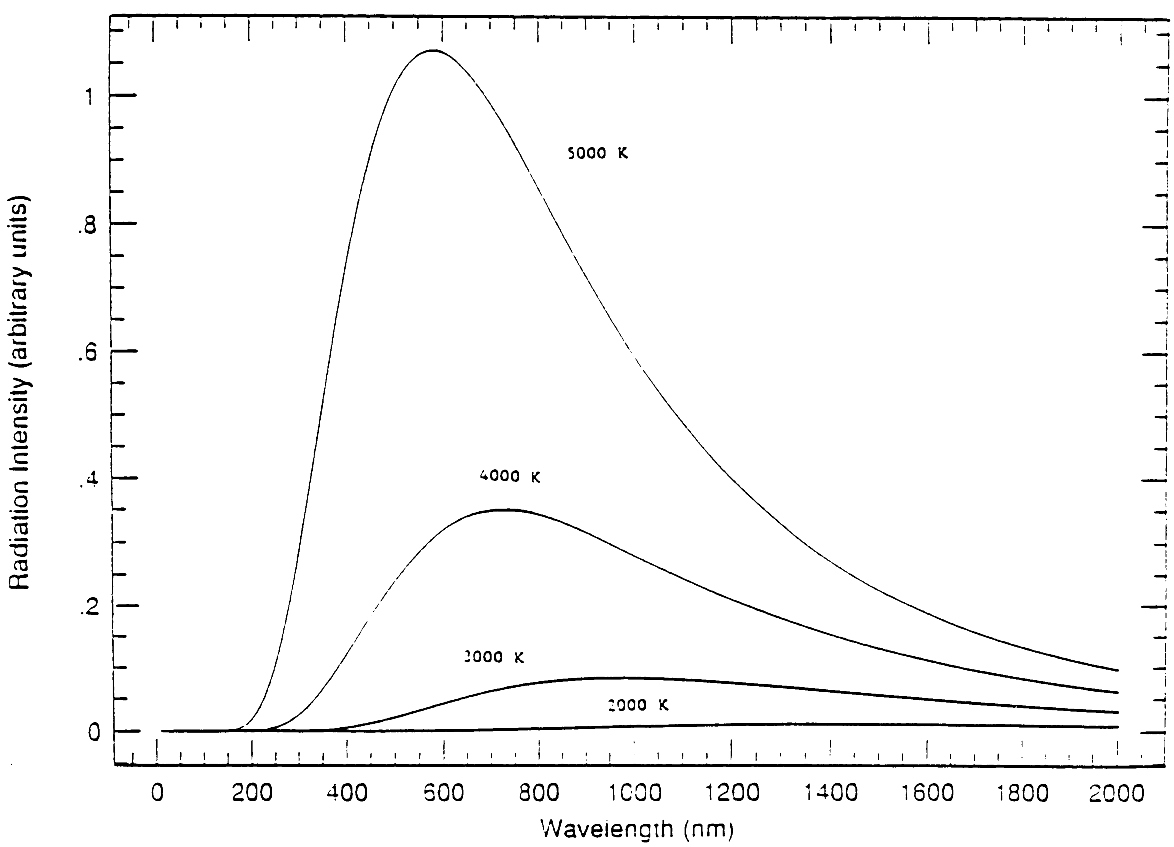


Figure 5.1 Relative intensities of the wavelength spectrum for a blackbody

5.2 Relative Efficiencies and Cost

The efficiency of a lightbulb is small. Incandescent bulbs convert 3-5% of the electrical energy consumed into visible light. The remaining 97% of the electrical energy is converted into heat. Fluorescent bulbs have an efficiency of 20-25%. In general, incandescent bulbs produce four to six times more heat than fluorescent bulbs for the same amount of visible light.

The amount of light produced by a source is measured in lumens. The power to produce the light is measured in watts. The luminous efficacy of a source is defined as the ratio of the total luminous flux emitted to the power consumption. The corresponding units for efficacy are lumens/watt. Efficacy is analogous to the concept of miles per gallon. Table 5.1 lists some typical light outputs and efficacies of various bulbs. Notice that it will take about two (1.8) of the 100-W incandescent bulbs (1.8 x 1750 = 3150 lm) to provide the same amount of light as a 40-W cool white fluorescent bulb. The incandescent bulbs will use five times as much power, (200-W vs 40-W), as the fluorescent bulbs and thus will produce five times as much heat for the same light output.

Table 5.1 Light outputs and efficacies of various bulbs

Wattage	Lumens	Lumens/Watt
Incandescent:		
25	235	9.4
40	455	11.4
60	890	14.8
75	1175	15.7
100	1750	17.5
150	2800	18.7
Fluorescent:		
20 cool white	1300	65.0
40 cool white	3150	78.8
40 daylight	2600	65.0
75 cool white	6300	84.0

Source: Handbook of Chemistry and Physics, 54th Edition

CHAPTER 6. INCANDESCENTS VERSUS COMPACT FLUORESCENTS

The lightbulbs chosen for this study were found at a local hardware store and their related characteristics are listed in Table 6.1. For this study, the bulbs were placed in three separate groups according to their illuminating ability (lumens); 505-645 lm, 700-870 lm, and 1100-1190 lm. For each of these groups the total cost for providing illumination based on energy cost, # hours of use each month, and bulb price were computed over a specified period of time (typically the longest bulb life). The total costs for lighting were plotted over time and discounted to give a present day value. The present day value is the amount of money that one would have to invest at a specified discount rate in order to meet the total lighting cost for a specified period of time.

Table 6.1 Lightbulb Characteristics

Bulb Make	Lumens	Wattage	Bulb Life	Bulb Cost	Efficacy
INCANDESCENT:					
GE STD.	505	40	1000	0.63	12.63
	870	60	1000	0.63	14.50
	1190	75	750	0.63	15.87
	1750	100	750	0.63	17.50
GE Soft White	490	40	1000	0.62	12.25
	855	60	1000	0.62	14.25
	1170	75	750	0.50	15.60
	1710	100	750	0.69	17.10
GE Energy Choice	780	52	1000	0.94	15.00
	1540	90	750	0.92	17.11
GE Miser	1140	70	825	0.92	16.29
FLUORESCENT:					
GE Energy Choice	570	11	10000	^20.99	51.82
	700	15	9000	10.99	46.67
Phillips Earth Light	1100	18	10000	24.99	61.11
Abco Comp. Fluor.	645	9	10000	^19.95	71.67

^ Total cost of bulb and adaptor, replacement bulbs cost $10.83

6.1 Calculating Total Lighting Costs

The total cost for operating a lighting device for a specified length of time will be equal to the sum of the cost of energy to run the device and the bulb replacement cost. The energy cost of operating a lighting device will depend on the rated power of the device (kilowatts), the length of time of operation (hours), and the cost of the electricity ($/kwh).

Energy Cost = (bulb wattage) x (operation time) x (electricity cost)

The total bulb cost for any time period will depend on the number of bulbs used and the cost per bulb. The number of bulbs used is equal to length of time the lighting device is on divided by the rated lifetime of the bulb.

Bulb Cost = (operation time/ bulb life) x (cost per bulb)

The total costs for lighting can be adjusted by a discount rate in order to give a present day value by the following equation with time measured in months.

Total Cost = (Energy Cost + Bulb Cost)/(1 + monthly discount rate) ^{time}

Table 6.2 Standard Set of Parameters

Bulb Type	GE STD INCAND	GE SW INCAND	GE EC INCAND	GE EC FLUOR
Lumens	870.00	855.00	780.00	700.00
Wattage	60.00	60.00	52.00	15.00
Efficacy	14.50	14.25	15.00	46.67
Bulb Life	1000.00	1000.00	1000.00	9000.00
Bulb Cost	0.63	0.62	0.94	10.99
Adaptor Cost	0.00	0.00	0.00	0.00

Standard Parameters		Variation of Parameters	
Cents/kwh -	7	Cents/kwh -	4 to 12
Hours/Month -	150	Hours/Month -	30 to 240
Discount Rate -	3.5%	Discount Rate -	0% to 6%

The standard set of parameters used for many of the variations are listed in Table 6.2. This level of lumens (700-870 lm) corresponds to the light output of a standard 60-W incandescent bulb. The standard set was used with a computer worksheet to compare the total costs of using a variety of different bulbs for the same lighting tasks. A printed copy of the worksheet is contained in the appendix of this report. The monthly cost of using each type of bulb were plotted versus time for cost comparison assuming 150 hours of use per month. Figure 6.1 on the next page depicts the monthly cost using the standard discount rate of 3.5%. Figure 6.2 depicts the monthly cost for a 0% discount rate. The 0% discount rate represents a "pay as you go" method for meeting the future cost of lighting. The large $ increases (spikes) seen here correspond to the purchase of a new bulb. In examining this graph, one finds that the intersection of two total cost $ lines represents the time to break even for purchasing a more expensive bulb. This is approximately 20 months for these bulbs under these conditions of use. Additional information concerning total cost and savings can be found in the table below each graph. Here there is also a calculation done that represents the amount of money the consumer would have if they had invested the initial bulb cost difference in a savings account at the same discount rate. Examining this table, we find that over this 120 month period, the cost of electricity accounts for 87% of the total costs for incandescents and only 42% of the total fluorescent cost.

