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The National Energy Audit (NEAT) Engineering Manual (Version 6)

M. B. Gettings

February 2001

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The National Energy Audit (NEAT) Engineering Manual (Version 6)

M. B. Gettings

February 2001

Prepared for the
Office of Building Technology, State and Community Programs
Weatherization Assistance Program
U.S. Department of Energy

Prepared by the
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UT-BATTELLE, LLC,
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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Acknowledgments

The author appreciates the continued support provided by Gail McKinley, Director of the Building Technology Assistance Office, U.S. Department of Energy, for this project. Appreciation is also extended to the reviewers, Sherry Livengood and the late Howard McClain, for their excellent comments, as well as many in the weatherization technical community who have contributed their expertise to the Program.

Abstract

Government-funded weatherization assistance programs resulted from increased oil prices caused by the 1973 oil embargo. These programs were instituted to reduce U.S. consumption of oil and help low-income families afford the increasing cost of heating their homes. In the summer of 1988, Oak Ridge National Laboratory (ORNL) began providing technical support to the Department of Energy (DOE) Weatherization Assistance Program (WAP). A preliminary study found no suitable means of cost-effectively selecting energy efficiency improvements (measures) for single-family homes that incorporated all the factors seen as beneficial in improving cost-effectiveness and usability.

In mid-1989, ORNL was authorized to begin development of a computer-based measure selection technique. In November of 1992 a draft version of the program was made available to all WAP state directors for testing. The first production release, Version 4.3, was made available in October of 1993. The Department of Energy's Weatherization Assistance Program has continued funding improvements to the program increasing its user-friendliness and applicability. Initial publication of this engineering manual coincides with availability of Version 6.1, November 1997, though algorithms described generally apply to all prior versions. Periodic updates of specific sections in the manual will permit maintaining a relevant document.

This Engineering Manual delineates the assumptions used by NEAT in arriving at the measure recommendations based on the user's input of the building characteristics. Details of the actual data entry are available in the NEAT User's Manual (ORNL/Sub/91-SK078/1) and will not be discussed in this manual.

1

INTRODUCTION

Government funded weatherization assistance programs resulted from increased oil prices caused by the 1973 oil embargo. These programs were instituted to reduce U.S. consumption of oil and help low-income families afford the increasing cost of heating their homes. In the summer of 1988, Oak Ridge National Laboratory (ORNL) began providing technical support to the Department of Energy (DOE) Weatherization Assistance Program (WAP) to maintain and, where necessary, upgrade the technical foundation and cost-effectiveness of their weatherization program for low-income housing. A preliminary study [Gettings and Kolb, 1991] was performed to identify the needs and possible avenues for improving the program and to make recommendations. The preliminary study found no suitable means of cost-effectively selecting energy efficiency improvements (measures) for single-family homes that incorporated all the factors seen as beneficial in improving cost-effectiveness and usability.

The study concluded that an upgraded measure selection technique should provide (1) consideration of an increased range of measures, including cooling energy saving measures and equipment measures, (2) the ability to determine net measure savings accounting for potential measure interactions, (3) use of economic criteria to establish measure cost-effectiveness, (4) the ability to model each house individually, providing measure recommendations tailored to each, and (5) encouragement in the use of improved diagnostic tools.

During this preliminary study, the state of North Carolina was identified as a willing partner in a cost-shared project to field test a new audit technique. In mid-1989, ORNL was authorized to begin development of a computer-based measure selection technique suitable for this field test. Development occurred during 1989 and 1990 with valuable feedback from North Carolina agencies as preliminary versions were used in the field.

The end-result was well received. North Carolina agencies found learning to use the audit relatively easy. The frequency of favorable reports from clients whose homes were weatherized with the audit also appeared to increase. This favorable reception and preliminary results showing expected increases in energy savings led in 1991 to authorization for expanding applicability of the program nationwide. The audit was tagged with the acronym, NEAT, for National Energy AudiT.
Throughout 1991 and 1992 development continued with periodic limited distributions for solicitation of comments and testing. In November of 1992, the program was made available to all WAP state directors for further testing and to allow their evaluation of NEAT for possible incorporation into their weatherization programs. A similar distribution, including a draft user's manual, was accomplished in March 1993. Following receipt and review of comments on both the program and manual, release of NEAT Version 4.3 occurred in October of 1993 with a revised User's Manual dated July 1993.

The Department of Energy's Weatherization Assistance Program has continued funding improvements to the program increasing its user-friendliness and applicability. The initial publication of this engineering manual coincides with availability of Version 6.1, November 1997, though algorithms described generally apply to all prior versions. Periodic updates of specific sections in the manual will permit maintaining a relevant document.

This manual divides the explanation of NEAT calculations into broad topics with as many as two additional levels of subtopics. Each first level subtopic will begin on a new page, with page numbering beginning again with one (1) prefaced by the subtopic number (e.g., 2.1-1). This will permit greater ease in updating the manual as changes to NEAT occur. Liberal use will be made of introductory paragraphs giving overviews of the ideas to be discussed in greater detail within the topic and subtopic sections. This will lend to some repetition, but hopefully also to a more easily understood document.

Although individual topics could be followed and understood without experience in using the NEAT software, understanding where the required data originates from and how the calculations affect the results and their presentation would be difficult without a working knowledge of the program. Thus, it is recommended that this manual be used with the User's Manual supplied with the software.

A goal of the manual is to provide sufficient information to allow the reader to manually duplicate the program's computations, if he so desired. Appendix A contains an example problem leading the reader through such an exercise.

The "National Energy Audit" (NEAT) is a computerized residential energy audit written in the programming language "C". It can be run on any IBM compatible personal computer having 640 Kbytes of random access memory (RAM). All files necessary to execute the program can be stored on a 720-Kbyte or larger disk. Execution times vary with computer type and complexity of the house being analyzed, but even on computers with slower processors, most applications of the audit would require less than a minute execution time.

The "audit" described in this manual is more correctly designated a "measure selection technique." An entire "audit" procedure encompasses many activities, including (1) selection of eligible homes, (2) obtaining utility billing information, (3) determining expenditure levels, (4) visiting the home to obtain building description data and perform diagnostic tests, (5) selecting appropriate and cost-effective measures, and (6) customer education. This manual addresses only item (5), selecting appropriate measures. However, for the sake of brevity, the term "audit" will be used to refer to the "measure selection technique."

The audit strongly suggests, but does not necessarily require, the use of existing infiltration reduction procedures using a blower-door. The blower-door establishes if infiltration reduction is necessary, then helps locate leaks and monitor progress in their elimination. Cost effectiveness is established by setting a priori a benefit-to-cost ratio for infiltration work and terminating work when that limit is reached. To require an auditor to describe all tasks deemed necessary in infiltration reduction, compute the cost and expected savings of each individual task, and rank these tasks with other envelope and equipment retrofit measures would require unnecessary time and computation. NEAT assumes that infiltration reduction will be performed in parallel to measures selected by the audit and according to guidelines chosen by the auditor. NEAT can evaluate the cost-effectiveness of infiltration reduction efforts, but it will not direct the work.

Selected "low-cost/no-cost" measures and those dependent on customer education (such as occupant controlled thermostat setback, water heater temperature reduction, energy efficient showerheads, etc.) are not included in the audit because (1) they can often be implemented in the time it takes to collect and enter the information into the program, (2) the energy savings cannot be accurately predicted, (3) a thorough occupant training session would be required to maintain any presumed savings, and (4) the extent that the measure will be used is not known (occupants will not generally remove attic insulation after it is installed, but may or may not continue to setback their manual heating system thermostat). Decisions regarding these measures should be determined outside of the audit and implemented in parallel to audit measures following the auditor's own guidelines.

The audit also differs from other similar programs in that energy savings are calculated assuming that the house is maintained at "average" conditions and that the climate is "average" for the geographic location. Because the weatherized houses will likely be occupied by different people over the lifetime assumed for the measures installed, this approach is more correct for a government funded program where energy savings must be realized over lifetimes up to 20 years to be cost effective. Basing the savings on actual conditions would (1) likely lead to better agreement between predicted and actual first year savings, but not necessarily to cumulative savings, (2) penalize energy minded occupants and restrict the measures installed in their homes, even though they may move in the near future, and (3) require additional data input and guesswork to establish actual conditions. Assuming average conditions is consistent with the approach of balancing higher accuracy with keeping information requirements simple and to a minimum.

The use of "average" conditions also distinguishes NEAT as a "measure selection technique" as opposed to a "building energy analysis program." The latter attempts to accurately predict a building's energy consumption under specific conditions of occupancy and weather. NEAT is not designed to satisfy this role, but rather to select measures that on the average will be cost effective over an extended life.

Data entry in NEAT involves describing to the program the construction details of the house being audited, information regarding the energy measures to be considered, and local weather and fuel cost data. Details of data entry are available in the NEAT User's Manual (ORNL/Sub/91-SK078/1) and will not be discussed in this manual. Only the assumptions based on the user's choices at data entry will be covered here. Following data entry the audit computes estimates of pre-retrofit whole building space heating and cooling energy consumptions based on the house description data supplied by the user. The consumptions are computed using a monthly heating and cooling variable base degree-day method by algorithms similar to those developed for the CIRA program [LBL, 1982]. The building consumptions are needed in computing the energy savings from measures affecting the efficiencies of the heating and cooling equipment.

NEAT then computes the energy savings and costs for each individual measure applicable to the building described as if it were the only measure installed in the house. From these energy savings, a discounted dollar savings over the life of each measure is computed. The ratio of this dollar savings to the cost of installing the measure, the "savings-to-investment ratio" (SIR), is used in an initial ranking of the measures' effectiveness.

The "interacted" savings and SIR of measures are then determined assuming the measures are added to the house collectively, in order of their ranking, e.g., the second ranked measure is installed in the house initially described by the user after having been modified by the first ranked measure. If this second-ranked measure's updated SIR is greater than a user-defined limit, the measure is left implemented, else it is removed so that the next measure's effectiveness is not dependent on it. The choice between two mutually exclusive measures (such as different levels of insulation) is made on the basis of their "net present value" (NPV), the difference of life-time savings and installation cost, rather than their SIR. This has been shown to be the more correct criterion on which to base the selection between two measures, both of which cannot be installed.

The audit computes and reports to the user the energy savings, discounted dollar savings, installation cost, and SIR for each measure considered cost-effective. For those with SIR greater than the user-designated cutoff, a materials list gives the material name, type, and quantity required for installation of the measure.

NEAT permits entry of pre-retrofit billing data for gas or electrically heated homes or homes with electric air-conditioning. The user may then make the decision to have the savings of the measures adjusted to reflect the difference in billed consumption and that predicted by the program.

2

WHOLE BUILDING ENERGY CONSUMPTION ESTIMATION

NEAT uses a monthly, variable-base, degree-hour (VBDH) calculation with the building description data supplied by the user to compute pre-retrofit whole house energy consumptions for heating and cooling. These consumptions are necessary to determine the savings resulting from measures which alter the equipment efficiencies. For example, the energy saved by replacing a 65% efficient furnace with a 90% efficient furnace depends on the total amount of heat that must be delivered by the furnace.

The VBDH method is patterned after algorithms used in the CIRA program [LBL, 1982]. Monthly building load coefficients (BLC), characterizing the building's response to the indoor-outdoor temperature differences, are computed from effective envelope conductances and infiltration characteristics. "Free heat" from solar and internal heat generation together with the values of BLC produce monthly estimates of the home's balance point temperature, that outdoor air temperature for which no heating or cooling need be supplied by the equipment. The VBDH method assumes that the energy consumption of a house is proportional to the difference between the mean daily temperature and this balance point temperature multiplied by the length of time over which this difference occurs—the number of degree-hours. From weather data contained in separate computer data files, the degree-hours at various balance points for the prescribed geographic location are obtained and used in a standard degree-hour determination of the energy consumption [ASHRAE, 1985].

The sum of the conductances (UA-values in Btu/hr-F) from the envelope components of a house and an effective conductance from infiltration produce monthly values of the building load coefficient (BLC). Although the envelope conductances are presumed to remain constant, the infiltration contribution to the BLC varies due to monthly climate variations. Therefore, individual monthly values of the BLC are used in the computations. For all components except foundation spaces (spaces whose walls are partially or totally underground), one dimensional heat flow is assumed. The assumptions used in determining the individual component conductances are discussed in the following sections.

WALLS

The following layer R-values are assumed for the various types of walls designated by the user on input. The majority are taken from ASHRAE's Handbook of Fundamentals (HOF) or the DOE-2 Building Energy Simulation program's material characteristics library. Except for the masonry or stone wall type, resistances for various types of siding chosen by the user are also added to both framing and cavity paths (see listing following). An exterior film R-value of 0.25 is added to exposed walls and an interior film R-value of 0.68 to buffered walls or walls to unconditioned attics.

<u>Frame Wall</u> (Balloon or Platform)

Framing	Cavity	Composition
1.32	1.32	½" sheathing
-	1.01	Non-reflective air space
4.35	-	2x4" wood stud
0.45	0.45	½" gypsum board
<u>0.68</u>	<u>0.68</u>	Interior film resistance
6.80	3.46	Total

<u>Masonry, Stone</u> (No siding R-value added)

Framing	Cavity	Composition
1.60	1.60	Common brick - 8"
0.94	-	1x3" furring
-	1.01	Non-reflective air space
0.45	0.45	½" gypsum board
<u>0.68</u>	<u>0.68</u>	Interior film resistance
3.67	3.74	Total

Concrete Block and Other

Framing	Cavity	Composition
2.00	2.00	8" light weight aggregate block
-	1.01	Non-reflective air space
0.94	-	1x3" furring
0.45	0.45	½" gypsum board
0.68	0.68	Interior film resistance
4.07	4.14	Total

The following listed R-values are added to the total R-values of each path listed above according to the exterior type given by the user on input.

R-Value	Material
0.8	Wood, Masonite, Brick, Stone
0.6	Aluminum, Steel, Vinyl, Other (includes air spaces)
0.2	Stucco
0.0	None

The framing and cavity paths are then combined in parallel with a 15 percent framing factor. Thus, the wall conductances (UA-values) equals,

$$UA_{wall} = A_{wall}*(0.15/R_{frame}+0.85/R_{cavity}).$$

The walls' contribution to the building load coefficient is the sum of the individual wall UA-values over all the walls described by the user.

WINDOWS

The following table lists the R-values and transmittances used for various types of windows. The values are taken from the LBL program "Window 3." They assume a one inch air space for storms and a 1/4" air space for the double pane windows. Other assumed conditions included the following:

30 F	Outdoor air temperature
70 F	Indoor air temperature
10 mph	Wind speed
124 Btu/hr-ft^2	Incident solar

The R-values listed below include both interior and exterior film resistances as determined by "Window 3" under the conditions given above. The transmittance are equal to the shading coefficient listed by "Window 3" times 0.87.

	R-Value Frame Type			Transmittance
Glazing Type	Wood Vinyl	Improved Metal	Metal	
Single	1.19	0.97	0.80	0.884
Single with metal storm	1.55	1.33	1.16	0.791
Single with wooden storm	2.08	1.86	0.59	0.791
Double	1.89	1.45	1.09	0.789
Double with metal storm	2.25	1.81	1.45	0.714
Double with wooden storm	2.78	2.34	1.98	0.714

The window conductances (UA-values) are equal to glazing area of each window type divided by the appropriate R-value from the table above.

$$UA_{wdw} = A_{glaz}/R_{wdw}.$$

The glazing area for each window is derived from the storm window dimensions supplied by the user. The storm window dimensions are the required window size parameters, whether a storm window is present or not. It was assumed easier for the user to measure and input the size of a storm window appropriate for each window than to measure the actual glazing area. Also, if storm windows are called for (or needed as a repair item), the contractor then has the proper dimensions recorded. The glazing area in square feet is derived from the storm window dimensions (in inches) using the following formula:

$$A_{glaz} = [\ (H_{wdw} - 7) * (W_{wdw} - 4) * N_{wdw}\ ] / 144$$

where,

A_{glaz} = glazing area [ft^2]
H_{wdw} = storm window height [in]
W_{wdw} = storm window width [in]
7, 4 = adjustments from storm window dimensions to glazing dimensions [in]
N_{wdw} = number of windows described on input line
144 = conversion from in^2 to ft^2

The windows' contribution to the building load coefficient is the sum of the individual window UA-values over all the windows described by the user.

The use of the transmittances are discussed in Section 2.3, Solar Gains. Infiltration through the windows is assumed included in the whole-house air-leakage characteristics, and not treated individually for each window.

DOORS

The following R-values are assigned to the door types chosen by the user. They are taken from ASHRAE HOF, 1985, p. 23.15 and include both interior and exterior films.

