Title

Improving the Thermal Integrity of New Single-Family Detached Residential Buildings: Documentation for a Regional Database of Capital Costs and Space Conditioning Load Savings

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ABSTRACT

This report summarizes the costs and space-conditioning load savings from improving new single-family building shells. It relies on survey data from the National Association of Home-builders (NAHB) to assess current insulation practices for these new buildings, and NAHB cost data (aggregated to the Federal region level) to estimate the costs of improving new single-family buildings beyond current practice. Space-conditioning load savings are estimated using a database of loads for prototype buildings developed at Lawrence Berkeley Laboratory, adjusted to reflect population-weighted average weather in each of the ten federal regions and for the nation as a whole.

I. INTRODUCTION

This report presents and documents a database of capital costs corresponding to different levels of thermal integrity in new, single-family residential buildings, for use in national policy analyses of the potential for energy savings in these buildings.[1] Previous analyses have focused on specific cities or regions of the country (e.g., Corum and O'Neal 1982, NPPC 1989). Until now, no study has analyzed the costs and energy savings for all regions of the United States. Our analysis uses cost data developed by the National Association of Homebuilders (NAHB 1986) and a simplified, regression-based database that was developed at Lawrence Berkeley Laboratory (EAP 1987) to calculate the capital costs and space conditioning loads associated with different amounts of building insulation, various window types, and different levels of air infiltration. Advanced window and shell technologies have not been included in the database, but will be the subject of a future report.

Section II describes the background information which is used in the rest of the report: definitions of the regions characterized in the analysis, comparisons of new housing starts and housing stock in 1987, and population-weighted average weather data for the ten Federal Regions. Section III describes the sources used to create a database of thermal integrity measures and capital costs. Section IV presents the sources used to estimate the heating and cooling loads and energy use for new single-family detached dwellings in 1987. Finally, Section V discusses limitations of and possible future improvements to the database.

II. BASELINE DATA

This section establishes the definitions of regions used in the analysis, presents the number of new single-family residences built in the U.S., and estimates the population-weighted average weather for each region.

A. Region Definitions

This analysis relies heavily on cost data from the National Association of Home Builders (NAHB) (1986). Since one version of the LBL Residential Energy Model (LBL-REM) uses the ten Federal regions for analysis, we decided to disaggregate our analysis to these ten regions. Table 1 compares the NAHB to the Federal Regions, and Figure 1 shows graphically the Federal Regions. Appendix B describes details of assumptions related to the definition of the NAHB regions.

B. Housing Starts and Number of Single-Family Dwellings

Table 2 shows the number of housing starts and number of households by Federal Region in 1987.[2] This table reveals that in 1987, Federal Regions 1, 4, and 9 were growing more quickly than the national average, because the number of housing starts as a percentage of households is larger for these regions than for the nation as a whole. Region 4 contains about one-quarter of the housing starts, and slightly less than one-fifth of the households.

Table 3 shows the number of existing dwellings by house type, for all houses and for those houses built between 1980-87, taken from US DOE (1989a).[3] This table reveals that while

[1] The primary purpose of this database is for use with the Lawrence Berkeley Laboratory's Residential Energy Model (LBL-REM) to create more accurate forecasts of residential energy use. It has also been adapted to create supply curves of conserved energy for the residential sector. See Koomey et al. (1991) for details.

[2] More recent housing data are available, but since 1987 survey data (NAHB 1989) were used to calculate thermal integrity levels for current practice buildings, 1987 is the appropriate year for comparison.

[3] We refer to the 1980-87 houses as new houses for simplicity.

single-family detached (SFD) and single-family attached (SFA) dwellings account for about two-thirds of all new and existing houses, the new homes have a larger percentage of SFA, multifamily with more than 4 units (MF [>4]), and mobile homes (MH) than the existing homes. SFD still comprise the majority of new homes.

We purchased state-level data from (NAHB) on 1987 construction practices for new SFD, SFA, and multifamily low-rise buildings (MFL) (NAHB 1989).[4] Table 2 shows that the geographic distribution of SFDs represented in this database is not exactly the same as the distribution of 1987 housing starts. The significance of these differences is unknown. Table 4 summarizes the number of respondents for each fuel type in the national sample. Only the SFD sample is large enough to do a federal-region-level analysis, and we restricted ourselves to this house type.

C. Weather

The cities that best represent average weather for each of the ten Federal Regions were derived using a program developed at LBL (Andersson et al. 1986). This program (called GLOM) selects population-weighted averages based on Heating Degree Days (HDDs), Cooling Degree Days (CDDs), latent enthalpy hours, and incident solar radiation, using a database for 125 SMSA's representing about 60% of the U.S. population. Table 5 shows the cities representing the actual population-weighted mean climate for the Federal Regions, along with their HDDs and CDDs. It also shows the cities chosen for use in the analysis. The cities closest to the population-weighted means were not available in DOE-2 simulations for Regions 4, 5, 6, or the national average, so we chose the next closest cities from the GLOM runs.

