

ZIP-The Zip-Code Insulation Program, Version 2.0

Economic Insulation Levels for New and Existing Houses by Three-Digit Zip Code

Users' Guide and Reference Manual (Revised edition)

Stephen R. Petersen

**U.S. DEPARTMENT OF COMMERCE
National Institute of Standards
and Technology
Gaithersburg, MD 20899**

**Sponsored by
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1000 Independence Avenue, SW
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NIST

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ABSTRACT

ZIP 2.0 (the ZIP Code Insulation Program) is a computer program developed to support the DOE Insulation Fact Sheet by providing users with estimates of economic R-values for thermal insulation in new or existing single-family houses. The ZIP program currently calculates economic levels of insulation for attics, cathedral ceilings, exterior wood-frame and masonry walls, floors over unheated areas, slab floors, basement and crawlspace walls, ductwork in unconditioned spaces, and water heaters. Site-specific estimates can be made for any location in the United States by entering the first three digits of its ZIP Code. Climate parameters are contained in a file on the ZIP diskette and automatically retrieved when the program is run. The user must designate the type of heating and cooling equipment present in the house. Default energy and insulation price data are also retrieved from the ZIP diskette, but these can be overridden to correspond to local prices. A comprehensive report is displayed with the economic R-values, advisory material, and a list of the user's input assumptions. The program and supporting files are contained on a single 5-1/4 inch diskette for use with microcomputers having an MS-DOS operating system capability. ZIP is intended for use by homeowners, homebuilders, architects, utilities, insulation manufacturers and installers, university extension services, conservation advocacy groups, and government agencies at any level.

PREFACE

The ZIP computer program was developed to support the calculations and data base used to estimate the economic levels of insulation published in the U.S. Department of Energy's Insulation Fact Sheet (DOE/CE-0180, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, 1987). Programmatic direction of this project and the DOE Insulation Fact Sheet has been provided by David McElroy of the Oak Ridge National Laboratory.

Sections 1 through 6 of this user's guide are included in a flat (ASCII) file on the ZIP disk under the name ZIP.DOC.

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1. INTRODUCTION

ZIP, the Zip Code Insulation Program, determines economic levels of insulation for new and existing houses in any location in the United States, given the first three digits of its Zip code. Economic insulation levels are determined for attics, cathedral ceilings, exterior walls, floors over unheated areas, slab floors, basement and crawlspace walls, and ducts in unconditioned spaces. In addition, ZIP will determine if a water heater insulation jacket is a cost effective investment, based on information supplied by the user.

The economic levels computed by ZIP reflect the type and approximate energy efficiency of the heating and cooling systems specified by the user, as well as local energy prices and current installed insulation costs. Local climate data for the three-digit Zip code are retrieved from the ZIP disk. Default energy and insulation price data are also retrieved from the ZIP disk, but it is recommended that users override these latter values with estimates of local energy and insulation prices if available.

ZIP is a public domain computer program developed by the National Institute of Standards and Technology (NIST, formerly the National Bureau of Standards) under the sponsorship of the United States Department of Energy (DOE)¹. As ZIP is in the public domain, it may be freely copied and distributed. However it is requested that attribution be given to the National Institute of Standards and Technology.

ZIP and its supporting data files are provided on a single 5-1/4 inch floppy disk (360K DSDD format) for use with microcomputers having an MS-DOS operating system (typical IBM-PC/XT/AT and compatible systems). This condensed guide to the ZIP program is contained in file ZIP.DOC on the ZIP disk and can be printed directly from the disk.

The original ZIP program was written to calculate economic levels of insulation reported by three-digit ZIP Code in the Department of Energy's "Insulation Fact Sheet" (DOE/CE-0180, January 1987). The "Insulation Fact Sheet" provides useful information related to the choice of insulation materials for particular applications and suggestions related to its proper installation. This 12 page publication can be obtained from the U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

The ZIP program has now been expanded and enhanced for more general use, allowing users to obtain more detailed recommendations based on local climate and cost conditions. ZIP is intended for use by any government or private agency (such as a utility company) being asked to provide advice to consumers on economic levels of insulation for new or existing houses. ZIP can also be used by insulation manufacturers, insulation installers, and by homeowners (either on their own personal computer or at some central location such as a home show, utility office, or energy conference). Where local building codes

¹ Neither NIST nor DOE assumes any liability resulting from the use of the information provided by the ZIP program or from any errors or omissions in the program.

require more insulation than suggested by ZIP, the building codes should take precedence.

2. CALCULATION OF ECONOMIC LEVELS OF INSULATION

The economic levels of insulation calculated by ZIP for each component are based on an incremental analysis. Successive levels of insulation in each component of the house are evaluated to determine how far it pays to keep adding insulation and where to stop. For example, the economic analysis for attic insulation is performed at R-0 (no insulation), R-11, R-19, R-22, R-30, R-38, and R-49. Only if an increase in R-value is found to generate additional savings greater than additional cost will that increase be included in the recommended insulation level for the component.

Economic calculations in ZIP are based on long-term reductions in heating and cooling costs. For new houses, a 30-year life is used in calculating present-value energy savings. The economic level of insulation calculated for a new house will be the level which has the lowest present-value insulation cost plus energy cost over a 30-year period. For existing houses, a 20-year life is used in the calculations.

In performing these calculations, a seven percent annual rate of return, over and above general inflation, is used to discount future savings to present value. If inflation is currently five percent, this is approximately equivalent to requiring a minimum 12 percent rate of return on the investment over its life. That is, the last increment of insulation used in each application must earn at least this rate of return to be considered cost effective. Moreover, residential energy savings are not taxed. Thus, for homeowners this 12 percent rate of return is an after-tax rate, significantly higher than most tax-free investments available to homeowners.

Note that the first increments of insulation typically return much higher dividends than the last increment. Thus the average rate of return on the entire investment tends to be considerably higher than the minimum acceptable level, especially if there is little insulation to start with.

In general, the more severe the climate, the higher the cost of energy, the lower the heating and cooling system efficiencies, and the lower the incremental cost of insulation from one level to the next, the more it pays to add insulation and the higher will be the economic level. In some cases the economic level of insulation is quite sensitive to these variables. For example, a relatively small change in the incremental cost of insulation (i.e., the cost of moving from one R-value to the next) or the cost of energy can change the economic level of insulation in a given location. You may want to determine the sensitivity of the economic levels of insulation to changes in these input variables before concluding your analysis.

There are other benefits from installing economic levels of insulation in houses. These might include increased occupant comfort, reduced demand for scarce energy resources, reduced peak energy demand, reduced pollution, and even reductions in global warming. However, none of these additional benefits are explicitly included in the ZIP analysis of insulation savings.

The energy savings computed in the ZIP analyses for each level of insulation are not reported. These calculations are based on an analysis of uniform surface areas (typically one square foot or one linear foot) for each component in a typical house under average operating conditions over a typical weather year. They would not provide any meaningful estimate of savings for the user's own house since the area of each component is unknown. Usually an energy audit of the house to be insulated is needed to make a meaningful estimate of the total savings that can be expected.

3. PROGRAM INSTALLATION

ZIP 2.0 can be installed on and run from a hard disk or run directly from a floppy disk. To install ZIP on a hard disk, make a subdirectory called ZIP and copy all the files on the ZIP disk to that subdirectory. (If the floppy is in drive A, type `COPY A:*. * d:\ZIP`, where d: is the drive location of subdirectory ZIP.) If you are going to run ZIP from a floppy drive, you should copy all the files on the original disk to a disk formatted on the drive you intend to run it from. Then run ZIP from the copy, saving the original as a backup. (Take care not to run the original (360 KB) disk in a high density (1.2 MB) disk drive; it will likely be destroyed during the disk write process.) In general, hard disk installation is preferred since ZIP will read and write the supporting data files much faster.

The following files are contained on the original ZIP disk. All of these files (except the user's guide file, ZIP.DOC) are needed to run the program.