6.2 Variation of External Parameters on the Total Cost

A lightbulb's lumen output, rated wattage, lifetime and replacement cost are all internal factors in calculating the total lighting cost that are determined by the lightbulb manufacturer and the retailer. With the exception of the lightbulb price, these internal factors will be consistent for a certain brand of bulb regardless of when and where it is used. The discount rate, cost of electricity and rate of usage are all external factors in the total lighting cost that are dependent on when and where the bulb is being used. Several variations in these external

Table 6.3 Light bulb comparison cost for 700-870 lumens @ 150 hrs/mth and 3.5%

	GE STD	GE SW	GE EC	GE EC
Bulb Type	INCAND	INCAND	INCAND	FLUOR
Lumens	870.00	855.00	780.00	700.00
Wattage	60.00	60.00	52.00	15.00
Efficacy	14.50	14.25	15.00	46.67
Bulb Life	1000	1000	1000	9000
Bulb Cost	0.63	0.62	0.94	10.99
Adaptor Cost	0.00	0.00	0.00	0.00

Summary after specified number of months 120

	GE STD	GE SW	GE EC	GE EC
# Bulbs Used	17.99	17.99	17.99	2.00
Tot. Energy $	53.27	53.27	46.17	13.32
Tot. Bulb $	8.18	8.05	12.21	18.74
Total $	61.46	61.33	58.38	32.06
Savings	0.00	0.13	3.08	29.40
Comp. Invest	0.00	0.01	0.44	14.69

Variable Parameters

$/KWH -	0.07
Hours/Month -	150
Discount Rate -	0.035

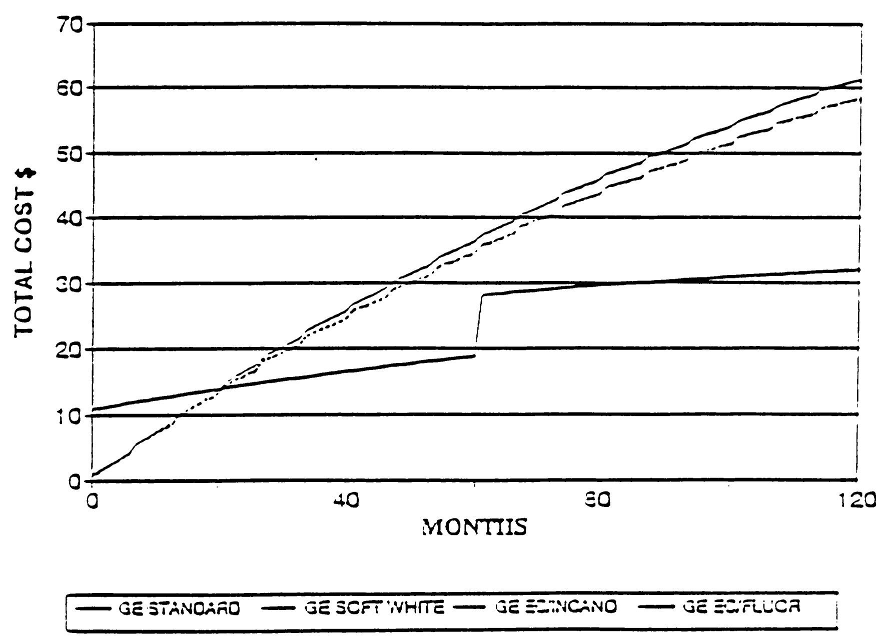


Figure 6.1 Monthly cost for standard set @ 150 hrs/mth and 3.5% discount rate

Table 6.4 Light bulb comparison cost for 700-870 lumens @ 150 hrs/mth and 0%

Bulb Type	GE STD INCAND	GE SW INCAND	GE EC INCAND	GE EC FLUOR
Lumens	870.00	855.00	780.00	700.00
Wattage	60.00	60.00	52.00	15.00
Efficacy	14.50	14.25	15.00	46.67
Bulb Life	1000	1000	1000	9000
Bulb Cost	0.63	0.62	0.94	10.99
Adaptor Cost	0.00	0.00	0.00	0.00

Summary after specified number of months 120

	GE STD	GE SW	GE EC	GE EC
# Bulbs Used	17.99	17.99	17.99	2.00
Tot. Energy $	75.54	75.54	65.47	18.88
Tot. Bulb $	11.34	11.16	16.92	21.98
Total $	86.88	86.70	82.39	40.86
Savings	0.00	0.18	4.49	46.01
Comp. Invest	0.00	0.01	0.31	10.36

Variable Parameters

$/KWH -	0.07
Hours/Month -	150
Discount Rate -	0

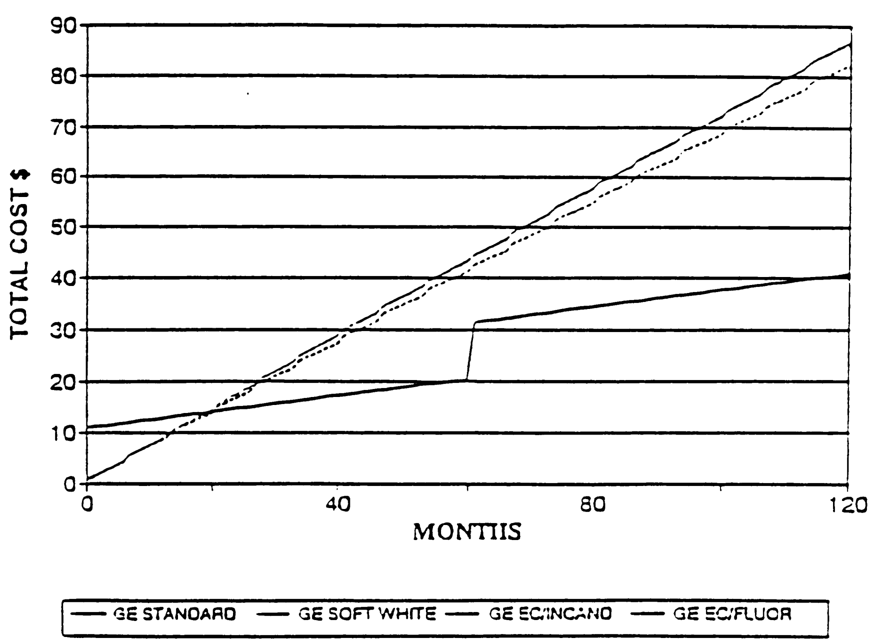


Figure 6.2 Monthly cost for standard set @ 150 hrs/mth and 0% discount rate

factors were considered in comparing the total cost of using a compact fluorescent versus using an incandescent for the same lighting task. Variations in the discount rate and the cost of electricity were performed using the standard set of parameters, while variations in the usage rate (hours/month) were performed for the three groups of lighting levels. The standard set of parameters is based on the set of bulbs with outputs of 700-870 lumens and the related parameters shown in Table 6.2.

6.2.1 Variation of Discount Rate

The after tax discount rate for the standard set was varied from 0% to 6% by 1% increments while keeping the cost of electricity at 7 cents/kwh and the rate of use 150 hours/month. The results of this variation for the time period of one fluorescent bulb life (9000 hours or 60 months) are shown in figure 6.3. The discount rate of 0% corresponds to a "pay as you go" method for meeting future lighting cost. The break-even time for using fluorescent bulbs in each case was around 20 months. It is worthwhile to note that as the discount rate is decreased from 6% to 0%, the net savings for using a compact fluorescent bulb increases. This is due to the fact that the majority of total cost for using compact fluorescent bulbs is tied up in the initial cost of the bulbs themselves and the initial cost of the bulbs is not discounted over time.