Door Type	R-Value
Wood, hollow core	2.17
Wood, solid	2.56
Metal, insulated	2.50

Conductances for doors equal the area of each door times the number of doors described having the indicated description, divided by the applicable R-value from the table above,

$$UA_{door} = A_{door} * N_{door} / R_{door}.$$

Even though conduction through doors may not be significant compared to the overall home's heat loss, their area is subtracted from the gross wall area specified by the user on the wall input screen. The reduction in wall area will also be seen in the wall insulation material listing, should the wall segment containing the door be recommended for insulation.

ATTICS/CEILINGS

The attic model performs an energy balance on the attic, assuming conduction through the attic ceiling to the living space temperature and through the roof to a sol-air temperature, with an assumed 0.3 cfm/ft_2 of attic floor area ventilation to the outside air. The UA-values (Btu/hr-F) used in this energy balance assume the following constructions and materials having the indicated R-values, the total U-values equaling the inverse of the sum of the R-values.

Roof Construction

Framing	Cavity	Composition
0.17	0.17	Exterior film resistance
0.44	0.44	Asphalt shingle
0.06	0.06	Felt
0.77	0.77	5/8" plywood sheathing
4.35	-	2x4" ceiling rafter
0.62	0.62	Interior film resistance
6.41	2.06	Totals ($1/U_{r,frm}$ $1/U_{r,cav}$)
2.21		Total both paths with 10% framing

Ceiling Construction

Framing	Cavity	Composition
0.40	0.40	Attic-side film resistance
6.89	See Below	2x6" ceiling joist / Insulation
0.45	0.45	½" gypsum board
0.76	0.76	Interior film resistance
8.50	1.61 + ins.	Totals ($1/U_{c,frm}$ $1/U_{c,cav}$)

Added to the cavity path of the ceiling is the insulation R-value, determined as the product of a user supplied insulation thickness and the R-values per inch for the various insulating materials, listed below. If this existing insulation depth is greater than 5.5", an R-value corresponding to a depth of the existing insulation thickness minus 5.5" is also added to the framing path.

Insulation R-values/Inch	Insulation Material
0.00	None
3.75	Blown cellulose
3.09	Blown fiberglass, Rockwool, Other
3.33	Fiberglass batt

These U-values are combined with appropriate framing factors and the assumption of a 1/3 rise-to-run pitch for the attic roof (unless a cathedral ceiling has been designated) to form the UA-values (Btu/hr-F) for the ceiling, roof, and ventilation, for use in the energy balance.

$$UA_{ceil} = (.15*U_{c,frm}+.85*U_{c,cav})*A_c$$

$$UA_{roof} = (.1*U_{r,frm}+.9*U_{r,cav})*\phi*A_c$$

$$UA_{vnt} = 1.08 * 0.3 * A_c$$

where,

A_c = area of the attic floor (ft^2)
ϕ = area ratio of roof to ceiling
= 1.054 (pitch of 1/3) or = 1.0 (cathedral ceiling)
0.3 = assumed attic ventilation rate (cfm/ft_2 of attic floor area)
1.08 = conversion constant (Btu/hr-f / cfm).

The energy balance on the attic yields

$$UA_{vnt}*(T_o-T_a) + UA_{roof}*(T_{sa}-T_a) + UA_{ceil}*(T_i-T_a) = 0$$

where,

T_o = average outdoor air temperature (F),
T_a = average attic air temperature (F),
T_{sa} = average outdoor sol-air temperature on the roof surface (F), and
T_i = average indoor air temperature (F).

The sol-air temperature, T_{sa}, is set equal to

$$T_{sa} = T_o + \alpha I/h_o,$$

where,

α = absorptance of roof surface (0.7)
I = average solar intensity on roof surface (Btu/hr)
h_o = exterior film coefficient for roof surface (Btu/hr-F)

and the energy balance equation solved for T_a. This value of T_a is then placed into the expression for the heat loss through the ceiling of the living space (the attic floor), Q

$$Q = UA_{ceil}*(T_i-T_a), \text{ yielding,}$$

$$Q = UA_{ceil}*(UA_{vnt}+UA_{roof})/UA_{sum} * (T_i-T_o) - UA_{ceil}*UA_{roof}*\alpha I/h_o/UA_{sum}$$

where,

$$UA_{sum} = UA_{ceil}+UA_{vnt}+UA_{roof}.$$

The coefficient of (T_i-T_o) in the first term of the equation for Q above gives an effective UA-value from the living space to the outside air temperature through the attic. It is used in the VBDH equations as an effective roof/attic UA-value.

$$UA_{attic} = UA_{ceil}*(UA_{vnt}+UA_{roof})/UA_{sum}$$

The second term represents heat added to the living space due to solar radiation incident on the roof surface. It defines a effective solar aperture for the roof/attic (see Section 2.3, Solar Gains) of

$$SA_{attic} = Ua_{ceil}*UA_{roof}*\alpha/h_o/UA_{sum}.$$

If more than one attic element has been described, the sum of the conductances over all such elements provides the contribution to the building load coefficient and the sum of the individual effective solar apertures contributes to the total free heat, also used in the VBDH equations (see Section 2.4, The Variable Base Degree Hour Calculations).

FOUNDATION SPACES

NEAT's model for heat loss through foundation spaces (spaces which may be partially or totally underground) is relatively more complex than other models thus far described. The algorithms used primarily follow the procedures described in the engineering assumptions of the CIRA program [LBL, 1982] with the addition of (1) a term to account for waste heat dumped to the space by equipment if the space has been designated as unintentionally conditioned and (2) heat flow through the sill. The model views the earth surrounding below-grade surfaces as resistances through the ground to the outside air temperature.

The following account will first describe the assumptions used in modeling the individual elements which may comprise the foundation space: the floor between it and the living space; the sill area; the walls, both above and below-grade; and the floor of the foundation space. Next, the means of computing the conductances attributed to each element will be described. This includes the equations used to model the heat flow through the earth surrounding below-grade elements. Finally, some or all of these elements will be combined in differing ways, depending on the foundation space type, to form effective conductances of the foundation spaces to be used as part of the BLC.

ELEMENT R-VALUES

The following material layers and R-values are assumed present in the various components defining the foundation space of the house. The concrete slab and block R-values are taken from ASHRAE HOF, 1985, p. 23.8.

Floor to Living Space

Framing	Cavity	Composition
0.76	0.76	Basement film resistance
9.06	See Below	2x8" floor joist / Insulation
0.95	0.95	Subfloor
0.68	0.68	Plywood
0.50	0.50	Floor covering
0.76	0.76	Interior film resistance
12.71	3.65	Totals ($1/U_{f,frm}$ $1/U_{f,cav}$)
3.93		Total both paths with 10% framing, no insulation ($=R_f$)

The R-value of existing insulation is added to the cavity path only, unless the R-value is less than 3.5, in which case the program assumes the user is describing a floor covering and adds the R-value to both paths.

Sill

R-Value	Composition
1.87	Wood joist
1.32	Sheathing
0.21	Interior film resistance
3.40	Total (= R_{sill})

Foundation Space Walls (above- and below-grade)

R-Value	Composition
0.25	Exterior film resistance
1.04	8" 36 lb 2-core concrete block
0.68	Interior film resistance
1.97	Total (= R_w)

The R-value of existing foundation space wall insulation is added to the above total component resistance.

Concrete Slab (slab-on-grade and basement floor)

R-Value	Composition
1.60	4" medium weight (80 lb/ft^3) concrete
0.76	Basement floor film resistance
2.36	Total (= R_{slab})

ELEMENT CONDUCTANCES

The expressions below define the conductances (UA-values in Btu/hr-F) for the floor to the living space, UA_f; the sill, UA_{sill}; the above-grade wall area, UA_{wa}; the below-grade wall area, UA_{wb}; and the effective conductance of the basement or crawlspace floor through the ground to the ambient air, U_g. As previously indicated, the algorithms modeling heat flow through the earth are taken from the CIRA program.

$$UA_f = A_f/R_f$$

$$UA_{sill} = P * \gamma/100 * 0.667 / R_{sill}$$

$$UA_{wa} = P * \chi/100 * H / R_w$$

$$UA_{wb} = A_{wb} * \delta \ln(1 + \delta/R_w)$$

$$UA_g = A_f * U_g$$

where,

A_f = area of floor to living space (ft^2)(assumed equal to the floor of the basement)
P = perimeter of foundation space (ft) (user-supplied)
γ = percent of perimeter exposed (%) (user-supplied)
χ = percent of wall exposed (%) (user-supplied)
0.667 = height of sill (ft) (assumed 8")
H = height of foundation space (ft) (user-supplied)
A_{wb} = P * (1-χ)/100 * H = Area of below-grade wall area (ft^2)
U_g = U-value of the ground, 0.38 for basements, 0.78 for crawlspaces (Btu/hr-ft^2-F)

$$\delta = 1 + \frac{\pi H(1-\chi)}{2C_{soil} R_w}$$

C_{soil} = soil conductivity (assumed 0.86 Btu/hr-ft-F)

EFFECTIVE FOUNDATION SPACE CONDUCTANCES

Depending on the foundation space type (basement, crawlspace, or slab-on-grade) and the degree of conditioning received by the space, the element conductances are combined in specified ways to arrive at an overall effective conductance of the foundation space from the inside air to the outdoor ambient air.

<u>Basements and Crawlspaces</u>

All foundation spaces not declared as "Slab" or "Exposed" are considered as basements or crawlspaces. Of these, those having wall height less than five feet are modeled as crawlspaces, with the only difference being the U-value used for the ground beneath the slab. Figure 2.2.1 shows the heat paths assumed for the model. An overall conductance between the foundation space and the outside ambient air, UA_{bsmt}, is defined as follows:

$$UA_{bsmt} = UA_{sill} + UA_{wa} + UA_{wb} + UA_g,$$

which includes heat flow paths through the sill, above and below-grade wall segments and the floor of the foundation.

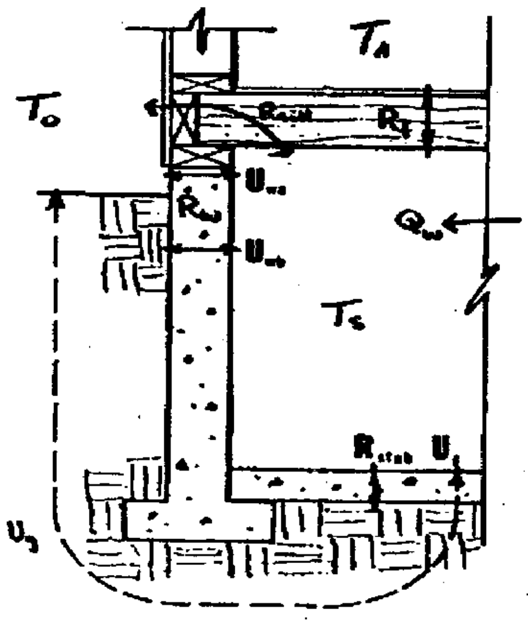

Fig. 2.2.1. Basement Schematic

If the foundation space is conditioned, this basement conductance represents the entire heat flow path between the indoor and outdoor air temperatures and forms the space's contribution to the BLC. Otherwise, an energy balance is formed on the basement space air and solved for the space's air temperature, which is used to define an effective conductance of the foundation space between the living space and the outside air. The energy balance is described by

$$UA_f*(T_S-T_i) + UA_{bsmt}*(T_S-T_O) - Q_E = 0$$

where,

T_S = foundation space air temperature (F),
T_i = average indoor air temperature (F),
T_O = average outdoor air temperature (F), and
Q_E = heat dumped into the space by the equipment and ducts (unintentionally heated spaces only) (Btu/hr).

Solving for the foundation space air temperature, T_S, gives

$$T_S = \frac{UA_f T_i + UA_{bsmt} T_o + Q_E}{UA_f + UA_{bsmt}}$$

Using this expression of T_S in the equation for the heat flow through the floor between the living space and the foundation space, Q_f, gives

$$Q_f = UA_f (T_i - T_S) = UA_f \left(\frac{UA_{bsmt} (T_i - T_O) - Q_E}{UA_{bsmt} + UA_f} \right)$$

An effective conductance, UA_{eff}, through the foundation space from the living space air temperature to the outdoor ambient air temperature may be defined by setting $Q_f = UA_{eff} (T_i - T_O)$, yielding

$$UA_{eff} = UA_f \left(\frac{UA_{bsmt} - Q_E /(T_i - T_O)}{UA_{bsmt} + UA_f} \right)$$

An estimate of Q_E is taken as seven percent of the heat output of the furnace (ASHRAE). However, since the load on the furnace is the value ultimately sought, using this value or the $(T_i - T_o)$ explicitly would make the problem nonlinear and require iteration for solution. Thus, estimates are used. A conventional modified HDD estimate is used for the load on the furnace in an average hour of the year and the $(T_i - T_o)$ term is replaced by a ΔT_{avg}, an average difference of average daily outdoor dry-bulb temperature and 65°F, over those months for which this difference is at least 10°F. The result is that

$$Q_E /(T_i - T_o) = \frac{0.07*(UA_{tot}' + UA_{inf})*HDD_{65}*24*0.7}{8760*\Delta T_{avg}}$$

where

Ua_{tot}' = total house conduction UA-value without foundation space currently being addressed (since its UA-value is not yet computed),
UA_{inf} = the equivalent infiltration UA-value (see Infiltration),
HDD_{65} = heat degree hours at base 65°F divided by 24 (hrs/day),
24 and 8760 are conversion factors, hours/day and hours/year, respectively,
0.7 = ASHRAE empirical correction factor, C_d, for use with HDD_{65}.
ΔT_{avg} = the average difference of average daily outdoor dry-bulb temperature and 65°F, over those months for which this difference is at least 10°F.

When tested over a wide range of climates and basement/crawlspace configurations, the above equation gave good estimates for effects of waste heat in unintentionally heated foundation spaces.

The program uses the equation above for T_s to compute the air temperature in the largest unintentionally heated subspace for later use with the duct insulation measure.

Slab-on-grade Foundations

Equations obtained directly from the CIRA program [LBL, 1982] are used in determining effective conductances of slab-on-grade foundations. An effective resistance, R_e, of the earth beneath the slab to the outdoor ambient air is defined by the following equations:

$$R_s = \frac{pF_c}{K_g}\left[0.1208 + 0.0195\ln\zeta + 0.0011(\ln\zeta)^2 + 0.2347\frac{t}{p} - 20.336\left(\frac{t}{p}\right)^2 - 0.1421\frac{t}{p}\ln\zeta\right]$$

where,

> R_s = modified soil thermal resistance (ft^2-hr-F/Btu)
> p = perimeter of slab (ft)
> F_c = non-dimensional shape correction factor (see below)
> $= 0.0904 + 1.1115x - 0.2038\ x^2$ where
> $x = 16A_f/p^2$
> K_g = soil thermal conductivity (Btu/hr-ft^2-F)
> $\zeta = K_g/(pC_f)$ = non-dimensional factor
> C_f = thermal conductance of slab $(1/R_{slab})$(Btu/hr-ft-F)
> t = average wall thickness

This value of soil resistance is combined with a U-value for the concrete slab and film to form the effective slab conductance,

$$UA_{eff} = A_f/(R_s + 1/U_{slab})$$

where,

> U_{slab} = 0.424 for uninsulated slab and
> 0.230 for insulated slab (Btu/hr-F)

Exposed Floors

The effective UA-value for exposed floors is simply the computed conductance of that particular floor element,

$$UA_{eff} = UA_f.$$

TOTAL EFFECTIVE FOUNDATION CONDUCTANCE

The total effective conductance (UA-value) for the foundation of the house is the sum of all individual conductances from as many foundation elements as were described by the user.

INFILTRATION

The monthly contributions of infiltration to the building load coefficient are evaluated using a method described by Sherman [1987]. As part of the data input, the user is asked the air leakage rate in cfm and the pressure differential in Pa at which this rate was measured using a blower door.

It must be noted that the audit recommends the infiltration reduction work be performed separately from the envelope and equipment measures, using a blower door to find the most significant air leaks and record the progress in tightening the house. If this work has been performed prior to the use of the computerized audit, a post-air infiltration retrofit air leakage rate will already be available for input. Otherwise, a default value representing the anticipated post-air infiltration retrofit level is entered.

