DOE/CE-0274
Volume 2 of 7

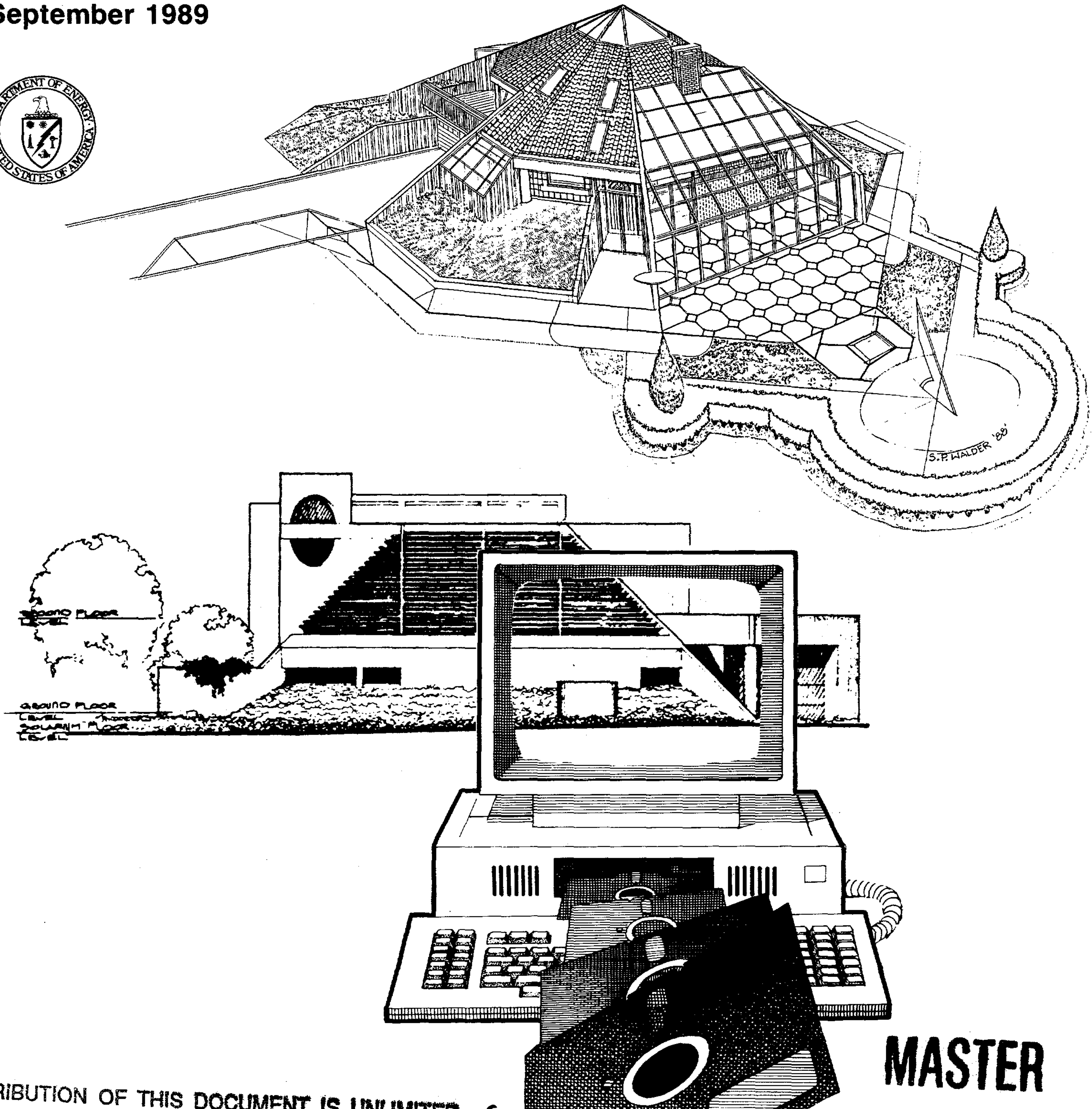
DOE/CE--0274-Vol. 2

U.S. Department of Energy
Assistant Secretary
Conservation and Renewable Energy
Office of Buildings and Community Systems
Buildings Systems Division
Washington, DC 20585

Technical Support Documentation for the Automated Residential Energy Standard (ARES)

In Support of Proposed Interim Energy Conservation Voluntary Performance Standards for New Non-Federal Residential Buildings

September 1989



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SUMMARY

The Automated Residential Energy Standard (ARES) program is designed to identify levels of thermal integrity (e.g., insulation levels, glazing layers, equipment efficiencies, etc.) that are cost effective for typical residential structures and to create a residential energy standard based on those levels. This document contains technical background that explains the data and algorithms used by the program.

To identify optimal combinations of Energy Conservation Measures (ECMs), ARES contains an optimization procedure that searches a list of measures which can be modified by the user and identifies the combination of ECM levels that results in the minimum overall cost of owning and operating a typical house over a specified period of analysis. The annual energy cost of a house equipped with the optimal ECM levels becomes the singular criterion of the standard. Any house that uses no more energy than a similar house built with the optimal levels complies.

The cost optimization relies on data bases of residential energy consumption, available ECMs and their costs, typical housing practices, climate factors, and economic and financial parameters. Many of these data bases are available to the user (a standard- or code-setting official) for modification via a user-friendly, menu-driven interface. Others cannot be modified. The most significant example of modifiable data is the ECM cost data base, which can be extensively modified to match local economic conditions. The most significant fixed data base is that of estimated energy consumption, which was developed through extensive computer simulations of residences with various thermal integrities in various climates across the United States.

The optimization is based on one of two optional tests of economic viability. The first, which is the default in the program, was developed by the Technical Evaluation Committee (TEC) for the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Special Project 53.

Documented in SP-53 Position Paper #3-1[a], this method demands that ECMs have economic returns over an assumed seven-year period of initial occupancy that at least equal the return available on an alternative investment. ARES embodies the economic test as a life-cycle cost function. The optimization, by an exhaustive search of all possible combinations of ECM levels, identifies the combination that minimizes the net present value of all energy-related costs, including construction and fuel costs. The cost optimization accounts for impacts on the property and income taxes of a typical homebuyer. The life-cycle costs are calculated according to common financial mathematics, with most parameters available for modification by the user. Thus a code official can tailor the cost calculations to reflect, for example, local mortgage costs if they differ from the default values. The second optional economic methodology is essentially identical to the first, but allows the user to modify the period of analysis and related parameters.

After finding the optimal ECM levels, ARES creates a set of prescriptive requirements for compliance with the standard (a "package" of ECMs). One package is produced for each fuel/equipment combination, meaning that the standard's requirements are fuel-specific, reflecting the differential costs between fuel types and associated equipment types. To accommodate builders' various preferences, ARES allows code officials to generate alternative packages that deviate from those based on the cost-optimal ECM levels but maintain energy costs at or below those of a building with the cost-optimal levels. To furnish even more flexibility, a point system is created that allows trading higher thermal integrity in some components of the house for lower levels in others. The points provide information on the energy cost impacts of changing the levels of the ECMs, ensuring that thermal integrity at least equivalent to that of the optimal building is maintained.

(a) This document frequently refers to Position Papers of the ASHRAE Technical Evaluation Committee for Special Project #53. These are to be published in <u>Background to the Development Process for the Automated Residential Energy Standard (ARES)</u> in support of the Proposed Interim Energy Conservation Voluntary Performance Standards for New Non-Federal Residential Buildings.

ACKNOWLEDGMENTS

A number of organizations and individuals contributed to the preparation of this document. Funding for the project was provided by the Department of Energy (DOE), Office of Buildings and Community Systems under the direction of John Millhone. Program management and contract monitoring at DOE was provided by Stephen Walder. Technical recommendations in this report were prepared by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Technical Evaluation Committee for Special Project 53. That committee consisted of the following persons:

- Faye C. McQuiston (chairman), Oklahoma State University, Stillwater
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David Conover of the National Conference of States on Building Codes and Standards provided invaluable expertise and insight throughout the development process. Joe Huang of Lawrence Berkeley Laboratory conducted the numerous computer simulations that formed the energy data bases discussed herein.

Michael R. Brambley and, previously, Raymond Reilly and Allen Lee served as project manager for the Voluntary Residential Standards Project at Pacific Northwest Laboratory (PNL). Victor Lortz wrote the software that embodies the algorithms described in this document.

The Automated Residential Energy Standard software has been used by the U.S. Department of Housing and Urban Development (HUD) in developing proposed new HUD mandatory standards for new manufactured housing. HUD funded work at PNL that was used jointly in HUD's new standard and in preparation of this document.

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1.0 OVERVIEW

The Automated Residential Energy Standard (ARES) program is designed to identify levels of thermal integrity (e.g., insulation levels, glazing layers, equipment efficiencies, etc.) that are cost effective for typical residential structures, and to create a residential energy standard based on those levels. Officials responsible for establishing building energy codes may use the program to provide optimal cost housing requirements on a local basis. Operation of the program is explained in the ARES User's Guide[a], which explains the data and algorithms used by the program.

ARES relies on a number of data bases to provide information on the costs and energy performance of various levels of Energy Conservation Measures (ECMs). Many of these data bases can be modified by the user of ARES to reflect local conditions. The origins and uses of the data bases are explained in Section 2.

ARES uses an optimization algorithm to identify the cost-optimal combination of ECMs in a given location. Cost-effectiveness is measured in terms of a life-cycle costing routine explained in Section 3. The procedure used to search through the numerous possible combinations of ECM levels to identify the most cost-effective combination is described in Section 4.

The outputs of the program comprise the requirements of the standard in a particular locale and are given in both a simple, easy-to-use prescriptive format and a more complex but flexible "point system" format. The algorithms used to generate these are explained in detail in Section 5.

(a) ARES 1.2 User's Guide (Automated Residential Energy Standard) in support of the Proposed Interim Energy Conservation Voluntary Performance Standards for New Non-Federal Residential Buildings, (to be published).

2.0 DATA BASES

The ARES software includes the following data bases:

- ECM costs
- residential space conditioning energy consumption
- climate descriptors
- dimensions of typical residential structures.

These are discussed in the sections that follow.

2.1 ECM COSTS

ARES contains separate cost data bases for three building types: 1) single family detached, 2) multifamily attached, and 3) manufactured housing. These are stored in the files SINGLE.DA$, MULTI.DA$, and MANUF.DA$. The menus in ARES allow users to modify the costs of any of the ECMs in the cost data base. In addition, users may add new levels to any ECM or delete existing levels if desired. This implies that the cost data base contains, in addition to cost information, descriptions of the ECMs' thermal characteristics. For example, Figure 2.1 shows an ARES input screen for the wall insulation ECM. Note that information is contained on first cost, operation and maintenance (O&M) costs, failure rates, and U-values. To add a new level, say R-30, the user must know the per-square-foot cost, annual O&M costs, percentage of installations that fail within the period of analysis, and U-value.

2.1.1 Construction Costs

The default construction costs in the ARES data base were obtained from a study commissioned by ASHRAE. Cost data were collected from cities representative of population centers across the U.S. and compiled into 12 regional data bases, as shown in Table 2.1. The data represent typical consumer costs to implement the various ECMs. Because only incremental costs were significant to the task at hand, the data do not necessarily reflect the total cost of the ECMs, but merely the costs that vary with ECM level. For example, foundation data do not include site preparation costs, which are constant regardless of the insulation level installed.

Current ECM: Wall Insulation Housing Type: Single Family

Level	U-Value	First Cost	O&M $/yr	Percent Failures
R-11	0.0881	1.20	0.00	0.00
R-13	0.0749	1.26	0.00	0.00
R-19	0.0600	1.43	0.00	0.00
R-23	0.0484	1.50	0.00	0.00
R-26	0.0422	1.70	0.00	0.00

KEEP CHANGES AND EXIT MENU
IGNORE CHANGES AND EXIT MENU
ADD A LEVEL

Type in text, use Arrows or Tab to move, ? for help.

Figure 2.1. Sample ECM Cost Input Screen

Table 2.1. Default Regional Construction Cost Data Bases

Region	States in Region
National Average	All
New England	CT, MA, ME, NH, RI, VT
Mid-Atlantic	DC, DE, MD, NJ, NY, PA
Mid-South	GA, NC, SC, VA, WV
Florida	FL
South Central	AL, AR, KY, LA, MS, OK, TN, TX
Central	IA, KS, MO, NE
North Central	IL, IN, MI, MN, ND, OH, SD, WI
Mountain	CO, NV, UT, WY
Southwest	AZ, NM
Pacific Southwest	AK, CA, HI
Pacific Northwest	ID, MT, OR, WA

2.1.2 Costs for Heating, Ventilating, and Air Conditioning Equipment

Heating, ventilating, and air conditioning (HVAC) equipment costs are stored in the cost data files in a format similar to that of other ECMs. Costs and rated efficiencies may be modified by the user. However, HVAC equipment costs are used differently by ARES. While searching its list of ECMs for the optimal combination of levels, ARES accounts for the potential cost savings realized by using smaller (lower capacity) equipment in well-insulated buildings. In support of this, ARES contains a set of equations that relate HVAC equipment costs to capacity and efficiency ratings.

Regression analyses were performed on a collection of published list prices to obtain functional relationships between equipment costs and rated efficiency and capacity. The form of those equations is as follows:

Oil, LPG furnaces:

$$\$_{list} = 0.1176(AFUE)^2 + 0.0515(AFUE)(CAP) + 0.00563(CAP)^2 \quad (2.1)$$

where $\$_{list}$ = list price of furnace ($),
AFUE = rated Annual Fuel Utilization Efficiency (%), and
CAP = output capacity (kBtu/hr).

Gas furnaces:

$$\$_{list} = 0.001185(AFUE)^3 + 0.00637(CAP)(AFUE)^{1.5} + 0.00856(CAP)^2 \quad (2.2)$$

Electric furnaces:

$$\$_{list} = 373.82 + 2.834(CAP) + 0.00537(CAP)^2 \quad (2.3)$$

Heat Pumps:

$$\$_{list} = 13.48(SEER)^2 + 3.26(SEER)(CAP) + 0.197(CAP)^2 \quad (2.4)$$

where SEER = rated Seasonal Energy Efficiency Ratio (Btu/W*hr).

Air conditioners:

$$\$_{list} = 9.814(SEER)^2 + 2.715(SEER)(CAP) + 0.188(CAP)^2 \quad (2.5)$$

The list prices resulting from these equations were further adjusted by retail price multipliers based on the experience of a major equipment supplier. The retail price adjustments are as follows:

Oil, Gas, LPG furnaces:

$$RetailMultiplier = 0.625 + (0.357 * (AFUE/100 - 0.6)) \quad (2.6)$$

Electric furnaces:

$$\text{RetailMultiplier} = 1.0 \quad (2.7)$$

Heat pumps and air conditioners:

RetailMultiplier =

$$0.575 \quad (\text{for SEER} \leq 9) \quad (2.8a)$$

$$0.575 + (0.0875 * (\text{SEER} - 9)) \quad (\text{for } 9 < \text{SEER} < 11) \quad (2.8b)$$

$$0.75 \quad (\text{for SEER} \geq 11) \quad (2.8c)$$

These equations are not used directly, because users can enter specific prices for the HVAC equipment options. However, the user-entered prices are adjusted depending on the capacity required to meet design loads in the house under analysis. During the optimization, as ARES sequentially analyzes different levels of insulation, it performs design load calculations on a prototype building. The user-entered equipment prices are adjusted based on the difference between the design load and the user-entered reference capacity. The adjustment is obtained by differentiating equations 2.1 through 2.5 with respect to capacity:

Oil, LPG furnaces:

$$\Delta\$_{list} = (\text{DesignLoad} - \text{CAP}) * \text{RetailMultiplier} * [(0.0515 * \text{AFUE}) + (0.01126 * \text{CAP})] \quad (2.9)$$

where $\Delta\$_{list}$ = change in equipment cost from user-entered cost ($),
DesignLoad = design heating load calculated by ARES (kBtu/hr),
CAP = the reference capacity of the equipment, entered by the user to correspond to the equipment price (kBtu/hr), and
RetailMultiplier = the multiplier from equation 2.6 above.

Gas furnaces:

$$\Delta\$_{list} = (\text{DesignLoad} - \text{CAP}) * \text{RetailMultiplier} * [(0.00637 * \text{AFUE}^{(3/2)}) + (0.01712 * \text{CAP})] \quad (2.10)$$

Electric furnaces:

$$\Delta\$_{list} = (\text{DesignLoad} - \text{CAP}) * \text{RetailMultiplier} * [2.834 + (0.01074 * \text{CAP})] \quad (2.11)$$

Air conditioners:

$$\Delta\$_{list} = (DesignLoad - CAP) * RetailMultiplier * [(2.715 * SEER) + (0.376 * CAP)] \quad (2.12)$$

Heat pumps:

$$\Delta\$_{list} = (DesignLoad - CAP) * RetailMultiplier * [(3.26 * SEER) + (0.394 * CAP)] \quad (2.13)$$

2.2 RESIDENTIAL SPACE CONDITIONING ENERGY DATA

Energy calculations used to establish cost-effective ECM levels are based on a data base of simulated building performance. The energy analysis program DOE-2.1 was used to analyze the energy impacts of various levels of the important energy conservation measures available to new homebuilders. These data are stored in the file ENERGY.DA$. There are two primary sources of the data. Data for the two site-built prototypes were generated by Lawrence Berkeley Laboratory[a], while the manufactured housing data were generated by Steven Winter Associates[b]. The format of the stored energy data and the process by which the two sources were consolidated are described in this section.