For each of the discount rates shown in Figure 6.3, the total savings for replacing the standard 60-W incandescent bulb with a 15-W compact fluorescent bulb exceeds the total savings for using an energy conserving incandescent bulb or investing the initial cost difference between the compact fluorescent and the standard incandescent at the specified discount rate (indicated by the comparable investment column). At the current interest rate of 2%, using a compact fluorescent would save the consumer about $18 over using an energy conserving incandescent.

Table 6.5 Total Savings $ for standard set with varying the discount rate
Summary after one fluorescent bulb lifetime (60 months)

Disc Rate	GE SW	GE EC/INC	GE EC/FLU	Comp Inv	Recovery Time (months)
0%	0.09	2.25	23.03	10.36	20
1%	0.09	2.12	21.4	10.89	20
2%	0.08	2.01	19.85	11.45	20
3%	0.08	1.89	18.38	12.03	20
4%	0.08	1.79	16.98	12.65	20
5%	0.07	1.68	15.66	13.3	20
6%	0.07	1.64	14.39	13.97	20

Variable Parameters
Cents/KWH - 7
Hours/Month - 150
Discount Rate - 0% - 6%

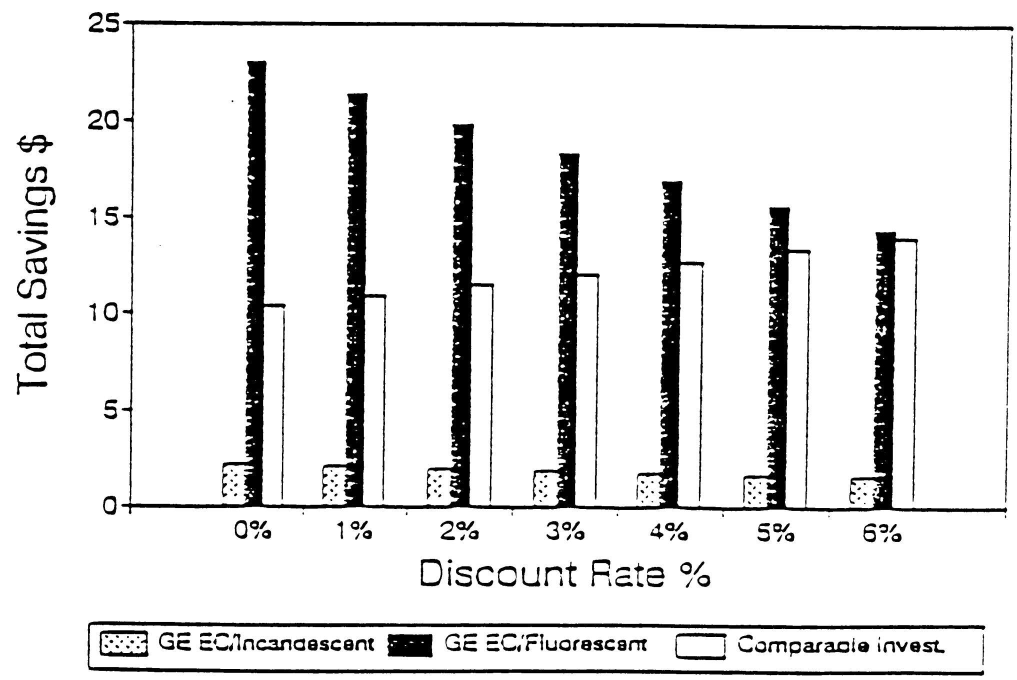


Figure 6.3 Total savings for standard set while varying the discount rate

6.2.2 Variation of Electrical Cost ($/kwh)

For the standard set of parameters, the cost of electricity was varied from 4 cents/kwh to 12 cents/kwh by one cent increments with the results for the total savings after a 60 month period shown in Figure 6.4.

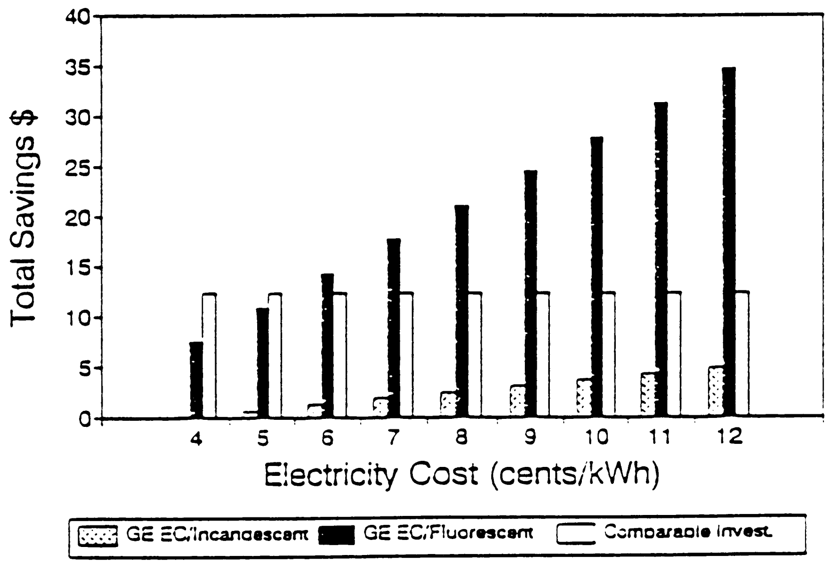


Figure 6.4 Total Savings for standard set with varying electricity cost

As the price of electricity was increased, the cost recovery time, (break-even time), for using a compact fluorescent bulb decreased from 33 months for 4 cents/kwh with a net savings of only $7.47 to 12 months for 12 cents/kwh with a net savings of $34.67. The fact that the cost of electricity for incandescents accounts for 80% to 90% of the total costs allows the compact fluorescents to provide substantial savings compared to using energy conserving incandescents or investing the initial cost difference in a savings account. The minimum price of electricity for which the consumer saves more money by using a compact fluorescent instead of investing the initial cost difference at 3.5% was found to be about 5.5 cents/kwh.

6.2.3 Variation of Monthly Usage (Hours/Month)

The number of hours/month that the bulbs were used was used was varied from 30 hrs/month (1 hr/day) up to 240 hrs/month (8 hrs/day). For each of the three specified lumen levels all of the other parameters were held constant. Each of these lumen levels will be evaluated separately.

505 - 645 Lumens

This lumen rating corresponds to the light output of a standard 40 W incandescent bulb. For use up to 90 hrs/month, it is more economical to use incandescent bulbs rather than either of the available compact fluorescents. These results are shown in Figure 6.5 on the next page. Higher values of hours/month will produce slight savings for the consumer, however these savings will be rather small. For 240 hrs/month, only $3.88 would be saved over 42 months. It is worth while to note that 80% of the total costs of using these compact fluorescent bulbs is the initial bulb costs. If less expensive compact fluorescent bulbs and adaptors could be purchased, or if the price of electricity was above $0.07/kwh, then the net savings for using compact fluorescents could be increased. This results from the fact that 40-W incandescent bulbs do not use very much electricity. In order to gain any savings by using a compact fluorescent bulb, the consumer would have to use the bulb 120 hours a month for 82 months just to recover the initial cost of the fluorescent bulb and its adaptor. Nearly half of the initial cost of the compact fluorescent bulbs for this lighting level is for the purchase of an adaptor for the lighting fixture. After the initial cost of the adaptor is recovered, replacement bulbs can be purchased for about $11.

700 - 870 Lumens

This lumen rating corresponds to the light output of a standard 60 W incandescent bulb. The total savings for using a compact fluorescent or an energy saving incandescent are shown in Figure 6.6. The net savings for using compact fluorescents at 30 hrs/month would be $3.58 over 300 months, while the net savings at 240 hrs/month would be $19.56 over 37 months when comparing to the cost of using a standard incandescent bulb. The low price of the 15-W GE Energy Conserving/Fluorescent bulb is largely responsible for the high savings and thus makes compact fluorescents very attractive for this lumen output level.