Population-weighted averages are not exactly the best parameter to use in estimating actual weather experienced by *new* homes, because these homes are distributed differently than existing homes. The extent of differences between new and existing housing distributions within each Federal Region is not well known. One example is that of the Northwest Power Planning Council (NPPC), which has analyzed conservation potential in most of Federal Region 10. The NPPC uses one estimate of heating degree days for simulating energy savings in existing buildings, and a different one for such simulations in new buildings. These estimates differ by about 5% (Corum 1991).

III. SETTING UP THE DATABASE

A. INPUTS

1. Prototypes

For this analysis, we assume that oil- and lpg-heated houses are the same as natural gas-heated houses. The error introduced by this assumption will be small, since oil and lpg comprise such a small fraction of new home construction.[5]

Table 6 shows the number of units by foundation type based on the NAHB builders' survey. All fuel types are added together in this table. We use the simple rule that the foundation type and building type with the most units built defines the simulation prototype in each region. For example, in Federal Region 6, we choose one-story slab as the prototype.

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4 The NAHB survey is based on a self-selected sample. However, it represents the most detailed source available on the characteristics of new residences in the U.S.

5 According to the 1987 RECS, 5.3% of houses built between 1980-87 used lpg as the main heating fuel, 1.8% used oil, and 33.8% used natural gas.

Table 7 shows the prototype choices based on this decision. The foundation prototypes for region 4 and the national average were not available in the database of DOE-2 simulations (see below). We chose to use one-story crawl space for Region 4, since that was the only prototype available for Charleston, SC weather. We chose the two-story basement prototype for the national average, since that is the next most common house nationally (after the one-story slab, which is not in the database for Washington, DC).

Table 8 illustrates that our decision rule results in prototypes that do not correspond to the appropriate ones for all regions for each heating fuel. A more comprehensive analysis using three different prototypes for each region would increase the coverage from 36% to 77% (assuming that the three largest foundation types in each region would be modelled).

Table 9 shows the percentage of houses of each fuel type covered by our prototype choices. Gas heated homes are best represented by our prototypes. Of these homes, 38% are represented by our prototypes (based on a weighted average over the regional prototypes). Heat-pump heated homes are next most well represented, followed by electrically heated homes. This table reiterates the importance of expanding the number of house types to three per region.

Table 10 shows window types by Federal Region. For each prototype, the window type chosen (wood or aluminum) is simply the type with the largest number of installations in each region. For example, since 65% of the windows in Region 6 are aluminum, the prototype in this region is assumed to have aluminum windows.

Table 11 describes other characteristics of the prototypes used in this analysis which correspond to the standard prototypes used by DOE-2. The load and energy results from these prototypes are scaled up or down using the floor area correction factors in Appendix D and Table 12, which shows average floor areas from the NAHB survey.

2. Conservation Measures

Table 13 shows ceiling insulation (C), wall insulation (W), glazing (G), floor insulation (F), and infiltration (I) measures considered in this analysis. We assume, as PEAR does, that the amount of energy savings from a particular measure (e.g., increasing wall insulation from R-11 to R-19) is independent of the energy savings from other measures. This assumption reduces the number of combinations, since these combinations are additive instead of multiplicative (as they would be if we had to simulate each combination together).[6]

Most basements are unheated, and the relevant ''foundation'' insulation measure for basement homes is floor insulation, which has the same characteristics and costs as floor insulation in a house with a crawlspace. Therefore, these two measures are combined. Table 6 shows that 32% of all new single-family homes built in 1987 had basements, and 16% of all new single-family homes in 1987 had crawlspaces. 43% of all new single-family residences were slab homes.

3. Cost of Measures

The cost data are taken from NAHB (1986). We assumed that all states in each NAHB region had the same costs (i.e., the costs assigned to that region by NAHB). We then sorted the states by Federal Regions and weighted the costs by 1987 housing starts by state to aggregate the costs to Federal Regions. For infiltration costs, we assumed that current practice reaches 0.7 air

[6] The PEAR simulations do not contain information on Low-E, Argon-filled glazing. See Appendix B for a description of how costs and changes in loads were calculated for this measure.

changes-per-hour (ach), and that addition of a tyvek infiltration barrier and some tape would reduce infiltration to 0.4 ach.

4. PEAR Database

The Program for the Energy Analysis of Residences (PEAR) is a model developed at LBL using the results of thousands of building simulation runs of DOE-2 (EAP 1987). It relies on regression equations derived from DOE-2 runs to quickly estimate heating and cooling energy use for single-family residential dwellings. At the time the work for this report was undertaken, PEAR only existed in a form that made multiple parametric runs difficult and time-consuming to undertake. To avoid this problem, we consulted the database of DOE-2 runs used to create the regressions in PEAR. A "batch" version of PEAR has recently become available and will be used in the future to validate the database of DOE-2 runs.

Tables 15 to 25 show the PEAR database entries for the selected cities and prototypes (Table 14 contains the key to Tables 15-25).[7] These tables contain a base case heating and cooling load, and changes from that base case value associated with installation of given levels of thermal integrity improvements. For example, the prototype for Region 1 (New England) with a floor area of 2240 square feet, no insulation, single-paned windows, and an air-exchange-rate of 0.7 ach, has a base case heating load of 192 MMBtus/year. If R-30 ceiling installation is installed, the annual heating load will be reduced by 37.49 MMBtus/year, to 154.5 MMBtus/year. Each set of measures is assigned a heating and cooling load by subtracting the entries for each measure from the base case loads. Heating and cooling loads for buildings with insulation levels between those in the database can be calculated using interpolation.