2.2.1 Energy Data Format

The format of the energy data base is identical for heating and cooling. The total annual heating or cooling load of a building is given by the following:

$$Load = ResidualLoad + \sum_{i=1}^{n} ComponentLoad_i \quad (2.14)$$

where ResidualLoad = a base load not associated with any of the major ECMs parameterized in the data base (MBtu)

(a) Huang, Y. J., et al. 1987. Technical Documentation for a Residential Energy Use Data Base Developed in Support of ASHRAE Special Project 53 (to be published).

(b) No report was published.

$ComponentLoad_i$ = the load associated with ECM number i (MBtu)

n = the number of ECMs.

The residual and component load data (file ENERGY.DA$) are stored in one of three formats: 1) quadratic equations, 2) discrete component loads, and 3) window equations. The quadratic equations are used for the component loads of all "U-value" ECMs, or ECMs that primarily affect conductive heat losses or gains. These include insulation in ceilings, walls, crawlspaces, and floors over unconditioned spaces. Infiltration loads are also calculated from quadratic equations, though the independent variable is not U-value. The discrete component loads are used for ECMs that are not easily described by a simple U-value. These include slab and basement perimeter insulation and the residual loads. Finally, window equations are used for the conductive and solar effects of window glazing and sash materials. Each of these formats is described below.

Quadratic Equations:

The heating or cooling component load of an ECM is given by the following:

$$\begin{aligned} \text{Load} &= \text{Intercept} * \text{Area} * 10^{-3} \\ &+ \text{Slope} * \text{U-value} * \text{Area} * \left[\frac{24}{10^6}\right] \\ &+ \text{Quad} * \text{U-value}^2 * \text{Area}^2 * \left[\frac{576}{10^9}\right] \end{aligned} \qquad (2.15)$$

where Load = annual heating or cooling component load (MBtu),

Intercept = the location-specific intercept coefficient from the energy data base

Slope = the location-specific linear coefficient from the energy data base

Quad = the location-specific quadratic coefficient from the energy data base

U-value = conductance of the ECM assembly (Btu/hr*sf*F),

Area	=	the net component area (ft^2) (e.g., opaque wall area)
constants	=	conversion factors to bring units to MBtu.

Infiltration loads are calculated similarly, but the units are different and the intercept term is always zero:

$$Load = Slope * ELA * 10^{-3} + Quad * ELA^2 * 10^{-6} \quad (2.16)$$

where

Load	=	annual heating or cooling infiltration load (MBtu)
Slope	=	the location-specific linear coefficient from the energy data base
Quad	=	the location-specific quadratic coefficient from the energy data base
ELA	=	equivalent leakage area of house (ft^2)
constants	=	unit conversion factors.

The equivalent leakage area (ELA) is stored in the cost data files but is not accessible through the cost-editing functions of the program. It is stored in terms of an equivalent leakage fraction (ELF), which is the ELA normalized by floor area.

Discrete Component Loads:

The component loads are given by:

$$Load = LevelLoad * Area * 10^{-3} \quad (2.17)$$

where

Load	=	annual heating or cooling component load (MBtu)
LevelLoad	=	area-normalized, location-specific discrete component load for the particular level of the ECM (e.g., slab insulation of R-5, 2 foot depth) ($kBtu/ft^2$)
10^{-3}	=	unit conversion factor.

Window Equations:

Because windows affect energy performance in two ways, conductive loads and solar loads, a more complex equation is used. The component load is divided into a conductive part and a solar part. The conductive part is calculated as follows:

$$\text{ConductiveLoad} = \text{Uslope} * \text{U-value} * \text{Area} * \left[\frac{24}{10^6} \right] \quad (2.18)$$

where ConductiveLoad = annual heating or cooling conductive load through windows (MBtu)

Uslope = the location-specific linear coefficient from the energy data base

U-value = the overall U-value of the window, including the sash and average indoor and outdoor film resistances (Btu/hr*ft^2*F)

Area = total window area of building (ft^2)

constants = unit conversion factors.

The load due to solar gains is calculated in a two-step process. First, the total solar gain through the windows is calculated as follows:

$$\text{SolarGain} = 10^{-3} * \sum_{i=N,E,S,W} [\text{Area}_i * SC_i * \alpha_i] \quad (2.19)$$

where SolarGain = total seasonal solar heat gain to the building (MBtu)

N,S,E,W = north, south, east, and west orientations

Area_i = area of windows facing direction i (ft^2)

SC_i = shading coefficient of windows facing direction i

α = location-specific solar gain coefficient from energy data base

10^{-3} = unit conversion factor.

Because not all winter solar gains are useful toward offsetting heating loads, the total solar gain is adjusted by applying a utilizability factor. A similar factor applies in the summer, though the conceptual basis is somewhat different because no summer solar gains are actually "usable." The utilizability is assumed to be a linear function of the total solar gain. Thus the annual solar load is calculated as follows (the term in parentheses is the utilizability factor):

$$\text{SolarLoad} = \text{SolarGain} * (1 + \beta * \text{SolarGain}) \quad (2.20)$$

where SolarLoad = annual heating or cooling load due to solar gains (MBtu) (is negative for heating), and

β = location-specific utilizability coefficient from data base.

The net annual heating or cooling component load of the windows is simply the sum of the conductive and solar parts:

$$\text{Load} = \text{ConductiveLoad} + \text{SolarLoad} \qquad (2.21)$$

where Load = annual heating or cooling component load of windows (MBtu).

2.2.2 Conversion of Manufactured Housing Data to New Format

The manufactured housing data, generated by Steven Winter Associates, were originally stored in a different format. The DOE-2 simulations were run for specific prototypes (single- and double-wide) and the results tabulated for those prototypes only. For a given location, the annual heating or cooling load was given as the sum of a base load corresponding to a house with minimal energy conservation features and a series of load differences attributable to specific ECM levels:

$$\text{Load} = \text{BaseLoad} + \sum_{i=1}^{n} \text{DeltaLoad}_i \qquad (2.22)$$

where Load = the annual heating or cooling load of the prototype building (MBtu)

BaseLoad = the annual heating or cooling load of a baseline building configuration (MBtu)

DeltaLoad_i = the change in heating or cooling load due to a change in building assembly i (MBtu)

n = the number of building assemblies available for analysis in the data base (including ceiling, wall and foundation insulation, window glazings and sash types, and infiltration levels).

This format is known as the delta load format, because energy performance of a particular ECM is expressed in terms of a change (delta) in energy consumption relative to a baseline. The base load and delta loads were tabulated separately for heating and cooling for each of the 45 locations. A partial delta load table is shown as an example in Figure 2.2.

Location:		Albuquerque, NM					
Prototype:		Single-section manufactured (902 sqft)					
Base Load:		35.841 MBtu/yr (heating)					
		30.865 MBtu/yr (cooling)					
		CHANGE IN HEATING LOAD (MBtu/yr)					
Ceiling		Wall		Floor		Infiltration	
R-7	0.000	R-7	0.000	.	.	.	.
R11	-1.816	R11	-1.606	.	.	.	.
R14	-2.618	R13	-2.308	.	.	.	.
R19	-3.398	.	.	.	.	.	.
R22	-4.044	.	.	.	.	.	.
.	.	.	.	.	.	.	.

Figure 2.2. Sample Delta Load Table

Because the delta load format allows analysis of only the specific prototypes used in the DOE-2 analyses, the manufactured housing data base was recast into the component load format. This allows houses of arbitrary size and dimensions to be analyzed and makes the data consistent with the site-built format. This section describes the process by which the delta load data were generalized and placed in component load format.

2.2.2.1 Ceiling, Wall and Crawlspace Insulation

Linear regressions were performed on the delta loads as a function of U-values to obtain component load equations for the ceilings, walls, and floors. The model used for these regressions is as follows:

$$\Delta = \beta_2 * (\text{U-value})^2 + \beta_1 * (\text{U-value}) + \beta_0 \quad (2.23)$$

where Δ = the energy delta from the base case for a particular level of an ECM (MBtu)

β_i = parameters to be estimated in the regression

U-value = the U-value of the ECM assembly (Btu/hr*ft^2*F).

The intercept, β_0, represents the delta load for a U-value of zero (i.e., infinite R-value). The U-value terms, β_1 and β_2, give the total load through the component relative to the "best case" condition of zero conductance. To convert this to the component load format, the intercept term can be subtracted from the regression equation and added (it will usually be negative) to the building base load. The resulting regression equation then gives the total load through the component as a function of U-value. The base load represents the load of a building with no heat loss or gain through the component. This is repeated for all insulation options. Because the resulting component loads are independent of the base load, they can be easily and accurately normalized by component area. The base load, which has become relatively small, can be normalized by floor area with very minimal error.

These processes were carried out for both single- and double-section mobile homes. However, the final data base used by the program contains data for a single manufactured housing prototype that represents both types. Wall and crawlspace energy coefficients were taken from the single-section data, while ceiling energy coefficients were taken from the double-section data. Because the site-built data base treats infiltration more rigorously than the manufactured housing data base, the site-built infiltration relationships were incorporated in the manufactured housing data.

2.2.2.2 Window Options

The window options in the original manufactured housing data base include one, two, and three glazing layers; three sash types; and either three or four discrete window areas, depending on the prototype and location. However, low-emissivity glass and other options not included in this list cannot be analyzed. The site-built window data base is functional in form, allowing analysis of virtually any window through knowledge of its U-value and shading coefficient. To take advantage of this generality, the site-built window data were used in the ARES manufactured housing data base. Sensitivity analyses indicated that the site-built window loads were not significantly affected by changing the volume and aspect ratio of the building, so transferring the data to the manufactured prototype resulted in little error.

The manufactured housing base loads, however, contain information about the specific windows used in the manufactured housing simulations. To correctly merge the new window data, these effects had to be removed from the base load. To do so, a quadratic curve was fit to the window deltas as a function of window area for each of nine window types (one, two, or three panes with metal, thermally improved metal, or wood sash). Assuming the regression equation can be extrapolated with little error, the intercept of each equation represents the delta load for a house with no windows. Confirming this assumption, the intercepts were virtually identical for all nine window types, indicating that subtraction of this intercept from the base load allows accurate prediction of building loads using the single family detached window data.

2.3 SUPPORTING DATA

In addition to the cost and energy data bases, ARES contains a number of ancillary data bases that support various calculations. These include:

- climate multipliers
- regional weather and other data
- overhang modifiers
- design load calculation information
- prototype building dimensions.

These are described in the sections that follow.

2.3.1 Climate Multipliers

Because the DOE-2 energy simulations were run for only 45 discrete locations, it is necessary to make minor adjustments to the data for locations that are near the base cities but differ slightly. Based on population, climate diversity, and data availability, 836 additional cities were selected for inclusion in the extended energy data base. Each city in the extended data base was assigned to one of the 45 reference cities for which DOE-2 results are available. The reference assignments were based on similarity of seasonal temperature and solar variations. The energy loads for a house in a city in the extended data base can be obtained by multiplying the loads for the reference city by the ratio of heating or cooling degree days between the two cities. The file CITIES.DA$ contains the list of cities, their reference city assignments, and the degree day ratios for both heating and cooling.

2.3.2 Regional Weather and Other Data

In the course of optimizing a building's ECM levels, ARES makes a number of location- or climate-specific adjustments. The data required to support these adjustments are included in a file named DESIGN.DA$. This file contains the following information for each of the 45 reference cities:

- design day temperatures - the ASHRAE 2½% summer dry bulb temperature, mean coincident wet bulb temperature and mean daily range, and the 99% winter dry bulb temperatures (used in calculating building design loads)
- average daily insolation - the average daily solar radiation incident on a south-facing surface tilted at the latitude angle plus 15 degrees (used in estimating energy consumption of solar assisted hot water systems)
- annual average ambient temperature - the average outdoor temperature over a typical year (used in estimating solar hot water system efficiency)
- annual average water main temperature - the average temperature of inlet water to the hot water system (used in calculating solar hot water system efficiency)
- heat pump and air conditioner efficiency adjusters - multipliers that adjust label ratings of SEER and HSPF to appropriate values for specific locations (used in calculating energy consumption of these systems in locations other than the base location used in developing the label ratings)
- prevalent foundation - an indicator of the type of foundation (crawlspace, basement, or slab) built most often in each city (used as the basis for optimizing a building in each location).[a]

2.3.3 Overhang Modifiers

The prototypes optimized by ARES were assumed to have overhangs 1.5 feet long and windows of 5.5 feet high. This constitutes an overhang ratio (ratio of overhang length to window height) of 0.273. To allow builders the option of claiming compliance credit for longer overhangs, ARES provides tables of overhang modifiers for use in the point system. The modifiers were developed

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(a) Not used for manufactured housing.

by simulating the daily and hourly solar positions in each of the 45 reference locations. Combined with information on typical annual sky conditions at each location, a set of ratios was developed for each of eight orientations. The ratios give the amount of solar gains experienced by a window with a given overhang ratio relative to the gains experienced by a window with the overhang ratio of 0.273.

These ratios, which are stored in the file OVERHANG.DA$, are applied directly (as multipliers) to window gain calculations in the point system. Because the file that contains these ratios is the only file used by ARES that is not in ASCII format (i.e., not readable with a text processor), tables of the multipliers are included in Appendix A.

2.3.4 Design Day Calculation Information

As each insulation level is analyzed in the optimization process, ARES performs a design load calculation to determine the required equipment capacity. The design loads are based on the ASHRAE residential methodology as described in the Cooling and Heating Load Calculation Manual (ASHRAE 1979). The cooling load factors (CLFs) and cooling load temperature differences (CLTDs) required by the technique are included in files called TABLE7-6.DA$ and TABLE7-8.DA$. The CLFs and CLTDs are taken from an update to the load manual (McQuiston 1984).

2.3.5 Prototype Building Dimensions

Although the ARES energy data base is formatted to allow analysis of buildings of arbitrary dimensions, the ARES program optimizes three specific prototypes, which are intended to represent typical construction practices. The user cannot modify these prototypes using the input screens. The building descriptions are contained in a text file on the ARES Data Disk. The file SIZE.DA$ contains descriptions of the three prototypes: 1) single family detached, 2) multifamily attached, and 3) manufactured housing. For each prototype, several dimensions are defined. They are labeled in the SIZE.DA$ file with the underlined names below:

- Slab - the length of the insulated slab perimeter (ft)
- Basement - the length of the insulated basement perimeter (ft)
- Crawlspace - the area of insulated crawlspace (ft^2)

- Infiltration - the normalization factor for infiltration calculations. Because infiltration is indexed on equivalent leakage fraction (ELF), which is defined as the equivalent leakage area divided by floor area, this factor is simply the floor area. It will differ from the crawlspace area in multistory buildings.
- Wall - the gross wall area (ft^2)
- Ceiling - the insulated ceiling area (ft^2)
- Window - the total window area (ft^2)
- DHW - three numbers that describe the domestic hot water temperature set point (°F), water heater volume (gal), and average daily use (gal), respectively
- Dist - three numbers that describe distribution efficiencies for central air systems, central hydronic systems, and distributed (baseboard, etc.) systems, respectively.

The slab and basement dimensions are ignored for manufactured houses.

3.0 LIFE-CYCLE COST FORMULAE

At each step in the optimization process, the ARES program calculates the life-cycle cost (LCC) of purchasing and operating a house for a specified period. It is assumed that the buyer purchases the house with a typical home mortgage, then sells the house at the end of the period of analysis.

The life-cycle cost may be calculated by one of two methods. The default method is based on a fixed period of analysis of seven years. The second method is an extended life-cycle cost method that allows a user-specified period of analysis. Basic assumptions about resale values and replacement costs differ between the two techniques and are addressed separately below. The two methods are referenced here as the "default 7-year LCC" or "default" method and the "extended LCC" method, respectively.

For both methods, the life-cycle cost is defined as follows:

$$\begin{aligned} \text{LifeCycleCost} = {} & \text{down payment} + \text{PV(mortgage)} - \text{PV(mortgage tax deductions)} \\ & + \text{loan fee} + \text{mortgage points} - \text{tax deductions on points} \\ & + \text{PV(fuel costs)} + \text{PV(operation \& maintenance costs)} \\ & + \text{PV(property taxes)} + \text{PV(capital replacements)} \\ & - \text{PV(resale)} + \text{PV(loan balance)} \end{aligned} \tag{3.1}$$

where down payment = the down payment made in purchasing the home ($)

PV(mortgage) = the present value of all mortgage payments ($)

PV(mortgage tax deductions) = the present value of all savings due to tax deductions on the mortgage interest ($)

loan fee = non-tax-deductible costs associated with obtaining a home mortgage - proportional to the loan amount ($)

mortgage points = up-front interest paid by the buyer to "buy down" the interest rate on the mortgage ($)

tax deductions on points = savings due to income tax deductions taken on mortgage points ($)

PV(fuel costs) = the present value of all heating and cooling fuel costs ($)

PV(operation & maintenance) = the present value of all non-fuel operating costs associated with the ECMs ($)

PV(property taxes) = the present value of all property taxes assessed on the value of the home ($)

PV(capital replacements) = the present value of all expenditures to replace ECMs that fail during the period of analysis ($)

PV(resale) = the present value of the proceeds of selling the house at the end of the period of analysis ($)

PV(loan balance) = the present value of the cost of paying off the loan balance upon sale of the house at the end of the period of analysis ($).