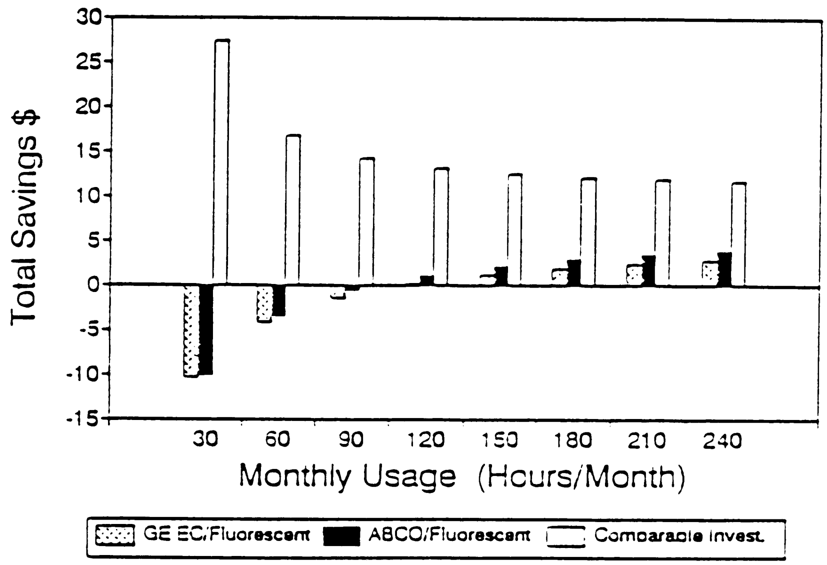


Figure 6.5 Total savings vs standard incandescents for 505-645 lumen bulbs

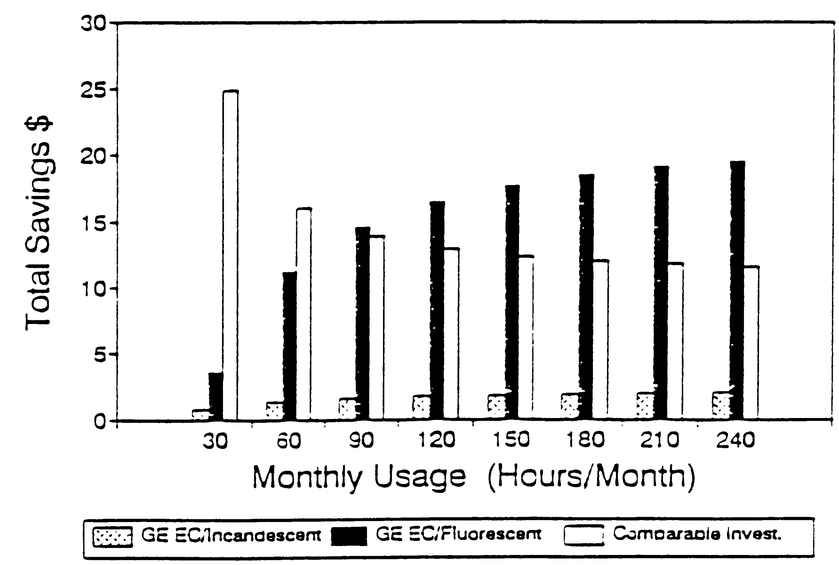


Figure 6.6 Total savings vs standard incandescents for 700-870 lumen bulbs

1100 - 1190 Lumens

This lumen rating corresponds to the light output of a standard 75-W incandescent bulb. At 7 cents/kwh, compact fluorescents would have to be used a minimum of 60 hrs/month in order to save money (Figure 6.7). For using 1100-1190 lumen incandescents at 7 cents/kwh, 85% of the total cost is for the electricity. For 240 hrs/month the cost of electricity was varied from 4 cents/kwh to 10 cents/kwh while correspondingly the total costs of using compact fluorescent bulbs were recalculated for the initial bulb prices of $14.99, $19.99, and $24.99, (Figures 6.8, 6.9, 6.10). As the price of electricity is increased and the compact fluorescent bulb price is decreased, the net savings for using compact fluorescents grows substantially and the cost recovery time is reduced (Figure 6.11).

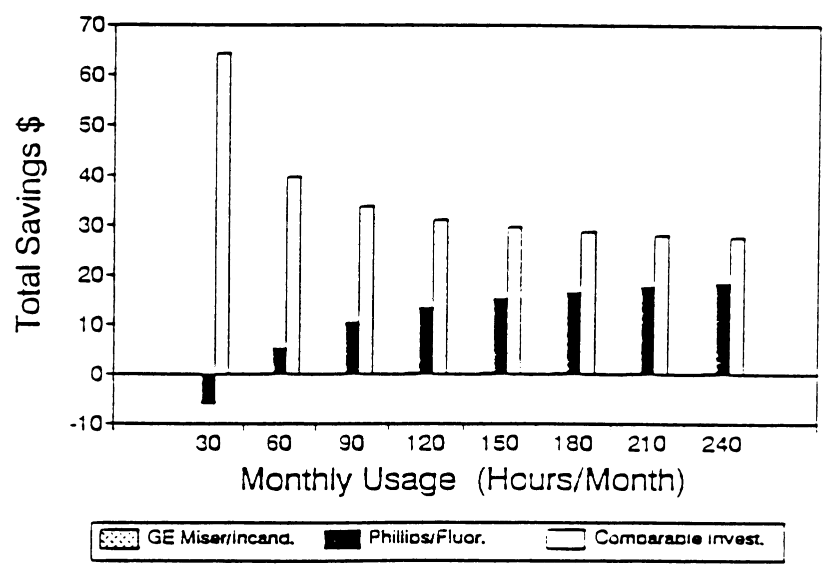


Figure 6.7 Total savings vs standard incandescents for 1100-1190 lumen bulbs

Table 6.8 Total Savings $ for 1100-1190 with varying initial bulb cost ($14.99) and $/kWh. Summary after one fluorescent bulb lifetime (42 months)

Cents/KWH	GE SW	GE Miser	Phillips	Comp Inv	Recovery Time (months)
4	1.63	-1.04	13.09	16.21	20
5	1.63	-0.6	18.13	16.21	17
6	1.63	-0.16	23.18	16.21	15
7	1.63	0.29	28.23	16.21	13
8	1.63	0.73	33.28	16.21	12
9	1.63	1.17	38.33	16.21	11
10	1.63	1.61	43.47	16.21	10

Variable Parameters		
Cents/KWH	-	4 - 10
Hours/Month	-	240
Discount Rate	-	3.5%
Fluorescent Bulb Price	-	14.99

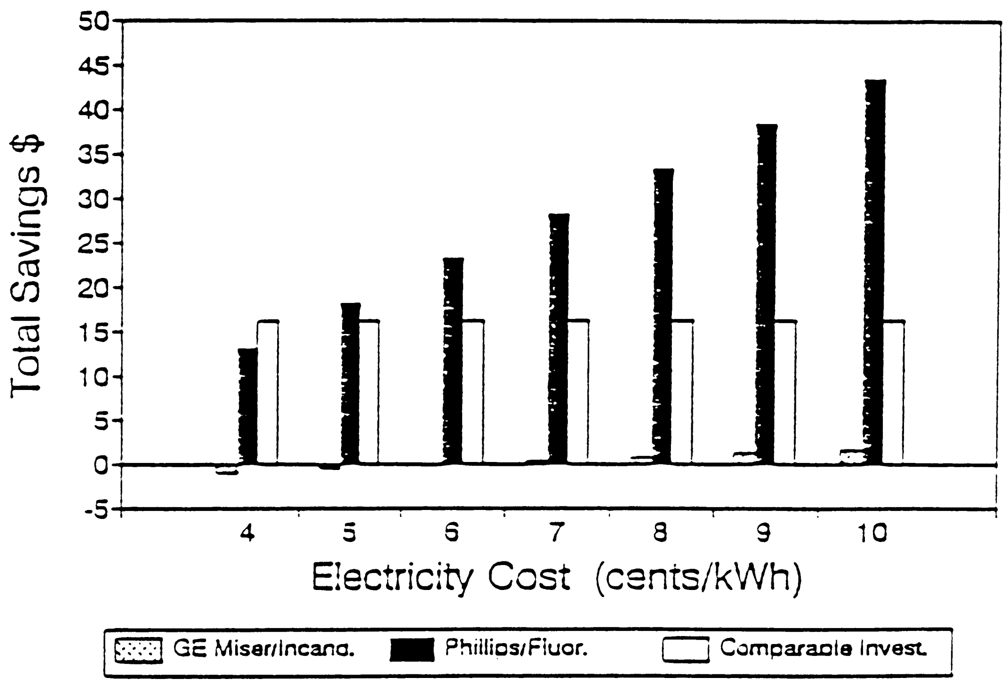


Figure 6.8 Total savings vs standard incandescents for 1100-1190 lumen bulbs with varying monthly usage and compact fluorescent price of $14.99