If the user's input indicates that the leakage rate entered, in CFM, is at a house pressure differential other than 50 Pa, it converts to CFM_{50} by using the following equation

$$CFM_{50} = CFM_{\Delta P} \left(\frac{50}{\Delta P} \right)^{1/2} .$$

Sherman's method computes an "effective leakage area" from this flow rate from the equation

$$ELA[m^2] = \frac{Q_{50}[m^3/s]}{14} \qquad \textbf{(8)}$$

in metric units, or in English units,

$$ELA[ft^2] = \frac{CFM_{50}[ft^3/min]}{2756} \qquad \textbf{(9)}$$

As defined, the effective leakage area is independent of weather conditions. Sherman's method obtains the infiltration (under natural conditions) by multiplying this leakage area by a weather dependent parameter, the "specific infiltration." The specific infiltration, S, is a function of the average wind speed and indoor-outdoor temperature difference over the period of time for which the average infiltration is being determined. It is determined using the equation

$$S = \left(f_w^2 v^2 + f_s^2 |\Delta T|\right)^{1/2} \qquad \textbf{(10)}$$

where,

S = specific infiltration,

f_w = infiltration wind parameter [unitless],
v = wind speed,
f_s = infiltration stack parameter,
ΔT = indoor-outdoor temperature difference.

Although values of the wind and stack parameters would most rigorously depend on the leakage distribution and siting of the home, Sherman suggests average values for f_w and f_s of 0.13 [unitless] and 0.12 m/s $K^{1/2}$, applicable to residences. Using these values and converting to English units, NEAT's equation for the specific infiltration becomes

$$S[ft/min] = 196.9\left(0.0169(.447v)^2 + 0.0144|5/9\Delta T|\right)^{1/2}. \quad \textbf{(11)}$$

where the velocity, v is in mi/hr and ΔT is F. The values .447, 5/9, and 196.9 all allow units of the other parameters to be in the English system.

NEAT uses monthly averages for the wind velocity, v, and the indoor-outdoor temperature difference, ΔT, in the equation for the specific infiltration, to obtain monthly average infiltration rates from the equation

$$Q[CFM] = ELA[ft^2]*S[ft/min] \; / \; C_f ,$$

as prescribed by Sherman's method. The parameter C_f adjusts the specific infiltration for the effects of building height, shielding of the home from the wind, and crack size. NEAT assumes normal crack size and wind shielding. This produces values of C_f which take values of 1.0, 0.9, 0.8, 0.7, and 0.6 for homes of 1, 1.5, 2, 3, and 4 stories, respectively. The 1.5 story assignment would apply to a split level home.

The infiltration's contribution to the building load coefficient (BLC) equals

$$UA_{inf} = 0.83*1.08*Q,$$

where the factor of 1.08 = $60*\rho c_p$ converts the flow rate in ft^3/min to an equivalent UA value in Btu/hr-F. The 0.83 factor adjusts for the possibility that some of the infiltration may be leaking to a buffered space, whose air temperature falls between the indoor and outdoor air temperatures.

TOTAL BUILDING LOAD COEFFICIENT

The total building load coefficient for the house is the sum of the individual component building load coefficients or UA-values:

$$BLC = \sum UA_{wall} + \sum UA_{wdw} + \sum UA_{door} + \sum UA_{attic} + \sum UA_{eff} + UA_{inf} .$$

Each component type (walls, windows, etc.) will have as many terms in its sum as components of that type defined by the user.

Not all of the energy required to meet the conductance and infiltration losses during the heating season need come from the heating equipment. Heat resulting from solar radiation and internal heat generation, termed "free heat," reduces the load seen by the equipment. During the cooling season, these same sources of heat add to the load which must be met by the cooling equipment.

SOLAR GAINS

The total free heat from solar is the sum of contributions from each of the exterior surfaces of the house, walls, doors, roof, and windows. Each of these contributions is the product of incident solar radiation on the surface (dependent on the orientation of the surface) times the solar aperture for the surface. Solar apertures depend on a surface's area and its ability to transmit the solar radiation into the interior of the house. Each orientation has both a direct and diffuse component of incident solar radiation.

The program uses average monthly values of solar radiation incident on a horizontal surface at the geographic location designated by the user to compute total (direct plus diffuse) values incident on vertical surfaces oriented in the four cardinal directions. Curve fits to data provided by ASHRAE [1985] perform this function. The minimum value over these four directions (usually north) is taken as the average daily diffuse radiation for all orientations. This is understood as an approximation and will most often underestimate the diffuse component of radiation.

Much of the free heat supplied from solar radiation incident on the building originates from radiation transmitted through windows. The radiation actually incident on the exterior surface of a window equals the direct component multiplied by a shading factor, supplied by the user on input, plus the diffuse component. The shading factor is meant to be an estimate of the time/area based average of the shading of the window due to objects in front of the surface of the window, such as trees, garages, or other parts of the house (if facing toward the window).

The solar aperture (SA) of a particular window is equal to the glazing area times the window's solar gain factor (SGF). The solar gain factors for windows were determined as 0.87 times the shading coefficient of the window, as given by LBL's Window 3.1 program. The factors account for both the transmitted solar through the window as well as heat conducted into the house due to solar radiation absorbed by the window. They may differ during the summer versus the winter months if, for example, shade screens are applied only during the summer months. Thus,

$$Q_{wdw} = I*SA$$
$$= I^o_{diff}\ SGF_{wdw}\ A_{wdw} + I^o_{dir}\ Sf_{wdw}\ SGF_{wdw}\ A_{wdw}$$
$$= SGF_{wdw}\ A_{wdw}\left[I^o_{diff} + I^o_{dir}\ Sf_{wdw}\right]$$

where,

Q_{wdw} = solar heat transmitted into the house through window,
I^o_{diff} = diffuse solar radiation incident on window of orientation "o" (N,S,E, or W),
I^o_{dir} = direct solar radiation incident on window of orientation "o" (N,S,E, or W),
SGF_{wdw} = solar gain factor,
A_{wdw} = glazing area of window,
Sf_{wdw} = shading factor for window.

The glazing area of a window is derived from the dimensions of the storm window supplied by the user. The user is asked for the size of a storm window which is or could be applied to a window instead of the actual glazing area because (1) it was felt easier to measure these dimensions and (2) in case the auditor found it necessary to install a storm window, he would have the correct dimensions for manufacturing the storm. If the storm window has been given dimensions H_{wdw} and W_{wdw}, then the glazing area is defined as $A_{wdw} = (H_{wdw}-7.0)*(W_{wdw}-4.0)/144$, with A_{wdw} is in ft^2, H_{wdw} and W_{wdw} in inches.

Solar radiation incident on opaque surfaces also contribute to the free heat, though to a lesser extent. The program uses a standard formula [LBL, 1982] to determine this value of free heat, equal to the product of the incident solar radiation and the surface's solar aperture. The solar aperture for an opaque is defined as the product of the surface's area, its absorptance, and the ratio of the conductance (UA) to the exterior film coefficient. Thus, for opaque surfaces,
where

$$Q_{opq} = I*SA$$
$$= I^o_{tot}\ A_{opq}\ \frac{\alpha_{opq}*UA_{opq}}{h_o},$$

Q_{opq} = solar heat transmitted into the house through an opaque surface,
$I^o_{tot} = I^o_{diff} + I^o_{dir}$ = total solar radiation incident on surface of orientation "o" (N,S,E,W or horizontal),
A_{opq} = area of opaque surface,
α_{opq} = solar absorptance of surface (0.8 for walls, 0.7 for roofs),
UA_{opq} = conductance (UA-value) of component,
h_o = exterior film coefficient = 4.0 Btu/hr-F-ft^2.

The total free heat from solar is taken as the sum of the individual contributions on all windows and exposed opaque surfaces. Since solar radiation values change over the year, the solar free heat differs from one month to another.

INTERNAL GAINS

In addition to solar contributions to the free heat, internal sources of heat from occupants and appliances also exist. Rather than attempt to design the program to accommodate individual life styles of families, the decision was made to use average occupant and appliance characteristics. The cost effectiveness of measures under average conditions was desired, not for specific conditions which were likely to change.

The program assumes heat output from a refrigerator, range, television, lighting, hot-water heater, and occupants. The contributions to the free heat from each of these sources was taken from the consumption listed in the ASHRAE Handbook of Fundamentals [1985, p F28.6]. Values assumed for each (in both the handbook tables units and the units used in the program) are listed below:

Table 2.3.1. Contributions to free heat

Source	Internal gain (kWh/day)	Internal gain (Btu/hr)
Refrigerator	4.7	668
Range	2.6	370
Television	1.1	156
Lighting	4.1	583
Hot water heater	4.0	571
Occupants		552
Total		2900

The reference gives 23.0 - 24.5 kBtu/day as reasonable heat output from occupants of a home for two adults and two children. ASHRAE [1985, p F26.21] also indicates that it is customary to assume heat output for a female adult is 85% of an adult male, and 75% for a child. Using 24 kBtu/day for a family of two adults and two children, implies that an adult male and female would produce heat output of approximately 13.2 kBtu/day or 552 Btu/hr. This is the value assumed in NEAT and shown in the table above.

A minimum value is used for the hot water heater since it may not even be in the conditioned space. Note also, however, that no allowance has been give for clothes dryers, dish washers, etc.

The 2900 Btu/hr value is the default for the internal heat gain, Q_{int}, assumed in NEAT at the time of distribution. The user may adjust this value, however, to whatever level he feels better meets the local average conditions. The program also will adjust the value depending on the number of occupants input by the user. The first occupant is assumed to be an adult male, the second an adult female, and any subsequent occupants as children, each with heat output values indicated above.

TOTAL FREE HEAT

The total free heat for a house is the sum of the contributions from solar and internal gains,

$$Q_{free} = \sum Q_{wdw} + \sum Q_{opq} + Q_{int}.$$

Since the solar contributions to this free heat vary over time, NEAT computes a separate value for each month of the year using average values over each month.

Given the building load coefficients (BLC) and the amount of free heat each month, the variable base degree hour (VBDH) method [ASHRAE, 1997] computes the average monthly balance point temperature of the house, that outdoor air temperature at which heating and cooling from equipment is not necessary to keep the indoor air temperature between the prescribed thermostat set points. This is determined by solving a simple energy balance equation which sets the heat loss from conduction equal to the free heat available from solar and internals. The balance point temperature is then used as the base temperature in a degree hour computation of heating and cooling loads. Whereas traditional degree-day computations assume a base temperature of 65°F and use the number of days the average outdoor temperature departs from this base, the VBDH method requires the number of hours the outdoor temperature departs from this computed base temperature, the balance point temperature of the house.

THE BALANCE POINT TEMPERATURE

The balance point temperature is that outdoor air temperature at which heating and cooling from equipment is not necessary to keep the indoor air temperature between the prescribed thermostat set points. It is obtained by solving the heat balance equation on the air inside of the house under these conditions. Generally, the heat balance equation on the inside air is
where,

$$UA_{tot}(T_o - T_i) + Q_{free} + Q_{equip} = 0.$$

UA_{tot} = total UA-value for the house, including infiltration (Btu/hr-F),
T_o = average outdoor air temperature (F),
T_i = average indoor air temperature (F),
Q_{free} = total free heat from solar and internals (Btu/hr-F),
Q_{equip} = heat supplied by the heating/cooling equipment (Btu/hr-F).

The total UA-value for the house is the building load coefficient, BLC, already determined. The balance point temperature, T_{bal}, is then simply T_o when Q_{equip} is zero. The above equation becomes,

$$BLC(T_{bal} - T_i) + Q_{free} = 0,$$

making,

$$T_{bal} = T_i - \frac{Q_{free}}{BLC}$$

Since both the solar contribution to the free heat and infiltration portion of the BLC change over time, NEAT computes separate balance points for each month of the year, using values for the parameters averaged over each month. In fact, NEAT computes four balance points each month, based on the four values of thermostat set point given by the user, heating and cooling, day- and night-time settings.

HEATING AND COOLING LOADS

The heating and cooling loads which must be met by the conditioning equipment in order to keep the indoor air temperature at the thermostat set point are determined from the basic equation of the VBDH method,

$$L_h = HDHRS*BLC \quad \text{and}$$
$$L_c = (CDHRS*BLC + q_l)*F_{cooled} ,$$

where,

L_h and L_c = heating and cooling loads, respectively,
HDHRS and CDHRS are the number of heating and cooling degree hours at the balance points previously determined (see "Weather Data" below),
BLC = the total building load coefficient,
q_l = the latent cooling load from infiltration (see "Latent Loads" below), and
F_{cooled} = fraction of the house cooled by air-conditioners (entered by user).

Each of the parameters, except F_{cooled}, in the above expressions are dependent on the month of the year. Heating and cooling degree hours (HDHRS and CDHRS) are determined separately for day and night conditions, then added to give total average monthly values used in the load equations above.

LATENT LOADS

When mechanical air-conditioning equipment cools air, it must also extract excess water vapor the air can no longer hold at its colder temperature. This process requires additional energy beyond that associated with lowering the temperature. Thus, cooling moist air from one temperature to another will require more energy than cooling dry air between the same two temperatures. This additional work that must be performed by the air-conditioning equipment in extracting excess moisture is the "latent cooling load."

NEAT computes the latent load required to extract excess moisture from the infiltration air. A measure of the moisture in the air is the "humidity ratio," W. If Q_s is the amount of infiltration, the equation for the latent load is

$$q_l = 60 \times 0.075 \times 1076\ Q_s\ \Delta W\ A_{adj} = 4840\ Q_s\ \Delta W\ A_{adj}$$

where,

q_l = latent cooling load due to infiltration (Btu/hr),
60 = conversion factor (min/hr),
0.075 = density of dry air (lb/ft^3),
1076 = approximate difference in the heat contents of vapor and water (Btu/lb),

Q_s = infiltration rate (ft^3/min),
ΔW = difference in humidity ratios of infiltration air and indoor air (lb water / lb dry air), and
A_{adj} = adjustment factor for altitude.

This equation is taken from ASHRAE Handbook of Fundamentals (HOF), equation 23, page 28.15 in the 1997 publication. The factor A_{adj} has been added since the expression given by ASHRAE assumes sea level conditions. The adjustment equals

$$A_{adj} = e^{-3.68x10^{-5}H}$$

where H is the altitude above sea level in feet.

The value for Q_s, the infiltration rate, is taken from the user's input. The value for ΔW depends on the indoor and outdoor air conditions. The indoor conditions assume air at 75°F at 50% relative humidity. The outdoor conditions are monthly average temperatures and humidities, taken from the weather data. Values for W are obtained for both the indoor and outdoor conditions, the difference being ΔW.

The equation for the indoor humidity ratio is also taken from the 1997 ASHRAE HOF, equation (22) page 6.12:

$$W_{in} = 0.62198 \frac{p_w}{p - p_w}$$

where,

0.62198 = ratio of molecular masses of water and air,
p_w = partial pressure of water vapor in the air/water mixture,
p = total pressure of mixture = p_{atm} A_{adj}, where p_{atm} is the atmospheric pressure at sea level (14.696 psia [lb/in^2]).

ASHRAE equations relate the partial pressures under natural conditions to those at saturation (when the air can hold no additional water vapor i.e., 100% relative humidity) through the relative humidity (see 1997 ASHRAE HOF, equation 24, page 6.13). This is done because standard equations are available to approximate the partial pressure of air and water vapor under saturated conditions. Thus,

$$p_w = \phi p_{ws}$$

where,

ϕ = relative humidity (assumed to be 50% for the indoor air),
p_{ws} = saturation pressure of water vapor.

The value of the saturation water vapor pressure, p_{ws}, is estimated by the Hyland and Wexler equation (1997 ASHRAE HOF, equation 6, page 6.2):

$$\ln(p_{ws}) = C_8/T + C_9 + C_{10}T + C_{11}T^2 + C_{12}T^3 + C_{13}\ln T$$

where,

ln implies the natural logarithm,
C_8 - C_{13} = constants, as follows:
$C_8 = -1.0440397 \times 10^4$,
$C_9 = -1.1294650 \times 10^1$,
$C_{10} = -2.7022355 \times 10^{-2}$,
$C_{11} = 1.2890360 \times 10^{-5}$,
$C_{12} = -2.4780681 \times 10^{-9}$,
$C_{13} = 6.5459673$,
T = air temperature (°R=°F + 459.67)(assumed to be 75°F for indoor air).

These equations are not used to compute the humidity ratio for the outdoor air since the outdoor relative humidity would have to be calculated first, and its calculation already entails determining the humidity ratio. The calculation is as follows:

$$W_{out} = \frac{(1093 - 0.566\, t^*)W_s^* - 0.240\,(t - t^*)}{1093 + 0.444\, t - t^*}$$

where

t^* = wetbulb temperature of the ambient air (°F),
t = drybulb temperature of the ambient air (°F), and
W_s^* = the humidity ratio of saturated moist air at the wetbulb temperature, given by

$$W_s^* = 0.62198 \frac{p_{ws}^*}{p - p_{ws}^*}.$$

The partial pressure of water vapor at saturation at the wetbulb temperature, p_{ws}^*, is evaluated using the Hyland and Wexler equation above at the absolute wetbulb temperature, $T^* = t^* + 459.67$.