ZIP2.EXE	The executable version of ZIP.
CLIMATE2.DAT	A file of climate data, keyed to three-digit ZIP Codes.
INSCOST2.NEW	A file of default insulation prices for new houses.
INSCOST2.RET	A file of default insulation prices for existing houses.
ZIPINFO.FIL	On-line summary of ZIP program.
ENPR90.ASC	Gas, oil and LPG (propane) prices by state.
ELEC90.ASC	Electricity prices (winter and summer) by ZIP code.
DOEENPR.NE	\
DOEENPR.MW	\ DOE projections of energy price escalation rates for the
DOEENPR.SE	/ four major regions of the U.S.
DOEENPR.W	/
ZIP.DOC	This user's guide.

4. RUNNING ZIP

To start ZIP, insert the disk into the current disk drive and type 'ZIP2'. If ZIP is run from a hard disk, make the ZIP subdirectory the current directory and type 'ZIP2'. If you have a color monitor, ZIP will automatically detect this and run in color. If you have a monochrome monitor that runs in the color mode, adding "/M" to "ZIP2" may make it easier to read the highlighted characters on the menus.

Screen 1 shows the initial screen display when ZIP is started. The user can proceed immediately into a ZIP analysis by pressing <Enter>. Further start-up options are provided in the menu bar at the bottom of the ZIP logo. For

If a new house application is selected, a wider range of insulation options for exterior walls and exterior foundations is allowed than for existing houses. If an existing house analysis is selected, you will be asked to specify the approximate existing level of insulation in the attic, floor, crawlspace walls, and supply ducts after these systems are selected for analysis.

Six different heating systems can be selected in ZIP: four furnace types, including natural gas, fuel oil, LPG, and electric resistance; electric baseboard; and electric heat pump. If a heat pump is designated for space heating, it will automatically be assumed to provide space cooling as well, and no cooling questions will be asked. Otherwise, two electric cooling systems can be selected: central and window air conditioners. (An evaporative cooling system can also be selected. However, no cooling savings from insulation are calculated for this latter system.) In addition, the user can specify the approximate operating efficiency of the heating and cooling systems (low, medium, high, or very high). These system specifications are needed to calculate the purchased energy savings corresponding to any given reduction in space heating and cooling loads. If there is ductwork in attics, crawlspaces, or other unconditioned spaces, an adjustment is also made to the equipment efficiency to reflect duct losses (10 percent for one-story houses, 15 percent for houses with two or more stories).

4.2 Energy Prices

Current energy prices for heating and cooling, corresponding to the type of systems selected, are then requested in the units shown (e.g., kWh, therms, gallons). Default values are retrieved from data files on the disk. These default values reflect energy prices at the state level (or, in the case of electricity, at a representative location within the state, based on the ZIP code entered for the analysis). However, it is recommended that the user overwrite these default values with energy prices that reflect the utility rates actually encountered at the building site. These prices should include all taxes and fuel adjustment costs (but not kW demand charges, if any). If declining (or increasing) block rates are applicable (for example, kWh prices are often lower for kWh usage above 500 kWh per month than for the first 500 kWh), the energy cost should reflect the cost of the last units purchased each month (during the months of major usage), not the average cost for all units. If there are different prices for summer and winter usage (as is often the case for electricity), the price used for cooling should be based on the summer rate and the price for heating on the winter rate. To change the default prices on the screen, press "Y" (Yes), then type the new prices over the old prices.

4.3 Selecting Insulation Systems for Analysis

Screen 2 shows the menu for selecting the insulation applications of interest to the user. Press <F3> to select all systems or use the cursor keys to move from box to box; press the space bar to toggle the selection marker (X) on or off in each box. Only data pertinent to the applications marked with an X will be requested and displayed after this point. Note that for some applications (e.g., cathedral ceilings and crawlspace walls) the analysis of rigid foam sheathing can be separately specified from mineral wool batts or

blankets (or loose fill insulation materials of any kind). This is primarily because typical R-values for rigid foam sheathing differ significantly from those of batts/blankets/loose fill insulation materials.

Since rigid foam sheathing typically costs more than mineral wool/loose fill for a given application, its economic R-value will be lower. However, for some applications rigid foam sheathing may be more suitable. Expert consultation may be needed to determine the appropriate material in specific circumstances. In the case of new wood-frame wall construction, a combination of mineral wool insulation and rigid foam sheathing is assumed for R-values above R-13.

<p>Select Insulation Systems for Analysis Press <Space Bar> to Toggle System On [X] or Off []. F3 = mark all. Use cursor keys to move around screen.</p>	
<p>ATTIC: [] 1. batt/blanket/loose fill</p> <p>CATHEDRAL CEILINGS: [] 1. batt/blanket/loose fill [] 2. rigid foam sheathing</p> <p>EXTERIOR WALLS (ABOVE GRADE): [] 1. Wood Frame (batt/blanket) 2. Concrete-Masonry: [] a. batt/blanket/loose fill [] b. rigid foam sheathing</p> <p>FLOORS: [] 1. Over unheated spaces (batt) [] 2. Concrete slab (rigid foam) [] DUCT INSULATION</p>	<p>CRAWLSPACE WALLS: [] 1. batt/blanket/loose fill [] 2. rigid foam sheathing</p> <p>BASEMENT WALLS (HEATED SPACES): [] 1. Exterior Insul. (rigid foam) 2. Interior Insulation: [] a. batt/blanket [] b. rigid foam sheathing</p> <p>BASEMENT WALLS (UNHEATED SPACES): [] 1. Exterior Insul. (batt/blk) 2. Interior Insulation: [] a. batt/blanket [] b. rigid foam sheathing</p> <p>[] WATER HEATER INSULATION</p>
<p>Press <PgDn> when finished.</p>	

Screen 2. Menu for selecting insulation systems of interest

4.4 Water Heater Data

If water heater insulation is checked, four questions are asked about the water heater: its type, its capacity (in gallons), its expected remaining life, and the price of the heating fuel. Six types of water heaters are displayed for selection: gas, oil, and electric, with either mineral wool or foam tank insulation. If the water heating fuel is the same as the space heating fuel, the default unit price will be the same as entered for space heating. If electric water heating is used, the user will be asked to enter both the winter electricity rate and the summer electricity rate. The actual electricity rate used in the analysis will be based on two-thirds (eight months) of the winter rate plus one-third (four months) of the summer rate.

The economic analysis of a water heater insulating jacket is limited to the owner's expectation of the water heater's remaining life, with no salvage value credited. The water heater is assumed to be located inside the house. However, potential beneficial heat gain from the tank during heating hours and undesirable heat gain during cooling hours is not considered in the analysis.

4.5 Existing Houses Only--Existing Levels of Insulation

If the ZIP analysis is being performed for an existing house, the user is asked to specify the approximate existing level of insulation in the attic, floors over unheated spaces, crawlspace walls, and supply heating ducts if these systems have been selected for analysis. These selections are made from a menu displaying several R-values and the approximate equivalent thickness of insulation in inches. An example of this selection menu is shown in Screen 3 for attic insulation. In most other applications in existing houses (e.g., exterior walls), ZIP asks if there is any existing insulation in the component. If the user indicates that some insulation already exists in such components, ZIP advises that further insulation is generally impractical, since the cost of removing or penetrating wall coverings is often prohibitively costly and the potential savings is significantly reduced.

Attic Insulation - Batt/Blanket/Loose Fill			
How much insulation is there in your attic now?			
Existing Insulation Level	Approximate Equivalent in Inches		
	Fiberglass		Cellulosic Blown
	Batt	Blown	
(0) None	0		
(1) R-7	2.5	2.0 -3.0	2.0-3.0
(2) R-11	3.5	3.75-5.0	3.0-3.5
(3) R-19	6.0	6.5 -8.75	5.0-6.0
(4) R-22	7.0	7.5 -10.0	6.0-7.0
(5) R-30	9.0	10.25-13.75	8.0-9.5
(6) R-38	12.0	13.75-18.25	10.3-12.0

Screen 3. Selecting existing level of insulation in attic

4.6 Insulation Costs

Default insulation costs for each application checked are displayed. For most applications, three to eight different insulation levels are shown along with default estimates of their installed cost. An example of this insulation cost menu is shown in Screen 4 for attic insulation. ZIP will evaluate each of these levels to determine which is the most cost effective in this analysis, using the costs shown. The user can accept these default values; however it is recommended that the user enter values specific to the building site.