The equations used to calculate these quantities are presented in this section. Common to all these equations are the following parameter definitions:

p = period of analysis (years)
T = term of mortgage (years)
n = minimum of p and T (years)
i = annual mortgage interest rate (per unit)
d = nominal annual discount rate (per unit)
e = nominal annual fuel price escalation rate (per unit)
inf = general annual inflation rate (per unit)
T_i = marginal income tax rate (per unit)
T_p = property tax rate (per unit of house value)
DP% = percentage of house value that is downpayment
LF% = percentage of loan amount required as a non-deductible loan fee
MP% = percentage of loan amount paid in up-front interest charges.

The costs associated with the mortgage are calculated as follows:

$$\text{down payment} = \text{FirstCost} * \text{DP\%} \div 100 \qquad (3.2)$$

where FirstCost = the initial price of the house or ECMs ($)

$$PV(mortgage) = LoanPmt * \left[\frac{(1 + d)^n - 1}{d * (1 + d)^n} \right] \quad (3.3a)$$

$$\text{where } LoanPmt = LoanAmount * \left[\frac{i * (1 + i)^T}{(1 + i)^T - 1} \right] \quad (3.3b)$$

$$\text{and } LoanAmount = FirstCost - \text{down payment} \quad (3.3c)$$

$$PV(\text{mortgage tax deductions}) = \sum_{j=1}^{n} \left\{ T_i * i * LoanPmt * \left[\frac{(1 + i)^{(T-j+1)} - 1}{i * (1 + i)^{(T-j+1)}} \right] * \left[\frac{1}{(1 + d)^j} \right] \right\} \quad (3.4)$$

$$LoanFee = LoanAmount * LF\% \div 100 \quad (3.5)$$

$$\text{mortgage points} = LoanAmount * MP\% \div 100 \quad (3.6)$$

$$\text{tax deductions on points} = (\text{mortgage points}) * T_i \quad (3.7)$$

In calculating the present value of fuel costs, ARES allows only a single price escalation rate for each fuel type. Prices escalate at the same yearly rate throughout the period of analysis. Though the user interface restricts the escalation rates, the algorithms in ARES are more general, allowing fuel price escalation rates that vary from year to year. Thus the price of a fuel in any given year may be described by a fuel price index (FPI) that incorporates the price escalations over all prior years. The present value of heating fuel costs over the period of analysis is calculated as follows:

$$\text{PvFuel} = \text{AnnualHeatCost} * \sum_{j=1}^{p} \left[\frac{FPI_j}{(1 + d)^j} \right] \quad (3.8a)$$

where $FPI_j = \prod_{k=1}^{j} (1 + e_k)$ (3.8b)

e_k = nominal heating fuel price escalation rate in year k

AnnualHeatCost = initial cost of heating the house before any escalation in fuel prices ($).

Annual cooling costs are calculated similarly.

If there are any annual non-fuel operation and maintenance costs, ARES assumes that they will be constant in real terms over the entire period of analysis. Because the discount rate is a nominal alternative investment rate entered by the user, this implies that the current-dollar O&M costs will rise with inflation each year. The net present value of those costs is thus calculated as follows:

$$\text{PV(operation \& maintenance)} = \text{O\&M} * \left[\frac{(1 + inf)}{(d - inf)} \right] * \left\{ 1.0 - \left[\frac{(1 + inf)}{(1 + d)} \right]^p \right\} \quad (3.9)$$

The default method makes three fundamental assumptions that differ from the extended LCC method. First, the period of analysis is fixed at seven years. This is intended to approximate the median time a homebuyer will occupy a house before selling it. Second, the resale value of the home at the end of the seven years is assumed to be identical in **nominal** (current) dollars to the initial cost of the home. This implies that the real value of the home (and its conservation features) depreciates at the rate of general inflation. Finally, because of the brevity of the analysis period, no capital replacements are generally expected. However, to account for the probability of early failure of any of the ECMs, the user may enter a failure rate for each. The failure rate is expressed as a percentage and represents the fraction of all installations expected to fail within seven years. This fraction, multiplied by the inflated cost of replacing the ECM, gives a replacement cost that is assumed to be incurred in the seventh year.

One cost that is affected by the differences between the default method and the extended LCC method is property taxes. These taxes would normally rise with inflation from year to year (assuming property values are reassessed each year), but they do not under the default method, because the value of the house does not increase:

$$PV(\text{property taxes}) = FirstCost * (T_p \div 100) * (1 - IncomeTaxRate) * \left[\frac{(1 + d)^p - 1}{d * (1 + d)^p} \right] \quad (3.10a)$$

The extended LCC method accounts for inflation effects on both the house value and the property taxes:

$$PV(\text{property taxes}) = FirstCost * (T_p \div 100) * (1 - IncomeTaxRate) * \left[\frac{1 + inf}{d - inf} \right] * \left[1 - \left(\frac{1 + inf}{1 + d} \right)^p \right] \quad (3.10b)$$

For the default method, capital replacements are simply a fraction of the inflated replacement cost at year seven:

$$PV(\text{capital replacement}) = \sum_{j=1}^{N_{ECMs}} \left[\frac{FirstCost_j * (1 + inf)^p * FF_j}{(1 + d)^p} \right] \quad (3.11a)$$

where N_{ECMs} = the number of ECMs under evaluation
FF_j = expected fraction of installations of ECM_j that fail during the period of analysis.

The extended LCC method, because it must account for longer periods of analysis in which ECM replacements are likely, must deal with replacements explicitly. It is assumed that the cost of replacing any ECM is constant in real terms (constant dollars), implying that the replacement cost will vary from year to year with inflation:

$$\text{PV(capital replacements)} = \sum_{j=1}^{N_{ECMs}} \sum_{k=1}^{int(q/L_j)} \left[\frac{FirstCost_j * [1 + inf]^{(k * L_j)}}{[1 + d]^{(k * L_j)}} \right] \quad (3.11b)$$

where L_j = physical life of ECM j

$q = p + 1$

$int(q/L_j)$ = the number of times ECM j has to be replaced (given by the integer division of one more than the period of analysis and the physical life of ECM j).

Under the default method, the present value of the resale is simply the first cost discounted for seven years, because no inflation in value is assumed:

$$\text{PV(resale)} = \left[\frac{FirstCost}{(1 + d)^p} \right] \quad (3.12a)$$

The extended LCC method requires explicit consideration of resale value at the time of sale, which may be within a relatively short period, or may be at the end of the physical life of the home (i.e., zero resale value). Because some ECMs depreciate faster than others or may have been replaced immediately prior to sale, the general method considers each ECM separately. The resale value of any ECM is assumed to decline linearly with time, having full value at time zero and no value at the end of its physical life (i.e., straight-line depreciation):

$$\text{PV(resale)} = \sum_{j=1}^{N_{ECMs}} FirstCost_j * \left[\frac{(1 + inf)^p}{(1 + d)^p} \right] * \left[\frac{L_j - (p \bmod L_j)}{L_j} \right] \quad (3.12b)$$

where L_j = the physical life of the j'th ECM

mod = the modulus operator (gives remainder of dividing p by L_j)

The final step in calculating life-cycle cost is computing the cost of paying off the loan balance (if the house is sold prior to completion of the loan term). The balance *at the time of sale* is the present value of the future stream of mortgage payments discounted at the interest rate. This value is then discounted at the discount rate to obtain the true present value:

$$PV(\text{loan balance}) = \text{LoanAmount} * \left[\frac{1}{(1 + d)^p} \right] * \left[\frac{(1 + i)^{(T-n)} - 1}{i * (1 + i)^{(T-n)}} \right] \qquad (3.13)$$

4.0 OPTIMIZATION PROCEDURE

4.1 OVERVIEW OF SEARCH METHOD

To perform an economic optimization, ARES must seek the minimum of the life-cycle cost function described in Section 3. Because a number of smart optimization algorithms are available for this purpose, the project team had to select the one best suited to the application at hand. The smart algorithms generally utilize information about the character of the function and its derivatives to expedite finding the minimum or maximum. However, these algorithms have a number of disadvantages. Some algorithms require the derivatives to be provided in closed algebraic form, which is not always convenient or even possible. Many of these algorithms require an initial guess of the location of the minimum. Often a local minimum in the function's range will deceive the algorithm, making the initial guess extremely important. Finally, most of these algorithms operate on continuous functions.

Several considerations make these algorithms undesirable for the optimization in ARES. First, the life-cycle cost function, though expressed in closed mathematical form, is actually a discrete function because ECMs are available only for discrete levels. Similarly, derivatives of the function are difficult to formulate. Second, because users are able to modify ECM costs and characteristics, the presence of local minima is quite likely.

The alternative to a smart search algorithm is an exhaustive search of all possible combinations of ECMs. In this scenario, the life-cycle cost of every possible combination of ECMs is computed and the minimum easily identified. The disadvantage of this method is that it is very slow because of the number of function evaluations required:

$$N_{eval} = (N_{walls}) * (N_{ceilings}) * (N_{floors}) * (N_{windows}) * (N_{HVACs}) \quad (4.1)$$

However, the character of the energy data base in ARES allows use of a much faster variation of the exhaustive search. The energy data base is designed such that all envelope ECMs are independent of one another. For example, the heating load through the walls is independent of the insulation level of the ceiling or floor. This implies that the optimal insulation level for walls may be computed independently, without knowledge of ceiling characteristics. There are, however, interactions between envelope components and HVAC components. The optimal wall insulation level depends on the efficiency of the HVAC equipment, for example.

The peculiarities of the ARES energy data base allow use of an abbreviated search of the ECM combinations. Because ECMs are independent at a fixed level of HVAC efficiency, the algorithm must calculate the life-cycle cost a number of times equivalent to the sum of the numbers of available ECM levels rather than their product. These life-cycle cost calculations must then be repeated for each possible combination of HVAC efficiencies. Thus the number of function evaluations required to find the minimum is:

$$N_{eval} = (N_{HVACs}) * (N_{walls} + N_{ceilings} + N_{floors} + N_{windows}) \qquad (4.2)$$

In summary, ARES sequentially evaluates each discrete combination of equipment efficiencies. If, for example, there are four defined heating efficiency levels and three defined cooling efficiency levels, ARES will explicitly loop over 4 * 3 = 12 discrete combinations. For each efficiency combination, ARES then operates on each building component independently to find the optimal component level. The life-cycle costs of all optimized building components are summed to obtain the total building life-cycle cost for the efficiency combination. After evaluating every equipment combination, the one with the minimum overall life-cycle cost is selected as the basis for the standard. The annual energy cost of heating and cooling the prototype house becomes the criterion for compliance with the standard.

4.2 CONSTRAINTS ON OPTIMIZATION

The basic optimization procedure used in ARES is very simple, as explained in Section 4.1. However, two important constraints are applied at various points in the process. These constraints are designed to streamline implementation of the standard and facilitate consistency between the package and point system compliance options.

4.2.1 Foundation Consolidation

If the simple optimization is used exactly as stated, separate optimizations are required for each combination of house type, fuel/equipment type, and foundation type. Because of obvious differences in cost and thermal behavior, separate standards for each house type are acceptable. Similarly, often drastic differences in fuel prices and equipment costs justify separate requirements for each fuel/equipment combination. Foundations, however, cannot logically be separated and targeted for separate standards. Often a house may contain two or more foundation types, as in a split-level house with both a "basement" as the lower level and a crawl space underneath the middle level. If the wall insulation requirements are different for the basement and crawl space houses, the standard is ambiguous. This scenario is entirely possible if the optimization is not constrained.

ARES forces the upper envelope and equipment requirements to be identical between foundation types. This is done by first optimizing the prototype building with a single foundation, then using the resulting optimal equipment efficiencies to separately optimize the insulation level of each additional foundation type. Because there are no interactions between foundation insulation levels and other envelope options, the foundations can be optimized knowing only the equipment efficiencies. The foundation type selected for the initial optimization is the one assumed to be prevalent in a given location. A list of prevalent foundation types corresponding to the 45 base climate cities is contained in the file DESIGN.DA$.

4.2.2 Window Area Adjustment

The ARES optimization is applied to prototypes that have window area (equivalent to 12% of the floor area) equally distributed on the four sides of the house facing the four cardinal directions. This window configuration, which is not typical of individual houses, is intended to capture average orientation effects across large numbers of residences. Thus the energy cost target of the standard is based on the optimal building configuration of an average house.

Real houses that are candidates for compliance with this standard must have annual energy costs no greater than the optimum-based target. If a builder uses explicit calculation techniques to demonstrate compliance (i.e., the "performance path"), there is no problem. However, because most builders will prefer simpler compliance alternatives, ARES generates prescriptive packages of options that result in acceptable energy costs. The simplest such package would be identical to the life-cycle cost optimal building configuration. A problem arises, however, in that few buildings will have equally distributed window area. A house built with a disproportionately large window area on the north wall, for example, would not perform as efficiently as the equally-distributed prototype. In this situation, using the optimal building configuration as the prescriptive package would result in compliance of houses that did not meet the energy cost target. Also, because the point system computes building costs directly, a house that complied through the prescriptive package might not comply through the point system.

To alleviate this problem, ARES produces basic prescriptive packages that differ from the optimal configurations. The intent is to create prescriptive requirements that meet the energy cost target regardless of window orientation. Doing so requires identification of the window placement scenario that results in the highest window-related energy costs. Using that scenario, ARES then performs a constrained optimization that identifies the least-first-cost combination of ECMs that meets the energy cost target. This process is described in detail in Section 5.1. However, because of the infinite variability in possible window placements, identification of the worst case is not trivial. ARES uses the assumption that windows equally distributed between the east and west walls represents the worst scenario in most locations and uses this constraint to define the basic prescriptive packages.

5.0 OUTPUT

The output available from ARES consists of compliance materials in the form of prescriptive packages and a flexible point system. The packages, consisting of prescriptive requirements for each component of a house, are designed for ease of use by builders. For builders who prefer more design flexibility, ARES provides a point system capable of evaluating the energy cost consequences of deviating from the prescriptive packages. This allows a builder to make trade-offs between building components or to take advantage of advanced conservation techniques, such as strategic window placement for solar benefits. This section describes how the packages are developed and how the points are calculated.

5.1 PRESCRIPTIVE PACKAGES

With every execution of the ARES program, a prescriptive package is generated for each fuel/equipment combination selected by the user. These packages are referred to as the basic packages. Without user intervention, these are the only prescriptive options produced by the program. However, if the user wishes to tailor the standard to meet local demands or provide additional options for builders, ARES provides the capability to interactively generate alternative packages that result in energy costs no greater than those of the basic packages. Each type of prescriptive package is defined in this section.

5.1.1 Basic Packages

The basic prescriptive packages are designed to represent the combination of ECM levels that most nearly achieves the minimum possible life-cycle cost for the prototype houses. The basic packages differ from the true life-cycle cost optimum as discussed in Section 4.2. The true optimum is based on a house with window area equally distributed on the four sides of the house. The basic packages result in no more energy cost than the optimal configurations but have windows equally distributed between the east and west faces of the house. It is assumed that this is the worst possible configuration, so any real house will perform at least as well. The basic packages are actually identified using the alternative package generator described in the following section.

Figure 5.1 is a sample basic prescriptive package produced by ARES. Notice that the package contains minimum requirements for ceiling and wall insulation, floor insulation for any of four foundation types, window characteristics, and heating and cooling efficiencies. These are the building components optimized by ARES. In addition, there are several components that were not involved in the optimization step. The maximum allowable window area equal to 12% of floor area is a fixed value not varied by ARES during the optimization. Notice that there is no minimum requirement for south-facing window area. The infiltration requirement of "NORMAL" is also fixed in ARES. The normal level corresponds to a specific set of infiltration measures that must be applied to all houses. A "TIGHT" infiltration option is available in the alternative package generator. Two other options for which no requirements are listed in the example are mass walls and solar domestic hot water (DHW) systems. These options are available only through the alternative package generator described in Section 5.1.2. The mass wall is available as an option to replace the frame wall. Solar-assisted domestic hot water systems may be used as a trade-off against lower insulation or efficiency levels in other house components.

Jurisdiction: District of Columbia — Bldg Type: Single Family Detached
Package Name: New Package — Equipment: Gas Furnace

	Basic Package	Alternative Package	Specifications
Ceiling:	R-30		
Frame Wall:	R-23		
Mass Wall:			
Crawlspace:	R-30		
Unheated Bsmnt:	R-11		
Heated Bsmnt:	R-5_4ft		
Slab Insul:	R-5_2ft		
Window Type:	Double_w/o_TB		
Window Area:	12% Max_Total 0% Min South		
Infiltration:	Normal		
Heating Eff:	AFUE_85%		
Cooling Eff:	SEER_10		
Solar DHW:			

GENERATE PACKAGE SAVE PACKAGE EXIT

Press <Return> to select, use Arrows or Tab to move, ? for help.

Figure 5.1. Sample Basic Package Produced by ARES.

5.1.2 Alternative Packages

ARES provides the capability to generate alternative packages that are equivalent in energy costs to the basic packages. This feature allows the user to constrain any of the options listed in Figure 5.1 while ARES seeks the least-cost package of options that results in no more energy cost than the target identified in the original optimization. For example, a user confronted with the basic package in Figure 5.1 might decide that R-23 walls are unlikely to be accepted by builders in the area. He or she could specify that the wall requirement be R-19. ARES would then adjust the unconstrained components to make up for the additional energy consumption resulting from the lower wall R-value. This example is illustrated in Figure 5.2.