The heating load is converted to energy consumption through division by the seasonal efficiency of the heating equipment. A steady-state heating equipment efficiency, input by the user, is converted to an approximate seasonal value by dividing by 0.95. If the user cannot establish an efficiency for the heating equipment, one is computed from values of input and output capacities, if entered by the user, or set to a standard efficiency appropriate for the type of system described.

The cooling load is converted to an energy consumption by dividing by the cooling seasonal energy efficiency ratio (SEER). The SEER used by the program is either a value input by the user or a value based on the age of the cooling equipment, if the user does not input the SEER. The relation between SEER and system age is given by:

$$SEER = 10.0 - 3.0/16 * (1992 - \text{yr. purchased}),$$

with a minimum value of 6.8 and a maximum of 10.4 [Honnold, 1989].

The heating and cooling energy consumptions as calculated represent baseline consumptions prior to installation of any energy conservation measures.

3

WEATHER DATA

NEAT uses a monthly variable base degree-hour calculation method [ASHRAE, 1997]. It therefore needs average monthly weather parameters in order to complete its calculations. These include the number of degree-hours (at varying base temperatures), the solar insolation (including the effects of cloud cover), wet- and dry-bulb temperatures (for the latent load calculations), wind speed (for surface film coefficients), and mean design temperatures (for the sizing calculations), as well as other miscellaneous parameters.

The "Weather Disk" which comes with NEAT has a single compressed file (weather.exe) which, when expanded by the program, contains separate files, each containing weather for one specific weather site, most often a city within the U.S. and Canada. The individual weather file is given a name abbreviating the city or site and state which the weather data represents and an extension of "wx." For instance, "buffalny.wx" is the weather file for Buffalo, NY weather. These files contain all of the weather data specific to the sites. NEAT reads the data from the weather files and processes it to obtain specific parameters needed within the program.

A single additional file, "slr.inp," located in the main execution directory, contains ASHRAE factors which are used to translate the solar insolation impinging on a horizontal surface to solar falling on surfaces facing the cardinal directions. Factors for orientations falling midway between the cardinal directions are also included, but not used in NEAT. These factors vary with the latitude and, therefore, must be repeated for various latitudes.

More detailed information on the data in these two files and how the program uses the data is contained in the following sections.

The weather processor routine in NEAT reads the contents of the specified weather file and computes parameters derived from the data needed in the program. The following sections will describe the contents of the files and the additional processing performed.

WEATHER FILE CONTENTS

A portion (two months) of an example weather file (buffalny.wx) is shown in Figure 3.2.1. The first month's data is annotated with field letters (in square brackets, [ ]) to allow the various values' identification below. More detailed discussion of the individual parameters will occur in the following sections.

[A] - City and state abbreviation of weather site
[B] - Month of year (1 - 12)
[C] - Average daily solar on a horizontal surface (Btu/ft^2/day)
[D] - Average monthly dry-bulb temperature (°F)
[E] - Average monthly wet-bulb temperature (°F)
[F] - Average wind speed (MPH)
[G] - Latitude (Deg)
[H] - Winter design temperature (99%) (°F)
[I] - Summer design dry-bulb temperature (1%) (°F)
[J] - Mean coincident wet-bulb temperature (°F)
[K] - Altitude (ft)
[L] - Monthly average four hour time-of-day dry-bulb temperatures (hours 1-4,5-8, etc.) (°F)
[M] - Monthly average four hour time-of-day wet-bulb temperatures (hours 1-4,5-8, etc.) (°F)
[N] - Monthly average four hour time-of-day wind velocities (1-4,5-8, etc.) (MPH)
[O] - Not used to avoid confusion with numeral "0."
[P] - Number of degree-hours at respective base temperatures (extreme left column), in the following order, heating day-time, heating night-time, cooling day-time, cooling night-time.

The above data is repeated for each month of the year, with the exception that months succeeding the first do not list items [G] through [K], since they do not vary from month to month. All of the data is stored for later as well a immediate use, as described below.

```
BUFFALO, NY[A]
 HEATING AND COOLING DEGREE HOURS FOR MONTH  1[B]
 342[C] 25.6[D] 23.4[E] 15.9[F] 42.9[G] 2.0[H]  88.0[I]  71.0[J]  705[K]
  24.4  24.3  25.9  27.7  26.2  24.9 [L]
  22.3  22.3  23.8  25.0  23.9  22.8 [M]
  15.7  16.0  17.1  16.9  15.1  14.6 [N]
  75    17999    18774       0       0
  70    16139    16914       0       0
  65    14279    15054       0       0
  60    12419    13194       0       0 [P]
  57    11306    12078       3       0
  55    10567    11334       8       0
  50     8731     9477      32       3
  45     6908     7681      69      67
  40     5169     5954     190     200
 HEATING AND COOLING DEGREE HOURS FOR MONTH  2
 527 25.9 23.2 14.3
  23.7  23.8  26.9  28.8  27.1  25.2
  21.5  21.5  23.9  25.4  24.1  22.6
  14.1  13.6  15.0  15.5  13.9  14.0
  75    15933    17059       0       0
  70    14253    15379       0       0
  65    12573    13699       0       0
  60    10893    12019       0       0
  57     9891    11011       6       0
  55     9227    10339      14       0
  50     7585     8661      52       2
  45     5982     7002     129      23
  40     4474     5440     301     141
```

Fig. 3.2.1. Sample contents of a weather file (buffalny.wx)

WEATHER DATA PROCESSING

After (or sometimes while) reading the data, the weather processor performs the following data manipulations to arrive at parameters needed in the program:

- The four hour time-of-day data (dry/wet-bulb temperatures and wind speeds, entries [L] - [N]) are combined to form average monthly day-time (hours 8 - 19) and night-time (hours 0 - 7 and 20 -23) values, where hour 0 represents 12:00 midnight through 1:00 AM.

- The monthly average specific infiltration factor (see "Infiltration" in Section 2.2) is computed using the equation

$$S[\mathrm{ft/min}] = 196.9\left(0.0169(.447v)^2 + 0.0144\left|5/9\Delta T\right|\right)^{1/2}, \qquad (27)$$

where v is the wind speed in mi/hr and ΔT is the difference between the day-time indoor air set point and the time-of-day outdoor drybulb temperature, in F [L]. Values are computed for each of the six time-of-day values of wind speed and outdoor temperature, then averaged to form the monthly average

- The weather processor computes several parameters needed to decide whether evaporative coolers are appropriate in the climate specified by the weather file. Using the four hour time-of-day values ([L] and [M]), the year's maximum dry-bulb and corresponding wet-bulb temperatures are determined. Also determined are the number of these four-hour periods during which the drybulb temperature is above 78°F and the number of these during which the relative humidity is below 50%.

- The weather processor computes the approximate efficiency of an evaporative cooler in the climate specified by the weather file using the annual maximum dry-bulb temperature, t_{max}, and its coincident wetbulb temperature, t^*_{max}. A supply air temperature, t_{sup}, is computed as

$$t_{sup} = t_{max} - 0.75(t_{max} - t^*_{max}).$$

The approximate energy efficiency ratio, EER_{ec}, is then

$$EER_{ec} = 3.1*8/.75 = 33.1 \quad \text{for } t_{sup} \geq 70°F \text{ and}$$
$$EER_{ec} = 3.1*(78 - t_{sup})/.75 \quad \text{for } t_{sup} < 70°F.$$

- Within the program segment including the weather processor is another routine which computes the relative humidity needed above and elsewhere in the program. The weather data gives the wet- and dry-bulb air temperatures. From these values, and an assumed standard atmospheric pressure adjusted for altitude, the procedure outlined in 1997 ASHRAE HOF, page 6.14 is followed. See the section "Relative Humidity Calculation" below for details.

RELATIVE HUMIDITY CALCULATION

The evaporative cooler energy conservation measure requires the monthly average relative humidity for its determination of applicability and energy savings. NEAT follows the derivation given in the 1997 ASHRAE Handbook Of Fundamentals (HOF), as outlined on page 6.14, with equations given on pages 6.2 and 6.12-13. The equations shown below have the HOF equation numbers in parentheses.

ASHRAE gives the equation for the relative humidity as

$$\phi = \frac{\mu}{1-(1-\mu)(p_{ws}/p)}$$

where

ϕ = fractional relative humidity (unitless)
μ = degree of saturation (unitless)
p_{ws} = partial pressure of water vapor at saturation (psia)

p = atmospheric pressure (adjusted for altitude) (psia)

The atmospheric pressure, p, used is standard pressure at sea level (14.696 psia) adjusted for altitude. Thus,

$$p = 14.696e^{-3.68\times10^{-5}H}$$

where H is the altitude in feet. The partial pressure of water vapor at saturation, p_{ws}, is taken from the Hyland and Wexler equation, also given in ASHRAE HOF, page 6.2:

$$\ln(p_{ws}) = C_8/T + C_9 + C_{10}T + C_{11}T^2 + C_{12}T^3 + C_{13}\ln T$$

where,

ln implies the natural logarithm,
C_8 - C_{13} = constants, as follows:
$C_8 = -1.0440397 \times 10^4$,
$C_9 = -1.1294650 \times 10^1$,
$C_{10} = -2.7022355 \times 10^{-2}$,
$C_{11} = 1.2890360 \times 10^{-5}$,
$C_{12} = -2.4780681 \times 10^{-9}$,
$C_{13} = 6.5459673$,
T = t + 459.67, the ambient air temperature in degrees Rankine (°R=°F + 459.67).

ASHRAE gives the following relation for the degree of saturation:

$$\mu = \frac{W}{W_s}.$$

where W_s, the humidity ratio at saturation, is given by

$$W_s = 0.62198\frac{p_{ws}}{p-p_{ws}}$$

and the humidity ratio of the moist air at existing conditions (ambient) by

$$W = \frac{(1093-0.556\,t^*)W_s^* - 0.240\,(t-t^*)}{1093 + 0.444\,t - t^*}$$

where

t^* = wetbulb temperature of the ambient air,

t = drybulb temperature of the ambient air, and
W_s^* = the humidity ratio of saturated moist air at the wetbulb temperature, given by

$$W_s^* = 0.62198 \frac{p_{ws}^*}{p - p_{ws}^*}.$$

The partial pressure of water vapor at saturation at the wetbulb temperature, p_{ws}^*, is evaluated using the Hyland and Wexler equation above at the absolute wetbulb temperature, $T^* = t^* + 459.67$.

The "slr.inp" file contains ratios of solar insolation incident on vertical surfaces with various orientations to the solar incident on a horizontal surface, as computed from the "Solar Irradiance and Solar Heat Gain Factors" tables in the 1997 ASHRAE Fundamentals Handbook (pgs. 29.30 - 25.33). The four groupings in "slr.inp" are for 24, 32, 40, and 48 degrees north latitude, respectively. A portion of this file annotated with information in square brackets, [ ], is seen in Figure 3.3.1 below.

[N]	[NNE/NNW]	[NE/NW]	[ENE/WNW]	[E/W]	[ESE/WSW]	[SE/SW]	[SSE/SSW]	[S]		
0.143	0.144	0.183	0.352	0.578	0.800	0.992	1.163	1.265	[Jan]	
0.138	0.141	0.226	0.390	0.560	0.694	0.776	0.816	0.852	[Feb]	
0.138	0.167	0.288	0.429	0.540	0.598	0.592	0.534	0.476	[Mar]	
0.160	0.235	0.363	0.468	0.522	0.516	0.447	0.322	0.233	[Apr]	
0.219	0.306	0.423	0.496	0.512	0.465	0.362	0.222	0.172	[May]	
0.259	0.342	0.448	0.507	0.507	0.445	0.330	0.199	0.171	[Jun]	24° N. Latitude
0.230	0.316	0.429	0.499	0.512	0.463	0.359	0.224	0.178	[Jul]	
0.174	0.248	0.372	0.471	0.522	0.513	0.443	0.321	0.236	[Aug]	
0.149	0.176	0.292	0.430	0.539	0.596	0.592	0.538	0.485	[Sep]	
0.144	0.149	0.231	0.391	0.557	0.687	0.766	0.806	0.840	[Oct]	
0.147	0.147	0.187	0.353	0.576	0.794	0.983	1.151	1.252	[Nov]	
0.147	0.147	0.172	0.335	0.585	0.849	1.096	1.331	1.452	[Dec]	
0.154	0.154	0.182	0.354	0.635	0.945	1.249	1.530	1.666	[Jan]	
0.145	0.147	0.218	0.394	0.604	0.796	0.946	1.058	1.129	[Feb]	
0.142	0.164	0.276	0.431	0.572	0.669	0.706	0.695	0.674	[Mar]	
0.159	0.221	0.346	0.465	0.544	0.566	0.525	0.430	0.355	[Apr]	32° N. Latitude
0.202	0.279	0.399	0.489	0.528	0.505	0.423	0.294	0.228	[May]	

Fig. 3.3.2. Sample contents of the "slr.inp" file

The columns are values for differing orientations, beginning with north, then progressing every 22½ degrees, the final column containing ratios for a south facing vertical surface. Ratios for the easterly facing orientations are equal to those facing westerly when averaged over periods longer than a day. Since NEAT computes solar for only the four cardinal directions (N, E, S, and W), only the first, fifth, and ninth columns of ratios are used. The twelve rows in each grouping represent mid-month values for each of the twelve months of the year.

Interpolation is used to obtain ratios for latitudes falling between the four standard latitudes listed in the "slr.inp" file. The ratios for each month are multiplied by the average daily insolation falling on a horizontal surface for that month (values [C] in Figure 3.2-1) to obtain the total insolation falling on the various oriented vertical surfaces. These values are then divided by 24 to obtain average hourly values.

NEAT assumes that the solar radiation falling on a north facing vertical surface is all diffuse and uses this value as the diffuse insolation on other vertical surfaces as well. Thus, to obtain the direct insolation on a vertical surface, this diffuse component is subtracted from the total.

4

ENERGY EFFICIENCY MEASURES

Following the determination of the baseline heating and cooling building energy consumptions, NEAT applies appropriate energy efficiency measures to the house and determines their individual first year energy savings. Within NEAT version 6.1, 29 measures are modeled, not including multiple levels of the insulation measures (see "Measure Models" for a listing and description of the measures). Any of these measures may be rejected from consideration by either the user during setup of the program or by the program due to specific applicability criteria. For example, no air-conditioner replacement is considered unless an air-conditioner was previously in place, or a house must have a kneewall before kneewall insulation is considered.

For each applicable measure, NEAT computes a dollar savings over the life of the measure from the first year savings. This lifetime savings discounts each year's savings after the first to account for the time-value of money. Future fuel cost changes are also anticipated through use of fuel price indices. The ratio of this lifetime, discounted savings to the total installed cost of each measure gives the savings-to-investment ratio (SIR) of a measure. The SIR is a gauge of a measure's cost-effectiveness, the higher the SIR, the more cost-effective it is to install the measure. See "Measure Economics" below for more detail.

Measures are then ranked by their SIR and installed in order of this ranking, each successive measure seeing all higher-ranked, cost-effective measures as already installed. A new "interacted" SIR is computed for each measure being considered, and only if this interacted SIR still implies cost-effectiveness is the measure assumed left installed when adding the remaining lower-ranked measures. Once all applicable measures have been considered, NEAT reports to the user all those measures whose interacted SIR is still above the minimum established. Additional energy and dollar savings and cumulative data are also reported.

Having determined baseline annual heating and cooling building energy consumption estimates, NEAT is prepared to look at the possible reduction of this consumption by application of energy efficiency measures. The program estimates the annual (first year) energy savings of each applicable measure assuming it were the only measure installed in the house, i.e., each measure is applied to the base house as described by the user on input. Section 4.3, "Measure Models" gives the methods used to compute this first year savings for each measure individually.

SAVINGS-TO-INVESTMENT RATIOS (SIR)

The first year dollar savings is determined using fuel costs supplied by the user. If the user has designated the existence of a secondary heating system and the savings resulting from the measure are not specific to the primary system, a composite fuel cost is used in determining the savings. For example, if the fraction, f, of the heat were supplied by a natural gas furnace having a seasonal efficiency of η_1 and the remaining by an space heater with efficiency η_2, a heating load savings of Ld would produce an annual, first year, dollar savings, D_a, of

$$D_a = Ld * \left(\frac{p_1 f}{\eta_1} + \frac{p_2(1-f)}{\eta_2}\right),$$

where p_1 and p_2 are the prices for fuels used by the two systems. The actual expressions used in the program differ from, but are equivalent to, the above. For convenience in computation and prevention of division by zero if no secondary system exists, the program uses the above cast into the form

$$D_a = E * \xi,$$

where ξ is the composite fuel price and E is the energy savings associated with the measure. Combining the two equations above indicate that,

$$\xi = \frac{\dfrac{p_1 f}{\eta_1} + \dfrac{p_2(1-f)}{\eta_2}}{\dfrac{f}{\eta_1} + \dfrac{1-f}{\eta_2}}$$

A similar situation arises with regard to cooling savings and the existence of multiple window air-conditioners having differing SEER's. However, here there is simplification provided by the price of fuel, electric, being the same for each unit.