Table 6.9 Total Savings $ for 1100-1190 with varying initial bulb cost ($19.99) and $/kWh. Summary after one fluorescent bulb lifetime (42 months)

Cents/KWH	GE SW	GE Miser	Phillips	Comp Inv	Recovery Time (months)
4	1.63	-1.04	8.09	21.86	27
5	1.63	-0.6	13.13	21.86	24
6	1.63	-0.16	18.18	21.86	20
7	1.63	0.29	23.23	21.86	18
8	1.63	0.73	28.28	21.86	16
9	1.63	1.17	33.33	21.86	14
10	1.63	1.61	38.37	21.86	13

Variable Parameters		
Cents/KWH	-	4 - 10
Hours/Month	-	240
Discount Rate	-	3.5%
Fluorescent Bulb Price	-	19.99

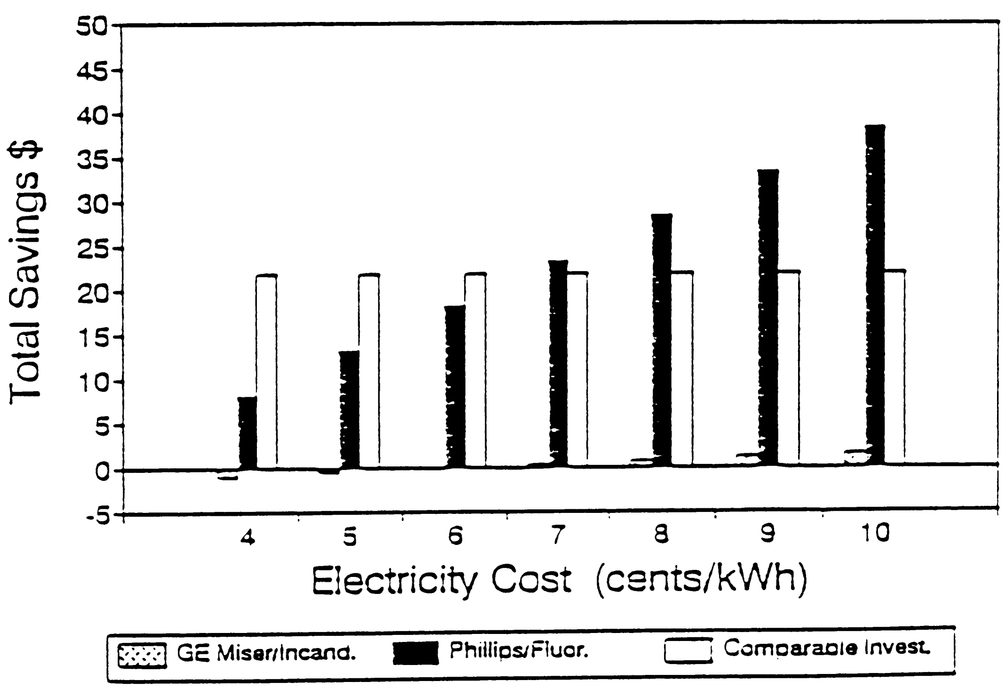


Figure 6.9 Total savings vs standard incandescents for 1100-1190 lumen bulbs with varying monthly usage and compact fluorescent price of $19.99

Table 6.10 Total Savings $ for 1100-1190 with varying initial bulb cost ($24.99) and $/kWh. Summary after one fluorescent bulb lifetime (42 months)

Cents/KWH	GE SW	GE Miser	Phillips	Comp Inv	Recovery Time (months)
4	1.63	-1.04	3.09	27.5	35
5	1.63	-0.6	8.13	27.5	30
6	1.63	-0.16	13.18	27.5	25
7	1.63	0.29	18.23	27.5	22
8	1.63	0.73	23.28	27.5	20
9	1.63	1.17	28.33	27.5	18
10	1.63	1.61	33.37	27.5	16

Variable Parameters
Cents/KWH - 4 - 10
Hours/Month - 240
Discount Rate - 3.5%
Fluorescent Bulb Price - 24.99

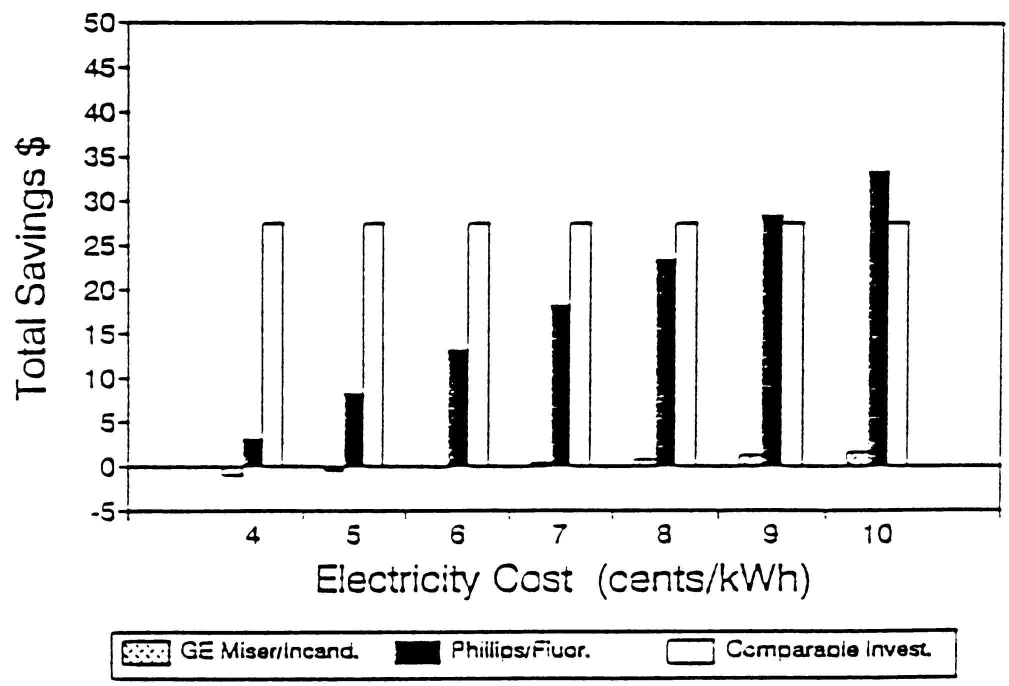


Figure 6.10 Total savings vs standard incandescents for 1100-1190 lumen bulbs with varying monthly usage and compact fluorescent price of $24.99

Table 6.11 Cost recovery time time (months) for 1100-1190 lumen bulbs @ 240 hrs/mth and fluorescent prices of $14.99, $19.99, and $24.99

Cents/KWH	Recovery Time @ (months)	$14.99	$19.99	$24.99
4		20	27	35
5		17	24	30
6		15	20	25
7		13	18	22
8		12	16	20
9		11	14	18
10		10	13	16

Variable Parameters
Cents/KWH - 4 - 10
Hours/Month - 240
Discount Rate - 3.5%
Fluorescent Bulb Price - $14.99, $19.99, $24.99

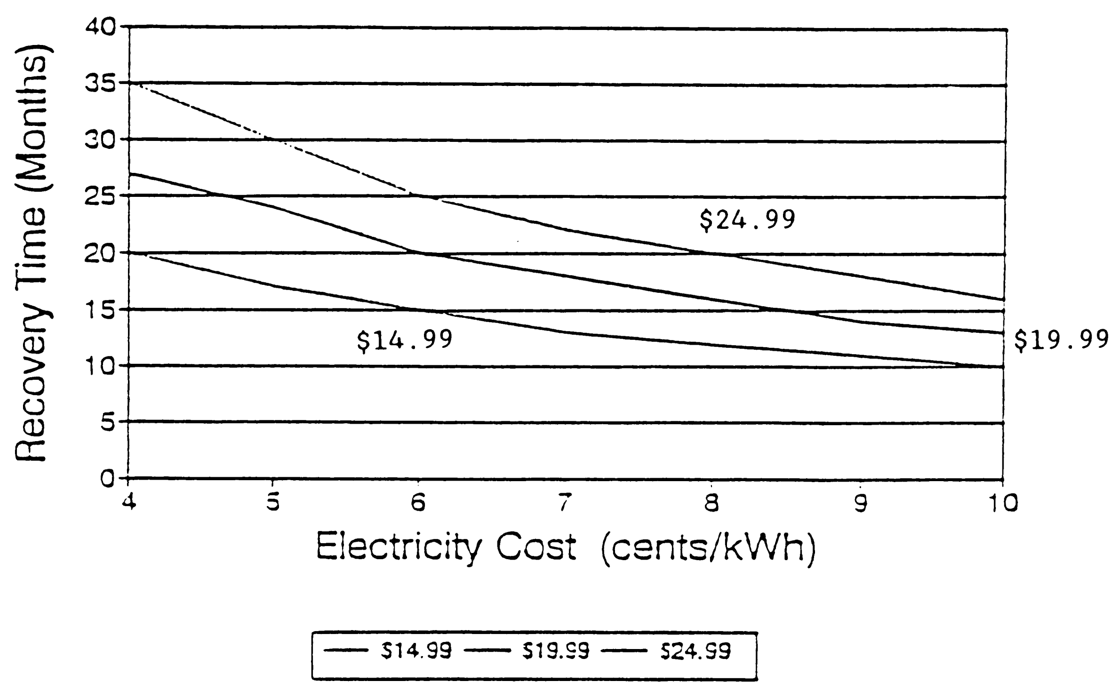


Figure 6.11 Cost revovery time for 1100-1190 lumen bulbs @ 240 hrs/mth, varying electrical cost and fluorescent prices of $14.99, $19.99 and $24.99