Jurisdiction: District of Columbia Bldg Type: Single Family Detached
Package Name: New Package Equipment: Gas Furnace

	Basic Package	Alternative Package	Specifications
Ceiling:	R-30	R-30	
Frame Wall:	R-23	R-19	R-19
Mass Wall:			
Crawlspace:	R-30	R-30	
Unheated Bsmnt:	R-11	R-11	
Heated Bsmnt:	R-5_4ft	R-5_4ft	
Slab Insul:	R-5_2ft	R-5_2ft	
Window Type:	Double_w/o_TB	Double_Low-E	
Window Area:	12% Max Total 0% Min South	12% Max Total 0% Min South	
Infiltration:	Normal	Normal	
Heating Eff:	AFUE_85%	AFUE_78%	
Cooling Eff:	SEER_10	SEER_10	
Solar DHW:			

GENERATE PACKAGE SAVE PACKAGE EXIT

Press <Return> to perform, use Arrows or Tab to move, ? for help.

Figure 5.2. Sample Alternative Package from ARES.

To maintain energy cost equivalency with the basic package, ARES changed the window requirements. Low-emissivity (low-E) glazing is now required to make up for the additional energy consumption of the R-19 walls. However, the low-E glazing saves more energy than was lost by reducing the wall insulation, so the heating efficiency was adjusted downward. After viewing the alternative package, the user may either accept it or add additional constraints and try again. Windows, for example, might be constrained to not require low-E glass. The user may constrain as many components as desired, allowing ARES to adjust the remaining components to maintain energy cost equivalence.

5.1.2.1 Constrained Optimization Algorithm

ARES generates a standard with a specific energy cost target as the primary criterion for compliance. Having identified that target through the life-cycle cost optimization discussed in Section 4.0, it is often necessary to identify different packages of options that result in the same or lower energy cost. The basic prescriptive packages, which are constrained such that windows only face east and west, are based on this process, as are any alternative packages specified by the user. This capability is called the alternative package generator. This section describes the algorithms used in the package generator.

Following the life-cycle cost optimization, the only criterion needed by the alternative package generator is the annual energy cost target. All information regarding which ECM levels were included in the optimal packages is disregarded. The generator works from the same data base of ECMs as the original optimization but allows constraints to be specified (e.g., the wall insulation level must be R-19, etc.). It then performs a second optimization, using initial cost rather than life-cycle cost as the objective function and constraining the optimization such that no package of options is accepted if it results in an annual energy cost that exceeds the target.

Although alternative package optimization is conceptually simple, accommodating the requirement that all component requirements are the same regardless of foundation type presents a complication (see Section 4.2.1). In reality, the original optimization produces four separate energy cost targets, one for each foundation type. The alternative package generator must identify a combination of options that meets the energy cost targets of all four foundation types. Simultaneously, it seeks to minimize initial costs. The process can be described as a series of five steps:

Step 1: Obtain (from the original optimization) the four energy cost targets corresponding to the four foundation types.

Step 2: "Design" four prototypes that have 1) all constrained ECMs (those specified by the user), and 2) the minimum possible initial cost based on the ECMs available in the cost data base.

Step 3: Create a list of all unconstrained ECMs that reduce energy consumption relative to the ECMs in the four prototypes. This list will contain, for example, several levels of ceiling insulation, several levels of wall insulation, etc. Sort the list based on initial cost of the options.

Step 4: Move through the sorted list and sequentially "adopt" ECMs and apply them to the four houses. Start with the least-cost option. If adopting an option causes other items in the list to become energy "losers" rather than savers, delete them from the list. After each option is adopted, update the list to account for changes in relative energy savings and costs. Continue until all four houses meet their respective energy cost targets.

Step 5: Compute the difference between each house's annual energy cost and its corresponding target energy cost. Examine the ECMs on the houses to search for items that can be removed from the house to decrease first costs without violating the energy cost budget. This is possible if the procedure adopts a low first-cost option that saves very little energy prior to higher-cost option that saves much more energy. It may be possible to eliminate the original option to minimize initial costs. This process of eliminating options begins with envelope and equipment options that are common to all foundation types. This is because each of these options benefits all four houses, whereas a foundation option benefits only the one foundation type. Higher-cost options are discarded before lower-cost options if more than one discard is possible. After no more common ECMs can be discarded, each individual foundation option is examined for possible discards.

After these steps have been completed, the four houses will be identical except for their foundations. They will represent the houses with the least possible first cost that 1) contain the constrained ECM levels specified by the user, 2) have all equipment and envelope options identical between foundation types, and 3) meet the energy cost budgets for all four foundation types.

5.1.2.2 Special Treatment of Optional ECMs

The primary ECMs involved in the economic optimization are ceiling, wall and floor insulation, equipment efficiency, and window characteristics. However, several additional ECMs that are not involved in the optimization process are available as options in the alternative packages (and points). These include thermally massive walls (e.g., concrete, brick, or log), tight infiltration control measures, strategic orientation of glazing, and solar-assisted domestic hot water systems. Each of these is described below.

Mass Walls. The economic optimization in ARES assumes each house has typical frame construction. The energy cost target is thus based on the optimal insulation levels of a frame wall house. However, thermally massive envelope components are used in many locations and applications and are often more thermally efficient than frame components of similar conductance. To allow builders to build complying houses with concrete, brick, or log walls, ARES provides these constructions as options in both the packages and the point system. In generating a "mass wall" alternative package, ARES simply constrains the prototype house to have the specific wall type specified by the user and minimizes the first cost of the remainder of the house while maintaining the original frame wall-based energy cost target. Energy data for the massive walls are contained in the energy data base in a format identical to that of the frame walls (see Section 2.2).

Infiltration. The economic optimization in ARES assumes that a "normal" set of infiltration control measures is applied to the house. Because the costs and efficiencies of specific control measures are uncertain, ARES makes no attempt to optimize the infiltration component. However, to allow builders the opportunity to credit tighter infiltration controls against looser requirements elsewhere in the building, this option is available in both the points and packages. In generating an alternative package with a tight infiltration control option, ARES simply adjusts the energy cost target by an amount equivalent to the change in annual energy costs due to the tighter control measures. The remainder of the house is then first-cost optimized as usual.

Only one set of tight infiltration control measures is included in the ARES data base. Its description, along with a description of the normal set of measures is in Position Paper #4-10.

Glazing Orientation. The original economic optimization in ARES assumes glazing area is equal to 12% of the floor area and is equally distributed among walls facing the four cardinal directions. No attempt is made to optimize window area or orientation. The basic prescriptive packages specify a maximum allowable window area of 12% of floor area and have no restrictions on window placement. To facilitate the development of alternative packages based on window area manipulations, ARES provides for adjustments to the assumed window configuration. The user may elect to either increase or decrease the minimum allowable window area, and/or may specify that a fraction of the glazing must be oriented on the south face of the house. To generate the alternative package for such a scenario, ARES simply adjusts the energy cost target by an amount equivalent to the change in energy cost resulting from the different window placement assumptions, then first-cost optimizes the remainder of the house.

Solar Hot Water. Because the Voluntary Residential Energy Standard contains minimum requirements for domestic water heaters, ARES has provisions for using solar-assisted domestic hot water (DHW) options in user-generated alternative packages (and the point system). Savings effected by these systems may be credited by builders against lower efficiency requirements for the house envelope and HVAC system.

The ARES program allows specification of six different solar hot water systems in the alternate packages and point systems. These correspond to three generic system types (active, passive integral, and passive thermosyphon) with either one or two collector panels. As described in Position Paper #8-5, the parameters of these six systems were chosen from a survey of those available as representative of conservative (but not minimum) performance. The calculation of energy savings due to each of these systems is described in the following sections. The background, justification, and detailed derivation of these algorithms are given in the position paper.

Active Systems. The solar savings fraction (SSF) for an active solar system is calculated as follows:

The monthly hot water load is calculated as:

$$Q_L = 8.33 * W_d * (T_w - T_m) * N \tag{5.1}$$

where Q_L = monthly hot water load (Btu)

8.33 = volumetric heat capacity of water (Btu/gal*F)

W_d = expected daily hot water use (gal/day), assumed to be 64.3 gal/day

T_w = outlet water temperature (°F), assumed to be 140 °F

T_m = annual average water mains temperature (F), taken from file CITIES.DA$

N = number of days in a month, assumed to be 30.

The ratio of a reference collector's total energy loss to the total water heating load during a month is then calculated:

$$X = (F_r{*}U_L) * (F'_r/F_r) * (T_{ref} - T_a) * (D_t/Q_L) * A \tag{5.2}$$

where X = the ratio of a reference collector's total energy loss to the total water heating load during the period D_t

A = the net collector area (ft^2), taken from cost data files

F_r = collector heat removal factor (see note below)

U_L = collector heat loss coefficient ($Btu/hr{*}ft^2{*}F$)

F'_r/F_r = correction factor for the collector-storage heat exchanger

T_{ref} = reference temperature (F), assumed to be 212 °F

T_a = average annual ambient temperature (F), taken from file CITIES.DA$

D_t = number of hours in a month (hr), assumed to be 720 hr.

Note: All collector test parameters (e.g., F_rU_L, F'_r/F_r, etc.) are stored in the cost data files, SINGLE.DA$, MULTI.DA$, and MANUF.DA$. However, to avoid problems associated with unreasonably efficient parameters being entered by the user, the ARES program option "EDIT ECONOMIC DATA" is unable to access or modify the numerical values. This prevents unreasonable trade-offs of solar options against insulation and HVAC efficiency.

This value is corrected according to the f-chart procedure for liquid-based systems for service water heating only (no space conditioning):

$$X_C = X * \frac{(-66.16 + 1.18*T_w + 3.86*T_m - 2.32T_a)}{(T_{ref} - T_a)} \qquad (5.3)$$

where X_C = corrected value of X.

The ratio of absorbed solar energy to the heating load is calculated using the test parameters as follows:

$$Y = (F_r\tau\alpha_n) * (F'_r/F_r) * (\tau\alpha/\tau\alpha_n) * N * A * (H_t/Q_L) \qquad (5.4)$$

where
- Y = ratio of total absorbed solar energy to total heating load
- H_t = annual average daily insolation on a south-facing plane tilted above the horizontal at an angle equal to the collector tilt angle, assumed to be equal to the latitude plus 15° (Btu), taken from file CITIES.DA$
- $\tau\alpha$ = transmittance-absorptance product of the solar collector, taken from cost data files
- $\tau\alpha_n$ = transmittance-absorptance product of the solar collector at normal solar incidence, taken from cost data files
- $F_r\tau\alpha_n$ = collector parameter
- F'_r/F_r = collector parameter.

The f-factor is calculated as follows:

$$f = 1.029*Y - 0.065*X_C - 0.245*Y^2 + 0.0018*X_C^2 + 0.025*Y^3 \qquad (5.5)$$

for $(0 < Y < 3)$ and $(0 < X_C < 18)$

If either X_C or Y is outside its valid range, it is set equal to the nearest limit before the f-factor is calculated.

The total annual solar energy collected is calculated:

$$Q_S = f * Q_L * 12 \qquad (5.6)$$

where 12 = number of months in a year.

The annual energy required by the backup system alone to meet the hot water load is given by the following:

$$Q_a = \frac{(Q_L * 12)}{EF} \tag{5.7}$$

where Q_a = annual purchased energy required to meet the hot water load with the backup system acting without the solar system (Btu)

EF = the energy factor (coefficient of performance) for the backup water heater.

The solar savings fraction for the solar system can then be calculated as follows:

$$SSF = \frac{Q_s}{Q_a} \tag{5.8}$$

However, because the SSF is a function of the energy factor (EF) of the backup system, which is unknown until the user of the standard enters a proposed value, the SSF is not useful in the point system. Points for the solar hot water system are calculated as follows:

$$Points = FuelPrice * (Q_a - Q_s) \tag{5.9}$$

On the point system compliance form, the energy factor becomes a variable, entered by the user:

$$Points = \frac{Factor1}{[\_\_\_\_]} - Factor2 \tag{5.10}$$

where Factor1 = FuelPrice * Q_L * 12

Factor2 = FuelPrice * Q_s

[____] = energy factor of backup unit (entered by user).

It has been shown (see Position Paper #8-5), that calculated SSFs of greater than about 0.6 are often difficult to achieve in practice. Thus any calculated SSF greater than 0.6 is adjusted as follows:

$$CSSF = SSF - \left[\frac{(SSF - 0.6)}{3}\right] \tag{5.11}$$

where CSSF = corrected solar savings fraction.

Expanding the SSF term according to its definition in equation (8), equation (11) becomes

$$CSSF = \left[\frac{Q_S * EF}{Q_L * 12}\right] - \left\{\left[\frac{Q_S * EF}{Q_L * 12} - 0.6\right] \div 3\right\} \quad (5.12a)$$

$$= \left[\frac{Q_S * EF}{Q_L * 12}\right] - \left[\frac{Q_S * EF}{Q_L * 36}\right] + \left[\frac{0.6}{3}\right] \quad (5.12b)$$

If the CSSF is defined to result from a "corrected" total collected solar value,

$$CSSF = \frac{Q_{S,corr}}{Q_a}, \quad (5.13)$$

then equation (12b) can be further manipulated and solved for the effective (corrected) annual collected solar energy:

$$Q_{s,corr} = \left[\frac{2 * Q_S}{3}\right] + \left[\frac{0.6 * Q_L * 12}{3 * EF}\right] \quad (5.14)$$

This corrected solar value can then be tabulated by EF, and substituted for the original Q_S in equations (9) and (10). This correction is only necessary when the SSF would exceed 0.6, which implies the following:

$$EF > \left[\frac{0.6 * Q_L * 12}{Q_S}\right]$$

Passive Systems. The solar savings fraction (SSF) for a passive solar system is calculated as follows:

$$w = \frac{W_d}{N} \tag{5.15}$$

where w = daily hot water use per solar unit (gal/unit)

W_d = expected daily hot water requirements (gal/day), assumed to be 64.3 gal/day

N = number of solar units to be installed, taken from the cost data files.

The water usage is adjusted to match conditions of the standard solar collector tests:

$$W_t = w * N_t \tag{5.16}$$

where W_t = daily hot water use during the solar collector test (gal/day)

N_t = number of units tested, taken from cost data files.

The daily thermal capacity requirements are calculated as:

$$D = W_t * C_p \tag{5.17}$$

where D = thermal mass (Btu/day*F)

C_p = volumetric heat capacity of water (8.33 Btu/gal*F)

A loss coefficient factor is then calculated:

$$LC = 18 * L \quad \text{(for integral systems)} \tag{5.18a}$$

$$LC = 16 * A \quad \text{(for thermosyphon systems)} \tag{5.18b}$$

where LC = collector loss coefficient factor

L = system overall heat loss coefficient (Btu/hr*F), taken from cost data files

A = net aperture of the system tested (ft^2), taken from cost data files.

The net daily energy provided by the solar system during the test (Q_{sav}) is then adjusted to account for differences in irradiation and draw between the test conditions and the local conditions:

$$Q_i = Q_{sav} * \left[\frac{H_t}{1500}\right] * \left\{1 - \left[\frac{LC * (833-D)}{833 * (D+LC)}\right]\right\} \tag{5.19}$$

where Q_i = insolation- and draw-adjusted net daily energy provided by solar system (Btu/day)

Q_{sav} = net daily energy provided by tested solar system (Btu/day), taken from cost data files

H_t = annual average daily insolation on a south-facing surface tilted above the horizontal at the tilt angle of the collector, assumed to be equal to the latitude plus 15° (Btu/ft^2*day), taken from file CITIES.DA$

constants = unit conversion factors.

The collected solar energy is then further adjusted to account for differences in ambient temperature between the test site and the local installation:

$$Q_t = Q_i + 24 * L * (T_a - T_m) \tag{5.20}$$

where Q_t = net daily energy provided by the solar unit, adjusted for insolation, draw, and ambient temperature (Btu/day)

24 = number of hours in a day

T_a = annual average ambient temperature (°F), taken from file CITIES.DA$

T_m = annual average water mains temperature (°F), taken from file CITIES.DA$.

Q_t is then adjusted to account for the number of units being installed:

$$Q_c = Q_t * \frac{N}{N_t} \tag{5.21}$$

where Q_c = final adjusted daily solar energy provided by the system (Btu/day).

The annual solar energy collected by the system is then calculated:

$$Q_s = Q_c * 365 \tag{5.22}$$

where Q_s = annual solar energy collected by the system (Btu)

365 = number of days in a year.

The annual purchased energy required by the backup system alone to meet the hot water load is calculated as follows:

$$Qa = \frac{W_d * 8.33 * (T_w - T_m) * 365}{EF} \tag{5.23}$$

where Q_a = annual purchased energy required by the backup system alone to meet the hot water load (Btu)

8.33 = volumetric heat capacity of water (Btu/gal*F)

T_W = outlet water temperature (°F), assumed to be 140 °F.

A solar savings fraction can then be calculated, and the point system is generated in a manner exactly analogous to that of the active system.

5.2 POINT SYSTEM

The point system generated by ARES allows compliance of houses that deviate from the prescriptive packages. It ensures that proposed designs result in estimated annual energy costs less than or equal to the energy cost target. This section defines and explains the points calculated by ARES and details how points for various ECMs are computed. Frequent references are made to the point tables printed by ARES. A sample point system is included in Appendix A to facilitate use of these references.