The default insulation costs include contractor installation, except for the water heater jacket, which is assumed to be installed by the homeowner. For do-it-yourselfers, these costs can be modified to reflect materials only or include the labor cost, as desired. In general, the higher the insulation cost, the lower will be the economic level of insulation, and vice versa.

Attic Insulation Costs (Batt/Blanket/Loose Fill):
(cost per square foot of gross attic area)

R-11 @ \$ 0.34 per square foot
R-19 @ \$ 0.47 per square foot
R-22 @ \$ 0.54 per square foot
R-30 @ \$ 0.67 per square foot
R-38 @ \$ 0.85 per square foot
R-49 @ \$ 1.05 per square foot

Screen 4. Designating attic insulation costs for selected R-values

Before the insulation costs are requested, ZIP will display guidelines related to appropriate selection and entry of cost data. These guidelines are as follows:

- o All costs are to be entered in terms of thermal resistance (R) value, not thickness.
- o All costs are to be entered per square foot or per linear foot for the indicated R-value (as specified). If your cost estimates are for the total job, you must convert them to dollars per square foot or per linear foot of the insulated area (as indicated).
- o Insulation costs should include both material and labor costs if professionally installed.
- o If you are doing the job yourself, you can omit labor costs, or include the cost of your time, as you prefer. Economic insulation levels will generally be higher if labor costs are not included.
- o All insulation costs should include the cost of structural modifications or coverings if these additional costs cannot be justified for other purposes.
- o Each R-value for any given application is expected to cost more than the previous R-value, never the same or less.
- o Technically speaking, the difference in cost for each additional increment of insulation relative to the previous increment (e.g., R-19 relative to R-11) is more important than the total cost of that increment. Therefore, take care to make the cost differentials reasonable.

Entering a price of \$99.99 for any level of insulation will eliminate that level from the economic analysis. (This is useful if a particular level is unavailable or inappropriate for the application of interest.) Note: the cost of each successive level of insulation must be higher than the previous level, unless \$99.99 has been entered for the previous level.

4.7 Duct Insulation

If insulation on supply and return ducts in unconditioned spaces is to be analyzed, the approximate cross-section dimensions must be identified for the most representative sizes. The approximate size for each is selected from a menu of choices, as shown in Screen 5. Insulation costs for ducts are stated in dollars per linear foot of duct. Insulation costs per linear foot are typically higher for larger perimeter ducts than for ducts with small perimeters. Moreover, these costs tend to increase faster with increases in R-value than for other applications. This is because the outside perimeter (and thus the amount of insulation needed to wrap around it) increases with each new level. Both of these factors should be considered when specifying duct insulation costs. If supply ducts are used for air conditioning, the duct insulation should include a vapor barrier on the outside, sealed to prevent moisture from condensing on the ducts and wetting the insulation. Economic insulation levels are computed and reported separately for supply and return ducts in attics, vented crawlspaces, and controlled-ventilation crawlspaces.

SUPPLY DUCTS in unconditioned spaces: What is most typical duct size (approximate size in inches)?			
	Round		Rectangular
	-----		-----
(A)	4	(F)	3 x 12
(B)	6	(G)	6 x 12
(C)	8	(H)	8 x 14
(D)	10	(I)	10 x 16
(E)	12	(J)	12 x 20

Screen 5. Selecting duct size to be insulated

5. ZIP REPORT FORMAT

The results of the economic analysis for the designated location are displayed directly on the screen as shown in Screen 6. The Zip code and reference location, number of annual heating degree days (base 65F) and cooling degree hours over 74F are shown. Also included at the top of the report are the types of heating and cooling equipment, seasonal energy efficiencies, and the fuel prices used in the analysis. If the ZIP analysis is for a new house, the economic level of insulation is shown for each application. For existing houses, the existing level, amount to be added, and total level for each application are shown.

Note that the economic levels of insulation for both floors over crawlspaces and for crawlspace walls are shown if both were selected for analysis. However, only one of these methods would be used in most houses. For crawlspaces that can be safely closed off, it is usually more economical to

insulate the walls than the floor above if the wall area is less than the floor area. If the crawlspace cannot be safely closed off (or it is not allowed by the local building code authority), the floor above should be insulated instead. In this latter case, care must be taken to insulate water pipes and any ductwork in the unheated area.

Screen 7 shows the additional information displayed at the end of a full ZIP analysis. This information is provided to help the user better interpret and utilize the results of the ZIP analysis. However, it is recommended that the user read the DOE Insulation Fact Sheet or other insulation guidelines, or consult an insulation expert, before selecting the type of insulation to be used and installing it.

6. FINISHING UP

While the ZIP output report is displayed on the screen, the following options are available by pressing the designated key, as indicated in the menu bar at the bottom of the screen:

- P The entire report displayed on the screen is sent to the printer. This report includes the economic levels of insulation for the applications considered in this analysis and the input data specified by the user, including the insulation prices used in the analysis. (Make sure that the printer is turned on and that the paper is properly positioned before selecting this option.)

- S Start over with another ZIP analysis, using the data input for the previous run as the default choices at every question in the new run.

- R Save this report as a flat file on your disk, for later retrieval by a word processor.

- I Save your input data to the disk for retrieval in a later ZIP analysis. You will be asked to enter a file name for this datafile. Use any valid DOS filename (eight character maximum). Do not enter a filename extension; the extension ".ZIP" is automatically tagged to the filename you enter.

- Q Quit and return to DOS.

You cannot back up after the ZIP report is displayed. You must press S and move through the data input screens again. However, you do not need to reenter your data since they are now the default responses to every question.

Economic Insulation Levels for Zip 111XX -- New House

Reference Location: Queens, NY

Heating Degree Days(65F)=approx. 5000 Cooling Degree Hrs(74F)=approx. 9000

Heating Equipment: Natural Gas	Cooling Equipment: Central- Electric
Seasonal Efficiency: 65%	SEER (seasonal eff.): 8.0 Btu/Wh
Unit Fuel Cost: \$0.650/therm	Unit Fuel Cost: \$0.140/kWh

Attic Insulation	R-38
Cathedral Ceiling Insulation	
Batt/Blanket	R-30
Rigid Foam	R-16
Wood-Frame Wall Insulation	R-23
Masonry Wall Insulation	
Batt/Blanket	R-19
Rigid Foam	R-12
Floors over Crawlspace (If crawlspace walls uninsulated)	
Batt/Blanket	R-19
Crawlspace Wall Insulation (If floor above is uninsulated)	
Batt/Blanket	R-11
Crawlspace Wall Insulation (If floor above is uninsulated)	
Rigid Foam	R- 5
Slab-Edge Insulation (Rigid Foam)	R- 5
Insulation of Basement Walls:	
Exterior Insul. for Heated Basement (RF)	R-10
Interior Insul. for Heated Basement	
Batt/Blanket	R-19
Rigid Foam	R-12
Exterior Insul. for Unheated Basement(RF)	R- 0
Interior Insul. for Unheated Basement	
Batt/Blanket	R- 3
Rigid Foam	R- 6
Insulation of Supply Ducts in Unconditioned Spaces:	
Ducts in Attics:	R- 8
Ducts in Vented Crawlspace:	R- 8
Ducts in Unvented Crawlspace:	R- 6
Insulation of Return Ducts in Unconditioned Spaces:	
Ducts in Attics:	R- 6
Ducts in Vented Crawlspace:	R- 4
Ducts in Unvented Crawlspace:	R- 4
Water Heater Insulation	Yes

Screen 6. Screen display of results of ZIP analysis (example)

Additional information:

Always specify insulation by R-value, not by thickness. If loose-fill materials are used, make sure that they are installed according to weight (e.g., pounds per square foot) or bag count and not simply to a target depth, as significant settling may occur after installation is completed.