To adjust to different floor areas, multiply heating and cooling loads and savings by the appropriate multipliers from Appendix D. These multipliers crudely account for differential changes in the surface area to volume ratio of the home. The new batch version of PEAR more accurately accounts for differences in floor area, and should be used in the future, except when less precision is acceptable.

B. OUTPUTS

1. Cost of Measures

Tables 26-30 show the results of the capital cost calculation by measure and by Federal Region. All costs are expressed in 1988 dollars per square-foot of total floor area for each prototype. Variations in costs per square-foot between regions can occur because of differences in labor and materials costs, or because of differences in prototypes. These costs should be scaled either linearly with the floor area (for ceiling insulation, crawl space or basement floor insulation, and window[8] measures) or with the square root of the floor area (for slab edge insulation, wall insulation, and infiltration measures).

Ceiling insulation

Table 26 shows the cost of blown-ceiling insulation, for insulation levels of R-11 to R-60. These costs vary regionally by a factor of two for R-11 applications, and by more than a factor of two and a half for R-60 applications. Blown insulation was assumed because it is uniformly

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[7] The PEAR database assumes that the temperature is set back at night from 70 degrees F to 60 degrees F from 11 PM to 7Am during the heating season.

[8] Window options scale linearly with floor area because we assume that window area is a fixed percentage (10%) of floor area.

cheaper than fiberglass batt insulation. This difference in cost is largest for high R values, and smallest for installation of low R values, which indicates that the variable cost of installing blown insulation is lower than that for installing batt insulation.

Wall insulation

Table 27 shows the cost of wall insulation, for insulation levels of R-11 to R-27.[9] Ceiling insulation costs vary much more by region than these costs. Wall insulation costs for R-11 and R-19 levels assume standard stud construction (2x4, 16" on-center for R-11, 2x6, 24" on-center for R-19). The R-19 wall insulation costs include the incremental costs of 2x6 studs. R-27 insulation levels are assumed to be achieved using R-19 stud construction plus R-8 Foamplas exterior sheathing.

Floor insulation

Table 28 shows the cost of floor joist insulation (batts), for insulation levels of R-11 to R-30 (for those prototypes that have basements or crawlspaces) or from R-5, 2ft to R-10, 4ft (for slab prototypes).[10]

Windows

Table 29 shows the installation cost for various types of windows. "Standard" (as opposed to "premium") windows have been used in all cases. Argon-filled, triple-glazed, low emissivity (low-e) windows are assumed to have a U-value of 0.2 and to have the same cost as indicated in the NAHB cost database for argon-filled triple pane windows (i.e., the low-emissivity coatings are assumed to be obtained for free). This assumption was justified in 1989 because several manufacturers were converting large segments of their production lines to produce argon-filled low-e windows, which would allow economies-of-scale to reduce costs. As noted below, window technologies have advanced significantly since the mid-1980s, and even the assumption that low-e coatings are free yields costs that are too high. Appendix B describes in detail the procedure for calculating heating and cooling load savings for argon-filled, triple glazed, low-e windows.

Infiltration

Table 30 shows the cost of installing a Tyvek infiltration barrier in each prototype. This cost includes the cost of installation, and the cost of tape to seal the barrier around doors, windows, and elsewhere. We assumed that the amount of tape (in linear feet) needed is 50% greater than the number of linear feet around windows and doors. See Table 11 for the length of window and door perimeters for each of the prototypes used in the analysis.

2. *Whole-House Heating and Cooling Loads*

Appendix A contains an abridged database of heating and cooling loads and associated capital costs for the U.S. as a whole, using the 2240 square foot standard DOE-2 prototype. The measures are independent, so that the change in heating or cooling loads from each measure can be derived from this Appendix.

9 The NAHB data do not distinguish between batt and blown insulation in exterior walls.

10 R-5, 2ft means R-5 exterior insulation is applied to the edge of the slab to a depth of 2ft.

IV. THERMAL INTEGRITY OF CURRENT PRACTICE BUILDINGS

A. INPUTS

1. Thermal Integrity Characteristics

Table 31 shows the thermal integrity characteristics of new, single-family dwellings heated by electricity, gas, and heat pumps, by Federal Region and nationally in 1987. These characteristics were derived by calculating weighted averages from the NAHB 1987 Builder's Survey, using 1987 housing starts by state. All buildings with infiltration barriers were assumed to reach 0.4 ach, and all those without are assumed to have infiltration rates of 0.7 ach.

B. OUTPUTS

1. Whole-House Heating and Cooling Loads

Table 32 shows heating and cooling loads for typical new buildings in 1987 by the ten Federal Regions. The absolute loads (in MMBtus), which reflect the building prototype characteristics from Table 31, were calculated using Tables 15-25 (through interpolation), the floor areas in Table 12, and the floor area multipliers in Appendix D. These loads vary substantially because of differences in climate, thermal integrity levels, floor area, and surface to volume ratios.

2. Whole-House Energy Use

Table 33 converts the heating and cooling loads in Table 32 into energy use, using the assumptions for space conditioning system efficiencies shown in Table 33. These efficiencies correspond to efficiency standards currently or soon to be in effect.