5.2.1 Overview of Points

Because the point system is designed to ensure performance equivalency on an annual fuel cost basis, the units of the points are necessarily annual energy dollars. The point system is merely a procedure that guides a builder through the necessary calculations to estimate the annual fuel bills of a proposed house. Because ARES contains all necessary data bases to estimate heating and cooling loads and fuel costs, the user of the point system only needs to provide information on the sizes of various building components (e.g., wall area, window areas, etc.) and on the proposed levels of the ECMs (e.g., R-values of insulation, HVAC efficiencies, etc.). Points are therefore defined as follows:

$$HeatPts_i = (HeatLoad_i * HeatFuelPrice) \div HeatEff \qquad (5.24)$$

where $HeatPts_i$ = heating points due to building component i

$HeatLoad_i$ = annual heating load due to building component i

HeatFuelPrice = price of heating fuel in units corresponding to the HeatLoad

HeatEff = annualized efficiency or coefficient of performance of the installed heating equipment.

Cooling points are defined analogously. The sum of both heating and cooling points for all ECMs is the final point total used in demonstrating compliance. It represents the estimated annual cost of heating and cooling the house based on current fuel prices. The ARES point system leads a builder through these types of calculations for two houses: 1) a "target" house based on the basic prescriptive package, and 2) the "design" house that is a candidate for compliance. If the design points do not exceed the target points, the design house complies.

The simplest incarnation of a point system would be a printout of equations based on the energy data base relationships described in section 2.2. ARES could simply print the appropriate coefficients and leave blanks in which the user could write the appropriate areas and lengths of components and the U-values or other thermal descriptors corresponding to a building design. However, such a system would require that the user understand the meaning of U-values and the like and would require algebraic manipulations too burdensome for some builders. Therefore, to simplify the calculation of annual energy costs, the ARES point system precalculates many of the necessary values and places them in tables. For any particular building component, the user must simply look up a number in a table and multiply it by the total area or length of the component to calculate the points.

To further simplify the point calculations, various transformations are made to eliminate the need to carry fractional values through the calculations. Most generally, points will be multiplied by a constant power of 10 to achieve acceptable integer values in a table. The final point values that are used demonstrate compliance have units of cents.

Although the definition of points given in equation 5.1 applies to all ECMs, the manner in which points are calculated varies between ECMs. Also, to minimize the number of calculations required, the point system removes the fuel price and efficiency from each individual ECM point calculation and applies these factors after the component energy consumption estimates have been summed. In summary, the point system leads the builder to calculate the estimated annual heating and cooling load of each ECM, sum these, then multiply by appropriate fuel prices and efficiency adjusters based on the selected HVAC equipment.

5.2.2 Detailed Calculations for Each ECM

5.2.2.1 U-Value Dominant Options

The point tables for the ECMs whose energy impacts are dominated by conductance all have nearly identical formats. These ECMs include ceiling, wall, crawlspace, slab and basement insulation, as well as glazing layers and sash type and infiltration control options. Although they are not specifically U-value oriented, the base load points are also included in this category because of their similar calculation format. For each of the ECMs, two tables are printed. The first gives target multipliers, which, when multiplied by the appropriate component area (or length in the case of slabs and heated basements), give the ECM's contribution to the annual space conditioning loads of the target house (Tables 7.2, 7.4, 7.6, 7.8, and 7.10). The second table gives design multipliers, which also must be multiplied by the appropriate component area or length (Tables 7.3, 7.5, 7.7, 7.9, and 7.11). The design multipliers are tabulated by the discrete levels of each ECM. The target multipliers, however, are tabulated by fuel/equipment combination. The target multipliers are simply the multipliers from the design table corresponding to the optimized ECM levels for each fuel/equipment combination. One exception is the table of glazing layer and sash multipliers (Table 7.10). In this table, the multipliers corresponding to the optimal level are multiplied by 0.12 to account for the fact that the prescriptive packages limit glazing area to 12% of floor area.

Within each design table, options are sorted in order of descending energy consumption. The sorting may be based on either heating or cooling loads, depending on which are larger. For example, if the largest heating load is greater than the largest cooling load, the options are sorted by heating energy loads.

Occasionally, the smallest load in the list of options will be negative. This most often occurs for foundation or window (U-value portion only) cooling loads, where free cooling during cool summer nights negates daytime loads.

This is possible because neither of these ECMs is affected by solar gains. To prevent the negative numbers from appearing in a table, ARES sets the points for the most negative option to zero, and adjusts all other points in the table by the same amount. This retains the marginal effects between levels but eliminates the potentially confusing negative numbers.

However, the negative loads cannot be completely ignored. To obtain a proper assessment of annual energy costs for the whole house, these negative loads must be counted. To satisfy this requirement, any negative loads that were subtracted from the ECM point tables are added into the "base load" points. The base load points (Table 7.16 printed by ARES) represent the overall heating and cooling loads not specifically attributable to particular ECMs and are usually relatively small. The base load points are scaled by floor area, so any negative ECM points are multiplied by the ratio of the component size to the floor area before being added to the base points.

In summary, to develop the entries in any of the design tables, the following procedure is followed:

1) For the given ECM and level, compute the annual heating and cooling loads with the appropriate equations from Section 2, using a unit area or length.

2) Transform the scale of the entries by multiplying by 1000 and rounding to the nearest integer value. This gives the entries units of kBtu/sf (or kBtu/ft for perimeter insulation options).

3) Identify the largest load. If this occurs for heating, sort the entries (both heating and cooling) according to descending heating loads. If the largest load is a cooling load, sort the entries by descending cooling loads.

4) If any of the heating entries are negative, subtract the most negative entry from all other heating entries. Multiply the same negative load by the ratio of the current ECM's size to the floor area of the prototype used in the optimization and add the product into the base load heating points. Repeat for cooling.

5.2.2.2 Solar Space Conditioning Options

The conceptual basis for solar points is the same as for other envelope ECMs. That is, the points from the tables, when multiplied by the appropriate areas, give the annual heating and cooling solar loads for the house in units of $kBtu/ft^2$. As described in Section 2.2.1, window solar gains are calculated as a sum of loads from the four cardinal orientations. The gains are then adjusted by a utilizability factor to produce solar loads. Recall that, for a given orientation i, the solar gain through glazing is given by:

$$SolarGain = Area_i * SC_i * \alpha_i \qquad \text{(from 2.19)}$$

Because the optimized shading coefficient is known, and the α is available in the data base, ARES can precalculate the product of these two values. Since the optimized window area is fixed at 12% of floor area, target fenestration points can easily be tabulated as a function of floor area (Table 7.12), requiring no computations by the builder. Since the window area of the design home is variable, ARES tabulates, for each orientation and generic window type, the product of the shading coefficient and the α (the design point multipliers in Table 7.13). These need only be multiplied by the actual window area to compute points for comparison with the target points from Table 7.12.

Before adjusting the points for solar utilizability, the point system allows builders to accommodate the energy impacts of overhang shading. A set of overhang multipliers is provided to adjust the solar gains of the typical house used in the optimization to those that would be experienced by houses with different overhang lengths. The multipliers were calculated from knowledge of daily and hourly solar positions and typical annual atmospheric conditions at each of the reference cities. They are stored in the file named OVERHANG.DA$. The entries printed in the table (Table 7.14) are percentages, representing the fraction of the 1.5-foot overhang solar gains experienced by houses with different overhang lengths. They are tabulated by orientation and by ratio of overhang length to window height.

The user is required to multiply the design fenestration multipliers (Table 7.13) by the overhang multipliers (Table 7.14) and the actual window area for each orientation to obtain what is termed the fenestration factor.

The sum of all fenestration factors is the value that must be modified to account for solar utilizability. ARES provides the solar utilizabilities in Table 7.15. These are tabulated by fenestration factor and are adjusted to bring the units of the final fenestration points to $kBtu/ft^2$.

5.2.2.3 HVAC Equipment

The envelope points described in the previous two sections have units of $kBtu/ft^2$. To convert these to units of dollars, several adjustments must be applied. First, the loads must be divided by the effective annual coefficient of performance of the HVAC equipment. Second, they must be divided by the appropriate distribution system efficiency. Finally, they must be multiplied by the appropriate fuel prices to convert them to dollars.

ARES defines HVAC factors that may be multiplied by the envelope points to perform these conversions and produce overall energy dollars (points). For the target points, the local fuel prices that were entered in ARES are divided by the optimized HVAC seasonal coefficients of performance to produce these factors. (For heat pumps and air conditioners, the seasonal coefficients of performance are multiplied by climate adjusters to adjust the rated values to realistic performance indicators for the specific location.) They are further divided by the appropriate distribution efficiencies and tabulated by distribution type and fuel type (Table 7.17).

To compute the HVAC factors for the design house, the user must be allowed to enter the appropriate seasonal efficiency indicators for the proposed equipment. Thus, the HVAC equipment multipliers tabulated by ARES (Table 7.18) are identical to the target multipliers, but have not been divided by the rated seasonal coefficients of performance (COPs.) They have also been multiplied by appropriate unit conversion factors so that users may simply enter the rated efficiency indicator from the equipment label (HSPF for heat pump heating; SEER for air conditioners and heat pump cooling; AFUE for oil, gas, and electric resistance). The design HVAC factor is then the tabulated number divided by the rated efficiency indicator of the proposed equipment.

5.2.2.4 Domestic Hot Water Equipment

The envelope points described in Sections 5.2.2.1 and 5.2.2.2 are divided by the HVAC factors described in Section 5.2.2.3 to obtain the space conditioning points for both the target and design houses. These are actually annual energy costs in units of cents. The annual energy costs of DHW equipment are calculated separately and added to the space conditioning points to obtain the total points for the houses. This allows compliance trade-offs between envelope or HVAC efficiencies and DHW efficiencies.

If no solar options are included in the user's proposed house, the target DHW points are simply the estimated annual energy consumption of the base DHW system multiplied by the appropriate local fuel price. Annual energy consumption is calculated as follows:

$$\text{DHWconsumption} = 365 * W_d * 8.33 * (T_{set} - T_{enter}) \div EF \div 10^6 \qquad \text{(from 5.23)}$$

where

where	365	=	number of days in a year
	W_d	=	average daily water use (assumed to be 64.3 gal/day)
	8.33	=	volumetric heat capacity of water (Btu/gal*F)
	T_{set}	=	water temperature set point (assumed to be 140 °F)
	T_{enter}	=	average annual temperature of water entering the tank (F)
	EF	=	the minimum energy factor allowed by federal appliance standards
	10^6	=	unit conversion factor.

Target DHW points are computed by multiplying the estimated consumption by the appropriate fuel price. They are tabulated by fuel type in Table 7.19.

If no solar assistance is applied to the hot water tank, design DHW points are computed similarly, but the user must be allowed to enter the actual energy factor of the proposed tank. Thus the equation above, without the EF division, is used to generate the DHW factors tabulated in Table 7.20. The user must simply divide the appropriate tabulated number by the actual energy factor to obtain design DHW points.

If a user proposes to utilize a solar-assisted DHW system to demonstrate compliance, the target points of Table 7.19 are not applicable. For conventional systems the user may arbitrarily select a hot water heating fuel. Performance of the design system is compared to the performance of the target system of the same fuel type. However, most solar water heating systems rely on an electric DHW tank for backup heat. To avoid difficulties in determining what fuel **would have been** used for water heating had no solar options been employed, ARES fixes that assumption. The target points for any solar DHW system are based on the fuel used for **space heating**. The design points are based on **electric** backup for the solar water heater.

Solar design points are computed analogously to those for conventional DHW systems. Annual energy consumption of the solar system is calculated as described in Section 5.1.2.2. Design points are tabulated by type of solar system (active, passive integral, or passive thermosyphon) and by space heating fuel.

6.0 REFERENCES

American Society of Heating Refrigerating and Air Conditioning Engineers, Inc. 1979. Cooling and Heating Load Calculation Manual. GRP-158, Atlanta, Georgia.

McQuiston, F. C. 1984. "A Study and Review of Existing Data to Develop a Standard Methodology for Residential Heating and Cooling Load Calculations." ASHRAE Transactions, Vol. 90, Part 2. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, Georgia.

APPENDIX A

OVERHANG MODIFIERS

APPENDIX A

OVERHANG MODIFIERS

This appendix contains tables of modifiers used by the ARES program to adjust the energy impacts of windows to account for overhangs. The modifiers are tabulated by the ratio of horizontal overhang width to the distance from the overhang to the bottom of the windows. They were developed based on a house with windows 5.5 feet high and overhangs 1.5 feet wide, as indicated by unity multipliers for the ratio of 0.273 (1.5 ÷ 5.5). To calculate the solar load of a window with a different overhang ratio, the load for the base house (ratio of 0.273) is simply multiplied by the number obtained from the appropriate of these tables. Modifiers are shown for each of the 45 base cities used in development of the ARES energy data base.

Albuquerque

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.053	1.000	0.955	0.912	0.874
East	1.156	1.000	0.860	0.697	0.524
SouthEast	1.196	1.000	0.817	0.586	0.361
South	1.208	1.000	0.792	0.505	0.226
SouthWest	1.196	1.000	0.817	0.586	0.361
West	1.156	1.000	0.860	0.697	0.524
NorthWest	1.053	1.000	0.955	0.912	0.874
Cooling					
North	1.048	1.000	0.970	0.945	0.922
NorthEast	1.161	1.000	0.880	0.757	0.645
East	1.200	1.000	0.842	0.670	0.515
SouthEast	1.290	1.000	0.781	0.599	0.509
South	1.430	1.000	0.821	0.746	0.746
SouthWest	1.290	1.000	0.781	0.599	0.509
West	1.200	1.000	0.842	0.670	0.515
NorthWest	1.161	1.000	0.880	0.757	0.645

Atlanta

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.040	1.000	0.976	0.947	0.920
East	1.130	1.000	0.894	0.768	0.636
SouthEast	1.172	1.000	0.842	0.645	0.461
South	1.191	1.000	0.810	0.554	0.331
SouthWest	1.172	1.000	0.842	0.645	0.461
West	1.130	1.000	0.894	0.768	0.636
NorthWest	1.040	1.000	0.976	0.947	0.920
Cooling					
North	1.031	1.000	0.983	0.967	0.960
NorthEast	1.114	1.000	0.915	0.830	0.753
East	1.152	1.000	0.878	0.748	0.630
SouthEast	1.212	1.000	0.844	0.717	0.653
South	1.256	1.000	0.892	0.855	0.855
SouthWest	1.212	1.000	0.844	0.717	0.653
West	1.152	1.000	0.878	0.748	0.630
NorthWest	1.114	1.000	0.915	0.830	0.753

Birmingham, Al

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.039	1.000	0.975	0.943	0.925
East	1.128	1.000	0.896	0.769	0.637
SouthEast	1.172	1.000	0.844	0.646	0.464
South	1.190	1.000	0.809	0.555	0.336
SouthWest	1.172	1.000	0.844	0.646	0.464
West	1.128	1.000	0.896	0.769	0.637
NorthWest	1.039	1.000	0.975	0.943	0.925
Cooling					
North	1.029	1.000	0.981	0.966	0.954
NorthEast	1.116	1.000	0.913	0.827	0.749
East	1.154	1.000	0.876	0.747	0.627
SouthEast	1.213	1.000	0.844	0.716	0.649
South	1.258	1.000	0.890	0.852	0.852
SouthWest	1.213	1.000	0.844	0.716	0.649
West	1.154	1.000	0.876	0.747	0.627
NorthWest	1.116	1.000	0.913	0.827	0.749

Bismark

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.029	1.000	0.978	0.945	0.922
East	1.124	1.000	0.892	0.753	0.585
SouthEast	1.141	1.000	0.864	0.664	0.408
South	1.135	1.000	0.865	0.639	0.346
SouthWest	1.141	1.000	0.864	0.664	0.408
West	1.124	1.000	0.892	0.753	0.585
NorthWest	1.029	1.000	0.978	0.945	0.922
Cooling					
North	1.026	1.000	0.981	0.962	0.944
NorthEast	1.104	1.000	0.920	0.830	0.736
East	1.158	1.000	0.869	0.721	0.572
SouthEast	1.231	1.000	0.808	0.615	0.507
South	1.351	1.000	0.749	0.613	0.598
SouthWest	1.231	1.000	0.808	0.615	0.507
West	1.158	1.000	0.869	0.721	0.572
NorthWest	1.104	1.000	0.920	0.830	0.736

Boise

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.035	1.000	0.975	0.940	0.917
East	1.128	1.000	0.890	0.749	0.589
SouthEast	1.153	1.000	0.854	0.648	0.410
South	1.153	1.000	0.847	0.597	0.310
SouthWest	1.153	1.000	0.854	0.648	0.410
West	1.128	1.000	0.890	0.749	0.589
NorthWest	1.035	1.000	0.975	0.940	0.917
Cooling					
North	1.035	1.000	0.976	0.950	0.930
NorthEast	1.133	1.000	0.899	0.788	0.676
East	1.185	1.000	0.848	0.679	0.514
SouthEast	1.272	1.000	0.779	0.570	0.457
South	1.440	1.000	0.733	0.583	0.583
SouthWest	1.272	1.000	0.779	0.570	0.457
West	1.185	1.000	0.848	0.679	0.514
NorthWest	1.133	1.000	0.899	0.788	0.676