These economic R-values are valid only if they can be installed without making structural modifications to accommodate them, unless the cost of such modifications is explicitly included in the insulation costs. Compression of insulation will generally reduce its effectiveness.

ALL insulation products should be kept away from unprotected heat sources.

Insulate the floor over the crawlspace or the crawlspace walls, not both. Crawlspace walls should only be insulated if the crawlspace is closed off, unventilated, and dry all year. The ground should be covered with a vapor barrier (e.g., 4- or 6-mil polyethylene sheeting) to minimize moisture migration into the crawlspace. Note: some building codes may not allow unventilated crawlspaces. If radon gas is a problem at the building site, closing off the crawlspace may not be advisable.

If insulating floors over crawlspaces or other unheated areas, make sure that exposed water pipes are freeze-protected and ductwork is properly insulated in those areas.

Before insulating ducts, loosen any existing insulation at all joints and tape all joints to minimize air leakage. A non-flammable vapor barrier should cover the insulation on any supply ducts used for air conditioning.

The water heater jacket should not cover combustion air inlets (if any), pipes, controls, relief valves, or the flue at the top of the heater.

Screen 7. Additional information displayed at the end of a ZIP analysis

APPENDIX A. COMPUTATIONAL ALGORITHMS

This appendix documents the computational algorithms used to determine the economic R-value for each insulation system evaluated in ZIP. The methodology is divided into five steps. The first four steps are repeated for each R-value evaluated for each insulation system. The fifth step is used to determine the economic R-value for that system.

For each R-value in each insulation system:

- (1) Calculation of reductions in annual energy usage
- (2) Calculation of savings in annual energy costs
- (3) Calculation of total present-value savings in energy costs
- (4) Calculation of net present-value savings

For each insulation system:

- (5) Determine R-value with greatest net present-value savings

(1) Calculation of reductions in annual energy usage

Reductions in annual heating requirements (ΔAHR), annual cooling requirements (ΔACR), and corresponding purchased energy requirements, are calculated for each R-value relative to the base case (no insulation in new houses, existing insulation in existing houses), on a square foot or linear foot basis as indicated. The methodology used in ZIP for calculating these reductions is basically the same for all envelope insulation systems. Different methods are used for evaluating insulation used to wrap heating and cooling ducts and water heater tanks.

ENVELOPE COMPONENTS

For all envelope components, reductions in annual heating requirements and annual cooling requirements for each R-value are estimated on a representative area basis: Btu per square foot of area for attics, ceilings, floors, and exterior walls and Btu per linear foot of wall perimeter for basement and crawlspace walls. Crawlspace walls are assumed to be 2 feet high; basement walls are assumed to be 8 feet high. The computational methodology used to calculate these reductions in annual energy consumption is as follows:

$$\Delta AHR = HSLOPE \times HDD65 \times \Delta U / 1000000$$

$$\Delta ACR = CSLOPE \times CDH74 \times \Delta U / 1000000$$

where HSLOPE = Btu/unit area-yr-HDD65,

CSLOPE = Btu/unit area-yr-CDH74,

HDD65 = heating degree days base 65F,

CDH74 = cooling degree hours base 74F,

and ΔU = reduction in the U-value of the attic or wall due to the increase in insulation level.

(a) HSLOPE AND CSLOPE coefficients for attics, cathedral ceilings, and exterior walls.

The reductions in annual heating requirements and annual cooling requirements for these components are estimated using HSLOPE and CSLOPE coefficients

derived from the Lawrence Berkeley Laboratory PEAR² program in support of the proposed ASHRAE 90.2P Standard for the Energy Efficient Design of New Low-Rise Residential Buildings³. These parameters are shown in table A1.

Table A1. HSLOPE and CSLOPE coefficients for attics, roofs, and exterior walls

Component	HSLOPE	CSLOPE
Attic	25.91	1.978
Cathedral Ceiling	23.18	1.702
Wood-Frame Exterior Walls	21.19	1.005
Masonry Exterior Walls	20.02	0.739

(b) HSLOPE and CSLOPE coefficients for floors over unheated crawlspaces, crawlspace walls, and basement walls:

The reductions in annual heating requirements and annual cooling requirements for these components are estimated using equations derived from "Selection of Optimal Foundation Insulation," by Jeff Christian⁴. These equations use HSLOPE and CSLOPE coefficients similar to those used for attics and exterior walls. However, in some cases these two variables are not constants, but are computed as a function of HDD65 (HSLOPE) and CDH74 (CSLOPE), using the coefficients shown in table A2 and the following equations:

For HDD65 < 2500, HSLOPE = HDD65/2500 x HSLOPE(1)

For HDD65 >= 2500, HSLOPE = HSLOPE(1)

For all CDH74, CSLOPE = I(z) + Slope(z) x CDH74

Christian reported three intercept (I) and slope (S) terms for each component in the cooling mode, depending on the magnitude of CDH74: (z=1) climates with less than 15000 CDH74, (z=2) climates with CDH74 between 15000 and 30000, and (z=3) climates with CDH74 greater than 30000. Note that this methodology differs slightly from Christian in that HSLOPE for locations with HDD65 < 2500 are computed as a fraction of the HSLOPE(1) parameter. This is done to force the HSLOPE functions for locations above and below 2500 HDD65 to intersect at

² Lawrence Berkeley Laboratory, "PEAR.1: Program for Energy Analysis of Residences," Berkeley, California, 1987.

³ American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., "Standard 90.2P: Energy Efficient Design of New Low-Rise Residential Buildings", Atlanta, Georgia, 1987.

⁴ Christian, J. E., "Worksheet for Selection of Optimal Foundation Insulation, Thermal Performance of the Exterior Envelopes of Buildings IV, proceedings of the ASHRAE/DOE/BTECC/CIBSE Conference December 4-7, Orlando, Florida, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1989, pp 800-814.

Table A2. HSLOPE and CSLOPE coefficients for floors
and basement and crawlspace walls

Component:	HSLOPE(1)	CSLOPE parameters					
		I(1)	S(1)	I(2)	S(2)	I(3)	S(3)
Floors over unheated spaces ^a	21.435	-1.78	0.000095	-1.07	0.00003	-1.16	0.00003
Slab floors on grade:							
2 ft vertical exterior	19.38	-1.90	0.00015	1.03	-0.00005	-1.94	0.00005
2 ft horizontal with R-5 gap	19.42	-3.02	0.00019	-0.33	-0.00001	-1.89	0.000045
Crawlspace walls:							
Wood-frame walls	17.4	-2.16	0.00016	1.43	-0.00007	-2.50	0.00006
Masonry walls	19.34	-2.38	0.00017	-1.23	0.00003	-1.23	0.00003
Basement Walls (Conditioned space)							
Full-wall insulation	155.1	-0.1	0.00010	4.74	-0.00018	-6.98	0.00020
Half-wall (4 ft)	80.4	0.21	0.00006	2.52	-0.00008	-3.05	0.00010
Basement Walls (Unconditioned space)							
Full-wall insulation	59.1	-10.68	0.00058	-1.34	-0.00006	-8.92	0.00021
Half-wall (4 ft)	5.07	-3.45	0.00022	0.71	-0.00005	-3.11	0.00008

2500 HDD65. (Christian's coefficients tend to be somewhat higher for values slightly below 2500 HDD65 than for the 2500 HDD65 value.)

Calculation of reductions in annual purchased energy requirements for all envelope components:

Reductions in annual energy purchases for heating and cooling (AEP_h and AEP_c) are calculated for each envelope component by dividing reductions in AHR and ACR by the corresponding seasonal energy efficiency of the heating and cooling systems:

$$\Delta AEP_h = \Delta AHR / EFF_h$$

$$\Delta AEP_c = \Delta ACR / EFF_c$$

where EFF_h = seasonal efficiency of the space heating system,
and EFF_c = seasonal efficiency of the space cooling system.