CHAPTER 7. ADDED COSTS AND ENVIRONMENTAL CONSIDERATIONS

Incandescent bulbs use roughly 4 times as much energy to produce the same amount of light as a compact fluorescent bulb. Thus the incandescents will produce at least four times more heat than compact fluorescents. This additional amount of heat may be a benefit during colder months, but it also could become an inconvenience during warmer months. A 75-W incandescent bulb will end up producing about 70-W of heat during use. A comparable 18-W compact fluorescent will produce about 14-W under the same conditions. The 56-W difference is heat gain that could benefit the consumer during colder months but also could increase cooling cost during warmer periods. For one bulb, the cost difference between producing 56-W of heat and removing 56-W of excess heat may be negligible but if a large number of bulbs are used then the individual consumer would have to evaluate their home/office's ability to produce or remove this 56-W per bulb difference.

The low energy consumption of compact fluorescent bulbs can be an environmental benefit especially if the local utility uses fossil fuels to produce electricity. Lower energy consumption will result in lower fossil fuel use which in turn reduces the amount of pollutants that contribute to the environmental problems of acid rain, global warming, and ozone depletion. The long lifetime of the compact fluorescents will result in fewer bulbs being used to accomplish the same lighting tasks as incandescent bulbs during an extended time period. This will slightly reduce the required room for the storage of garbage.

CHAPTER 8. CONCLUSION TO LIGHTBULB COMPARISON STUDY

Although compact fluorescent bulbs consume less than 25 % of the energy as comparable incandescents, the high cost of the fluorescent bulbs themselves do not make them economically desirable for all applications. For low frequency usage (less than 90 hours/month), incandescents are the more economical choice. For high frequency uses (greater than 120 hours/month), the use of compact fluorescent bulbs can save the consumer a substantial amount of money and also slightly reduce our dependence on fossil fuels for electricity production.

The results of this study demonstrate that the best use of compact fluorescents would be for lighting tasks requiring 700-870 lumens. This corresponds to 15-W compact fluorescent bulb replacing a 60-W standard incandescent bulb. The total savings using compact fluorescents for lighting tasks requiring 500-650 lumens or 1100-1190 lumens is not as great as the 700-870 lumen compact fluorescents because of the high initial cost of the bulbs. Compact fluorescents for these lumen levels would have to have a high frequency of usage in order to overcome their initial cost and produce significant savings compared to using standard incandescents.

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APPENDIX

The appendix to this report contains a copy of the worksheet used to perform the calculations involved. The appendix also contains tables listing some of the data used to generate the graphs discussed in chapters 2 through 6.

ENERGY PERFORMANCE WORKSHEET FOR A BUILDING IN IOWA

Directions: Enter all information requested on screens 1 through 12 (screens are numbered at the bottom right). The numbers in the worksheet will recalculate automatically. Press key F10 to see a graph.

GENERAL INFORMATION ABOUT THE PROJECT

Enter below the name, address, and builder for the project.

PROJECT: The House That Jack Built
ADDRESS: 1234 Beanstalk Drive, Des Moines, Iowa 55555
BUILDER: Jack's Pretty Good Construction Company

-1-

6800 - HEATING DEGREE-DAYS AT PROJECT LOCATION
Enter approximate heating degree-days for the location of the project, using the numbers below as a guide.

6874 Ames	6671 Cedar Rapids	6482 Clinton
6200 Council Bluffs	6554 Des Moines	7375 Dubuque
7175 Fort Dodge	5587 Keokuk	7881 Mason City
6339 Ottumwa	6947 Sioux City	7537 Waterloo

GENERAL INFORMATION ABOUT THE HOUSE

2500 - TOTAL HEATED FLOOR AREA IN SQUARE FEET
Enter here the total heated floor area of the building in square feet. Count all levels, including the basement level if it is heated.

21250 - INTERIOR VOLUME OF BUILDING IN CUBIC FEET
Enter here the interior volume of the building in cubic feet. This is the heated floor area times the average ceiling height. Count all heated spaces, including basement if it is heated. -2-

INFORMATION ABOUT WINDOWS

---

3 - TYPE OF WINDOWS. Enter the number corresponding to the main type of window used in the home:
1 for single-pane or ordinary double-pane windows
2 for double-pane windows with night insulation
3 for windows that are low-E or that have 3 or more panes.

On the next screen, use the manufacturer's U-value for the windows or estimate it from the following information:
1.13 for single-pane windows (1/4 inch thick)
0.55 for 1/8-inch double-pane windows, 1/4-inch air space
0.47 for 1/4-inch double-pane windows, 1/2-inch air space
0.44 for double-pane low-E windows, 1/4-inch air space
0.39 for 1/8-inch triple-pane windows, 1/4-inch air space
0.34 for 1/4-inch triple-pane windows, 1/2-inch air space
0.23 for Heat Mirror window (2 panes + H.M. film)

-3-

INFORMATION ABOUT WINDOWS

List the area, clear % (percentage of rough window area that consists of clear glass, usually 70-80 %), and U-value (using numbers on screen 4 as a guide) in the table below.

Area (sq.ft.)	Clear %	U	Description	
80	75	0.40	South	Only what is on
			South	these 9 lines will
40	75	0.40	East	be accepted.
			East	
80	75	0.40	North	U-values may be
			North	entered as 1/R
40	75	0.40	West	(for example,
			West	as 1/2.85).
			Skylights	

-4-

INFORMATION ABOUT WALLS

Below, include information about the walls of the home. Include the opaque portions of the walls, but not the windows.
The area should be the area above the conditioned space.
Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq.ft.)	R	Description	
2106	30	Main level (N, E, S, W)	Only
0	0	Main level	what is
300	25	Rim joists	on these
54	10	Doors	7 marked
			lines
			will be
			accepted.

-5-

INFORMATION ABOUT ROOF AND/OR CEILING

Below, include information about the roof or ceiling of the home.
Include only the opaque portions of the roof, not skylights.
The area should be the area above the conditioned space.
Space is left to include a description of the different parts of the roof or ceiling if you have more than one part

Area (sq.ft.)	R	Description	
1125	50	Ceiling - through insulation	Only
125	40	Ceiling - through joists	what is
			on these
			7 marked
			lines
			will be
			accepted.

-6-

FLOORS OVER UNHEATED SPACES

Enter below the area and the R-value of any floors over unheated areas.

Area (sq.ft.)	R	
		Enter 0's if you have no
0	0	floors over unheated spaces

HEATED SLAB ON GRADE

Enter below the area and the R-value under any heated slab on grade.

Area (sq.ft.)	R	
		Enter 0's if you have no
0	0	heated slab on grade

-7-

UNHEATED SLAB ON GRADE

Enter below the area and the R-value under any unheated slab on grade.

Area (sq.ft.)	R	
		Enter 0's if you have no
0	0	unheated slab on grade

CRAWL SPACE WALLS

Enter below the area and the R-value of the exterior walls of any crawl spaces below uninsulated floors.

Area (sq.ft.)	R	
		Enter 0's if you have no
0	0	such crawl space walls

-8-

INFORMATION ABOUT BASEMENT WALLS

Area (sq.ft.)	R	Mid-depth	Description
300	15	0	Above-ground basement walls
900	15	3	Underground walls (N, E, S)
0	0	0	Underground walls (W)
0	0	0	

Enter above information about the basement walls of the building. In column A enter the area in square feet. In column B enter the R-value of the wall. In column C enter the depth (in feet) of the middle of the wall; for example, a wall extending from a depth of 0 feet to 7 feet would have a mid-depth of 3.5 feet. In column D, do not extend description past the last dash marks above and below.