Brownsville, Tx.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.046	1.000	0.964	0.934	0.911
East	1.132	1.000	0.890	0.764	0.643
SouthEast	1.188	1.000	0.836	0.653	0.499
South	1.234	1.000	0.776	0.515	0.396
SouthWest	1.188	1.000	0.836	0.653	0.499
West	1.132	1.000	0.890	0.764	0.643
NorthWest	1.046	1.000	0.964	0.934	0.911
Cooling					
North	1.057	1.000	0.972	0.953	0.938
NorthEast	1.150	1.000	0.892	0.787	0.699
East	1.174	1.000	0.864	0.721	0.599
SouthEast	1.226	1.000	0.845	0.727	0.667
South	1.182	1.000	0.918	0.918	0.918
SouthWest	1.226	1.000	0.845	0.727	0.667
West	1.174	1.000	0.864	0.721	0.599
NorthWest	1.150	1.000	0.892	0.787	0.699

Boston

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.026	1.000	0.981	0.955	0.939
East	1.111	1.000	0.906	0.785	0.649
SouthEast	1.143	1.000	0.864	0.676	0.461
South	1.145	1.000	0.855	0.626	0.345
SouthWest	1.143	1.000	0.864	0.676	0.461
West	1.111	1.000	0.906	0.785	0.649
NorthWest	1.026	1.000	0.981	0.955	0.939
Cooling					
North	1.021	1.000	0.985	0.970	0.959
NorthEast	1.093	1.000	0.930	0.853	0.778
East	1.141	1.000	0.884	0.757	0.634
SouthEast	1.205	1.000	0.835	0.683	0.602
South	1.303	1.000	0.829	0.733	0.733
SouthWest	1.205	1.000	0.835	0.683	0.602
West	1.141	1.000	0.884	0.757	0.634
NorthWest	1.093	1.000	0.930	0.853	0.778

Buffalo

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.019	1.000	0.981	0.967	0.949
East	1.089	1.000	0.920	0.823	0.715
SouthEast	1.127	1.000	0.879	0.715	0.528
South	1.135	1.000	0.866	0.651	0.419
SouthWest	1.127	1.000	0.879	0.715	0.528
West	1.089	1.000	0.920	0.823	0.715
NorthWest	1.019	1.000	0.981	0.967	0.949
Cooling					
North	1.021	1.000	0.985	0.971	0.959
NorthEast	1.094	1.000	0.926	0.850	0.775
East	1.138	1.000	0.886	0.756	0.636
SouthEast	1.204	1.000	0.836	0.683	0.604
South	1.304	1.000	0.826	0.735	0.735
SouthWest	1.204	1.000	0.836	0.683	0.604
West	1.138	1.000	0.886	0.756	0.636
NorthWest	1.094	1.000	0.926	0.850	0.775

Burlington, Vt.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.026	1.000	0.985	0.960	0.944
East	1.098	1.000	0.911	0.803	0.677
SouthEast	1.132	1.000	0.873	0.695	0.487
South	1.137	1.000	0.864	0.636	0.389
SouthWest	1.132	1.000	0.873	0.695	0.487
West	1.098	1.000	0.911	0.803	0.677
NorthWest	1.026	1.000	0.985	0.960	0.944

Cooling

North	1.021	1.000	0.987	0.969	0.962
NorthEast	1.087	1.000	0.932	0.856	0.782
East	1.139	1.000	0.888	0.762	0.637
SouthEast	1.200	1.000	0.837	0.681	0.596
South	1.295	1.000	0.814	0.710	0.710
SouthWest	1.200	1.000	0.837	0.681	0.596
West	1.139	1.000	0.888	0.762	0.637
NorthWest	1.087	1.000	0.932	0.856	0.782

Cheyenne

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.043	1.000	0.971	0.932	0.902
East	1.137	1.000	0.873	0.722	0.548
SouthEast	1.166	1.000	0.842	0.621	0.375
South	1.164	1.000	0.836	0.581	0.255
SouthWest	1.166	1.000	0.842	0.621	0.375
West	1.137	1.000	0.873	0.722	0.548
NorthWest	1.043	1.000	0.971	0.932	0.902

Cooling

North	1.034	1.000	0.983	0.958	0.948
NorthEast	1.122	1.000	0.906	0.804	0.712
East	1.172	1.000	0.862	0.709	0.562
SouthEast	1.248	1.000	0.803	0.622	0.526
South	1.387	1.000	0.789	0.674	0.674
SouthWest	1.248	1.000	0.803	0.622	0.526
West	1.172	1.000	0.862	0.709	0.562
NorthWest	1.122	1.000	0.906	0.804	0.712

Charleston, SC

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.037	1.000	0.969	0.943	0.913
East	1.128	1.000	0.889	0.762	0.629
SouthEast	1.175	1.000	0.840	0.644	0.461
South	1.195	1.000	0.804	0.546	0.328
SouthWest	1.175	1.000	0.840	0.644	0.461
West	1.128	1.000	0.889	0.762	0.629
NorthWest	1.037	1.000	0.969	0.943	0.913

Cooling

North	1.031	1.000	0.982	0.967	0.960
NorthEast	1.114	1.000	0.917	0.834	0.759
East	1.148	1.000	0.882	0.752	0.640
SouthEast	1.205	1.000	0.848	0.726	0.666
South	1.236	1.000	0.899	0.868	0.868
SouthWest	1.205	1.000	0.848	0.726	0.666
West	1.148	1.000	0.882	0.752	0.640
NorthWest	1.114	1.000	0.917	0.834	0.759

Chicago

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.031	1.000	0.979	0.951	0.933
East	1.114	1.000	0.899	0.775	0.635
SouthEast	1.148	1.000	0.860	0.666	0.450
South	1.152	1.000	0.848	0.612	0.330
SouthWest	1.148	1.000	0.860	0.666	0.450
West	1.114	1.000	0.899	0.775	0.635
NorthWest	1.031	1.000	0.979	0.951	0.933

Cooling

North	1.030	1.000	0.982	0.955	0.931
NorthEast	1.104	1.000	0.920	0.832	0.740
East	1.154	1.000	0.876	0.737	0.598
SouthEast	1.221	1.000	0.822	0.661	0.575
South	1.336	1.000	0.816	0.722	0.722
SouthWest	1.221	1.000	0.822	0.661	0.575
West	1.154	1.000	0.876	0.737	0.598
NorthWest	1.104	1.000	0.920	0.832	0.740

Cincinnati

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.025	1.000	0.981	0.958	0.940
East	1.110	1.000	0.910	0.794	0.667
SouthEast	1.148	1.000	0.862	0.678	0.483
South	1.156	1.000	0.844	0.615	0.354
SouthWest	1.148	1.000	0.862	0.678	0.483
West	1.110	1.000	0.910	0.794	0.667
NorthWest	1.025	1.000	0.981	0.958	0.940
Cooling					
North	1.022	1.000	0.983	0.971	0.959
NorthEast	1.100	1.000	0.925	0.847	0.771
East	1.144	1.000	0.882	0.754	0.635
SouthEast	1.207	1.000	0.837	0.695	0.622
South	1.303	1.000	0.857	0.786	0.786
SouthWest	1.207	1.000	0.837	0.695	0.622
West	1.144	1.000	0.882	0.754	0.635
NorthWest	1.100	1.000	0.925	0.847	0.771

El Paso, Tx.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.063	1.000	0.949	0.902	0.866
East	1.164	1.000	0.857	0.690	0.520
SouthEast	1.211	1.000	0.809	0.575	0.365
South	1.235	1.000	0.765	0.466	0.236
SouthWest	1.211	1.000	0.809	0.575	0.365
West	1.164	1.000	0.857	0.690	0.520
NorthWest	1.063	1.000	0.949	0.902	0.866
Cooling					
North	1.054	1.000	0.965	0.942	0.916
NorthEast	1.170	1.000	0.876	0.751	0.638
East	1.203	1.000	0.840	0.671	0.519
SouthEast	1.290	1.000	0.792	0.623	0.539
South	1.360	1.000	0.841	0.803	0.803
SouthWest	1.290	1.000	0.792	0.623	0.539
West	1.203	1.000	0.840	0.671	0.519
NorthWest	1.170	1.000	0.876	0.751	0.638

Denver

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.047	1.000	0.968	0.927	0.895
East	1.143	1.000	0.870	0.714	0.539
SouthEast	1.173	1.000	0.835	0.611	0.369
South	1.174	1.000	0.826	0.564	0.240
SouthWest	1.173	1.000	0.835	0.611	0.369
West	1.143	1.000	0.870	0.714	0.539
NorthWest	1.047	1.000	0.968	0.927	0.895
Cooling					
North	1.036	1.000	0.981	0.956	0.944
NorthEast	1.130	1.000	0.901	0.793	0.698
East	1.179	1.000	0.857	0.701	0.551
SouthEast	1.257	1.000	0.797	0.617	0.522
South	1.406	1.000	0.800	0.694	0.694
SouthWest	1.257	1.000	0.797	0.617	0.522
West	1.179	1.000	0.857	0.701	0.551
NorthWest	1.130	1.000	0.901	0.793	0.698

Fort Worth Tx.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.039	1.000	0.970	0.941	0.909
East	1.134	1.000	0.885	0.754	0.616
SouthEast	1.179	1.000	0.836	0.634	0.447
South	1.200	1.000	0.800	0.535	0.315
SouthWest	1.179	1.000	0.836	0.634	0.447
West	1.134	1.000	0.885	0.754	0.616
NorthWest	1.039	1.000	0.970	0.941	0.909
Cooling					
North	1.038	1.000	0.980	0.961	0.955
NorthEast	1.129	1.000	0.904	0.810	0.725
East	1.165	1.000	0.868	0.725	0.599
SouthEast	1.230	1.000	0.828	0.691	0.623
South	1.281	1.000	0.879	0.844	0.844
SouthWest	1.230	1.000	0.828	0.691	0.623
West	1.165	1.000	0.868	0.725	0.599
NorthWest	1.129	1.000	0.904	0.810	0.725

Fresno

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.045	1.000	0.967	0.930	0.904
East	1.135	1.000	0.882	0.741	0.591
SouthEast	1.177	1.000	0.835	0.625	0.419
South	1.192	1.000	0.808	0.547	0.289
SouthWest	1.177	1.000	0.835	0.625	0.419
West	1.135	1.000	0.882	0.741	0.591
NorthWest	1.045	1.000	0.967	0.930	0.904
Cooling					
North	1.049	1.000	0.972	0.942	0.920
NorthEast	1.164	1.000	0.876	0.747	0.634
East	1.206	1.000	0.837	0.660	0.495
SouthEast	1.299	1.000	0.770	0.576	0.477
South	1.480	1.000	0.797	0.702	0.702
SouthWest	1.299	1.000	0.770	0.576	0.477
West	1.206	1.000	0.837	0.660	0.495
NorthWest	1.164	1.000	0.876	0.747	0.634

Honolulu

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.062	1.000	0.960	0.920	0.884
East	1.148	1.000	0.877	0.745	0.616
SouthEast	1.204	1.000	0.827	0.642	0.494
South	1.273	1.000	0.757	0.481	0.408
SouthWest	1.204	1.000	0.827	0.642	0.494
West	1.148	1.000	0.877	0.745	0.616
NorthWest	1.062	1.000	0.960	0.920	0.884
Cooling					
North	1.043	1.000	0.980	0.965	0.961
NorthEast	1.159	1.000	0.891	0.794	0.722
East	1.171	1.000	0.867	0.729	0.606
SouthEast	1.206	1.000	0.859	0.743	0.672
South	1.170	1.000	0.939	0.931	0.926
SouthWest	1.206	1.000	0.859	0.743	0.672
West	1.171	1.000	0.867	0.729	0.606
NorthWest	1.159	1.000	0.891	0.794	0.722

Great Falls

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.972	0.950	0.920
East	1.122	1.000	0.896	0.755	0.587
SouthEast	1.140	1.000	0.866	0.670	0.414
South	1.133	1.000	0.867	0.646	0.358
SouthWest	1.140	1.000	0.866	0.670	0.414
West	1.122	1.000	0.896	0.755	0.587
NorthWest	1.028	1.000	0.972	0.950	0.920
Cooling					
North	1.027	1.000	0.979	0.963	0.936
NorthEast	1.109	1.000	0.913	0.822	0.723
East	1.158	1.000	0.866	0.711	0.561
SouthEast	1.237	1.000	0.802	0.601	0.489
South	1.358	1.000	0.734	0.594	0.572
SouthWest	1.237	1.000	0.802	0.601	0.489
West	1.158	1.000	0.866	0.711	0.561
NorthWest	1.109	1.000	0.913	0.822	0.723

Jacksonville, Fl.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.044	1.000	0.967	0.936	0.901
East	1.139	1.000	0.883	0.750	0.613
SouthEast	1.188	1.000	0.830	0.631	0.453
South	1.217	1.000	0.783	0.517	0.330
SouthWest	1.188	1.000	0.830	0.631	0.453
West	1.139	1.000	0.883	0.750	0.613
NorthWest	1.044	1.000	0.967	0.936	0.901
Cooling					
North	1.036	1.000	0.982	0.964	0.960
NorthEast	1.121	1.000	0.910	0.823	0.747
East	1.154	1.000	0.878	0.748	0.634
SouthEast	1.208	1.000	0.850	0.732	0.675
South	1.214	1.000	0.906	0.892	0.892
SouthWest	1.208	1.000	0.850	0.732	0.675
West	1.154	1.000	0.878	0.748	0.634
NorthWest	1.121	1.000	0.910	0.823	0.747

Juneau

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.016	1.000	0.987	0.971	0.955
East	1.080	1.000	0.922	0.814	0.667
SouthEast	1.095	1.000	0.908	0.763	0.530
South	1.088	1.000	0.912	0.766	0.505
SouthWest	1.095	1.000	0.908	0.763	0.530
West	1.080	1.000	0.922	0.814	0.667
NorthWest	1.016	1.000	0.987	0.971	0.955

Cooling

North	1.018	1.000	0.982	0.968	0.945
NorthEast	1.063	1.000	0.951	0.888	0.816
East	1.107	1.000	0.908	0.790	0.663
SouthEast	1.159	1.000	0.857	0.684	0.570
South	1.209	1.000	0.805	0.644	0.587
SouthWest	1.159	1.000	0.857	0.684	0.570
West	1.107	1.000	0.908	0.790	0.663
NorthWest	1.063	1.000	0.951	0.888	0.816

Kansas City, Mo.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.029	1.000	0.972	0.951	0.924
East	1.122	1.000	0.891	0.762	0.619
SouthEast	1.159	1.000	0.850	0.646	0.430
South	1.163	1.000	0.837	0.593	0.297
SouthWest	1.159	1.000	0.850	0.646	0.430
West	1.122	1.000	0.891	0.762	0.619
NorthWest	1.029	1.000	0.972	0.951	0.924

Cooling

North	1.026	1.000	0.979	0.965	0.950
NorthEast	1.115	1.000	0.913	0.824	0.737
East	1.158	1.000	0.871	0.726	0.596
SouthEast	1.234	1.000	0.820	0.660	0.578
South	1.352	1.000	0.834	0.753	0.753
SouthWest	1.234	1.000	0.820	0.660	0.578
West	1.158	1.000	0.871	0.726	0.596
NorthWest	1.115	1.000	0.913	0.824	0.737

Lake Charles

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.039	1.000	0.969	0.943	0.919
East	1.123	1.000	0.893	0.772	0.650
SouthEast	1.175	1.000	0.844	0.656	0.494
South	1.206	1.000	0.794	0.544	0.374
SouthWest	1.175	1.000	0.844	0.656	0.494
West	1.123	1.000	0.893	0.772	0.650
NorthWest	1.039	1.000	0.969	0.943	0.919

Cooling

North	1.037	1.000	0.980	0.964	0.953
NorthEast	1.122	1.000	0.911	0.823	0.746
East	1.153	1.000	0.879	0.749	0.637
SouthEast	1.207	1.000	0.853	0.736	0.678
South	1.204	1.000	0.904	0.892	0.892
SouthWest	1.207	1.000	0.853	0.736	0.678
West	1.153	1.000	0.879	0.749	0.637
NorthWest	1.122	1.000	0.911	0.823	0.746

Las Vegas

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.058	1.000	0.960	0.912	0.876
East	1.165	1.000	0.866	0.697	0.517
SouthEast	1.194	1.000	0.820	0.585	0.350
South	1.200	1.000	0.800	0.518	0.221
SouthWest	1.194	1.000	0.820	0.585	0.350
West	1.165	1.000	0.866	0.697	0.517
NorthWest	1.058	1.000	0.960	0.912	0.876

Cooling

North	1.049	1.000	0.968	0.941	0.922
NorthEast	1.162	1.000	0.879	0.754	0.638
East	1.204	1.000	0.834	0.658	0.494
SouthEast	1.301	1.000	0.773	0.578	0.479
South	1.485	1.000	0.797	0.698	0.698
SouthWest	1.301	1.000	0.773	0.578	0.479
West	1.204	1.000	0.834	0.658	0.494
NorthWest	1.162	1.000	0.879	0.754	0.638

Los Angeles

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.051	1.000	0.966	0.922	0.900
East	1.148	1.000	0.877	0.726	0.570
SouthEast	1.191	1.000	0.826	0.606	0.400
South	1.206	1.000	0.794	0.517	0.272
SouthWest	1.191	1.000	0.826	0.606	0.400
West	1.148	1.000	0.877	0.726	0.570
NorthWest	1.051	1.000	0.966	0.922	0.900
Cooling					
North	1.035	1.000	0.976	0.958	0.940
NorthEast	1.138	1.000	0.899	0.793	0.700
East	1.178	1.000	0.859	0.710	0.573
SouthEast	1.250	1.000	0.817	0.664	0.585
South	1.332	1.000	0.860	0.810	0.810
SouthWest	1.250	1.000	0.817	0.664	0.585
West	1.178	1.000	0.859	0.710	0.573
NorthWest	1.138	1.000	0.899	0.793	0.700