3. Whole-House Energy Costs

Table 34 converts the heating and cooling energy use in Table 33 into annual fuel costs, using 1987 weighted average prices for electricity and natural gas by Federal Region and nationally. These prices have been converted to 1988 dollars using the U.S. consumer price index.

In many cases, electricity prices for electric heating customers are lower than regional average prices because of promotional rates for these customers. Electric rates for air-conditioning customers are usually higher than the regional average because generating costs are higher in the summer than in the winter. Neither of these effects is accounted for in Tables 34 and 35, because no data exist to estimate their magnitudes. Lower rates for electric heating would reduce the cost effectiveness of switching to gas, but would leave intact the relative ranking of electric resistance and heat pump heating.

Table 34 shows that electric resistance heating[11] results in higher annual expenditures for energy than either gas heating or heat pumps. Whether one heating fuel is more cost effective than another depends on the relative capital costs of the heating systems, which have not been analyzed in this report. Without knowing these capital-cost relationships, we can derive from Table 34 the allowable increase in heating system capital cost per square-foot for cost-effective switching from electric resistance to gas heating or heat pumps in 1987 current practice homes. This allowable increase is simply the present value (PV) of heating fuel costs for electric resistance heating minus the PV of heating fuel costs for gas or HP heating.

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[11] In general, electric resistance baseboard heating is both more efficient than central electric furnaces (because duct losses are eliminated) and less costly to install. We assume baseboard heating here.

The results of this calculation are shown in Table 35. This table shows that in all regions except for Region 9, the allowable increase in heating system capital cost is from $1500 to $16,000 for HPs, and from $2700 to almost $14,000 for gas heat. Caution must be used in interpreting these results, since gas heat is not available in all locales, gas prices may escalate more rapidly than electricity prices, and HPs may not work well in extremely cold climates. It is clear that in many new (1987) homes, electric resistance heat can have annual costs that are significantly higher than those for gas heating or HPs. Future work is needed to determine when switching to gas or HPs from electric resistance is economically justified.

V. IMPROVEMENTS AND ADDITIONS TO THIS ANALYSIS

This database can be improved by making the following changes:

(1) validating the loads database using the batch version of PEAR. This computer program would also allow expanding the number of prototypes without major additional effort.

(2) estimating costs and energy savings from advanced window technologies. The NAHB data is about five years old, and window technologies currently on the market have advanced significantly since that time. For example, a window with effective U-value (including frame effects) of about 0.2 Btus/hr/sf/^{o}F is now being sold. It uses two panes of glass, two transparent films between the glass, a low-emissivity coating, and krypton or argon-filled spaces, and costs 30-40 percent more than typical *double-paned* glass. The market has advanced rapidly, and the window costs must be assessed to ensure that the cost data reflect currently available technology;

(3) advanced wall technologies, including I-beam construction (used in Sweden) and solid-core foam walls (used in the U.S., but not included in the NAHB cost database) may reduce the costs of achieving higher insulation levels in walls. This analysis assumes that wall insulation levels beyond R-19 are achieved through use of exterior sheathing, which is relatively expensive. Few data are available on costs for these new wall technologies, but some time spent talking to manufacturers may uncover estimates of these costs;

(4) air infiltration is treated relatively simply in this study, principally because of lack of data. One option that has not been included is the use of a blower door to pressurize a house and seal leaks. The cost of this measure in existing homes is about $300, but in new homes (many of which are tract houses with identical construction) this cost may be lower. Such air sealing techniques can probably reduce natural air-exchange-rates to roughly 0.1 air changes per hour. Infiltration levels this low require use of forced ventilation systems with heat recovery, which adds additional energy use and cost, and makes estimating net energy savings difficult. Analyzing the costs and energy savings from extremely tight new houses is thus more complicated than for the comparatively simple measures considered above. In colder climates, infiltration is an extremely important source of heating load, especially in houses that have high levels of wall, ceiling, floor, and window insulation;

An additional complexity affecting infiltration rates is that of duct leakage. This effect is potentially a large one (see Koomey et al. 1991 for discussion), and it should be included as soon as measured data become available. Andrews and Modera (1991) have taken the first steps toward assessing the importance of this problem, but many unknowns remain.

(5) multifamily buildings and mobile homes have not been treated in this study, but are important to include in forecasts of energy use for new buildings. Previous studies have included work by the Northwest Power Planning Council (NPPC 1986 and 1989) for all house types,

Ritschard and Huang (1989) for multifamily building baseline energy use, and Baylon et al. (1990) for manufactured housing;

(6) the cost-effective potential energy savings by Federal Region should be calculated, but this task requires information on forecasted equipment saturations and efficiencies by Federal Region;

(7) the shell costs and heating/cooling loads must be incorporated into LBL-REM;

(8) the number of prototypes should be expanded to roughly three per region to capture the vast majority of all new single-family homes in the U.S. Such an expansion would be a difficult, but useful task;

(9) the use of highly insulated shells and advanced infiltration reduction allows capital cost savings from heating and cooling systems. For example, to condition a superinsulated, "low-energy" house requires only a few electric resistance heaters and room air conditioners, which have low capital costs. Ducting is eliminated, which saves money. The net cost of efficiency can be affected by such savings, which need to be investigated in the U.S. context. EPRI (1987) has completed the first part of that task, by calculating capital costs of heating and cooling equipment of various types as a function of heating and cooling load. The load characteristics of the buildings analyzed in our study could then be used to estimate the capital cost savings (if any) from achieving high insulation levels.