This is limited to four lines of information.

-9-

MISCELLANEOUS INPUT

0.35 - AIR CHANGES PER HOUR. Enter the estimated air infiltration rate in the home. For an energy-efficient home this is typically about 0.5 air changes per hour.

100000 - AVERAGE DAILY TOTAL INTERNAL HEAT IN Btu. This number is not critical but has some effect on utility costs. A reasonable estimate is 25,000 times one more than the number of occupants of the home.

1 - AMOUNT OF THERMAL STORAGE. This is only important in passive solar homes. Enter the number corresponding to the amount of thermal storage in the building:

1. Low amount
2. Intermediate amount
3. High amount

-10-

INFORMATION ABOUT POSSIBLE HEATING SYSTEMS

The input numbers on this page are used only to determine the estimated utility costs for an average heating season.
If you are using an electric heat pump or a gas furnace in the home, be sure to put in the correct value below.

2.00 - SCOP FOR ELECTRIC HEAT PUMP
Enter the seasonal COP (coefficient of performance) of the electric heat pump to be installed.

90 % - AFUE FOR GAS, PROPANE OR OIL-FIRED FURNACE
Enter the AFUE (Annual Fuel Utilization Efficiency) of the natural gas or propane or oil-fired furnace to be installed.

-11-

ENERGY PRICES

Enter below the prices of energy for your locality. It is the price of the energy used as a heating fuel that is relevant.

PRICE OF ELECTRICITY:
7.0 cents per kWh for first 500 kWh
5.0 cents per kWh for next 300 kWh
2.2 cents per kWh above that

55 cents per therm (100,000 Btu) - PRICE OF NATURAL GAS

60 cents per gallon - PRICE OF PROPANE

90 cents per gallon - PRICE OF FUEL OIL

-12-

SUMMARY OF COMPLIANCE WITH IOWA ENERGY CODE

Home Heating Index: 3.45 Btu/degree-day per square foot

Comparison of project with code requirements:

		CODE	PROJECT
Walls:	maximum U =	0.113	0.068
Roof/Ceiling:	maximum U =	0.026	0.020
Floors over unheated spaces:	maximum U =	0.050	0.000
Heated slab on grade:	minimum R =	7.7	0.000
Unheated slab on grade:	minimum R =	5.5	0.000
Basement wall:	maximum U =	0.094	0.067
Crawl space wall:	maximum U =	0.060	0.000

-13-

April 1992 version of worksheet prepared by:

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****
BUILDING HEAT LOSS CALCULATION
****

	SQ.FT.	EFFECTIVE R VALUE	Btu/DD	
Walls,	2525	28.8	2102	Walls
ceilings	1250	48.8	615	Roof/ceiling
and	0	0.0	0	Floors over unheated spaces
floors	0	0.0	0	Heated slab on grade
	0	0.0	0	Unheated slab on grade
	1200	19.1	1509	Basement walls
	0	0.0	0	Crawl space walls
Windows	80	2.5	768	South windows
	80	2.5	768	East/West windows
	80	2.5	768	North windows
	0	0.0	0	Skylights

AIR INFILTRATION HEAT LOSS: 3213 Btu/degree-day
BUILDING HEAT LOSS COEFFICIENT: 9743 Btu/degree-day
ESTIMATED HEATING LOAD: 27605 Btu/hour at winter dry-bulb T

Abbreviations: Btu - British thermal units
DD - Fahrenheit heating degree-day
MBtu - Million Btu

THERMAL PERFORMANCE

ASSUMED AIR CHANGES PER HOUR: 0.35 air changes per hour
BUILDING HEAT LOSS COEFFICIENT: 9743 Btu/DD
MAXIMUM HEATING SYSTEM LOAD: 27,605 Btu/hour

	OCT	NOV	DEC	JAN
Heating degree-days	343	804	1181	1340
Gross heat loss (MBtu)	3.34	7.84	11.51	13.06
Internal heat (MBtu)	3.10	3.00	3.10	3.10
Net heat loss (MBtu)	0.24	4.84	8.41	9.96
Solar Gain (MBtu)	2.42	1.84	1.92	2.46
Solar Load Ratio (SLR)	9.897	0.380	0.228	0.247
Solar Heating Fraction	1.000	0.224	0.135	0.146
Useful solar (MBtu)	0.24	1.09	1.13	1.45
Auxiliary heat (MBtu)	0.00	3.75	7.27	8.51
	FEB	MAR	APR	TOTAL
Heating degree-days	1111	920	448	6148
Gross heat loss (MBtu)	10.82	8.96	4.37	59.90
Internal heat (MBtu)	2.80	3.10	3.00	21.20
Net heat loss (MBtu)	8.02	5.86	1.37	38.70
Solar Gain (MBtu)	2.47	2.73	2.21	16.05
Solar Load Ratio (SLR)	0.308	0.465	1.619	
Solar Heating Fraction	0.182	0.275	0.719	
Useful solar (MBtu)	1.46	1.61	0.98	7.97
Auxiliary heat (MBtu)	6.56	4.25	0.38	30.73

SUMMARY FOR AVERAGE HEATING SEASON (OCTOBER-APRIL):

Total internal heat:	21.2 MBtu	35%
Total useful solar heat:	8.0 MBtu	13%
Total auxiliary heat:	30.7 MBtu	51%

Total heat loss:	59.9 MBtu	100%

HOME HEATING REQUIREMENT: 8628 Btu/DD
HOME HEATING INDEX: 3.5 Btu/DD-sq.ft.

UTILITY COSTS

Costs below assume all internal heat generation is from electricity.

55 cents/CCF natural gas 60 cents/gallon propane 90 cents/gallon fuel oil		Total annual heating cost	Average January bill (all fuels)	Average utility bill (October to April)
Electric resistance	1.00 - COP	$198	$107	$80
Electric heat pump	2.00 - COP	$99	$80	$66
Natural gas furnace	90 % - AFUE	$188	$104	$79
Propane furnace	90 % - AFUE	$225	$115	$84
Oil-fired furnace	90 % - AFUE	$215	$112	$83

The rest of this worksheet includes material needed to carry out the calculations. None of it prints out unless you change the printing options. Do not erase any of the rest of this worksheet.

A reminder:

* Press key F10 to see a graph, and ESC to return from the graph back to the worksheet.

SOLAR GAIN WORKSHEET: ENTER DATA FOR EACH TYPE OR LOCATION OF W

		OCT	NOV	DEC	JAN	FEB	M
SOUTH	GAIN/SQ.FT.	728	640	671	836	830	695
	AREA	60	60	60	60	60	60
	SHADING FACTOR	1	1	1	1	1	1
	TOTAL GAIN	1.35	1.15	1.25	1.55	1.39	1.29
NORTH	GAIN/SQ.FT.	135	99	100	135	178	211
	AREA	60	60	60	60	60	60
	SHADING FACTOR	1	1	1	1	1	1
	TOTAL GAIN	0.25	0.18	0.19	0.25	0.30	0.39
E & W	GAIN/SQ.FT.	438	282	261	352	465	561
	AREA	60	60	60	60	60	60
	SHADING FACTOR	1	1	1	1	1	1
	TOTAL GAIN	0.81	0.51	0.49	0.65	0.78	1.04
OTHER	GAIN/SQ.FT.	0	0	0	0	0	0
	AREA	0	0	0	0	0	0
	SHADING FACTOR	1	1	1	1	1	1
	TOTAL GAIN	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL SOLAR GAIN:		2.42	1.84	1.92	2.46	2.47	2.73

SOUTH VERTICAL INSOLATION THROUGH 2 OR 3 PANES (AMES, IOWA NORMAL):

2 panes	788	690	724	900	898	755	500
3 panes	728	640	671	836	830	695	455

NORTH VERTICAL INSOLATION THROUGH 2 OR 3 PANES (AMES, IOWA NORMAL):

2 panes	149	109	110	149	196	232	235
3 panes	135	99	100	135	178	211	213

EAST/WEST VERTICAL INSOLATION THROUGH 2 OR 3 PANES (AMES, IOWA NORMAL):