Memphis

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.036	1.000	0.974	0.944	0.925
East	1.122	1.000	0.893	0.764	0.630
SouthEast	1.169	1.000	0.844	0.647	0.455
South	1.184	1.000	0.816	0.564	0.325
SouthWest	1.169	1.000	0.844	0.647	0.455
West	1.122	1.000	0.893	0.764	0.630
NorthWest	1.036	1.000	0.974	0.944	0.925
Cooling					
North	1.030	1.000	0.981	0.964	0.949
NorthEast	1.121	1.000	0.910	0.817	0.734
East	1.162	1.000	0.873	0.736	0.610
SouthEast	1.225	1.000	0.830	0.690	0.619
South	1.300	1.000	0.878	0.828	0.828
SouthWest	1.225	1.000	0.830	0.690	0.619
West	1.162	1.000	0.873	0.736	0.610
NorthWest	1.121	1.000	0.910	0.817	0.734

Medford

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.976	0.955	0.929
East	1.109	1.000	0.901	0.783	0.652
SouthEast	1.147	1.000	0.861	0.671	0.463
South	1.153	1.000	0.846	0.606	0.349
SouthWest	1.147	1.000	0.861	0.671	0.463
West	1.109	1.000	0.901	0.783	0.652
NorthWest	1.028	1.000	0.976	0.955	0.929
Cooling					
North	1.031	1.000	0.978	0.957	0.940
NorthEast	1.127	1.000	0.900	0.796	0.698
East	1.173	1.000	0.858	0.696	0.546
SouthEast	1.258	1.000	0.794	0.602	0.502
South	1.411	1.000	0.765	0.644	0.644
SouthWest	1.258	1.000	0.794	0.602	0.502
West	1.173	1.000	0.858	0.696	0.546
NorthWest	1.127	1.000	0.900	0.796	0.698

Miami

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.053	1.000	0.961	0.926	0.893
East	1.144	1.000	0.877	0.742	0.609
SouthEast	1.199	1.000	0.827	0.631	0.469
South	1.246	1.000	0.764	0.487	0.362
SouthWest	1.199	1.000	0.827	0.631	0.469
West	1.144	1.000	0.877	0.742	0.609
NorthWest	1.053	1.000	0.961	0.926	0.893
Cooling					
North	1.044	1.000	0.978	0.960	0.955
NorthEast	1.128	1.000	0.908	0.821	0.748
East	1.150	1.000	0.883	0.757	0.650
SouthEast	1.191	1.000	0.870	0.769	0.718
South	1.142	1.000	0.934	0.934	0.934
SouthWest	1.191	1.000	0.870	0.769	0.718
West	1.150	1.000	0.883	0.757	0.650
NorthWest	1.128	1.000	0.908	0.821	0.748

Minneapolis

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.975	0.956	0.929
East	1.115	1.000	0.896	0.767	0.618
SouthEast	1.143	1.000	0.862	0.668	0.431
South	1.142	1.000	0.859	0.623	0.342
SouthWest	1.143	1.000	0.862	0.668	0.431
West	1.115	1.000	0.896	0.767	0.618
NorthWest	1.028	1.000	0.975	0.956	0.929
Cooling					
North	1.023	1.000	0.983	0.967	0.953
NorthEast	1.099	1.000	0.921	0.837	0.755
East	1.145	1.000	0.879	0.738	0.606
SouthEast	1.218	1.000	0.820	0.649	0.558
South	1.328	1.000	0.789	0.670	0.670
SouthWest	1.218	1.000	0.820	0.649	0.558
West	1.145	1.000	0.879	0.738	0.606
NorthWest	1.099	1.000	0.921	0.837	0.755

New York City

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.981	0.956	0.938
East	1.107	1.000	0.904	0.788	0.657
SouthEast	1.144	1.000	0.863	0.676	0.473
South	1.151	1.000	0.849	0.619	0.347
SouthWest	1.144	1.000	0.863	0.676	0.473
West	1.107	1.000	0.904	0.788	0.657
NorthWest	1.028	1.000	0.981	0.956	0.938
Cooling					
North	1.024	1.000	0.988	0.971	0.964
NorthEast	1.093	1.000	0.928	0.851	0.779
East	1.141	1.000	0.887	0.763	0.644
SouthEast	1.200	1.000	0.841	0.697	0.622
South	1.293	1.000	0.848	0.770	0.770
SouthWest	1.200	1.000	0.841	0.697	0.622
West	1.141	1.000	0.887	0.763	0.644
NorthWest	1.093	1.000	0.928	0.851	0.779

Nashville

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.033	1.000	0.979	0.951	0.936
East	1.116	1.000	0.905	0.786	0.660
SouthEast	1.158	1.000	0.855	0.667	0.480
South	1.171	1.000	0.828	0.591	0.352
SouthWest	1.158	1.000	0.855	0.667	0.480
West	1.116	1.000	0.905	0.786	0.660
NorthWest	1.033	1.000	0.979	0.951	0.936
Cooling					
North	1.028	1.000	0.982	0.966	0.955
NorthEast	1.112	1.000	0.916	0.829	0.750
East	1.154	1.000	0.875	0.744	0.621
SouthEast	1.218	1.000	0.836	0.698	0.627
South	1.300	1.000	0.879	0.824	0.824
SouthWest	1.218	1.000	0.836	0.698	0.627
West	1.154	1.000	0.875	0.744	0.621
NorthWest	1.112	1.000	0.916	0.829	0.750

Oklahoma City

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.038	1.000	0.971	0.942	0.912
East	1.137	1.000	0.886	0.749	0.605
SouthEast	1.175	1.000	0.837	0.628	0.426
South	1.189	1.000	0.812	0.550	0.290
SouthWest	1.175	1.000	0.837	0.628	0.426
West	1.137	1.000	0.886	0.749	0.605
NorthWest	1.038	1.000	0.971	0.942	0.912
Cooling					
North	1.032	1.000	0.979	0.963	0.953
NorthEast	1.125	1.000	0.907	0.814	0.728
East	1.164	1.000	0.867	0.724	0.594
SouthEast	1.236	1.000	0.823	0.675	0.601
South	1.325	1.000	0.866	0.810	0.810
SouthWest	1.236	1.000	0.823	0.675	0.601
West	1.164	1.000	0.867	0.724	0.594
NorthWest	1.125	1.000	0.907	0.814	0.728

Omaha

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.971	0.950	0.922
East	1.128	1.000	0.891	0.755	0.604
SouthEast	1.157	1.000	0.851	0.646	0.415
South	1.157	1.000	0.843	0.599	0.296
SouthWest	1.157	1.000	0.851	0.646	0.415
West	1.128	1.000	0.891	0.755	0.604
NorthWest	1.028	1.000	0.971	0.950	0.922

Cooling

North	1.025	1.000	0.978	0.966	0.947
NorthEast	1.112	1.000	0.915	0.826	0.737
East	1.158	1.000	0.871	0.725	0.592
SouthEast	1.233	1.000	0.815	0.648	0.562
South	1.362	1.000	0.811	0.720	0.720
SouthWest	1.233	1.000	0.815	0.648	0.562
West	1.158	1.000	0.871	0.725	0.592
NorthWest	1.112	1.000	0.915	0.826	0.737

Phoenix

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.055	1.000	0.956	0.916	0.871
East	1.161	1.000	0.862	0.705	0.540
SouthEast	1.201	1.000	0.816	0.588	0.376
South	1.220	1.000	0.780	0.488	0.241
SouthWest	1.201	1.000	0.816	0.588	0.376
West	1.161	1.000	0.862	0.705	0.540
NorthWest	1.055	1.000	0.956	0.916	0.871

Cooling

North	1.058	1.000	0.970	0.942	0.932
NorthEast	1.168	1.000	0.876	0.753	0.642
East	1.202	1.000	0.838	0.663	0.509
SouthEast	1.293	1.000	0.781	0.606	0.518
South	1.405	1.000	0.827	0.769	0.769
SouthWest	1.293	1.000	0.781	0.606	0.518
West	1.202	1.000	0.838	0.663	0.509
NorthWest	1.168	1.000	0.876	0.753	0.642

Philadelphia

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.030	1.000	0.978	0.954	0.932
East	1.112	1.000	0.898	0.776	0.639
SouthEast	1.151	1.000	0.857	0.663	0.456
South	1.157	1.000	0.842	0.607	0.325
SouthWest	1.151	1.000	0.857	0.663	0.456
West	1.112	1.000	0.898	0.776	0.639
NorthWest	1.030	1.000	0.978	0.954	0.932

Cooling

North	1.025	1.000	0.987	0.970	0.961
NorthEast	1.099	1.000	0.924	0.842	0.770
East	1.145	1.000	0.884	0.757	0.636
SouthEast	1.206	1.000	0.837	0.694	0.618
South	1.303	1.000	0.852	0.776	0.776
SouthWest	1.206	1.000	0.837	0.694	0.618
West	1.145	1.000	0.884	0.757	0.636
NorthWest	1.099	1.000	0.924	0.842	0.770

Pittsburgh

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.020	1.000	0.980	0.965	0.946
East	1.097	1.000	0.914	0.812	0.700
SouthEast	1.136	1.000	0.872	0.698	0.514
South	1.145	1.000	0.855	0.637	0.389
SouthWest	1.136	1.000	0.872	0.698	0.514
West	1.097	1.000	0.914	0.812	0.700
NorthWest	1.020	1.000	0.980	0.965	0.946

Cooling

North	1.020	1.000	0.984	0.973	0.960
NorthEast	1.095	1.000	0.928	0.853	0.780
East	1.136	1.000	0.887	0.761	0.645
SouthEast	1.202	1.000	0.842	0.700	0.626
South	1.297	1.000	0.851	0.776	0.776
SouthWest	1.202	1.000	0.842	0.700	0.626
West	1.136	1.000	0.887	0.761	0.645
NorthWest	1.095	1.000	0.928	0.853	0.780

Portland, Maine

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.023	1.000	0.983	0.958	0.942
East	1.109	1.000	0.907	0.787	0.651
SouthEast	1.138	1.000	0.868	0.681	0.461
South	1.139	1.000	0.861	0.634	0.358
SouthWest	1.138	1.000	0.868	0.681	0.461
West	1.109	1.000	0.907	0.787	0.651
NorthWest	1.023	1.000	0.983	0.958	0.942
Cooling					
North	1.020	1.000	0.985	0.973	0.960
NorthEast	1.087	1.000	0.933	0.860	0.787
East	1.136	1.000	0.888	0.763	0.642
SouthEast	1.199	1.000	0.838	0.686	0.604
South	1.292	1.000	0.823	0.722	0.722
SouthWest	1.199	1.000	0.838	0.686	0.604
West	1.136	1.000	0.888	0.763	0.642
NorthWest	1.087	1.000	0.933	0.860	0.787

Portland, Oregon

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.021	1.000	0.982	0.966	0.947
East	1.093	1.000	0.914	0.808	0.686
SouthEast	1.128	1.000	0.878	0.706	0.496
South	1.130	1.000	0.870	0.653	0.408
SouthWest	1.128	1.000	0.878	0.706	0.496
West	1.093	1.000	0.914	0.808	0.686
NorthWest	1.021	1.000	0.982	0.966	0.947
Cooling					
North	1.023	1.000	0.985	0.967	0.955
NorthEast	1.096	1.000	0.923	0.840	0.760
East	1.143	1.000	0.880	0.742	0.610
SouthEast	1.214	1.000	0.821	0.649	0.557
South	1.322	1.000	0.783	0.665	0.660
SouthWest	1.214	1.000	0.821	0.649	0.557
West	1.143	1.000	0.880	0.742	0.610
NorthWest	1.096	1.000	0.923	0.840	0.760

Reno, Nv.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.051	1.000	0.964	0.921	0.887
East	1.146	1.000	0.868	0.709	0.533
SouthEast	1.177	1.000	0.831	0.605	0.365
South	1.181	1.000	0.819	0.551	0.237
SouthWest	1.177	1.000	0.831	0.605	0.365
West	1.146	1.000	0.868	0.709	0.533
NorthWest	1.051	1.000	0.964	0.921	0.887
Cooling					
North	1.048	1.000	0.975	0.942	0.925
NorthEast	1.158	1.000	0.880	0.751	0.636
East	1.204	1.000	0.837	0.658	0.488
SouthEast	1.297	1.000	0.766	0.559	0.451
South	1.501	1.000	0.758	0.633	0.633
SouthWest	1.297	1.000	0.766	0.559	0.451
West	1.204	1.000	0.837	0.658	0.488
NorthWest	1.158	1.000	0.880	0.751	0.636

Salt Lake City

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.038	1.000	0.967	0.937	0.904
East	1.138	1.000	0.883	0.735	0.571
SouthEast	1.169	1.000	0.842	0.627	0.391
South	1.169	1.000	0.831	0.574	0.270
SouthWest	1.169	1.000	0.842	0.627	0.391
West	1.138	1.000	0.883	0.735	0.571
NorthWest	1.038	1.000	0.967	0.937	0.904
Cooling					
North	1.035	1.000	0.970	0.952	0.926
NorthEast	1.142	1.000	0.893	0.780	0.669
East	1.188	1.000	0.845	0.673	0.514
SouthEast	1.281	1.000	0.777	0.577	0.473
South	1.464	1.000	0.759	0.635	0.635
SouthWest	1.281	1.000	0.777	0.577	0.473
West	1.188	1.000	0.845	0.673	0.514
NorthWest	1.142	1.000	0.893	0.780	0.669

San Antonio

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.048	1.000	0.969	0.939	0.906
East	1.138	1.000	0.886	0.757	0.624
SouthEast	1.186	1.000	0.833	0.638	0.466
South	1.217	1.000	0.783	0.520	0.344
SouthWest	1.186	1.000	0.833	0.638	0.466
West	1.138	1.000	0.886	0.757	0.624
NorthWest	1.048	1.000	0.969	0.939	0.906
Cooling					
North	1.043	1.000	0.979	0.958	0.953
NorthEast	1.137	1.000	0.900	0.803	0.719
East	1.167	1.000	0.868	0.728	0.603
SouthEast	1.225	1.000	0.838	0.711	0.648
South	1.229	1.000	0.892	0.884	0.884
SouthWest	1.225	1.000	0.838	0.711	0.648
West	1.167	1.000	0.868	0.728	0.603
NorthWest	1.137	1.000	0.900	0.803	0.719

San Francisco

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.038	1.000	0.967	0.937	0.905
East	1.133	1.000	0.881	0.743	0.596
SouthEast	1.172	1.000	0.839	0.629	0.415
South	1.181	1.000	0.819	0.561	0.280
SouthWest	1.172	1.000	0.839	0.629	0.415
West	1.133	1.000	0.881	0.743	0.596
NorthWest	1.038	1.000	0.967	0.937	0.905
Cooling					
North	1.036	1.000	0.977	0.955	0.939
NorthEast	1.136	1.000	0.897	0.792	0.693
East	1.177	1.000	0.857	0.698	0.556
SouthEast	1.259	1.000	0.799	0.628	0.540
South	1.400	1.000	0.827	0.742	0.742
SouthWest	1.259	1.000	0.799	0.628	0.540
West	1.177	1.000	0.857	0.698	0.556
NorthWest	1.136	1.000	0.897	0.792	0.693

San Diego

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.053	1.000	0.964	0.921	0.897
East	1.153	1.000	0.876	0.725	0.568
SouthEast	1.195	1.000	0.823	0.603	0.401
South	1.214	1.000	0.786	0.504	0.272
SouthWest	1.195	1.000	0.823	0.603	0.401
West	1.153	1.000	0.876	0.725	0.568
NorthWest	1.053	1.000	0.964	0.921	0.897
Cooling					
North	1.034	1.000	0.978	0.960	0.944
NorthEast	1.136	1.000	0.900	0.799	0.710
East	1.173	1.000	0.862	0.717	0.585
SouthEast	1.241	1.000	0.824	0.680	0.605
South	1.302	1.000	0.867	0.828	0.828
SouthWest	1.241	1.000	0.824	0.680	0.605
West	1.173	1.000	0.862	0.717	0.585
NorthWest	1.136	1.000	0.900	0.799	0.710

Seattle

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000
Heating					
North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.021	1.000	0.982	0.967	0.949
East	1.090	1.000	0.918	0.815	0.695
SouthEast	1.122	1.000	0.884	0.717	0.507
South	1.124	1.000	0.876	0.669	0.428
SouthWest	1.122	1.000	0.884	0.717	0.507
West	1.090	1.000	0.918	0.815	0.695
NorthWest	1.021	1.000	0.982	0.967	0.949
Cooling					
North	1.022	1.000	0.983	0.964	0.949
NorthEast	1.096	1.000	0.922	0.834	0.751
East	1.146	1.000	0.878	0.734	0.595
SouthEast	1.219	1.000	0.815	0.632	0.533
South	1.327	1.000	0.760	0.644	0.627
SouthWest	1.219	1.000	0.815	0.632	0.533
West	1.146	1.000	0.878	0.734	0.595
NorthWest	1.096	1.000	0.922	0.834	0.751

Washington D.C.