For air conditioners, EFF_c is derived by dividing SEER by 3.412 Btu/Wh. For heat pumps, EFF_h is derived from the HSPF to reflect the severity of the winter climate (heating degree days 65F, HDD65F):

$$EFF_h = HSPF/6.5 \times 1.06 \times [2.3 - 0.1(HDD65F/1000)]$$

DUCT INSULATION

The analysis of duct insulation savings is based primarily on the methodology developed for the California Energy Commission (CEC) by Charles Eley Associates⁵. These reports provide coefficients, summarized in table A3, for computing HVAC supply duct efficiency factors for heating and cooling in ventilated attics, ventilated crawlspaces, and controlled-ventilation crawlspaces. Efficiency factors are based on the effective R-value of the duct insulation, and are computed separately for one-story and two-or-more story houses, as follows:

$$EFF_{duct} = C_1 - C_2 / (R_{inst} + 0.7)$$

where

- EFF_{duct} = efficiency of HVAC ducts,
- R_{inst} = installed R-value of ducts,
- C_1 and C_2 = coefficients as shown in table A3, and
- 0.7 = surface conductance on the outside surface of the ducts.

Table A3. Duct coefficients for attics, vented crawlspaces (vcs), and controlled ventilation crawlspaces (cvcs)⁶

	Heating (attic & vcs)	Cooling (attic)	Cooling (vcs)	Heating (cvcs)	Cooling (cvcs)
One-story houses:					
C_1	0.891	0.892	0.892	0.923	0.910
C_2	0.323	0.425	0.147	0.201	0.126
Two or more stories:					
C_1	0.927	0.928	0.928	0.949	0.941
C_2	0.215	0.283	0.098	0.126	0.084

⁵ Charles Eley and subcontractors, Volume 1, Assumptions and Algorithms, California Energy Commission, Sacramento, CA, June 1988. A preliminary report with the same title dated May 19, 1987 provides a more comprehensive methodology for this analysis.

⁶ Coefficients for controlled ventilation crawlspaces were derived from table 2-1 in the CEC June 1988 methodology.

While duct efficiencies can be expected to change somewhat as a function of climate, the change in duct efficiency as a function of insulation R-value was found to vary little with climate within the extremes of the state of California, where this methodology was developed.

The energy losses per square foot of duct surface area can be calculated on an annual basis by using a ratio of duct surface area to floor area of 15 percent for one-story houses and 10 percent for two-or-more-story houses, as prescribed in the CEC methodology. The savings per square foot of duct surface for each increase in duct efficiency can then be calculated, based on the AHR and ACR per square foot of floor area.

Annual energy savings (AES) for insulation level i , relative to insulation level $i-1$, on supply ducts in any location are estimated separately for heating ($s=1$) and cooling ($s=2$) as follows:

$$\begin{aligned} \text{AES}(k,s,i) &= \text{AHR}/\text{EFF}_h \times [1/\text{EFF}_{\text{duct}}(k,s,i-1) - 1/\text{EFF}_{\text{duct}}(k,s,i)] \\ \text{AES}(k,s,i) &= \text{ACR}/\text{EFF}_c \times [1/\text{EFF}_{\text{duct}}(k,s,i-1) - 1/\text{EFF}_{\text{duct}}(k,s,i)] \end{aligned}$$

where

- AES = annual energy savings per square foot of duct surface area,
- AHR = annual space heating requirements per square foot of floor area,
- ACR = annual space cooling requirements per square foot of floor area,
- EFF_h = heating system efficiency or HSPF,
- EFF_{duct} = duct efficiency corresponding to k , h , and i),
- EFF_c = cooling system efficiency or SEER,
with indexes:
 - k = location (1 = attic, 2 = vented crawlspace, 3 = controlled ventilation crawlspace),
 - s = season (1 = heating, 2 = cooling),
 - i = insulation level (0, 1, 2, ..., n ; 0 = base case before adding insulation).

Note: EFF_h and EFF_c do not include additional adjustments for duct losses as described above for the calculation of insulation savings in the building envelope.

Savings for insulation on the return ducts are estimated using adjustment factors derived from a more comprehensive analysis based on the 1987 version of the CEC methodology. The analysis of return ducts was based on a 70F return air temperature. The adjustment factors are 0.35 for heating in attics and crawlspaces, 0.6 for cooling in attics, and 0.8 for cooling in crawlspaces. The adjustment factors are applied directly to the savings computed for the supply ducts.

To compute the actual savings from improvements in duct efficiency, estimates of the annual space heating (AHR) and annual cooling requirements (ACR) per square foot of floor area are needed. However, AHR and ACR per square foot vary significantly from house to house, even in the same climate, due to differences in design, air leakage, and operational profile. Furthermore, these requirements will vary significantly with the degree to which the various insulation recommendations for the structural components of the house

are implemented. Thus it is difficult to estimate the actual savings from improvements in duct efficiency without detailed thermal modeling of the house. For this reason, conservative estimates of AHR and ACR per square foot in each three-digit Zip code area were sought so as not to overestimate the savings from duct insulation in ZIP.

Two sets of estimates of the annual heating and cooling requirements of a 1500 square-foot house in 323 locations, calculated in support of ASHRAE 90.2P standards development by Merle McBride⁷, were used for this purpose. The first set was calculated using the design requirements specified in ASHRAE Standard 90-80A (1980) for energy conservation in the design of new single-family housing. The second set was based on design criteria similar to the proposed ASHRAE Standard 90.2P expected to supersede Standard 90-80A in 1990. It is assumed that most existing houses, even with upgraded insulation, will have AHR and ACR per square foot at least as great as those for houses built to the 1980 standard, while new houses will have lower AHR and ACR, consistent with the more stringent requirements of ASHRAE 90.2P. Thus ZIP uses the first set of AHR and ACR estimates for computing savings from improvements in duct efficiency in existing houses and the second set for computing savings in new houses.

Regression equations were developed from these two sets of annual heating and cooling requirements, using heating degree days (65F, HDD65) and cooling degree hours (74F, CDH74) as independent variables. (These are the same climate-related parameters used by ZIP for estimating energy savings from insulation in the structural components.) Separate regression equations were calculated for ten regions of the United States, with regions based on the first digit of the Zip code (e.g., 0XXXX serves Maine, Vermont, New Hampshire, Connecticut, Massachusetts, and Rhode Island, and New Jersey). In cases where there is significant variation in AHR or ACR within a region, insufficiently explained by HDD65 or CDH74, separate regression equations were calculated by state or even within a state. These regression equations, shown in table A4, are used to estimate AHR and ACR for both new and existing houses in the ZIP methodology for duct insulation analysis.

WATER HEATER INSULATION JACKET

The primary reference for calculating energy savings from water heater insulation jackets is a National Bureau of Standards report entitled Evaluation of Energy-Conserving Modifications for Water Heaters⁸. Standby losses before and after wrapping five water heaters with a 1.5 in. fiberglass insulation kit were measured in an NIST laboratory. The results of this testing, as generalized for ZIP 2.0, are shown in table A5.

⁷ Private communication from Dr. Merle McBride, Owens Corning Fiberglas Corporation, Research Center, Granville, OH, 1989.

⁸ Pall, R. Jr., Evaluation of Energy-Conserving Modifications for Water Heaters, NBSIR 79-1783, National Bureau of Standards, July 1979.

Table A4. Regression equations for estimating annual heating and cooling requirements by ZIP region

AHR1 = Annual heating requirements (Btu/yr-1500 sq ft) for new house,
 ACR1 = Annual cooling requirements (Btu/yr-1500 sq ft) for new house,
 AHR2 = Annual heating requirements (Btu/yr-1500 sq ft) for existing house,
 ACR2 = Annual cooling requirements (Btu/yr-1500 sq ft) for existing house,
 hdd = hdd65 / 100, and
 cdh = cdh74 / 100.