(10) a careful comparison should be made between the NAHB cost database, and the costs calculated in other studies of efficiency improvements in new single-family buildings. These studies include EPRI (1987), Eto et al. (1986), Hunn et al. (1986), Krause et al. 1987, and NPPC (1986 and 1989). All of these analyses (except for EPRI 1987) are based on regional or state-level data, which complicates comparisons with the national database;

VI. CONCLUSIONS

This paper describes a federal-region-level database of capital costs and heating and cooling loads associated with new single-family detached dwellings with various insulation levels. Both the costs and insulation characteristics of new homes in 1987 were derived from data obtained from the National Association of Homebuilders, and aggregated to 10 Federal Regions for use in assessing current building practice for these dwellings. A database supporting a regression-based energy model (PEAR) was used to estimate heating and cooling loads for current construction materials and for a variety of energy conservation measures affecting ceiling insulation, wall insulation, foundation insulation, and windows. This paper analyzes current costs for space conditioning in new 1987 dwellings, and compares the costs in homes using electric resistance heat, gas heat, and heat pumps. A future paper will assess conservation potential in new, single-family detached homes.

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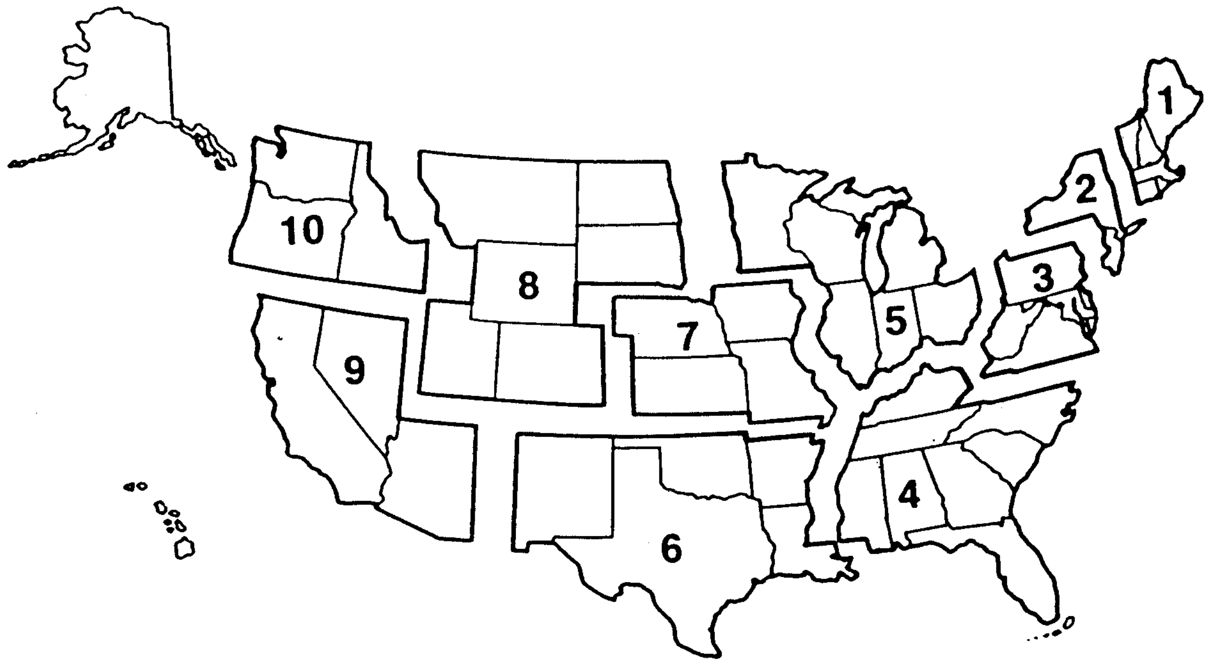
Figure 1: Federal Regions



Region 1
New England
Connecticut (CT)
Maine (ME)
Massachusetts (MA)
New Hampshire (NH)
Rhode Island (RI)
Vermont (VT)

Region 2
New York/
New Jersey
New Jersey (NJ)
New York (NY)

Region 3
Mid Atlantic
Delaware (DE)
District of Columbia (DC)
Maryland (MD)
Pennsylvania (PA)
Virginia (VA)
West Virginia (WV)

Region 4
South Atlantic
Alabama (AL)
Florida (FL)
Georgia (GA)
Kentucky (KY)
Mississippi (MS)
North Carolina (NC)
South Carolina (SC)
Tennessee (TN)

Region 5
Midwest
Illinois (IL)
Indiana (IN)
Michigan (MI)
Minnesota (MN)
Ohio (OH)
Wisconsin (WI)

Region 6
Southwest
Arkansas (AR)
Louisiana (LA)
New Mexico (NM)
Oklahoma (OK)
Texas (TX)