OH Width	0.000	1.500	3.000	5.500	11.000
Ratio	0.000	0.273	0.545	1.000	2.000

Heating

North	1.000	1.000	1.000	1.000	1.000
NorthEast	1.028	1.000	0.975	0.953	0.929
East	1.114	1.000	0.898	0.778	0.645
SouthEast	1.154	1.000	0.856	0.662	0.461
South	1.161	1.000	0.838	0.601	0.326
SouthWest	1.154	1.000	0.856	0.662	0.461
West	1.114	1.000	0.898	0.778	0.645
NorthWest	1.028	1.000	0.975	0.953	0.929

Cooling

North	1.025	1.000	0.985	0.968	0.958
NorthEast	1.104	1.000	0.921	0.839	0.763
East	1.146	1.000	0.882	0.750	0.630
SouthEast	1.210	1.000	0.835	0.692	0.617
South	1.309	1.000	0.858	0.785	0.785
SouthWest	1.210	1.000	0.835	0.692	0.617
West	1.146	1.000	0.882	0.750	0.630
NorthWest	1.104	1.000	0.921	0.839	0.763

APPENDIX B

SAMPLE POINT SYSTEM

APPENDIX B

SAMPLE POINT SYSTEM

This appendix contains a sample point system exactly as it is created by the ARES program. The tables are numbered according to a sequence from the textual portion of the energy standard (ASHRAE TEC SP-53 1989). Tables 4-3a through 4-3e are the prescriptive packages supplied by ARES. Tables 5-2 through 5-21 comprise the point system.

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Prescriptive Compliance Packages

Housing Type: Single Family Detached
Jurisdiction: Example

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Table 4-3a Prescriptive Compliance Package

Housing Type: Single Family Detached
Jurisdiction: Example
Heating Type: Oil Furnace
Description : Basic Single Family Oil Furnace Package

Component	Requirement
Ceiling Insulation	R-30
Wall Insulation	R-23
Floor over Crawlspace Insulation	R-13
Floor over Basement Insulation	R-13
Basement Wall Insulation	R-5_4ft
Slab Insulation	R-5_2ft
Window Type	Double_w/o_TB
Max window area/floor area	12.0% Max Total
Minimum south window area	0.0% Min South
Infiltration	Normal
Heating Efficiency	AFUE_85%
Cooling Efficiency	SEER_10

Table 4-3b Prescriptive Compliance Package

Housing Type: Single Family Detached
Jurisdiction: Example
Heating Type: Gas Furnace
Description : Basic Single Family Gas Furnace Package

Component	Requirement
Ceiling Insulation	R-30
Wall Insulation	R-23
Floor over Crawlspace Insulation	R-30
Floor over Basement Insulation	R-13
Basement Wall Insulation	R-5_4ft
Slab Insulation	R-5_2ft
Window Type	Double_w/o_TB
Max window area/floor area	12.0% Max Total
Minimum south window area	0.0% Min South
Infiltration	Normal
Heating Efficiency	AFUE_85%
Cooling Efficiency	SEER_10

Table 4-3c Prescriptive Compliance Package

Housing Type: Single Family Detached
Jurisdiction: Example
Heating Type: LPG Furnace
Description : Basic Single Family LPG Furnace Package

Component	Requirement
Ceiling Insulation	R-30
Wall Insulation	R-23
Floor over Crawlspace Insulation	R-30
Floor over Basement Insulation	R-30
Basement Wall Insulation	R-10_4ft
Slab Insulation	R-5_2ft
Window Type	Double_Low-E
Max window area/floor area	12.0% Max Total
Minimum south window area	0.0% Min South
Infiltration	Normal
Heating Efficiency	AFUE_85%
Cooling Efficiency	SEER_10

Table 4-3d Prescriptive Compliance Package

Housing Type: Single Family Detached
Jurisdiction: Example
Heating Type: Electric Furnace
Description : Basic Single Family Electric Furnace Package

Component	Requirement
Ceiling Insulation	R-30
Wall Insulation	R-26
Floor over Crawlspace Insulation	R-30
Floor over Basement Insulation	R-30
Basement Wall Insulation	R-10_4ft
Slab Insulation	R-5_2ft
Window Type	Double_Low-E
Max window area/floor area	12.0% Max Total
Minimum south window area	0.0% Min South
Infiltration	Normal
Heating Efficiency	Elec_Resistance
Cooling Efficiency	SEER_10

Table 4-3e Prescriptive Compliance Package

Housing Type: Single Family Detached
Jurisdiction: Example
Heating Type: Heat Pump
Description : Basic Single Family Heat Pump Package

Component	Requirement
Ceiling Insulation	R-30
Wall Insulation	R-19
Floor over Crawlspace Insulation	R-30
Floor over Basement Insulation	R-30
Basement Wall Insulation	R-5_4ft
Slab Insulation	R-5_2ft
Window Type	Double_w/o_TB
Max window area/floor area	12.0% Max Total
Minimum south window area	0.0% Min South
Infiltration	Normal
Heating Efficiency	HSPF 7.3
Cooling Efficiency	SEER 10.0

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Point System (Section 7)

Housing Type: Single Family Detached
Jurisdiction: Example

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Table 5-2 TARGET Ceiling Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Heating Equipment Type	Multiplier Heating	Cooling
Oil	37	12
Natural Gas	37	12
L. P. Gas	37	12
Electric Res.	37	12
Elec. Heat Pump	37	12

Table 5-3 DESIGN Ceiling Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-11	R-19	81	27
R-19	R-30	57	19
R-30	R-38	37	12
R-38	R-49	29	10
R-49	R-60	23	8
R-60	--	20	7

Table 5-4 TARGET Wall Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Heating Equipment Type	Multiplier Heating	Cooling
Oil	56	10
Natural Gas	56	10
L. P. Gas	56	10
Electric Res.	49	9
Elec. Heat Pump	69	13

Table 5-5a DESIGN Frame Wall Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-11	R-13	101	18
R-13	R-19	86	16
R-19	R-23	69	13
R-23	R-26	56	10
R-26	--	49	9

Table 5-5b DESIGN Mass Wall Insulation Multipliers
Medium Weight (40 to 110 lb/sf)

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0_Medium_Wt	R-5_Medium_Wt	292	32
R-5_Medium_Wt	R-10_Medium_Wt	136	12
R-10_Medium_Wt	R-15_Medium_Wt	80	7
R-15_Medium_Wt	R-30_Medium_Wt	56	5
R-30_Medium_Wt	--	28	3

Table 5-5c DESIGN Mass Wall Insulation Multipliers
Heavy Weight (greater than 110 lb/sf)

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0_Heavy_Wt	R-5_Heavy_Wt	289	26
R-5_Heavy_Wt	R-10_Heavy_Wt	134	8
R-10_Heavy_Wt	R-15_Heavy_Wt	78	4
R-15_Heavy_Wt	R-30_Heavy_Wt	55	2
R-30_Heavy_Wt	--	27	0

Table 5-5d DESIGN Solid Wood (Log) Wall Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Nominal Thickness (inches)		Multiplier	
At least	but less than	Heating	Cooling
6_inch_Log	8_inch_Log	122	19
8_inch_Log	10_inch_Log	94	15
10_inch_Log	12_inch_Log	76	14
12_inch_Log	--	65	14

Table 5-6 TARGET Floor/Foundation Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Heating Equipment Type	Heating Multiplier: Slab	Crawl Space	Unheated Basement	Heated Basement
Oil	143	26	21	458
Natural Gas	143	0	21	458
L. P. Gas	143	0	0	388
Electric Res.	143	0	0	388
Elec. Heat Pump	143	0	0	458

Heating Equipment Type	Cooling Multiplier: Slab	Crawl Space	Unheated Basement	Heated Basement
Oil	12	32	20	20
Natural Gas	12	31	20	20
L. P. Gas	12	31	24	12
Electric Res.	12	31	24	12
Elec. Heat Pump	12	31	24	20

Table 5-7a DESIGN Slab Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Insulation at least 2 feet deep:

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-5_2ft	388	0
R-5_2ft	R-10_2ft	143	12
R-10_2ft	--	97	15

Insulation to depth of footing:

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-5_4ft	388	0
R-5_4ft	R-10_4ft	72	19
R-10_4ft	--	0	24

Table 5-7b DESIGN Floor-Over-Crawlspace Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-11	203	31
R-11	R-13	38	32
R-13	R-19	26	32
R-19	R-30	17	32
R-30	--	0	31

Table 5-7c DESIGN Floor-Over-Unheated-Basement Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-11	119	3
R-11	R-13	30	18
R-13	R-19	21	20
R-19	R-30	12	22
R-30	--	0	24

Table 5-7d DESIGN Basement Wall Insulation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Insulation at least 4 feet deep:

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-5_4ft	726	51
R-5_4ft	R-10_4ft	458	20
R-10_4ft	--	388	12

Insulation at least 8 feet deep:

R-value		Multiplier	
At least	but less than	Heating	Cooling
R-0	R-5_8ft	726	51
R-5_8ft	R-10_8ft	363	19
R-10_8ft	--	244	11

Table 5-8 TARGET Air Infiltration Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Heating Equipment Type	Multiplier Heating	Multiplier Cooling
Oil	159	5
Natural Gas	159	5
L. P. Gas	159	5
Electric Res.	159	5
Elec. Heat Pump	159	5

Table 5-9 DESIGN Air Infiltration Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Infiltration Package *	Multiplier Heating	Multiplier Cooling
Normal	159	5
Tight	113	4

*(see Section 5.2.5 of Standard)

Table 5-10 TARGET Glazing Layers and Sash Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Heating Equipment Type	Multiplier Heating	Multiplier Cooling
Oil	74	4
Natural Gas	74	4
L. P. Gas	38	2
Electric Res.	38	2
Elec. Heat Pump	74	4

Table 5-11 DESIGN Glazing Layers and Sash Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Glazing Type	Multiplier Heating	Multiplier Cooling
Single_w/o_TB	1138	57
Double_w/o_TB	619	31
Double_TB	469	24
Triple_TB	369	19
Single_Heat_abs	1138	57
Double_Heat_abs	619	31
Triple_Heat_abs	469	24
Double_Low-E	319	16
Triple_Low-E	250	13

Table 5-12 TARGET Fenestration Area and Orientation Points

Housing Type: Single Family Detached
Jurisdiction: Example

Heated Floor Area (sf)	Points					
	Oil Furnace		Gas Furnace		LPG Furnace	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
Less than 500	44	16	44	16	35	13
500 to 750	64	25	64	25	52	20
750 to 1000	83	34	83	34	68	27
1000 to 1250	101	44	101	44	84	35
1250 to 1500	119	55	119	55	99	43
1500 to 1750	135	66	135	66	113	51
1750 to 2000	150	77	150	77	126	60
2000 to 2250	165	89	165	89	139	69
2250 to 2500	178	102	178	102	151	78
2500 to 2750	191	115	191	115	163	88
2750 to 3000	202	128	202	128	174	98
3000 to 3250	212	142	212	142	184	108
3250 to 3500	222	157	222	157	194	118
3500 to 3750	230	172	230	172	203	129
3750 to 4000	238	187	238	187	211	141
4000 to 4250	244	203	244	203	219	152
4250 to 4500	249	220	249	220	226	164
4500 to 4750	254	237	254	237	233	177
4750 to 5000	257	255	257	255	238	189
5000 to 5250	260	273	260	273	244	202
5250 to 5500	261	291	261	291	248	216
Greater than 5500	261	291	261	291	248	216

Table 5-12 TARGET Fenestration Area and Orientation Points, cont'd.

Heated Floor Area (sf)	Points			
	Electric Furnace		Heat Pump	
	Heating	Cooling	Heating	Cooling
Less than 500	35	13	44	16
500 to 750	52	20	64	25
750 to 1000	68	27	83	34
1000 to 1250	84	35	101	44
1250 to 1500	99	43	119	55
1500 to 1750	113	51	135	66
1750 to 2000	126	60	150	77
2000 to 2250	139	69	165	89
2250 to 2500	151	78	178	102
2500 to 2750	163	88	191	115
2750 to 3000	174	98	202	128
3000 to 3250	184	108	212	142
3250 to 3500	194	118	222	157
3500 to 3750	203	129	230	172
3750 to 4000	211	141	238	187
4000 to 4250	219	152	244	203
4250 to 4500	226	164	249	220
4500 to 4750	233	177	254	237
4750 to 5000	238	189	257	255
5000 to 5250	244	202	260	273
5250 to 5500	248	216	261	291
Greater than 5500	248	216	261	291

Table 5-13 DESIGN Fenestration Area and Orientation Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

	Shading Coefficient					
	1.0 to 0.8		0.79 to 0.5		less than 0.5	
Orientation	Heat	Cool	Heat	Cool	Heat	Cool
North	50	12	40	10	25	6
Northeast	70	19	55	15	34	9
East	89	25	71	20	44	12
Southeast	121	24	95	19	59	12
South	152	24	120	19	75	12
Southwest	118	28	93	22	58	14
West	83	32	66	26	41	16
Northwest	67	22	53	18	33	11
Northwest	67	22	53	18	33	11

Typical Shading Coefficients:

Single_w/o_TB	1.000
Double_w/o_TB	0.880
Double_TB	0.880
Triple_TB	0.740
Single_Heat_abs	0.750
Double_Heat_abs	0.660
Triple_Heat_abs	0.560
Double_Low-E	0.710
Triple_Low-E	0.600

Table 5-14 DESIGN Overhang Multipliers

Jurisdiction: Example

	Overhang Ratio (L/H)			
	0.000 to 0.548	0.549 to 0.999	1.0 to 1.999	2.0 and above
Heating				
North	10	10	10	10
NorthEast	10	10	9	9
East	11	9	7	6
SouthEast	12	9	6	4
South	12	8	6	3
SouthWest	12	9	6	4
West	11	9	7	6
NorthWest	10	10	9	9
Cooling				
North	10	10	9	9
NorthEast	11	9	8	7
East	12	8	7	5
SouthEast	13	8	6	5
South	14	7	6	6
SouthWest	13	8	6	5
West	12	8	7	5
NorthWest	11	9	8	7

Table 5-15 DESIGN Glazing Area and Orientation Points

Housing Type: Single Family Detached
Jurisdiction: Example

Heating F-Factor	Heating Points	Cooling F-Factor	Cooling Points
Less than 300	31	Less than 60	6
300 to 600	63	60 to 120	13
600 to 900	98	120 to 180	19
900 to 1200	134	180 to 240	27
1200 to 1500	171	240 to 300	34
1500 to 1800	211	300 to 360	42
1800 to 2100	252	360 to 420	50
2100 to 2400	295	420 to 480	58
2400 to 2700	340	480 to 540	67
2700 to 3000	386	540 to 600	76
3000 to 3300	434	600 to 660	86
3300 to 3600	484	660 to 720	95
3600 to 3900	535	720 to 780	105
3900 to 4200	588	780 to 840	116
4200 to 4500	643	840 to 900	126
4500 to 4800	700	900 to 960	137
4800 to 5100	758	960 to 1020	149
5100 to 5400	818	1020 to 1080	160
5400 to 5700	880	1080 to 1140	172
5700 to 6000	944	1140 to 1200	185
6000 to 6300	1009	1200 to 1260	197
6300 to 6600	1076	1260 to 1320	210
6600 to 6900	1145	1320 to 1380	223
6900 to 7200	1215	1380 to 1440	237
7200 to 7500	1287	1440 to 1500	251
7500 to 7800	1361	1500 to 1560	265
7800 to 8100	1437	1560 to 1620	280
8100 to 8400	1514	1620 to 1680	295
8400 to 8700	1593	1680 to 1740	310
8700 to 9000	1674	1740 to 1800	325
9000 to 9300	1756	1800 to 1860	341
9300 to 9600	1840	1860 to 1920	357
Greater than 9600	1840	Greater than 1920	357

Table 5-16 TARGET and DESIGN Base Load Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

Foundation Type	Multiplier Heating	Multiplier Cooling
Crawlspace	44	-43
Unheated Basement	56	-43
Heated Basement	88	-43
Slab	84	-50

Table 5-17 TARGET HVAC Equipment Points

Heating Equipment Type	Heating Multiplier			Cooling Multiplier	
	Ducted	Hydronic	Baseboard	Ducted	Hydronic
Oil	64	63	N/A	40	39
Natural Gas	67	66	N/A	40	39
L. P. Gas	115	113	N/A	40	39
Electric Res.	129	126	123	40	39
Heat Pump	59	58	N/A	40	39

Table 5-18 TARGET and DESIGN HVAC Equipment Multipliers

Housing Type: Single Family Detached
Jurisdiction: Example

	Heating Equipment Type					Cooling
	Oil	Gas	LPG	Elec. Res.	Heat Pump (Heating)	DX, Heat Pump (Cooling)
Ducted	5432	5729	9817	12208	431	402
Hydronic	5321	5612	9616	11959	423	394
Baseboard	--	--	--	11720	--	--

Table 5-19 TARGET Domestic Hot Water Points

Water Heating Fuel	TARGET POINTS
Oil	18159
Gas	17394
LPG	29804
Electric	21343

Table 5-20 DESIGN Domestic Hot Water Factor

Water Heating Fuel	DESIGN DHW FACTOR
Oil	8971
Gas	9462
LPG	16213
Electric	20163

Table 5-21 TARGET and DESIGN Solar Domestic Hot Water Points

Space Heating Fuel	TARGET POINTS	DESIGN POINTS Active 1-Panel	Active 2-Panel	Integral 1-Panel	Integral 2-Panel	Thermosyphon 1-Panel	Thermosyphon 2-Panel
Oil	18159	15462	13425	16141	14590	15689	14020
Gas	17394	14549	12400	15265	13629	14788	13028
LPG	29804	24929	21248	26155	23353	25340	22323
Electric	21343	15280	10703	16806	13321	15792	12040