The first year cost savings for the measures are computed for the users information, but not used in the cost-effectiveness calculations. Instead, a savings over the expected life of each measure is used. In this way, measures which cost more to install, but last longer, are not penalized for their higher initial cost. However, the first year dollar savings is not simply multiplied by the life of the measure to obtain this lifetime savings, since it is assumed that future years' dollars are not worth as much as present-day dollars. They cannot be invested or used for other purposes immediately as can present day dollars. For this reason, future years' savings are "discounted," or made somewhat less valuable. The discount rate is a annual percent reduction in the worth of a dollar.

Fuel and electric prices will also vary over the life of the measures. The Department of Energy estimates future fuel prices, as well as acceptable discount rates, in its annual publication, "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis,"(NIST, 1997), which is the source of these factors used by NEAT. Discount rates and fuel price indices are applied to first year energy savings using the following formula,

$$D_{life} = E * \rho^{L} = E * \frac{p}{c_f} \sum_{i=1}^{L} \left(\frac{I_i}{(1+d)^i}\right) ,$$

where,

D_{life} = discounted dollar savings of the measure over its lifetime,
E = the first year energy savings of the measure,
ρ^L = discounted fuel price for measure of life L years,
p = price of fuel saved by the measure,
c_f = conversion factor for the fuel price,
L = life of measure in years,
I_i = fuel price index for the i'th year
d = fractional discount rate.

A similar expression is found in the NIST publication referred to above (NIST, 1997, pg. 12). Individual measure energy savings are in Mbtu while fuel prices are often quoted in units of dollars per therm or dollars per kWh. The c_f factor merely provides consistency of units between the savings and fuel prices.

If a measure saves energy from both a primary and a secondary heat source, likely having different efficiencies and possibly fuels, an equation similar to the one for the first year savings is used,

$$D_{life} = E * \xi_d,$$

where ξ_d is the discounted composite fuel price,

$$\xi_d = \frac{\frac{\rho_1^L f}{\eta_1} + \frac{\rho_2^L (1-f)}{\eta_2}}{\frac{f}{\eta_1} + \frac{1-f}{\eta_2}},$$

where ρ_1^L and ρ_2^L are the individual discounted fuel prices over the life of the measure,

$$\rho_j^L = \frac{p_j}{c_f^j} \sum_{i=1}^{L} \left(\frac{I_i^j}{(1+d)^i}\right) .$$

Using material, labor, installation, and additional costs supplied by the user, the program computes the cost of implementing each measure. The ratio of the discounted lifetime dollar savings to this cost is the individual savings-to-investment ratio (SIR) for each measure.

MEASURE GROUPS

In describing the house to the program, the user will likely choose to describe the total wall area in separate segments. For example, the north wall area separate from the south wall area, or a portion of wall buffered by an unconditioned garage separate from the remainder of the exposed wall area. A similar concept holds true for the attic and floor areas. Perhaps part of the attic is insulated and the remainder uninsulated. NEAT version 6.1 allows the user to group segments of the same component type (wall, attic, or floor) together for the purpose of reporting the SIR associated with the insulation measure for that component type. Thus, a single SIR will be reported for insulating all wall segments the user chooses to place in the same group. Alternatively, separate SIRs will be reported for insulating wall segments placed in separate groups. In the case of attic and floor insulation, all segments placed in the same group are forced to have the same level of insulation recommended for them.

After computing all applicable measures' savings-to-investment ratios (SIR), the measures are ranked in decreasing order of their individual SIR's, then applied to the house collectively in that order. Assuming its SIR was greater than one, the measure with the highest individual SIR is applied first by modifying the building description to reflect implementation of the measure. The second ranked measure is then applied to this modified building, a new energy and dollar savings for the second measure are determined, and an "interacted" SIR is computed. This new SIR is "interacted" because its energy savings is computed assuming the first measure had already been implemented.

For each measure whose interacted SIR is greater than one, the building description is updated to reflect its implementation so that all succeeding measures' savings will be determined assuming it has been installed.

Two measures are considered "mutually exclusive" if installation of either one precludes the implementation of the other. For example, the program considers the heating system replacement and IID installation measures mutually exclusive since the system replacement would already include an IID as part of the measure. In such instances, the program selects the measure with the highest net present value (NPV), defined as the difference between the discounted lifetime dollar savings and the total installation cost.

All measures whose interacted SIR ratios are greater than one and, if mutually exclusive with other measures, having the largest NPV, are tagged as being recommended for installation. The material quantity necessary for its installation is reported to the user. Also reported are the measure's first year energy and dollar savings, installation cost, and discounted SIR ratio. The preceding economic analysis generally follows the techniques suggested by the Alliance to Save Energy [ASE, 1990].

The National Energy Audit, Version 6.1 currently models 29 energy efficiency measures, not including multiple levels of insulation measures:

Attic insulation - R-11, 19, 30, or 38
Attic insulation - filling ceiling cavity
Wall insulation - 3.5" or user-defined
Kneewall insulation - R-11
Sill box insulation - R-19
Foundation wall insulation - user-defined
Floor insulation - R-11, 19, or 30
Storm windows
Duct insulation
Infiltration reduction

Window shading (awnings)
Sun screens - fabric / louvered
Window films
Low-E windows

Vent damper - thermal / electric
Intermittent ignition device (IID)
Electric vent damper and IID
Flame retention burner
Furnace tuneup
Heating system replacement
High efficiency furnace replacement
Smart thermostat (setback thermostat)

Window A/C replacement
A/C tuneup
Evaporative cooler
Heat pump replacement

Lighting retrofits

The first grouping of ten measures listed above are considered heating envelope measures since they primarily affect the heating load of the house. However, they alter the conductance of the building shell, thus affecting both the heating and cooling loads and the last two, duct insulation and infiltration reduction, do affect cooling energy use substantially for warm climates. The next group of five measures (counting fabric and louvered sun screens separately) are also envelope measures but whose effect is mainly to reduce the cooling load. Note that they will also slightly increase the heating load by partially blocking some of the solar insolation entering the house during the heating season, reducing the free heat. By considering both heating and cooling, the program can account for any such effects. The next group of nine measures (counting thermal and electric vent dampers separately) alter the efficiency of the heating system, decreasing the net heating energy consumed by the house but not affecting the load. Similarly the next group of four measures increases the efficiency of the cooling equipment, reducing the cooling energy. Lighting retrofits save neither heating of cooling energy, but reduce the electric consumption of the house.

The algorithms used to model each will be briefly described in the sections which follow. For more general descriptions of the measures, see "National Energy Audit Users Manual," ORNL/Sub/91-SK078/2, October, 1997.

ENVELOPE / INSULATION MEASURES

The first year savings for envelope measures, when applied individually to the base house, are computed by first determining the change in whole building conductance (UA-value) and free heat associated with each measure. The variable-base degree-day computations are then performed with the whole house UA and free heat adjusted by these changes and the resulting whole house energy consumptions subtracted from those obtained from the base-case computations. In this way, no modifications to the actual building description are performed while simply testing the measures for cost-effectiveness. This is necessary because all other applicable measures must also be compared to the base house. Also, a measure may not prove cost-effective, in which case the base house will never be modified by the measure's implementation. Only after a measure has been found cost-effective when applied to the house with all higher-ranked cost-effective measures installed is the actual building description changed.

Insulation measures having multiple levels (attic and floor insulation) view each level (R-11, R-19, etc.) as a separate measure but as mutually exclusive of other levels associated with the measure. Thus, only the level with the highest net present value (NPV) will be recommended (see "Measure Interactions).

ATTIC INSULATION

The attic insulation measure adds standard levels of insulation (R-11, 19, 30, and 38), of type indicated by the user on input, to the cavity path of each attic segment defined. If insulation already exists in the attic, the level added is in addition to the insulation already present. If the thickness of insulation added plus the thickness of any insulation existing prior to retrofit is greater than the assumed 5.5" ceiling joist depth, the thickness of insulation beyond 5.5" is also added to the joist path. If the user has specified in the input a maximum depth of insulation which can exist in the attic, no attic insulation measure creating a total insulation depth greater than this thickness will be considered. The retrofitted ceiling conductance is re-computed using the new cavity and joist path R-values and the previously assumed framing factor, 0.15. This conductance is then used to compute the change in UA-value and free heat, if the measure is only being tested for cost-effectiveness, or to replace the existing attic segment conductance, if the measure is to actually be implemented.

ATTIC INSULATION - FILL CAVITY

This measure is implemented in a manner similar to the addition of the standard levels of attic insulation, except that the thickness, and therefore R-value, of insulation added is exactly the difference between the existing depth, if any, and the maximum depth indicated by the user's input. This measure is not considered for attic segments for which no maximum depth of insulation has been specified.

WALL INSULATION

Addition of wall insulation to any wall segment not adjacent to an unconditioned attic increases the R-value of the cavity path by 11.9. This assumes a reduction of 1.1 R due to the loss of an air space. If the wall segment is adjacent to an unconditioned attic, no sheathing is assumed to exist on the attic side of the wall and only R-11 batt insulation is considered.

The overall wall conductance, assuming a 0.15 framing factor, is re-computed. If the wall is adjacent to an unconditioned space, the change in wall conductance due to the measure is reduced by a factor of two-thirds to simulate the decrease in temperature difference which would be seen across the wall. The variable-base degree day methodology is again applied to determine the effect of this conductance change on the building energy consumption.

Consistent with the assumptions used in computing the base building energy consumption, the change in component conductance also produces a small change in the free heat introduced into the house due to solar incident on the wall's exterior surface. Thus, the free heat is reduced by an amount equal to the ratio of the change in conductance to the exterior film coefficient times the product of the incident solar radiation and the surface's absorptance. This reduction occurs only if the wall is exposed to the outside air.

KNEEWALL INSULATION

Kneewall insulation is treated as an attic insulation measure, except only R-11 faced batt insulation is allowed to be installed. The wall is treated like an attic instead of a wall because it is adjacent to an unconditioned attic, whose thermal characteristics are different from either an exposed or buffered wall segment.

SILL BOX INSULATION

This measure adds R-19 faced batt insulation to the fraction of a foundation's band joist declared exposed by the user during input. The resulting change in the overall effective conductance of the foundation space is then determined using the same assumptions applied during the determination of the base house energy consumption (see "Foundation Spaces, under Section 2.2). No sill box insulation measure is applied to a slab-on-grade, exposed, or vented foundation space. The measure is considered mutually exclusive to the floor insulation measure, assuming that in insulating the floor, the band joist is also insulated.

FLOOR INSULATION

The floor insulation measure adds R-11, 19, or 30 faced batt insulation to the floor between the living space and the foundation space. The measure is not considered for slab-on-grade, conditioned, or exposed foundation spaces, or spaces with wall height less than two feet. It is also mutually exclusive of the sill box insulation measure, assuming that the sill will be insulated automatically with installation of the floor insulation. The user may wish to deactivate this measure if the space is an unconditioned basement with water pipes which may freeze. The change in effective foundation space conductance and the resulting change in building energy consumption are computed using assumptions consistent with the initial base building computations.

FOUNDATION WALL INSULATION

The foundation wall insulation measure adds a user-prescribed R-value to both the above- and below-grade wall areas of a foundation space. No stud or cavity paths are assumed. If such exist, or are created by the method of insulating foundation walls selected by the user, their effect must be already accounted for in the overall R-value specified to be added. This measure will not be examined for slab-on-grade, exposed, or vented foundation types or any foundation with walls less than two feet in height. The foundation wall insulation measure is mutually exclusive of the floor insulation measure.

STORM WINDOWS

This measure adds 0.59 R to existing windows not already having storms. The measure also decreases the transmittance of a window assembly by 0.093 for single and 0.075 for double pane windows. These values were determined from the same source as were the original window characteristics [LBL, 1988]. An improved metal storm window creating a one inch air space was assumed. The R-value added accounts for the bridging effect of the storm window's framing.

DUCT INSULATION

The duct insulation measure is assumed applicable to only forced air or gravity furnaces, heat pumps, or central air-conditioners. The measure adds an R-4 to existing uninsulated (R-1.5) supply ducts in unconditioned spaces, whose dimensions are given by the user on input. In the heating mode, the supply air temperature is assumed to be 120°F for furnaces and 95°F for heat pumps. The temperature of the space surrounding the ducts is assumed to be the temperature of the largest unintentionally heated foundation space or attic space (see Section 2.2. "The Building Load Coefficient"), depending on the duct location specified by the user.

For cooling, the supply air temperature is assumed to be 55°F with the temperature of the surrounding space that of the largest attic space. Cooling energy savings are assumed to occur only for months when the surrounding air temperature is above the supply air temperature. No cooling component of duct savings is assumed to occur for insulating ducts located in a foundation space.

The temperature differences across the ducts are assumed to exist for a time approximated by the ratio of the monthly heating or cooling load of the house (in Mbtu) and the size of the heating or cooling equipment (in Mbtu/hr) and the heat loss calculations are performed for each month using average monthly values.

INFILTRATION REDUCTION

NEAT does not direct the infiltration reduction component of a retrofit. Input of all the data necessary to make estimates of infiltration reductions due to work on individual components (each window, door, or crack) would be tedious, at best, and likely still not able to allow accurate calculation of savings. Instead, NEAT encourages use of blower-doors to direct and quantify results of infiltration work. If the user inputs the pre- and post-retrofit CFM readings from the blower-door for the work and the cost of the work, NEAT will compute the SIR for the effort and rank the infiltration reduction with the other measures tested. The energy savings associated with the reduction in CFM are computed by subtracting heating and cooling (including latent) whole house consumptions of the base house, before and after the work has been performed. This treatment of infiltration reduction as a separate component of work is necessitated by the relative inability of a computer program to accurately predict savings associated with infiltration reduction.

SOLAR REDUCTION MEASURES

The solar reduction measures modify the amount of solar insolation which falls on treated windows. As such, they alter the effective solar gain factors associated with these windows. Most of the measures assign a percent reduction in this factor whose affect is to create a change in the free heat from solar. The reductions may differ from summer to winter. These changes in free heat are used by the program much as are the changes in UA-values for insulation measures. The variable-base degree-day computations are performed with the whole house UA and free heat adjusted by these changes and the resulting whole house energy consumptions subtracted from those obtained from the base-case computations to obtain the savings. As with insulation measures, the actual solar heat gain factors assigned to the windows are not actually altered until the measure has proven to be cost-effective when interacted with other measures previously installed.

All of the solar reduction measures are mutually exclusive of one another as well as with the application of storm windows.

WINDOW SHADING (Awnings)

The window shading measure reduces the direct solar insolation incident on a window. All windows not facing north and shaded less than 50% without the measure are assumed to be shaded by the measure. The measure assumes that the installed shading device reduces the direct solar incident on a window during the months of April through September to 10% of the totally unobstructed value. For the remaining months, the direct solar radiation is reduced to 80% of its value without the measure added. Thus, if a window is 30% shaded prior to implementation of the window shading measure, it will be either 90% shaded during the summer months (10% unobstructed => 90% shaded) or 44% shaded in winter (30% shaded => 70% unobstructed, 80% of which is 56% unobstructed or 44% shaded) after implementation of the shading.

SUN SCREENS AND FILMS

As with awnings, the sun screen measure installs screens on all windows not facing north and shaded less than 50% without the measure. Sun screens are assumed to reduce both the direct and diffuse components of solar insolation incident on the windows to which they are installed. Review of product information indicates that for typical products fabric sun screens reduce the incident solar to 34% of the untreated level and louvered screens to 11%. In addition, a 10% decrease in conductivity is attributed to the screens. Window films reduce the incident solar by 26% without changing the effective conductance of the window.

LOW-E WINDOWS

Low-emissivity window characteristics for units having varying features were examined using the Lawrence Berkeley Laboratory program "Window 3.1." An average solar gain factor of 0.68 and U-value of 0.4545 (R-2.2) were determined for use in NEAT. As for other solar reduction measures, low-emissivity windows are considered only for windows not facing north and shaded less than 50% without the measure.