Region 7
Central
Iowa (IA)
Kansas (KS)
Missouri (MO)
Nebraska (NE)

Region 8
North Central
Colorado (CO)
Montana (MT)
North Dakota (ND)
South Dakota (SD)
Utah (UT)
Wyoming (WY)

Region 9
West
Arizona (AZ)
California (CA)
Hawaii (HI)
Nevada (NV)

Region 10
Northwest
Alaska (AK)
Idaho (ID)
Oregon (OR)
Washington (WA)

Table 1: NAHB and Federal Regions

NAHB Region	States Within Region
New England (1)	CT, MA, ME, NH, RI, VT
Mid Atlantic (2)	DC, DE, MD, NJ, NY, PA, VA, WV
Mid South (3)	AL, GA, KY, MS, NC, SC, TN
Florida (4)	FL
South Central (5)	AR, LA, OK, TX
Central (6)	IA, KS, NE, MO
North Central (7)	IL, IN, MI, MN, ND, OH, SD, WI
Mountain (8)	CO, ID, MT, UT, WY
Southwest (9)	AZ, NM, NV
SW Pacific (10)	CA
NW Pacific (11)	OR, WA

Federal Region	States Within Region
New England (1)	CT, MA, ME, NH, RI, VT
New York/New Jersey (2)	NY, NJ
Mid Atlantic (3)	DC, DE, MD, PA, VA, WV
South Atlantic (4)	AL, FL, GA, KY, MS, MC, SC, TN
Midwest (5)	IL, IN, MI, MN, OH, WI
Southwest (6)	AR, LA, NM, OK, TX
Central (7)	IA, KS, MO, NE
North Central (8)	CO, MT, ND, SD, UT, WY
West (9)	AZ, CA, HI, NV
Northwest (10)	AK, ID, OR, WA

(1) States within NAHB regions were not identified in the report (NAHB 1986). Association of states within regions was based on discussions with Lee Fisher at NAHB. (See Appendix B).

Table 2: Housing Starts and Number of Households by Federal Region in 1987

Region	Starts Thousands	Starts % of Total	Households Thousands	Households % of Total	Housing Starts % of Households	NAHB Bldgs (%)
1	105.8	6.5	4797	5.3	2.2	3
2	110.5	6.8	9529	10.6	1.2	7
3	165.1	10.2	9467	10.5	1.7	17
4	426	26.3	16212	18.0	2.6	28
5	232.4	14.3	17080	19.0	1.4	12
6	101.9	6.3	10198	11.3	1.0	9
7	61.8	3.8	4563	5.1	1.4	2
8	36	2.2	2764	3.1	1.3	4
9	323.2	19.9	12058	13.4	2.7	15
10	58.1	3.6	3367	3.7	1.7	2
Nat'l.	1620.8	100	90035	100	1.8	100

(1) Source: Census (1989) for 1987 starts and households.
(2) "NAHB Bldgs" are the buildings surveyed in NAHB (1989) expressed as a percent of total.

Table 3: Housing Units by Type (Number of Units in Millions or Percent of Total)

House Type	Millions		Percent	
	Existing 1987	Built 1980-1987	Existing 1987	Built 1980-1987
SFD	55.2	5.8	60.9	52.7
SFA	5.3	1.3	5.9	11.8
MF (2-4 units)	10.1	0.6	11.1	5.5
MF (>4 units)	14.9	2.1	16.5	19.1
MH	5.1	1.2	5.6	10.9
Total	90.6	11.0	100	100

(1) Source: RECS 1987 (US DOE 1989a).

Table 4: Respondents and Number of Units Built by Fuel and House Type -- Respondents (Units Built) [Buildings Built]

House Type	Electric	Natural Gas	Oil	HP
SF Detached	347 (5111)	1163 (22858)	256 (1476)	818 (18808)
SF Attached	52 (3035)	201 (8641)	25 (416)	190 (9314)
MF Low Rise	31 (8282) [771]	44 (6454) [691]	2 (50) [3]	19 (3762) [360]
MF Low Rise Units/Building	10.7	9.34	16.7	10.5

(1) Source: NAHB 1989

Table 5: Weather Choices

Federal Region	Closest City To Mean	Mean Weather HDD	Mean Weather CDD	City We Used	Weather We Used HDD	Weather We Used CDD
1	Boston, MA	5732	675	Boston, MA	5620	661
2	New York, NY	5414	913	New York, NY	5033	1022
3	Philadelphia, PA	5024	1000	Philadelphia, PA	4864	1103
4	Jackson, MS	2349	2330	Charleston, SC	2146	2077
5	Detroit/Ann Arbor, MI	6387	757	Chicago, IL	6125	923
6	Shreveport, LA	2138	2600	Dallas/Fort Worth, TX	2335	2670
7	Kansas City, MO	5328	1311	Kansas City, MO	5357	1283
8	Denver/Boulder, CO	6044	703	Denver, CO	6016	625
9	Los Angeles, CA	2107	934	Los Angeles, CA	1818	614
10	Seattle/Tacoma, WA	5183	212	Seattle, WA	5184	128
US	Baltimore, MD	4392	1194	Washington, DC	5008	940

(1) Both Heating Degree Days and Cooling Degree Days are 65^{O}F base.
(2) Population weather derived from a computer program described in Andersson, et al. (1986).