2 panes	476	307	284	383	506	611	610
3 panes	438	282	261	352	465	561	561

PARAMETERS FOR SOLAR LOAD RATIO CALCULATION

	A	B	C	D
VALUES USED	0.5906	1.0060	1.0650	0.8099
LOW MASS:	0.5906	1.0060	1.0650	0.8099
2 PANES, NO NIGHT INSULATION	0.5650	1.0090	1.0440	0.7175
3 PANES, NO NIGHT INSULATION	0.5906	1.0060	1.0650	0.8099
2 PANES, R-9 NIGHT INSULATION	0.5442	0.9715	1.1300	0.9273
INTERMEDIATE MASS:	0.6180	1.0000	1.2760	1.1560
2 PANES, NO NIGHT INSULATION	0.5739	0.9948	1.2510	1.0610
3 PANES, NO NIGHT INSULATION	0.6180	1.0000	1.2760	1.1560
2 PANES, R-9 NIGHT INSULATION	0.5601	0.9839	1.3520	1.1510
HIGH MASS:	0.6763	0.9994	1.4000	1.3940
2 PANES, NO NIGHT INSULATION	0.6344	0.9887	1.5270	1.4380
3 PANES, NO NIGHT INSULATION	0.6763	0.9994	1.4000	1.3940
2 PANES, R-9 NIGHT INSULATION	0.6182	0.9859	1.5660	1.4370

Lightbulb Comparison Worksheet

This worksheet calculates the total cost of using various incandescent and compact fluorescent lightbulbs under the s operating conditions.

Light Bulb Comparison 700-870 Lumens

Bulb Type	GE STD INCAND	GE SW INCAND	GE EC INCAND	GE EC FLUOR
Lumens	870.00	855.00	780.00	700.00
Wattage	60.00	60.00	52.00	15.00
Efficacy	14.50	14.25	15.00	46.67
Bulb Life	1000	1000	1000	9000
Bulb Cost	0.63	0.62	0.94	10.99
Adaptor Cost	0.00	0.00	0.00	0.00

Summary after specified number of months 120

	GE STD	GE SW	GE EC	GE EC
# Bulbs Used	17.99	17.99	17.99	2.00
Tot. Energy $	75.54	75.54	65.47	18.88
Tot. Bulb $	11.34	11.16	16.92	21.98
Total $	86.88	86.70	82.39	40.86
Savings	0.00	0.18	4.49	46.01
Comp. Invest	0.00	0.01	0.31	10.36

Variable Parameters

$/KWH =	0.07
Hours/Month =	150
Discount Rate =	0

TOTAL COST OF BULBS AND ENERGY ON CONSECUTIVE MONTHLY BASIS

MONTH	GE STD	GE SW	GE EC	GE EC
0	0.63	0.62	0.94	10.99
1	1.25	1.24	1.48	11.15
2	1.88	1.87	2.03	11.30
3	2.51	2.50	2.57	11.46
4	3.14	3.13	3.12	11.62
5	3.77	3.76	3.66	11.78
6	4.40	4.39	4.21	11.93
7	5.66	5.64	5.70	12.09
8	6.29	6.27	6.24	12.25
9	6.92	6.90	6.79	12.41
10	7.55	7.53	7.33	12.56
11	8.18	8.16	7.88	12.72
12	8.81	8.79	8.43	12.88
13	9.44	9.42	8.97	13.04
14	10.70	10.67	10.46	13.19
15	11.33	11.30	11.00	13.35
16	11.96	11.93	11.55	13.51
17	12.59	12.56	12.10	13.67
18	13.22	13.19	12.64	13.82
19	13.85	13.82	13.19	13.98
20	14.48	14.45	13.73	14.14

21	15.74	15.70	15.22	14.30
22	16.37	16.33	15.77	14.45
23	17.00	16.96	16.31	14.61
24	17.63	17.59	16.86	14.77
25	18.26	18.22	17.40	14.93
26	18.89	18.85	17.95	15.08
27	20.15	20.10	19.44	15.24
28	20.78	20.73	19.98	15.40
29	21.41	21.36	20.53	15.56
30	22.04	21.99	21.07	15.71
31	22.67	22.62	21.62	15.87
32	23.30	23.25	22.17	16.03
33	23.93	23.88	22.71	16.19
34	25.19	25.13	24.20	16.34
35	25.82	25.76	24.74	16.50
36	26.45	26.39	25.29	16.66
37	27.08	27.02	25.84	16.82
38	27.71	27.65	26.38	16.97
39	28.34	28.28	26.93	17.13
40	28.97	28.91	27.47	17.29
41	30.23	30.16	28.96	17.45
42	30.86	30.79	29.51	17.60
43	31.49	31.42	30.05	17.76
44	32.12	32.05	30.60	17.92
45	32.75	32.68	31.14	18.08
46	33.38	33.31	31.69	18.23
47	34.64	34.56	33.18	18.39
48	35.27	35.19	33.72	18.55
49	35.90	35.82	34.27	18.71
50	36.53	36.45	34.81	18.86
51	37.16	37.08	35.36	19.02
52	37.79	37.71	35.91	19.18
53	38.42	38.34	36.45	19.34
54	39.68	39.59	37.94	19.49
55	40.31	40.22	38.48	19.65
56	40.94	40.85	39.03	19.81
57	41.57	41.48	39.58	19.97
58	42.20	42.11	40.12	20.12
59	42.83	42.74	40.67	20.28
60	43.46	43.37	41.21	20.44
61	44.72	44.62	42.70	31.59
62	45.35	45.25	43.25	31.74
63	45.98	45.88	43.79	31.90
64	46.61	46.51	44.34	32.06
65	47.24	47.14	44.88	32.22
66	47.87	47.77	45.43	32.37
67	49.13	49.02	46.92	32.53
68	49.76	49.65	47.46	32.69
69	50.39	50.28	48.01	32.85
70	51.02	50.91	48.55	33.00

71	51.65	51.54	49.10	33.16
72	52.28	52.17	49.65	33.32
73	52.91	52.80	50.19	33.48
74	54.17	54.05	51.68	33.63
75	54.80	54.68	52.22	33.79
76	55.43	55.31	52.77	33.95
77	56.06	55.94	53.32	34.11
78	56.69	56.57	53.86	34.26
79	57.32	57.20	54.41	34.42
80	57.95	57.83	54.95	34.58
81	59.21	59.08	56.44	34.74
82	59.84	59.71	56.99	34.89
83	60.47	60.34	57.53	35.05
84	61.10	60.97	58.08	35.21
85	61.73	61.60	58.62	35.37
86	62.36	62.23	59.17	35.52
87	63.62	63.48	60.66	35.68
88	64.25	64.11	61.20	35.84
89	64.88	64.74	61.75	36.00
90	65.51	65.37	62.29	36.15
91	66.14	66.00	62.84	36.31
92	66.77	66.63	63.39	36.47
93	67.40	67.26	63.93	36.63
94	68.66	68.51	65.42	36.78
95	69.29	69.14	65.96	36.94
96	69.92	69.77	66.51	37.10
97	70.55	70.40	67.06	37.26
98	71.18	71.03	67.60	37.41
99	71.81	71.66	68.15	37.57
100	72.44	72.29	68.69	37.73
101	73.70	73.54	70.18	37.89
102	74.33	74.17	70.73	38.04
103	74.96	74.80	71.27	38.20
104	75.59	75.43	71.82	38.36
105	76.22	76.06	72.36	38.52
106	76.85	76.69	72.91	38.67
107	78.11	77.94	74.40	38.83
108	78.74	78.57	74.94	38.99
109	79.37	79.20	75.49	39.15
110	80.00	79.83	76.03	39.30
111	80.63	80.46	76.58	39.46
112	81.26	81.09	77.13	39.62
113	81.89	81.72	77.67	39.78
114	83.15	82.97	79.16	39.93
115	83.78	83.60	79.70	40.09
116	84.41	84.23	80.25	40.25
117	85.04	84.86	80.80	40.41
118	85.67	85.49	81.34	40.56
119	86.30	86.12	81.89	40.72
120	86.93	86.75	82.43	40.88
121	88.19	88.00	83.92	52.03
122	88.82	88.63	84.47	52.18
123	89.45	89.26	85.01	52.34
124	90.08	89.89	85.56	52.50
125	90.71	90.52	86.10	52.66
126	91.34	91.15	86.65	52.81
127	92.60	92.40	88.14	52.97
128	93.23	93.03	88.68	53.13
129	93.86	93.66	89.23	53.29
130	94.49	94.29	89.77	53.44

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