ZIP 0XXXX:

AHR1 = -14.37 + 1.648 x hdd
 ACR1 = 2.35 + 0.332 x cdh
 AHR2 = -21.4 + 0.814 x AHR1
 IF ACR1 < 8 THEN ACR2 = 0 ELSE ACR2 = -5.7 + 0.727 x ACR1

ZIP 1XXXX:

AHR1 = 11.79 + 1.265 x hdd
 ACR1 = 5.36 + 0.198 x cdh
 AHR2 = -30.6 + 0.909 x AHR1
 IF ACR1 < 8 THEN ACR2 = 0 ELSE ACR2 = -8.4 + 0.968 x ACR1

ZIP 2XXXX:

AHR1 = -17.7 + 1.851 x hdd
 ACR1 = 7.73 + 0.172 x cdh
 AHR2 = 0.0 + 0.464 x AHR1
 IF ACR1 < 8 THEN ACR2 = 0 ELSE ACR2 = -6 + 0.98 x ACR1

ZIP 3XXXX:

IF STATES\$ = FL THEN
 AHR1 = -1.78 + 1.296 x hdd
 FOR ALL OTHERS:
 AHR1 = -6.43 + 1.536 x hdd
 FOR ALL STATES:
 ACR1 = 9.08 + 0.148 x cdh
 AHR2 = 3.4 + 0.405 x AHR1
 ACR2 = -5.3 + 0.967 x ACR1

ZIP 4XXXX:

AHR1 = 21.86 + 1.123 x hdd
 ACR1 = 4.17 + 0.176 x cdh
 AHR2 = -22.2 + 0.813 x AHR1
 IF ACR1 < 8 THEN ACR2 = 0 ELSE ACR2 = -7.5 + 0.872 x ACR1

Table A4 (continued)

ZIP 5XXXX:

$AHR1 = -54.76 + 2.17 \times hdd$
 FOR STATES IA, WI, and MN:
 $ACR1 = 3.04 + 0.166 \times cdh$
 FOR STATES SD, ND, and MT
 $ACR1 = 2.27 + 0.104 \times cdh$
 FOR ALL STATES:
 $AHR2 = 28.9 + 0.417 \times AHR1$
 IF $ACR1 < 8$ THEN $ACR2 = 0$ ELSE $ACR2 = -1.4 + 0.189 \times ACR1$

ZIP 6XXXX:

$AHR1 = 2 + 1.41 \times hdd$
 FOR IL:
 $ACR1 = 4.66 + 0.153 \times cdh$
 FOR MO:
 $ACR1 = 9.18 + 0.094 \times cdh$
 FOR KS and NE:
 $ACR1 = 7.54 + 0.084 \times cdh$
 FOR ALL STATES:
 $AHR2 = -19.1 + 0.783 \times AHR1$
 $ACR2 = -10.3 + 1.028 \times ACR1$

ZIP 7XXXX:

$AHR1 = -6.031 + 1.488 \times hdd$
 FOR LA:
 $ACR1 = 42$
 FOR AR, TX, and OK :
 $ACR1 = 5.92 + 0.135 \times cdh$
 FOR ALL STATES:
 $AHR2 = 5.2 + 0.356 \times AHR1$
 $ACR2 = -4.3 + 0.901 \times ACR1$

ZIP 8XXXX:

IF $hdd < 20$ THEN
 $AHR1 = 15$
 IF $hdd \geq 20$ THEN
 $AHR1 = 8.39 + 1.211 \times hdd$
 FOR WY and ID:
 $ACR1 = 2.82 + 0.125 \times cdh$
 FOR CO, UT, AZ, NM, and NV:
 $ACR1 = 5.3 + 0.093 \times cdh$
 FOR ALL STATES:
 $AHR2 = -10.6 + 0.707 \times AHR1$
 IF $ACR1 < 7$ THEN $ACR2 = 0$ ELSE $ACR2 = -6.4 + 0.953 \times ACR1$

Table A4 (continued)

ZIP 9XXXX:

FOR CA:

$$\text{AHR1} = -1.09 + 0.963 \times \text{hdd}$$

$$\text{AHR2} = 4.6 + 0.564 \times \text{AHR1}$$

IF cdh < 3 THEN

$$\text{ACR1} = 0$$

$$\text{ACR2} = 0$$

IF cdh >= 3 THEN

$$\text{ACR1} = 14.63 + 0.069 \times \text{cdh}$$

$$\text{ACR2} = -2.14 + 0.54 \times \text{ACR1}$$

FOR HI:

$$\text{AHR1} = 0: \text{ACR1} = 0: \text{AHR2} = 0: \text{ACR2} = 0$$

FOR OR, WA, and AK:

$$\text{AHR1} = 4.95 + 1.238 \times \text{hdd}$$

$$\text{AHR2} = -18.75 + 0.734 \times \text{AHR1}$$

IF cdh < 3 THEN

$$\text{ACR1} = 0: \text{ACR2} = 0$$

IF cdh >= 3 THEN

$$\text{ACR1} = 4.79 + 0.111 \times \text{cdh}$$

$$\text{ACR2} = 0$$

FOR ALL REGIONS:

Convert to Btu/sq ft for new or existing house as needed:

$$\text{AHR} = \text{AHR1} \times 1000000 / 1500$$

$$\text{ACR} = \text{ACR1} \times 1000000 / 1500$$

$$\text{AHR} = \text{AHR2} \times 1000000 / 1500$$

$$\text{ACR} = \text{ACR2} \times 1000000 / 1500$$

Table A5. Reduction in water heater standby losses (SBL)
due to the installation of an insulating jacket

	<u>Reduction in SBL (%)</u>
Electric (standard)	30
Electric (high efficiency tank)	18
Gas (standard)	25
Gas (high efficiency tank)	15
Oil (standard)	25
Oil (high efficiency tank)	15

Annual purchased energy savings (ΔAEP) attributable to the addition of a water heater jacket are calculated as follows:

$$\Delta AEP = \frac{SBL \times \text{reduction}(\%) \times (t_{\text{tank}} - t_{\text{air}}) \times v_{\text{tank}} \times 8.25/\text{EFF} \times 8760}{10000}$$

where

SBL = standby losses (%/hr),
reduction = percentage reduction in standby losses due to water heater jacket,
 t_{tank} = tank water temp (avg),
 t_{air} = ambient air temp (avg),
 v_{tank} = tank volume in gallons,
8.25 = density of water (lb-gal),
EFF = water heater recovery efficiency, and
8760 = hours/year.

The GAMA Consumers' Directory of Certified Water Heater Efficiency Ratings⁹ provides standby losses for all currently marketed water heaters in units comparable with the approach outlined above. Standby losses vary with the type of water heater, its volume, and the degree to which the tank is insulated. The relationships between tank volume and stand-by losses shown in table A6 were derived from the 1986 GAMA Directory.

In ZIP 2.0, water heater tanks with foam insulation are considered to be high efficiency tanks, while tanks with fiberglass insulation are considered to be standard tanks.

Calculation of savings in annual energy costs

Savings in annual heating and annual cooling costs (AES_h and AES_c) are calculated by multiplying reductions in purchased energy requirements by the unit cost of energy and the units per million Btu.

$$AES_h = \Delta AEP_h \times (\$/\text{unit}_h) \times (\text{unit}_h/\text{million Btu})$$
$$AES_c = \Delta AEP_c \times (\$/\text{unit}_c) \times (\text{unit}_c/\text{million Btu})$$

where:

$\$/\text{unit}_h$ = the current cost per unit of energy used for heating (e.g.,
\$.08/kWh),
 $\$/\text{unit}_c$ = the current cost per unit of energy used for cooling,
 unit_h = the number of units of heating energy per million Btu (e.g.,
293 kWh = one million Btu), and
 unit_c = the number of units of cooling energy per million Btu.

⁹ Gas Appliance Manufacturers Association, Consumers' Directory of Certified Water Heater Efficiency Ratings, Arlington, VA, 1986.