HEATING EQUIPMENT MEASURES

Heating equipment measures alter the efficiency with which the heating load in a house is met, without affecting the load itself. Modified equipment efficiencies are computed for each equipment measure, representing that measure's effect on the efficiency. This modified efficiency is then applied to the house load to compute a whole house consumption after implementing the measure. The measure's savings is the difference in this consumption from the previously computed consumption (either the base house consumption, if computing the savings of the measure applied individually to the house, or the consumption after installing all higher-ranked cost-effective measures, if determining the interacted savings). The efficiency of the system used when computing the savings of other measures is not changed unless the equipment measure has proven cost-effective when applied interactively with the higher-ranked measures.

Summaries of the assumptions used to model the equipment measures are given below.

VENT DAMPERS

A vent damper reduces the heat loss from a furnace by closing off the vent stack whenever the furnace is not operating, thus preventing the residual warm air from escaping. Thermal vent dampers close whenever they sense a stack temperature below that normally retained during operation of the furnace. Electric vent dampers are electrically connected to the thermostat or furnace solenoid circuit, allowing detection of furnace shutoff.

The savings of vent dampers is modeled as a percent of the monthly heating energy consumption of the house. The following table lists these percentages as used in the audit program. Thermal vent dampers are not advised on oil-fired systems due to potential fouling of the damper, preventing proper operation.

	Percent savings	
Heating system/fuel type	Thermal	Electric
Gas-fired furnace	4%	6%
Gas-fired boiler	6%	9%
Oil-fired furnace		4%
Oil-fired boiler		6%

INTERMITTENT IGNITION DEVICE

The intermittent ignition device (IID) saves energy by eliminating the need for a standing pilot light. The device ignites the fuel in the furnace, usually electrically, whenever the thermostat calls for heating. Fuel which is normally consumed by keeping the pilot lit is thus conserved.

Estimates of the energy savings from the use of an IID are based on estimated run-times of a furnace in varying climates, characterized by the heating degree days (HDD) base 65°F [Gettings, 1980]. Curve fits to data thus obtained produce the following estimates of energy saved, E:

$$E \text{ (therms)} = 145.875 \text{ HDD}^{(-0.12188)} \quad \text{pilot on during summer}$$
$$E \text{ (therms)} = 0.042392 \text{ HDD}^{(0.74214)} \quad \text{pilot off during summer}$$

A separate measure formed from the combination of the electrical vent damper and the IID has been included in the measure list to allow consideration of the two measures jointly, since taken separately, they might not be allowed. For example, most electric vent dampers seal the vent stack sufficiently that a pilot light cannot be properly vented. Thus, the combination of the two measures has to be considered together if a pilot is present.

FLAME RETENTION HEAD BURNER

The installation of a flame retention head burner in an oil-fired furnace or boiler can increase the steady state efficiency of the system to about 80%. Since the burner also restricts air flow, a savings analogous to the vent damper savings is also normally realized. Thus, the measure is modeled as altering the steady state efficiency to 80% and adding the savings of an electric vent damper on an oil-fired system.

FURNACE TUNEUP

NEAT will consider a furnace tuneup measure for gas or oil fired furnaces or boilers. This measure's savings is specified as an improvement in the steady state efficiency of the unit, ΔSSE, expressed as a percentage and depending on the existing steady state efficiency, SSE, as indicated in Table 4.1.1 below.

Table 4.1.1. Equipment efficiency increase from tuneup of gas/oil fired furnaces and boilers

Unit type	Existing SSE	ΔSSE
Gas-fired furnaces	SSE≤70%	4%
	70<SSE<76%	0.67*(76-SSE)%
	76<SSE	0%
Oil-fired furnaces	SSE≤69%	7%
	69%<SSE<76%	(76-SSE)%
	76%≤SSE	0%
Conversion burner units	SSE≤65%	7%
	65%<SSE<72%	(72-SSE)%
	72%≤SSE	0%

In addition to the assumed equipment efficiency increase, additional system efficiency improvement is attributed to the distribution system of forced-air and gravity units, as given in Table 4.1.2.

Table 4.1.2. Distribution efficiency increase from tuneup of forced-air and gravity systems

Condition / Distribution type	Forced-air	Gravity
Good	2.5%	1.875%
Fair	5.0%	3.750%
Poor	7.5%	5.625%

FURNACE REPLACEMENT

The furnace replacement measure changes the steady state efficiency of the heating system to a percentage specified by the user and adds IID and vent damper savings if these features were not present on the old system. Furnaces and boilers must be fueled by oil, gas, or propane to be considered for replacement. Space heaters will not be considered for replacement if fueled by wood, coal, or electric. All systems qualifying for replacement may have those replacements designated as mandatory in case the existing system is considered unsafe. A gas furnace will also be evaluated for replacement by a high efficiency furnace, considered mutually exclusive with replacement by a standard efficiency furnace. If the existing system is a gas furnace, replacement with a high efficiency unit may be designated as mandatory.

SETBACK THERMOSTAT

The program computes the savings of a setback thermostat from algorithms used in the CIRA program [LBL, 1982], modified to reduce the maximum setback period to 8 hours per day. The technique computes an alternate average monthly nighttime indoor air temperature based on the average nighttime outdoor temperature and the massiveness of the house (assumed average for the program). The computation assumes an exponential decrease in the indoor air temperature at the time of the setback, with time constant,

$$\tau = M * \frac{A}{BLC},$$

where,

M = specific thermal mass of medium mass house (3.8 Btu/F-ft^2 from CIRA manual),
A = the conditioned floor are of the house (ft^2), and
BLC = the building load coefficient (Btu/hr-F).

The average nighttime setback temperature lies between the normal nighttime indoor air temperature (assumed equal to 68°F unless altered by the user) and that temperature minus the number of degrees setback, also specified by the user in setup. The program uses this altered nighttime indoor air temperature in the standard variable-base degree-day calculations previously used to determine the whole-house load and energy consumption.

COOLING EQUIPMENT MEASURES

WINDOW AIR CONDITIONER REPLACEMENT

The window air conditioner replacement measure replaces all window air conditioners with SEER less than 9.0 with units assumed to have an SEER of 9.5. Since the program allows multiple air conditioners with varying SEER's and capacities, the savings from replacement of each air conditioner is properly weighted to reflect its individual characteristics. The program also permits the user to designate what portion of the entire house is cooled by the air conditioners, and uses only this fraction of the total cooling load to compute the air conditioner replacement savings. Replacement of each air conditioner is considered a separate measure, thus allowing the program to request replacement of only those units whose replacement would be cost-effective.

A/C TUNEUP

A literature survey of energy efficiency measures appropriate for warm climates (Martin, 1998) gives average percent savings for routine air-conditioner maintenance procedures. Possible savings for replacing air filters, cleaning evaporator coils, and correcting refrigerant charge are listed as 9%, 8%, and 12%, respectively, totaling 29%. Another source indicates possible savings as high as 36%. NEAT uses a multi-staged assignment of percent savings, based on the existing SEER of the unit. For units having initial SEER's below 5, a 36% increased efficiency is assigned, for a maximum tuned SEER of 6.8. Beyond this, linear relationships are established, as given in Figure 4.4.1 below.

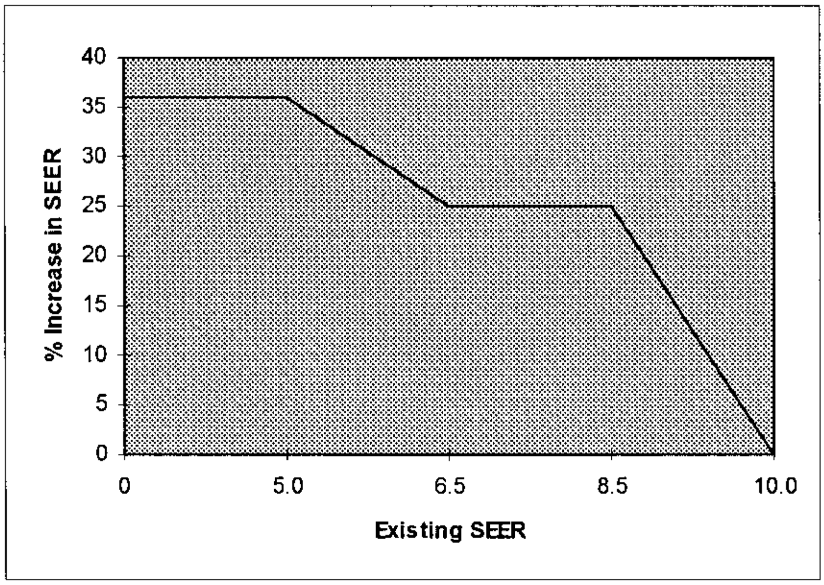

Fig. 4.4.1. Efficiency increase from tuneup of air-conditioner by existing SEER

The air-conditioner tuneup measure is mutually exclusive with the air-conditioner and heat pump replacement measures and the evaporative cooler measure.

EVAPORATIVE COOLER

Evaporative coolers are low energy alternatives to air conditioners applicable only in dry climates. Direct evaporative coolers cool a house by drawing outside air through wetted pads, cooling the air by evaporating the water in the pads, and blowing the moistened, cool air into the living space.

Evaporative coolers are assumed to be applicable in a specific climate if at least 90% of the four-hour, time-of-day monthly average periods with dry-bulb temperature above 78°F have coincident relative humidities below 50%. Provided this condition is met, there exists an air-conditioner which can be replaced by the evaporative cooler, and the user has not turned this measure off in setup, the program will evaluate the cost-effectiveness of replacing all existing air-conditioning equipment with a direct evaporative cooler.

The weather processor computes the approximate efficiency of an evaporative cooler in the climate specified by the weather file using the annual maximum dry-bulb temperature, t_{max}, and its coincident wetbulb temperature, t^*_{max}. A supply air temperature, t_{sup}, is computed as

$$t_{sup} = t_{max} - 0.75(t_{max} - t^*_{max}).$$

The approximate energy efficiency ratio, EER_{ec}, is then

$$EER_{ec} = 3.1*8/.75 = 33.1 \quad \text{for } t_{sup} \geq 70°F \text{ and}$$
$$EER_{ec} = 3.1*(78 - t_{sup})/.75 \quad \text{for } t_{sup} < 70°F.$$

The energy savings associated with this replacement is given by,

$$E_{ec} = 3.413*(\frac{1}{SEER} - \frac{1}{EER_{ec}})*L_c$$

where,

3.413 = conversion factor associated with use of the energy efficiency ratios,
SEER = the average seasonal energy efficiency ratio (SEER) of all existing air-conditioning units, weighted by the fractional area cooled by each, and
L_c = the annual cooling load of the house.

HEAT PUMP REPLACEMENT

The heat pump replacement measure considers replacing an existing heat pump with a more energy efficient heat pump. The measure will be considered only if the primary source of heat is a heat pump and at least one of the cooling systems is a heat pump. Energy savings, E_{hp}, is a direct result of the increase in efficiency of the equipment. Thus,

$$E_{hp}^{c} = 3.413*(\frac{1}{SEER_{hp}} - \frac{1}{SEER_{hp}^{*}})*L_c*F_{cooled}^{hp}$$

where,

E_{hp}^{c} = cooling energy saved by heat pump replacement measure,
3.413 = conversion factor associated with use of the energy efficiency ratios,
$SEER_{hp}$ = seasonal energy efficiency ratio of existing heat pump,
$SEER_{hp}^{*}$ = seasonal energy efficiency ratio of replacement heat pump,
L_c = the annual cooling load of the house, and
F_{cooled}^{hp} = fraction of total annual cooling load met by the existing heat pump.

LIGHTING RETROFITS

The lighting retrofit measure evaluates the cost-effectiveness of replacing existing incandescent lamps with more energy efficient compact fluorescent lamps. The user supplies information on only those lamps believed to be most cost-effective for replacement, those which are on most often. The energy savings (in Mbtu) is

$$E_{lites} = (W_{inc} - W_{cf}) * Hrs * N * 0.365/293,$$

where,

E_{lites} = annual energy savings for lamp replacement,
W_{inc} = watts for each incandescent lamp to be replaced,
W_{cf} = watts of replacement compact fluorescent lamp,
Hrs = hours per day the lamp is on,
N = number of lamps considered for replacement
0.365/293 = conversion factors for watts/day to Mbtu/year.

The factor of 293, changing kWhr to Mbtu, is used only for consistency in the program, where all energies are store in units of Mbtu, despite later being reconverted to kWhr for display purposes.

5

NEAT AUXILIARY FUNCTIONS

NEAT has an optional feature of adjusting the savings predicted for the energy efficiency measures by a ratio of the actual and the NEAT predicted energy consumptions. Implementation assumes that if the actual heating and/or cooling consumptions differ from the NEAT predicted values, then the savings estimates may differ by a similar factor. To implement the feature, the user must enter utility billing or metered consumption data for up to a year's time.

BILLING DATA INPUT

The user must supply pre-retrofit heating and cooling billing data information. Since the program has no ability to separate heating and cooling consumptions of the same fuel, it is not advised that the feature be used under such circumstances. However, if the user were to manually separate a fuel consumption into heating and cooling components, the separated consumptions could be entered into the program. Post-retrofit billing data may similarly be input to the program, but such data is not used in any adjustment or calculation. Post-retrofit billing data would be entered if available in order to keep all data associated with a specific house in a common location, within the NEAT building description file. It is assumed that post-retrofit billing data might be used later in validation efforts.

The majority of the data is input into a tabular format, each row of the table containing information on a specific bill. Data required includes the month and day of the month of each meter reading and the energy consumption for the period. Units of consumption may be in either kWh or Therms for the heating fuel and KWh for cooling.

An optional data item for each billing period is the heating or cooling degree days associated with the billing period. Entries do not affect other calculations in the program, but, if entered, do allow the user to compare these periods' degree days with analogous values derived from the program's weather data. Thus, if there was a significant difference between NEAT's predicted consumption and the billed consumption, the user is able to determine if the difference in weather data used might be the cause.

Additional singular entries include the number of days in the first billing period; the units of the consumptions entered (heating only); the degree-day base of the period degree-day data, if entered by the user; and the user's estimate of the base load per month for the fuel being considered. The user may use the program's estimate of base load, determined from the period data supplied as described in the section below. The user is also asked if he wishes to have the savings predictions adjusted to reflect the billing data entered. If adjustment is chosen, output reports will contain data both with and without the adjustment, in order not to lose any information.

BILLING DATA CALCULATIONS

NEAT estimates a base load associated with the fuel data entered. The user can use this value or enter a base load determined by some other means. Sometimes the fuel bills themselves list this information.

NEAT computes the average daily consumption for each billing period for which data has been entered by dividing the period's consumption by the number of days in the billing period. The program then uses the minimum of these values over all the periods as an estimated daily base load for the metered data. This value times 30 is the default monthly base load provided to the user.

The primary task for the program at this point is to compare the metered (billed) consumptions entered by the user with the heating and cooling consumptions predicted by NEAT. In order to do this, the program must make two adjustments. First, the metered values are assumed to be total consumption, not just the heating or cooling consumptions needed to compare with NEAT's predicted values. To compensate, the program subtracts from the metered consumptions of each billing period the daily base load (either the default value computed as indicated above, or an alternative value provided by the user) times the number of days in the period. This gives metered heating or cooling consumptions for the billing periods needed for the comparison.

The second adjustment needed assumes that the billing periods do not exactly correspond to months of the year, as do the NEAT predicted values. Therefore, the program computes an equivalent predicted consumption for each metered billing period by adding the products of average daily predicted consumption for a particular month times the number of days of that month in the billing period.

For example, if a particular billing period, N, went from October 14 through December 13, inclusive, and $P_{10,11,12}$ represent the average predicted daily consumptions for October, November, and December, respectively, the equivalent predicted consumption for this billing period would equal:

$$P_N = 18*P_{10} + 30*P_{11} + 13*P_{12} ,$$

where the 18, 30, and 13 are the number of days during October, November, and December, respectively, in the billing period.

The program now has pairs of metered and predicted consumptions for each billing period to compare. These values are displayed side-by-side to the user in the View / Energy Consumption/Sizing report along with the ending date and number of days for each period. The totals of metered and predicted consumptions over all the periods together with the % difference between these two totals are also displayed.

As indicated in the "Billing Data Input" section above, if available, the user may input the number of heating or cooling degree days corresponding to each billing period, as well as the degree-day base for these values. NEAT uses its variable-base degree-day weather data to determine the number of degree-days during each month of the year at the given base. The program then adjusts these values to correspond to the days actually in each billing period, much as it does with the average predicted daily consumptions, so that the degree-days from the billing data and that from NEAT correspond to the same days of the year.

These actual billed and NEAT weather-based degree-day values are displayed side-by-side for each period, along with the metered and predicted consumptions. The totals of these degree-day values over all periods are also displayed. This allows the user to judge whether any differences in the metered and predicted consumptions might be due to differences in the average weather used by NEAT and the weather corresponding to the billing data.