Table 6: Total Single-Family Detached Buildings by Foundation Type from NAHB survey										
	Federal Region									
	1	2	3	4	5	6	7	8	9	10	Nat'l.
One Story											
Units Built	76	1321	1015	8866	1745	2058	446	542	4663	373	21105
Basement	61	480	648	356	1037	96	420	309	20	18	3445
Crawl Space	5	148	317	1093	318	272	24	198	960	351	3686
Slab	3	693	50	7417	390	1690	2	35	3683	4	13967
Two Story											
Units Built	422	1256	5776	4008	2907	1604	477	644	2525	439	20058
Basement	402	811	5009	1147	2235	110	475	516	205	57	10967
Crawl Space	7	182	359	1574	273	119	2	42	741	374	3673
Slab	4	263	408	1287	399	1375	0	86	1579	8	5409
Bi Level											
Units Built	133	71	412	177	342	261	75	119	55	57	1702
Split Level											
Units Built	14	21	483	226	718	116	72	392	167	116	2325
Total	645	2669	7686	13277	5712	4039	1070	1697	7410	985	45190

(1) Source: Survey responses from NAHB (1989).

Table 7: Prototype Choices Based on NAHB Data			
Federal Region	Number of Stories	Foundation Type	Percent of Survey Captured by Prototype
1	Two	Basement	64%
2	Two	Basement	30%
3	Two	Basement	65%
4	One	Crawl Space (1)	8%
5	Two	Basement	39%
6	One	Slab	42%
7	Two	Basement	44%
8	Two	Basement	30%
9	One	Slab	50%
10	Two	Crawl Space	38%
Weighted average			36%
US	Two	Basement (2)	24%

(1) The most numerous foundation type for Region 4 is a one-story slab; however, the PEAR database of DOE-2 runs only has a one-story crawlspace for Charleston, SC, which is the next closest weather city to Jackson, MS.
(2) The most numerous foundation type for the nation is a one-story slab; however, the PEAR database of DOE-2 runs did not have this prototype for Washington, DC. Therefore, we used the next most numerous foundation type (two-story basement).

Table 8: Foundation Types by Main Heating Fuel for Comparison to Prototype Choices				
	Electricity	Natural Gas	Heat Pump	Total (1)
1	2S Bsmt	2S Bsmt	2S Bsmt	2S Bsmt
2	1S Slab	2S Bsmt	1S Bsmt	2S Bsmt
3	2S Bsmt	2S Bsmt	2S Bsmt	2S Bsmt
4	1S Slab	2S Bsmt	1S Slab	1S Crawl
5	1S Bsmt	2S Bsmt	1S Slab	2S Bsmt
6	1S Slab	2S Slab	1S Slab	1S Slab
7	1S Bsmt	2S Bsmt	2S Bsmt	2S Bsmt
8	2S Slab	2S Bsmt	(2)	2S Bsmt
9	1S Slab	1S Slab	1S Slab	1S Slab
10	1S Crawl	2S Crawl	1S Crawl	2S Crawl
Nat'l.	1S Slab	2S Bsmt	1S Slab	2S Bsmt

(1) Total is taken from Table 7.
(2) There were no HP houses in 1987 NAHB sample in Region 8.

Table 9: Percent of Survey Captured by Prototype Choice (by Fuel Type)				
	Electricity	Gas	HP	Total
1	57%	64%	100%	64%
2	19%	40%	21%	30%
3	41%	77%	68%	65%
4	3%	10%	9%	8%
5	15%	40%	33%	39%
6	42%	42%	40%	42%
7	39%	45%	46%	44%
8	12%	33%	(2)	30%
9	74%	33%	73%	50%
10	17%	51%	12%	38%
Weighted average	27%	38%	37%	36%
U.S.	16%	28%	22%	24%

(1) Total is taken from Table 7.
(2) There were no HP houses in 1987 NAHB sample in Region 8.

Table 10: Single-Family Detached Buildings by Window Type (All Fuel Types)

	Federal Region										
Number	1	2	3	4	5	6	7	8	9	10	U.S.
Aluminum	104	255	510	3001	519	2806	416	875	2321	1879	12686
Wood	4996	2504	4762	6097	5644	1222	3082	3023	478	2637	34445
Other	0	37	29	104	36	270	5	3	0	83	567
Total	5100	2796	5301	9202	6199	4298	3503	3901	2799	4599	47698
% of Total											
Aluminum	2	9	10	33	8	65	12	22	83	41	27
Wood	98	90	90	66	91	28	88	77	17	57	72
Other	0	1	1	1	1	6	0	0	0	2	1
Total %	100	100	100	100	100	100	100	100	100	100	100
Choice	W	W	W	W	W	A	W	W	A	W	W