Table A6. Standby losses (as percent of annual energy requirements) used in ZIP analysis of water heater jackets

	Capacity (gallons)	Standby losses	
		Hi Eff	Standard
gas:	30	4.0	5.8
	40	4.0	5.5
	50	3.5	5.3
	70	3.3	5.0
oil:	30	3.0	4.0
	50	2.0	3.0
		Hi Eff	Standard
electric:	30	1.0	2.0
	40	0.9	1.7
	50	0.7	1.7
	70	0.6	1.5

Calculation of total present-value savings in energy costs

Calculate the total present-value savings (PVS) in energy costs over the designated insulation life (30 years for new houses, 20 years for existing houses). Annual savings for heating and cooling are multiplied by the modified uniform present worth factor (UPW*) corresponding to the life, discount rate (7 percent real, i.e., net of general inflation), and corresponding DOE energy price escalation rates (see appendix B), and summed. (DOE projections of price escalation rates (in real terms) for the specified energy type and region of the country are retrieved from a ZIP data file.)

$$PVS = AES_h \times UPW*_h + AES_c \times UPW*_c$$

where

UPW*_h = the modified uniform present worth factor for heating energy, given a study period, the discount rate, and the annual rate of heating energy price escalation over the study period, and

UPW*_c = the modified uniform present worth factor for cooling energy, given a study period, the discount rate, and the annual rate of cooling energy price escalation over the study period.

The UPW* factor is calculated as follows:

$$UPW^* = \sum_{t=1}^N \frac{I_t}{(1+d)^t}$$

where

- N = life or study period in years,
- $I_t = I_{t-1} \times (1+e_t)$ (energy price index in year t),
- $I_0 = 1$
- e_t = rate of energy price increase in year t, and
- d = discount rate

Calculation of net present-value savings

Calculate the net present-value savings for each increment of insulation by subtracting the cost of the insulation from its present-value savings.

$$NS = PVS - C$$

where

C = initial cost (installed) for the insulation level of interest.

Determine R-value with greatest net present-value savings

Determine the insulation R-value for each application of interest that has the greatest net present-value savings. This is designated as the economic R-value for that application. The rate of return for any higher level of insulation evaluate in this analysis will fall below the seven percent discount rate.

APPENDIX B. ENERGY PRICE AND INSULATION COST FILES

I. Energy Price Files

There are six supporting data files in ZIP 2.0 related to energy prices. Two of these files provide default energy prices by state or, in the case of electricity, by three-digit ZIP code; the last four provide the Department of Energy's forecast of residential energy price increases year by year for the years 1990-2020, one file for each major region (North East, East Central, South, and West).

(1) Gas, oil and LPG (propane) prices by state (file ENPR90.ASC)

Gas prices by state were derived from the U.S. Department of Energy's (DOE) Natural Gas Monthly¹⁰, table 28. Prices in dollars per 1000 cubic foot (cf) were divided by the corresponding heat value (Btu/cf) for each state from DOE's Natural Gas Annual¹¹, and again by 10 to convert to dollars per therm (1 therm = 100,000 Btu). These prices are in 1990 dollars.

Residential fuel oil prices for each state were derived from DOE's Winter Fuels Report¹² and State Energy Price and Expenditure Report¹³. Residential fuel oil prices in the first reference are published for 21 selected states (table 6). For the remaining states, the ratios of state prices to the national average, calculated from the second reference, were used to adjust the average U.S. price in 1990 to reflect state differences. This adjusted price was not allowed to fall below \$1.20/gallon. (Note: these prices were based on current oil prices at as of October 15, 1990, in a market reflecting considerable uncertainty about developments the Middle East.)

Propane prices per state were also derived from DOE's Winter Fuels Report (table 7) and State Energy Price and Expenditure Report. The same methodology used to estimate state-specific fuel oil prices was used for propane prices, with a lower bound of \$0.80/gallon.

¹⁰Energy Information Agency, Natural Gas Monthly, July 1990, DOE/EIA-0130(90/07), U.S. Department of Energy, Washington, D.C., 1990.

¹¹Energy Information Agency, Natural Gas Annual, 1989, DOE/EIA-0131(89), U.S. Department of Energy, Washington, D.C., 1990.

¹²Energy Information Administration, Winter Fuels Report, (Week Ending October 26, 1990), DOE/EIA-0538(90/91-05), U.S. Department of Energy, Washington, D.C., 1990.

¹³Energy Information Administration, State Energy Price and Expenditure Report (1988), DOE/EIA-0376(88), U.S. Department of Energy, Washington, D.C., 1990.

(2) Electricity prices by ZIP code (file ELEC90.ASC)

The default summer and winter kWh prices in ELEC90.ASC were derived from an annual DOE report on electricity bills for all electric utilities¹⁴. The default kWh prices are representative of the price of last kWhs used monthly in the peak cooling and heating months in each three-digit ZIP Code region. Up to eight major electric utilities (based on number of customers) were identified for each state, and one of these utilities was designated for each three-digit ZIP Code region in the state. The residential kWh rate schedule for the designated utility was used as the basis for calculating these default prices. (Many towns and cities are served by a local municipal utility. Rate schedules for these local utilities were not incorporated into this analysis.) Typical monthly electricity bills for usage rates of 250, 500, 1000, and 2500 kWh are reported annually by the DOE for all U.S. utilities. Summer kWh prices were calculated as the average price of a kWh for monthly kWh usage rates between 500 and 1000 kWh. Winter kWh prices were calculated as the average price of a kWh for monthly usage rates between 1000 and 2500 kWh. 1988 kWh prices were updated to 1990 prices using a price index factor of 1.1. All kWh prices were rounded to the nearest cent.

(3)-(6) Energy Price Escalation Rates (files DOEENPR.*)

Energy price escalation rates (rates of energy price increase) for the years 1990 to 2020 are derived from the DOE Energy Information Administration's forecast of residential energy prices, as published by NIST in Energy Prices and Discount Factors for Life-Cycle Cost Analysis (1990)¹⁵. Four files are available (with corresponding filename extensions), one for each major Census region: (1) Northeast (NE), (2) Midwest (MW), (3) Southeast (SE), and (4) West (W). These files contain DOE projections of residential energy prices for electricity, fuel oil, LPG, and natural gas, in constant 1990 dollars. ZIP reads these data and converts them to energy price escalation rates as follows:

$$e_i = EP_i/EP_{i-1} - 1$$

where e_i = escalation rate in year i , and
 EP_i = energy price in year i .

Because the energy price projections are in constant dollars, the resulting price escalation rates are in real terms (i.e., exclusive of general inflation), consistent with the use of a real discount rate. The methodology for calculating modified uniform present worth factors, based on these escalation rates, is outlined in Appendix A. These energy price projections are used only to calculate price escalation rates; they are not used as default energy prices.

¹⁴ Energy Information Administration, Electric Sales, Revenue, and Bills (1988), DOE/EIA-0540(1988), U.S. Department of Energy, Washington, D.C., 1990.

¹⁵ Lippiatt, B. C., and Ruegg, R. T., Energy Prices and Discount Factors for Life-Cycle Cost Analysis (1990), NISTIR 85-3273-5 (Revised 10/90), National Institute of Standards and Technology, Gaithersburg, MD, 1990.

II. Insulation Cost Files

There are two insulation cost files, one for new houses (INSCOST2.NEW) and one for existing houses (INSCOST2.RET). These files provide a general inflation factor to convert 1985 costs to 1990 costs, a regional cost adjustment factors for all insulation costs, and specific data for the technical and economic analysis of insulation in each component of the house. The structure of these two files is identical. The file for existing houses specifies R-value increments to be evaluated for exterior walls and basement walls differently than those in the file for new houses.

The first two lines in the insulation cost file are remark lines that are ignored.

The third line contains the general inflation index to be used to update all insulation prices in this file to the desired year. The prices in this file are currently in 1985 dollars. The general inflation index of 1.2 is used to update these prices to 1990 dollars.