ADJUSTMENT FACTOR

If the user has input billing data, as described above, and chooses to use this billing data to make adjustments to the measure savings predictions of NEAT, separate heating and cooling measure savings adjustment factors are computed by dividing the total billed consumption by the total predicted consumption, having been previously adjusted for base load and unequal periods, as described in the previous section. Using these adjustment factors assumes that the savings for each measure is incorrect by the same proportion as are the total heating and/or cooling consumptions. The heating energy savings for each measure is multiplied by the heating measure savings adjustment factor, while the cooling energy savings is multiplied by the cooling factor. Both unadjusted and adjusted results are reported to the user in order not to lose any information.

NEAT provides heating equipment sizing estimates based on the "Manual J" sizing methodology [Rutkowski, 1986]. However, the estimates are based on the input which NEAT requires for its measure selection process, which is not always consistent with the data needed for the formal Manual J technique. Also, only a whole house estimate is performed, not as accurate as a full room-by-room Manual J computation with ducts considered. Thus, users of the program are strongly encouraged to use the estimates as a guide and not as a definitive sizing tool. Comparison between NEAT's estimates and those from a reputable HVAC contractor for a specific climate is encouraged, at least initially, in order to obtain a feel for NEAT's predictions versus those from more accustomed sources.

COMPONENT-BY-COMPONENT CONTRIBUTIONS

NEAT computes the contribution of each building component described by the user to the peak heating load (Btu/h). U-Values (Btu/h-ft^2-F), mostly from Table 2 of the Manual J publication, are assigned each component. When the values are a function of a continuous variable (such as insulation R-value), curve fits to the table entries are used. Whenever an R-value is used in an expression below, it refers to the R-value of insulation present in the component, not including the R-value of the basic construction materials of the component. Table values based on discrete parameters (such as the number of panes in a window) are used directly.

The U-value contributions from all components are multiplied by their respective areas. Each are then multiplied by the temperature difference, $(70 - T_{hdes})$, where T_{hdes} is the 97½ winter design temperature for the specific weather site chosen, taken from the weather data. This results in a peak load contribution in Btu/h for each component. These individual values are displayed to the user in the View / Energy Consumption/Sizing report. Finally, the individual components are added and a duct loss factor applied, which depends on the equipment type, yielding the final estimate of equipment size.

Below are outlines of the sizing determinations for the individual component types, i.e. walls, windows, doors, etc. Table 2 from the Manual J publication is divided into sections, each containing data for a different component type. The sections are numbered, 1 - 23. These section numbers appear in parenthesis below. Note, that there will be a contribution for each wall and each window, etc., described by the user.

FRAME WALLS (Section 12)

$U_{wlf1} = 0.2714\ e^{(-0.2789\ R)}$ $R \leq 2.6$ and

$U_{wlf2} = 0.1505\ e^{(-0.4908\ R)}$ $R > 2.6$,

MASONRY WALLS (Section 14)

Exterior not brick or stone

$U_{wlm1} = 0.00564\ R^2 - 0.1014\ R + 0.51$ $R \leq 5.0$

$U_{wlm2} = 0.00054\ R^2 - 0.01979\ R + 0.22946 \quad R > 5$

Exterior brick of stone

$U_{wlm3} = 0.00396\ R^2 - 0.0732\ R + 0.40 \quad R \leq 5.0$

$U_{wlm4} = 0.00046\ R^2 - 0.01721\ R + 0.20754 \quad R > 5$

WINDOWS (Sections 2, 3, and 4)

Table 5.2.1. Manual J window U-values

Frame / Glazing	Wood	Metal	Improved metal
Single	0.990	1.155	1.045
Single w storm	0.475	0.650	0.525
Double	0.551	0.725	0.609
Double w storm	0.341	0.490	0.385
Low-E	0.711	0.830	0.751

DOORS (Sections 10 and 11)

Table 5.2.2. Manual J door U-values

Door type / Storm door	Hollow wood	Solid wood	Insulated metal
With storm	0.345	0.305	0.342
Without storm	0.560	0.460	0.530

ROOFS/CEILINGS (Sections 16 and 18)

Attempts were made to correlate the Manual J U-values given in Table 2 with U-values derived from heat flow principles applied to physical models using insulation R-values and framing factors. However, no success was obtained. Thus, the closest correlations were acquired from curve fits of the inverse of the Manual J U-values and the insulation R-values.

Attics

$$U_{a1} = \frac{1}{206.9193} + \frac{1}{R+1.683028} \qquad R < 23$$

$$U_{a2} = \frac{1}{0.996\ R + 0.555} \qquad R \geq 23 \quad \text{and}$$

Cathedral ceilings

$$U_{cc} = \frac{1}{0.830\ R + 3.945}$$

FOUNDATION SPACES

Vented space or exposed floor (Section 20)

$$U_{fs1} = \frac{1}{0.801\ R + 4.081}$$

Non-conditioned or unintentionally heated space (Section 19)

$$U_{fs2} = U_{fs1}/2 = \frac{1}{1.602\ R + 8.162}$$

Uninsulated slab (Section 22)

$U^{*}_{fsus} = 0.810$,

where * indicates the U-value is per linear foot of perimeter

Insulated slab (Section 22)

$U^{*}_{fsis} = 0.410$,

where * indicates the U-value is per linear foot of perimeter

Conditioned space - below-grade wall area extending 5 or more feet below grade (Section 15)

$$U^{**}_{fsbg1} = \frac{1}{1.09R+11.45},$$

where ** indicates the U-value is multiplied by below-grade wall area only

Conditioned space - below-grade wall area extending less than 5 feet below grade (Section 15)

$$U^{**}_{fsbg2} = \frac{1}{1.12R+7.83},$$

where ** indicates the U-value is multiplied by below-grade wall area only

Conditioned space - above-grade wall area insulated with R-5 or less insulation (Section 14)

$$U^{\ddagger}_{fsag1} = 0.00564R^2 - 0.1014R + 0.51 \ ,$$

where ‡ indicates the U-factor is multiplied by above-grade wall area only

Conditioned space - above-grade wall area insulated with more than R-5 insulation (Section 14)

$$U^{\ddagger}_{fsag2} = 0.00054R^2 - 0.01979R + 0.22946 \ ,$$

where ‡ indicates the U-factor is multiplied by above-grade wall area only

Conditioned space - concrete floor (Section 21)
U = .024

INFILTRATION

Two methods of computing the infiltration's contribution to the peak load are used in the sizing routines in NEAT. If the program detects the default post-retrofit value of infiltration (2500 cfm at 50 Pa) or no entry for the pre-retrofit air leakage, it uses the following equation for computing the infiltration peak load, taken from the Manual J publication, Figure 3-4:

$$U[\frac{Btu}{hr\text{-}F}] = \alpha[\frac{A/C}{hr}] \times V[\frac{ft^3}{A/C}] \times \frac{hr}{60min} \times \frac{1.1\frac{Btu}{hr\text{-}F}}{ft^3/min},$$

where,

V = house volume (taken as the living space floor area times an assumed 8 foot ceiling height),
α = winter air changes per hour (as indicated in the Manual J publication and in the following table:

Table 5.2.3. Manual J air-changes per hour

Floor area	900 or less	900 - 1500	1500 - 2100	over 2100
α (Air changes)	1.2	1.0	0.8	0.7

Note, this conductance has already been multiplied by a characteristic dimension and has units of Btu/hr-F instead of Btu/hr-F-ft^2 of other components to the peak load thus far presented.

If values for pre- or post-retrofit air leakage from blower-door measurements have been entered by the user, the program multiplies the corresponding air infiltration at natural conditions (See Infiltration in Section 2.2) during the month of January by the same 1.1 Btu/hr-F per CFM conversion factor used above to determine the infiltration's contribution to the peak load.

If the user has not entered pre-retrofit air leakage information and the pre-retrofit infiltration level computed using the table above yields a lower value than for post-retrofit, the pre-retrofit level is set equal to the post-retrofit value.

DUCT LOSS

The total peak heating load from all components above is multiplied by a duct loss factor whose value depends on the heating equipment type. The following table indicates the duct loss factors:

Table 5.2.4. Duct loss factors for heating equipment sizing

Heating equipment type	Duct loss factor
Portable electric resistance heaters Unvented space heaters Vented space heaters	1.00
Hot water boiler	1.01
Steam boiler	1.02
Furnaces (including electric) Heat pumps "Other" types	1.15
Systems with more than 10' uninsulated duct	1.20

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A

APPENDIX A: SAMPLE PROBLEM

A.1 House Description and Conductance Calculations

The house modeled in this example was taken from the description of a home weatherized by a New York State utility. Below is a brief listing of its characteristics, sufficient to provide the entries required for NEAT.

General - House is 888 ft^2 (24'x37'), single story, ceiling height of 7.8 feet. Blower-door measured leakage rate is 1762 cfm at 50 Pascal.

Walls - 2x4" 16" oc. uninsulated wood frame, aluminum siding except for east side which has a brick facing.

Windows - metal frame single pane windows with metal framed storms. Eaves are located over the east and south sides of the house. (This is likely in error, but is the assumption the analysis assumed.) Assume no additional shading.

Doors - solid core, 21 ft^2 doors are located on the south and east sides.

Attic - 24" oc. rafters, uninsulated

Basement - Unintentionally heated (from furnace/water heater) with 8 ft uninsulated concrete block walls only 25% above-grade.

Furnace - natural gas, 80% steady state efficient.

Summary of areas

Areas (ft^2)	North	East	South	West	Total
Gross wall area	290	188	290	188	956
Glazing area	26	21	27	17	91
Door area	0	21	21	0	42
Net wall area	264	146	242	171	823

U*A CALCULATIONS

Components	U-Value	Area	UA Contribution
Walls (except East)	0.2168	676.6	146.7
East wall	0.2076	145.9	30.3
Windows	0.86	91.5	78.7
Doors	0.39	42.0	16.4
Attic	(See below)		288.1
Subspaces			120.0
Total			680.2

Attic Model

The attic model performs an energy balance on the attic, assuming conduction through the attic ceiling to the living space temperature and through the roof to a sol-air temperature, with an assumed 0.3 cfm/ft_2 of attic floor area ventilation to the outside air. The UA's (Btu/hr-F) for the specific house modeled are:

UA_{ceil} = .54559*888 = (.15*.1176+.85*.6211)*888 = 484.5
Framing Cavity

UA_{roof} = .452*1.054*888 = (.1*.156+.9*.485)*1.054*888 = 423.1
Pitch Framing Cavity Pitch

UA_{inf} = 1.08 * .3 * 888. = 287.7

These values give an effective attic UA of:

$$UA_{attic} = UA_{ceil}*(UA_{inf}+UA_{roof})/(UA_{ceil}+UA_{inf}+UA_{roof}) = 288.1$$

$$= 484.5 * (287.7 + 423.0) / (484.5+287.7+423.0)$$

The effective solar aperture for the attic is equal to

$$SA_{attic} = UA_{ceil}*UA_{roof}*\alpha/h_o/(UA_{ceil}+UA_{inf}+UA_{roof}) = 30.0,$$

where a 0.7 absorptance is now used.

Solar Apertures for Walls and Windows

The solar aperture for each cardinal direction is defined as given in the LBL's CIRA manual, having a contribution from windows as well as opaque surfaces. For windows the solar aperture is equal to simply the glazing area times the window's solar gain factor (SGF). The solar gain factors for windows were determined as 0.87 times the shading coefficient of the window type, as given by LBL's Window 3.1 program. For the windows in this example, the SGF is .791. For opaque surfaces, the solar aperture is equal to

$$SA = Area * \alpha * U/h_o,$$ where

α = solar absorptance of surface = 0.8 for walls
U = conductance of component = .217 $Btu/hr\text{-}F\text{-}ft^2$ for the aluminum siding, .208 for the brick siding
h_o = exterior film coefficient = 4.0 $Btu/hr\text{-}F\text{-}ft^2$

The solar aperture for direct solar uses a shading multiplier. For the overhangs present over the windows on the east and south sides of the house, this multiplier is 0.8. The diffuse solar apertures differ from the direct only in elimination of the shading multiplier.

Thus, the solar aperture for the west-facing portion of the house is computed as follows:

$$SA_w = U_{wl} * A_{wl} * \alpha/h_o + A_{wn} * SGF * shading$$

$$= .217 * 171 * .8/4 + 17 * .791 * 1.0 = 20.8$$

as seen in the printout under "Heating/cooling direct solar apertures..." The following section gives more detailed derivations of the solar apertures by direction.

Solar aperture derivations by orientation

North	East	South	West	Direction
264	146	242	171	Net wall area
0.217	0.208	0.217	0.217	U-value of wall
57.2	30.3	52.4	37.1	UA of wall
11.4	6.1	10.5	7.4	Solar aperture = Alpha * /ho * area = .8/4.*UA
26	21	27	17	Window area
0.791	0.791	0.791	0.791	SGF of window
1	0.8	0.8	1	Shading factor
20.7	13.4	17.3	13.4	Direct solar aperture
20.7	16.7	21.6	13.4	Diffuse solar aperture
32.1	19.4	27.8	20.8	Cumulative direct aperture
32.1	22.8	32.1	20.8	Cumulative diffuse aperture
	21	21		Door area
	0.39	0.39		Door U-value
	8.19	8.19		Door UA
	1.6	1.6		Solar aperture = Alpha * /ho * area = .8/4.*UA
32.1	21.1	29.4	20.8	Total direct aperture
32.1	24.4	33.7	20.8	Total diffuse aperture

The Basement Model

The basement model is relatively complex and will not be described in detail here. It was taken from LBL's CIRA program with the addition of a term to account for waste heat dumped to the space by equipment. The model uses resistances through the ground to the outside air temperature. The space is treated as part of the building load coefficient (i.e. a UA), rather than a negative heat source (in winter) together with the other internals. The resulting effective subspace UA, 120.0, is also printed on the output sheet.

Free Heat from Solar and Total Free Heat

The "Free Heat from Solar" column is the sum of contributions from the four oriented walls, the windows on those walls, plus the attic. Each component's contribution is equal to the "Diffs" solar intensity times the component's diffuse solar aperture plus the direct solar intensity on the surface times its direct solar aperture. However, the solar apertures have already been summed over all components facing each of the four cardinal directions and horizontal. Therefore, all that remains is to multiply the values by the solar intensities incident on those directions. Thus, the 2164 Btu/hr value for January is a result of the following calculation:

8.6*21.05 + 36.5*29.41 + 8.6*20.84 + 11.5*30.01 (Direct)

+ 2.7 * (32.1 + 24.39 + 33.74 + 20.84 + 30.01) (Diffuse)

which equals 2160, round off accounting for the 4 Btu/hr difference from the 2164 the computer program obtains.

The total free heat adds to the solar free heat the internals from lights, appliances, and people, 2900 Btuh.

The VBDH Calculation

The monthly balance point temperature is determined by solving the house heat balance equation for the outdoor temperature for which the conduction losses equal the gains. That is:

$T_{bal} = T_{int} - Q_{int}/BLC$, where

T_{int} = Interior set-point temperature = 68 F
Q_{int} = Total free heat, discussed above
BLC = The building load coefficient

The building load coefficient (BLC) equals the UA for entire building (680.2 Btu/h-F) plus the infiltration component equal to 1.08 * cfm * 0.83. The 0.83 factor adjusts for some of the air exchange occurring with buffered spaces whose temperature is somewhere between the indoor and outdoor air temperature. The actual cfm values at normal conditions come from a measured leakage rate of 1762 cfm at 50 Pascal, measure via a blower door, and calculations using the Sherman-Grimsrud method. Thus, for January:

BLC = 680.2 + 1.08*115*.83 = 783.0 (with round-off)

such that

T_{bal} = 68 - 5064/783.0 = 61.5, as listed.

Load and consumption calculations

Monthly degree-hours corresponding to specific balance point temperatures are taken from a table of values listing degree-hours for each month at nine different base temperatures, from 45 to 75 degrees F. Linear interpolation is used for balance points lying between the listed base temperatures. The degree-hours so obtained are multiplied by the total building load coefficient (783.0 for January) and divided by 10^6 to obtain the monthly load in MBtu. These are summed over the entire year to arrive at a yearly load. The furnace was declared an 80% steady state efficient unit. The program translated this into a seasonal efficiency of 76%. Thus the energy consumption predicted is 101.81/0.76 = 133.96.

No air-conditioning was indicated, thus no cooling load or energy are computed. However, cooling loads are determined in a manner analogous to the heating loads, except using the variable-base degree-hour values for cooling. The latent load of cooling is computed, as described in the body of the report, and the SEER of the cooling equipment is used to directly translate the total cooling load (latent plus sensible) into an energy consumption.