The fourth line contains 12 regional cost adjustment factors. These factors were taken from an NAHB Research Foundation report¹⁶ for ASHRAE SPC 90.2 (energy standard for new low-rise residential buildings). These states in each region and the adjustment factor currently used in both insulation cost files are shown in table B1.

Table B1. Regional cost adjustment factors

Region	States	Factor
1	MA, RI, NH, ME, VT, CT	1.03
2	NJ, NY, PA, DE, DC, MD	1.04
3	VA, WV, NC, SC, GA	0.81
4	FL	0.97
5	AL, TN, MS, LA, AR, OK, TX,	0.95
6	KY, IA, MO, KS, NE,	0.98
7	OH, IN, MI, WI, MN, SD, ND, IL	1.03
8	MT, CO, WY, ID, UT, NV	0.97
9	AZ, NM	0.97
10	CA, HI	1.22
11	OR, WA	1.04
12	AK	1.30

¹⁶NAHB Research Foundation, Inc., An Economic Data Base in Support of SPC 90.2: Costs of Residential Energy, Thermal Envelope and HVAC Equipment, NAHB National Research Center, Upper Marlboro, MD, December 1986.

The remaining data in the insulation cost files provide not only the U.S. average cost for each insulation R-value in each component, but provide the uninsulated U-value, R-value increments, and corresponding U-values for each increment that drive the ZIP analysis. The fifth line specifies the number of insulation systems contained in this file (currently 18).

The structure of the remaining lines is the same for each insulation system. Lines for each system are numbered from 1 for clarity here:

line 1:

Code number for this insulation system (1-18; these are mandatory identity codes and cannot be changed without making corresponding changes to the ZIP source code).

Insulation system designator (B/B = batt/blanket, RF = rigid foam)

Number of increments (1-9)

Component type (1 = upper envelope (attic, cathedral ceiling, exterior walls), 2 = lower envelope (floors, crawlspace and basement walls), 3 = ducts, 4 = water heater insulation).

Area/perimeter designator (1 = analysis on square foot basis, 2 = analysis on linear foot basis)

line 2: Comment that shows on screen with insulation costs

line 3: The uninsulated component U-value (Btu/sqft-hr-F)

Remaining lines (one for each R-value):

R-value of insulation increment to be evaluated (sqft-hr-F/Btu)

Corresponding U-value (Btu/sqft-hr-F)

Price per square foot or linear foot, consistent with area/perimeter designator

Insulation prices in the INSCOST2.NEW and INSCOST2.RET files were taken from the NAHB Research Foundation report and from Christian¹⁷. The prices in these files are currently in 1985 dollars. They are updated to 1990 dollars in ZIP using the general inflation index for that period (1.20).

¹⁷Christian, J. E., "Worksheet for Selection of Optimal Foundation Insulation, Thermal Performance of the Exterior Envelopes of Buildings IV, proceedings of the ASHRAE/DOE/BTECC/CIBSE Conference December 4-7, Orlando, Florida, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1989, pp 800-814.

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date	02. Summary prepared by (Name and Phone) Stephen R. Petersen (301) 975-6136	03. Summary action
Yr. Mo. Day 9 0 0 1 0 3	05. Software title ZIP-Code Insulation Program (ZIP) Version 2.0	New <input type="checkbox"/> Replacement <input checked="" type="checkbox"/> Deletion <input type="checkbox"/>
04. Software date		Previous Internal Software ID <input type="checkbox"/>
Yr. Mo. Day 9 0 0 1 0 3		07. Internal Software ID
06. Short title		

08. Software type	09. Processing mode	10. Application area				
<input type="checkbox"/> Automated Data System <input checked="" type="checkbox"/> Computer Program <input type="checkbox"/> Subroutine/Module	<input checked="" type="checkbox"/> Interactive <input type="checkbox"/> Batch <input type="checkbox"/> Combination	<table style="width: 100%;"> <tr> <th style="text-align: center;">General</th> <th style="text-align: center;">Specific</th> </tr> <tr> <td> <input type="checkbox"/> Computer Systems Support/Utility <input checked="" type="checkbox"/> Scientific/Engineering <input type="checkbox"/> Bibliographic/Textual </td> <td> <input type="checkbox"/> Management/Business <input type="checkbox"/> Process Control <input type="checkbox"/> Other </td> </tr> </table> <p style="text-align: center;">Economic Analysis of Thermal Insulation</p>	General	Specific	<input type="checkbox"/> Computer Systems Support/Utility <input checked="" type="checkbox"/> Scientific/Engineering <input type="checkbox"/> Bibliographic/Textual	<input type="checkbox"/> Management/Business <input type="checkbox"/> Process Control <input type="checkbox"/> Other
General	Specific					
<input type="checkbox"/> Computer Systems Support/Utility <input checked="" type="checkbox"/> Scientific/Engineering <input type="checkbox"/> Bibliographic/Textual	<input type="checkbox"/> Management/Business <input type="checkbox"/> Process Control <input type="checkbox"/> Other					

11. Submitting organization and address National Institute of Standards and Technology Gaithersburg, MD 20899	12. Technical contact(s) and phone Stephen R. Petersen (301) 975-6136
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13. Narrative ZIP 2.0 is a revised and updated version of ZIP, the ZIP-Code Insulation Program. ZIP is a computer program developed to support the DoE Insulation Fact Sheet by providing users with customized estimates of economic levels of residential insulation. These estimates can be made for any location in the United States by entering the first three digits of its ZIP code. The revised ZIP program calculates economic levels of insulation for attics, cathedral ceilings, exterior wood-frame and masonry walls, floors over unheated areas, slab floors, basement and crawlspace walls, ducts in unconditioned spaces, and water heaters. Climate parameters, energy prices and insulation costs are contained in a file on the ZIP diskette and are automatically retrieved by ZIP code.

14. Keywords
building design; building economics; energy conservation; engineering economics; insulation; life-cycle cost; residential construction; space cooling; space heating; thermal insulation

15. Computer manufr and model IBM PC/XT/AT and compatible	16. Computer operating system MS-DOS	17. Programing language(s) BASIC	18. Number of source program statements 3000
19. Computer memory requirements 256K	20. Tape drives 0	21. Disk/Drum units 1	22. Terminals 1

23. Other operational requirements
Printer

24. Software availability	25. Documentation availability
Available <input checked="" type="checkbox"/> Limited <input type="checkbox"/> In-house only <input type="checkbox"/>	Available <input checked="" type="checkbox"/> Inadequate <input type="checkbox"/> In-house only <input type="checkbox"/>

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ZIP--The Zip-Code Insulation Program, Version 2.0
(Addendum to User's Guide and Revised Short Guide)

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Stephen R. Petersen

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Building Systems Division
1000 Independence Avenue, S.W.
Washington, D.C. 20585

10. SUPPLEMENTARY NOTES

DOCUMENT DESCRIBES A COMPUTER PROGRAM; SF-185, FIPS SOFTWARE SUMMARY, IS ATTACHED.

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

ZIP 2.0 is a revised and updated version of ZIP, the Zip-Code Insulation Program. ZIP is a computer program developed to support the DoE Insulation Fact Sheet by providing users with customized estimates of economic levels of residential insulation. These estimates can be made for any location in the United States by entering the first three digits of its ZIP code. The program and supporting files are contained on a single 5-1/4 in. diskette for use with microcomputers having an MS-DOS operating system. The revised ZIP program calculates economic levels of insulation for attics, cathedral ceilings, exterior wood-frame and masonry walls, floors over unheated areas, slab floors, basement and crawlspace walls, ducts in unconditioned spaces, and water heaters. Climate parameters are contained in a file on the ZIP diskette and are automatically retrieved by ZIP code. Regional energy prices and insulation costs are also retrieved from the diskette, but these can be overridden to better reflect local conditions. A short guide to ZIP is included on the ZIP diskette. An addendum to the ZIP User's Guide and Reference Manual (NISTIR 88-3801) is also included under separate cover as NISTIR 88-3801-1.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

building design; building economics; energy conservation; engineering economics; insulation; life-cycle cost; residential construction; space cooling; space heating; thermal insulation

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