The following pages contain actual output from the NEAT program when run in a debugging mode, used to analyze computations producing the results. The printouts are for the example problem described in the last section.

Weather data readin

month/tbal	40.0	45.0	50.0	55.0	57.0	60.0	65.0	70.0	75.0
Daytime heating degree hours									
1	5169	6908	8731	10567	11306	12419	14279	16139	17999
2	4474	5982	7585	9227	9891	10893	12573	14253	15933
3	2498	4059	5741	7456	8163	9242	11069	12915	14775
4	531	1139	2007	3064	3547	4325	5754	7372	9112
5	0	13	200	691	985	1563	2786	4350	6142
6	0	0	0	2	20	84	375	979	1985
7	0	0	0	0	0	0	1	85	544
8	0	0	0	0	0	6	66	414	1291
9	0	1	16	129	237	486	1140	2224	3605
10	35	228	685	1575	2017	2750	4184	5793	7590
11	1307	2203	3485	5045	5701	6709	8458	10248	12048
12	3743	5362	7103	8899	9624	10730	12590	14450	16310
Total	17757	25895	35553	46655	51491	59207	73275	89222	107334
Nighttime heating degree hours									
1	5954	7681	9477	11334	12078	13194	15054	16914	18774
2	5440	7002	8661	10339	11011	12019	13699	15379	17059
3	3785	5471	7200	8972	9705	10811	12665	14525	16385
4	1082	2067	3320	4736	5354	6327	8057	9851	11651
5	85	432	1243	2406	2960	3835	5517	7351	9211
6	0	0	44	302	520	936	1871	3197	4859
7	0	0	0	51	113	244	709	1635	3081
8	0	0	1	31	79	246	904	2174	3909
9	32	112	325	832	1159	1794	3112	4583	6225
10	188	698	1595	2879	3454	4369	6054	7846	9706
11	1626	2784	4231	5894	6590	7646	9408	11199	12999
12	4469	6243	8052	9887	10626	11742	13602	15462	17322
Total	22661	32490	44149	57663	63649	73163	90652	110116	131181
Total	40418	58385	79702	104318	115140	132370	163927	199338	238515
Total	1684	2433	3321	4347	4798	5515	6830	8306	9938

month/tbal	40.0	45.0	50.0	55.0	57.0	60.0	65.0	70.0	75.0
Daytime cooling degree hours									
1	190	69	32	8	3	0	0	0	0
2	301	129	52	14	6	0	0	0	0
3	743	444	266	121	84	47	14	0	0
4	4019	2827	1895	1152	915	613	242	60	0
5	6890	5043	3370	2001	1551	1013	376	80	12
6	11072	9272	7472	5674	4972	3956	2447	1251	457
7	13717	11857	9997	8137	7393	6277	4418	2642	1241
8	12262	10402	8542	6682	5938	4828	3028	1516	533
9	9454	7655	5870	4183	3571	2740	1594	878	459
10	5467	3800	2397	1427	1125	742	316	65	2
11	1859	955	437	197	133	61	10	0	0
12	453	212	93	29	10	0	0	0	0
Total	66427	52665	40423	29625	25701	20277	12445	6492	2704
Nighttime cooling degree hours									
1	200	67	3	0	0	0	0	0	0
2	141	23	2	0	0	0	0	0	0
3	420	246	115	27	16	6	0	0	0
4	2031	1216	669	285	183	76	6	0	0
5	3894	2381	1332	635	445	204	26	0	0
6	7747	5947	4191	2649	2147	1483	618	144	6
7	10008	8148	6288	4479	3797	2812	1417	483	69
8	9118	7258	5399	3569	2873	1924	722	132	7
9	6417	4697	3110	1817	1424	979	497	168	10
10	3502	2152	1189	613	444	243	68	0	0
11	1227	585	232	95	71	47	9	0	0
12	167	81	30	5	0	0	0	0	0
Total	44872	32801	22560	14174	11400	7774	3363	927	92
Total	111299	85466	62983	43799	37101	28051	15808	7419	2796
Total	4637	3561	2624	1825	1546	1169	659	309	117

Monthly total solar radiation on horizontal surface (Btu/sqft)

												Total
342	527	891	1280	1680	1799	1769	1485	1180	724	350	267	12294

Heating/cooling direct solar aperatures for cardinal directions

N	E	S	W	H
32.10	21.05	29.41	20.84	30.01
32.10	21.05	29.41	20.84	30.01

Heating/cooling diffuse solar aperatures for cardinal directions

N	E	S	W	H	Total
32.10	24.39	33.74	20.84	30.01	141.08
32.10	24.39	33.74	20.84	30.01	141.08

Month	Solar incident on surfaces North	East	South	West	Horz	Diffs	Free heat from solr	Total free ht	Tbal
1	0.0	8.6	36.5	8.6	11.5	2.7	2164	5064	61.5
2	0.0	12.0	33.8	12.0	18.4	3.5	2547	5447	61.0
3	0.0	18.3	32.1	18.3	31.5	5.6	3450	6350	59.8
4	0.0	23.0	22.0	23.0	44.6	8.7	4180	7080	58.8
5	0.0	25.7	12.4	25.7	55.9	14.1	5107	8007	57.3
6	0.0	24.7	7.0	24.7	57.9	17.1	5384	8284	56.8
7	0.0	26.3	12.1	26.3	58.3	15.4	5386	8286	56.8
8	0.0	25.6	24.0	25.6	51.0	10.9	4847	7747	57.5
9	0.0	23.3	41.8	23.3	41.1	8.1	4580	7480	57.8
10	0.0	15.8	44.8	15.8	25.0	5.1	3456	6356	59.5
11	0.0	8.5	35.9	8.5	11.8	2.8	2160	5060	61.3
12	0.0	6.9	34.9	6.9	8.9	2.2	1900	4800	61.7
Tot/Avg	0	219	337	219	416	96	45161	79961	59.1

Average monthly infiltration (cfm)

												Average
115	107	100	96	76	64	68	63	59	80	86	93	84

Monthly building load coefficients

												Average
783.0	775.8	770.0	766.7	748.6	737.6	741.1	736.6	733.5	751.9	757.6	763.2	755.5

Monthly balance point temperatures

												Average
61.5	61.0	59.8	58.8	57.3	56.8	56.8	57.5	57.8	59.5	61.3	61.7	59.1

Heating/cooling degree-hours at computed balance temperatures

												Total	DD
26753	23570	19873	9931	4092	513	107	107	1632	6870	15282	23745	132477	5520
0	0	1	111	263	2527	4933	2768	1535	101	0	0	12240	510

Heating degree-hours * building load coefficient/10^6 = MBtu consumption

												Total
20.95	18.28	15.30	7.61	3.06	0.38	0.08	0.08	1.20	5.17	11.58	18.12	101.81

The annual heating load = 101.811790 MBtu
The annual cooling load = 0.000000 MBtu

The annual heating energy = 133.962891 Mbtu
The annual cooling energy = 0.000000 Mbtu

The following describes the changes in the program computations when two measures are implemented, R-19 attic insulation and R-13 wall insulation. The last page of the section is an annotated printout from the debugging version of the program showing these changes in the output.

EFFECT OF ADDING R-19 ATTIC INSULATION

The addition of R-19 insulation to the attic adds R-19 to the cavity path of the attic. Below is a comparison of parameters which change with the implementation of this measure.

Pre-retrofit	Post-retrofit	Parameter
1.61	20.61	Ceiling cavity R-value
.6211	.0485	Ceiling cavity path U-value
.5456	.0589	U-value of ceiling
484.5	52.3	UA of ceiling
288.1	48.7	Effective UA of attic
30.0	5.07	Solar aperture of attic

Thus, the building load coefficients are less by (288.1-48.7) = 239.4, making January's value 783.0-239.4 = 543.6. The internal heat gain is affected by less heat entering the house through the ceiling by an amount corresponding to the decrease in solar aperture. For instance, whereas January's free heat from solar was 2164 Btu/h, it now equals:

8.6*21.05 + 36.5*29.41 + 8.6*20.84 + 11.5*5.07 (Direct)

+ 2.7 * (32.1 + 24.39 + 33.74 + 20.84 + 5.07) (Diffuse)

which equals 1806, listed as 1809 on printout, the difference due to roundoff error. The total free heat adds the 2900 Btu/h internals, for a January total of 4709 Btu/h.

The balance points change to reflect the new building load and free heat. A comparison of the January values shows,

T_{bal} = 68 - 5064/783.0 = 61.5 (Pre-retrofit)
T_{bal} = 68 - 4709/543.6 = 59.3 (With attic ins.)

This lower balance point produces less heating degree-hours, 25120 compared to 26753 for January. The combination of less degree-hours and lower building load coefficient produce the smaller predicted heating load, as shown in the following comparison for the month of January:

Load (MBtu) = Htg Deg Hrs * Bld Ld Coeff / 10^6
20.95 = 26753 * 783.0 / 10^6 (Pre-retrofit)
13.65 = 25120 * 543.6 / 10^6 (With Attic ins.)

This represents a 35% reduction in load. The consumptions are obtained by dividing by 0.76, the estimated seasonal efficiency.

EFFECT OF ADDING R-13 WALL INSULATION

The addition of R-13 cellulose to the walls adds an R-13.0 to the cavity path of the walls. Below is a comparison of parameters which change with the implementation of this measure.

Pre-retrofit East	Pre-retrofit Others	Post-retrofit East	Post-retrofit Others	Parameter
4.51	4.31	16.4	16.2	Wall cavity R-value
.2217	.2320	.0609	.0617	Wall cavity path u-value
.2076	.2168	.0709	.0720	Wall U-value
145.9	676.6	145.9	676.6	Wall area
30.3	146.7	10.3	48.7	Wall UA
177.0		59.0		Total wall UA

Thus, the building load coefficients are less by (177.0-59.0) = 118.0, making January's value 543.6-118.0 = 425.6.

The internal heat gain is affected by less heat entering the house through the walls. The change in solar aperture for each wall equals the change in UA times 0.2 ($=\alpha/h_o=.8/4$). The change in U for the east wall is .1367 = .2076-.0709 and .1448 = .2168-.0720 for the others. Thus, the change in solar aperture for each cardinal direction is computed as indicated below:

North	East	South	West	
264	146	242	171	Area
.1448	.1367	.1448	.1448	Δ U
38.2	20.0	35.0	24.8	Δ UA
7.65	3.99	7.01	4.95	Δ SA = .2*ΔUA

These differences can be seen in the direct and diffuse solar aperture listings of the output. This reduction in solar aperture results in smaller free heat from solar. For instance, whereas January's free heat from solar was 1809 Btu/h with only the R-19 attic insulation measure incorporated, with the added wall insulation it now equals:

8.6*17.07 + 36.5*22.42 + 8.6*15.89 + 11.5*5.07 (Direct)

+ 2.7 * (24.46 + 20.41 + 26.74 + 15.89 + 5.07) (Diffuse)

which equals 1410, listed as 1412 on the printout, the difference due to roundoff error. The total free heat adds the 2900 Btu/h internals, for a January total of 4312 Btu/h.

The balance points change to reflect the new building load and free heat. A comparison of the January values shows,

T_{bal} = 68 - 5064/783.0 = 61.5 (Pre-retrofit)
T_{bal} = 68 - 4709/543.6 = 59.3 (With attic ins.)

T_{bal} = 68 - 4312/425.7 = 57.9 (With attic and wall ins.)

This lower balance point requires less heating degree-hours, 24030 in January, compared to 25120 for the case with only ceiling insulation. The combination of less degree-hours and lower building load coefficient produce the smaller predicted heating load, as shown in the following comparison for the month of January:

Load (MBtu) = Htg Deg Hrs * Bld Ld Coeff / 10^6

20.95 = 26753 * 783.0 / 10^6 (Pre-retrofit)

13.65 = 25120 * 543.6 / 10^6 (With attic ins.)

10.23 = 24030 * 425.7 / 10^6 (With attic and wall ins.)

This represents a further decrease of 25% in load. As before, the consumptions are obtained by dividing by 0.76, the estimated seasonal efficiency.

COMPARISON OF MONTHLY PARAMETERS FOR THREE TRIAL CASES

BASE, (R-19 ATTIC INS), [R-19 ATTIC + WALL INS]

Monthly total solar radiation on horizontal surface (Btu/sqft)

												Total
342	527	891	1280	1680	1799	1769	1485	1180	724	350	267	12294

Heating direct solar apertures for cardinal directions

N	E	S	W	H
32.10 [24.46]	21.05 [17.07]	29.41 [22.42]	20.84 [15.89]	30.01 (5.07)

Heating diffuse solar apertures for cardinal directions

N	E	S	W	H	Total
32.10 [24.46]	24.39 [20.41]	33.74 [26.74]	20.84 [15.89]	30.01 (5.07)	141.08 (116.14) [92.57]

Month	Solar incident on surfaces North	East	South	West	Horz	Diffs	Free heat from solar			Total free heat		
1	0.0	8.6	36.5	8.6	11.5	2.7	2164	(1809)	[1412]	5064	(4709)	[4312]
2	0.0	12.0	33.8	12.0	18.4	3.5	2547	(1999)	[1572]	5447	(4899)	[4472]
3	0.0	18.3	32.1	18.3	31.5	5.6	3450	(2524)	[2003]	6350	(5424)	[4903]
4	0.0	23.0	22.0	23.0	44.6	8.7	4180	(2850)	[2285]	7080	(5750)	[5185]
5	0.0	25.7	12.4	25.7	55.9	14.1	5107	(3362)	[2713]	8007	(6262)	[5613]
6	0.0	24.7	7.0	24.7	57.9	17.1	5384	(3515)	[2843]	8284	(6415)	[5743]
7	0.0	26.3	12.1	26.3	58.3	15.4	5386	(3548)	[2864]	8286	(6448)	[5764]
8	0.0	25.6	24.0	25.6	51.0	10.9	4847	(3304)	[2650]	7747	(6204)	[5550]
9	0.0	23.3	41.8	23.3	41.1	8.1	4580	(3354)	[2663]	7480	(6254)	[5563]
10	0.0	15.8	44.8	15.8	25.0	5.1	3456	(2704)	[2128]	6356	(5604)	[5028]
11	0.0	8.5	35.9	8.5	11.8	2.8	2160	(1796)	[1403]	5060	(4696)	[4303]
12	0.0	6.9	34.9	6.9	8.9	2.2	1900	(1622)	[1263]	4800	(4522)	[4163]
Tot/Avg	0	219	337	219	416	96	45161	(32387)	[25799]	79961	(67187)	[60599]

Average monthly infiltration (cfm)

												Average
115	107	100	96	76	64	68	63	59	80	86	93	84

Monthly building load coefficients

													Average
783.0	775.8	770.0	766.7	748.6	737.6	741.1	736.6	733.5	751.9	757.6	763.2		755.5
(543.6	536.4	530.6	527.3	509.2	498.2	501.7	497.2	494.1	512.5	518.2	523.8		516.1)
[425.7	418.5	412.7	409.4	391.3	380.3	383.8	379.3	376.2	394.6	400.3	405.9		398.2]

Monthly balance point temperatures

61.5	61.0	59.8	58.8	57.3	56.8	56.8	57.5	57.8	59.5	61.3	61.7	59.1
(59.3	58.9	57.8	57.1	55.7	55.1	55.1	55.5	55.3	57.1	58.9	59.4	57.1)
[57.9	57.3	56.1	55.3	53.7	52.9	53.0	53.4	53.2	55.3	57.2	57.7	55.3]

Heating degree-hours at computed balance temperatures

												Total	DD
26753	23570	19873	9931	4092	513	107	107	1632	6870	15282	23745	132477	5520
(25120	22152	18434	8956	3396	318	56	44	1036	5508	13623	22003	120646	5027)
[24030	21112	17234	7985	2653	195	30	21	740	4586	12462	20801	111849	4660]

Heating degree-hours * building load coefficient/10^6 = MBtu consumption

												Total
20.95	18.28	15.30	7.61	3.06	0.38	0.08	0.08	1.20	5.17	11.58	18.12	101.81
(13.65	11.88	9.78	4.72	1.73	0.16	0.03	0.02	0.51	2.82	7.06	11.53	63.90)
[10.23	8.83	7.11	3.27	1.04	0.07	0.01	0.01	0.28	1.81	4.99	8.44	46.10]

The annual heating load = 101.81 (63.90) [46.10] MBtu

The annual heating energy = 133.96 (84.08) [60.66] Mbtu

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40. Mark B. Ginsberg, U.S. Department of Energy, 1000 Independence Avenue, S.W., Forrestal Building, Route Symbol: EE-40, Mail Stop: 6A-116, Room: 5E-052, Washington, DC 20585
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