(1) Source: Survey responses from NAHB 1989

Table 11: Characteristics of DOE-2 Prototypes by Federal Region

Federal Region	Prototype	Floor Area (FA-sf)	Window Area % of FA	Wall Area(1) % of FA	Insulated Floor or Ceiling Area % of FA	Slab Edge(2) Area % of FA 2 ft	Slab Edge(2) Area % of FA 4 ft	Window Type	Window and Door Perimeters ft
1	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
2	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
3	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
4	1S Crawl	1540	10	74.0	100	-	-	Wood	167.5
5	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
6	1S Slab	1540	10	74.0	100(3)	21.56	43.1	Alum (4)	167.5
7	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
8	2S Bsmt	2240	10	85.6	50	-	-	Wood	259
9	1S Slab	1540	10	74.0	100(3)	21.56	43.1	Alum (4)	167.5
10	2S Crawl	2240	10	85.6	50	-	-	Wood	259
US	2S Bsmt	2240	10	85.6	50	-	-	Wood	259

(1) Excludes door area (2 doors) of 35sf (17.5sf each) and window area.
(2) Foundation perimeter is 28 x 55 = 166 ft for 1S house, and 28 x 40 = 136 ft for 2S house. "2 ft" and "4 ft" signify depth of slab insulation in feet below ground.
(3) Prototypes for regions 6 and 9 are slab homes, which means that this column only indicates the insulated ceiling area as a % of floor area. The slab insulation options are indicated in the next two columns.
(4) Aluminum windows are assumed not to have thermal breaks in them, because only about one-third of aluminum windows installed in Regions 6 and 9 have such a feature (according to NAHB 1989).

Table 12: Average Floor Areas of New Single-Family Dwellings 1987 (sf)											
	Federal Region										
	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	2207	1803	1788	1980	2063	1752	1987	1514	1817	1557	1848
Natural Gas	2200	2235	2433	2196	1963	2193	1934	1913	1782	1960	2045
HP	2013*	2887	2242	1852	2008	1800	2411	2013*	1783	1805	2013
Average	2195(1)	2482	2206	1957	1968	2058	1960	1859(1)	1784	1854	2011

(1) Region 1 HP is 3855sf, which is surely an outlier. It has been replaced by the national average value, as has Region 8 (no HP in sample).
(2) Source: NAHB (1989).

Table 13: TI Measures for New Single-Family Detached Dwellings					
Ceiling	Wall	Glazing	Floor		Infiltration
			Crawl+Bsmt	Slab	
R	R	Panes	R	-	ach
0	0	1	0	R0	0.7
11	11	2	11	R5-2ft	0.4
19	19	3	19	R10-4ft	-
30	27	Low E,Ar	-	-	-
49	-	-	-	-	-
60	-	-	-	-	-

Table 14: Energy Use Database for the Ten Federal Regions Derived from the PEAR Database--Key to Tables 15-25							
Base Heating Load (kBtus/sf)							
Base Cooling Load (kBtus/sf)							
Ceiling Insulation (HTG)	R0	R11	R19	R30	R38	R49	R60
Ceiling Insulation (CLG)	R0	R11	R19	R30	R38	R49	R60
Wall Insulation (HTG)	R0	R11	R19	R27			
Wall Insulation (CLG)	R0	R11	R19	R27			
Foundation (HTG)(1)	R0	R11	R19	R5,2ft	R10,4ft		
Foundation (CLG)(1)	R0	R11	R19	R5,2ft	R10,4ft		
Infiltration (ACH-HTG)	1	0.7	0.4				
Infiltration (ACH-CLG)	1	0.7	0.4				
Windows (#Panes-HTG)	1	2	3	3+Argon+Low-E			
Windows (#Panes-CLG)	1	2	3	3+Argon+Low-E			

(1) Foundation insulation is either floor insulation (for crawl and basement homes) or slab edge insulation (for slab homes). Slab edge insulation is characterized by its R-value and the number of vertical feet below ground level that the insulation covers.

Table 15: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 1

Base Heating Load (MMBtus)	192.017						
Base Cooling Load (MMBtus)	17.924						
Ceiling Insulation (HTG)	0	-31.5	-34.84	-37.49	-38.45	-39.25	-39.75
Ceiling Insulation (CLG)	0	-2.28	-2.51	-2.60	-2.63	-2.68	-2.72
Wall Insulation (HTG)	0	-33.57	-40.69	-44.92			
Wall Insulation (CLG)	0	-1.38	-1.69	-1.87			
Foundation (HTG)	0	-8.17	-10.21				
Foundation (CLG)	-0.3	-0.06	0				
Infiltration (HTG)	0	-13.32	-26.64				
Infiltration (CLG)	0	-0.15	-0.3				
Windows (HTG)	-25.39	-37.08	-41.47	-44.15			
Windows (CLG)	-5.95	-6.67	-6.97	-7.15			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Boston, MA.

Table 16: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 2

Base Heating Load (MMBtus)	150.348						
Base Cooling Load (MMBtus)	27.514						
Ceiling Insulation (HTG)	0	-25.01	-27.66	-29.77	-30.53	-31.18	-31.6
Ceiling Insulation (CLG)	0	-3.66	-3.96	-4.09	-4.13	-4.21	-4.23
Wall Insulation (HTG)	0	-26.46	-32.11	-35.47			
Wall Insulation (CLG)	0	-2.36	-2.79	-3.08			
Foundation (HTG)	0	-6.54	-8.18				
Foundation (CLG)	0	-0.29	-0.37				
Infiltration (HTG)	0	-11.07	-22.14				
Infiltration (CLG)	-0.69	-0.35	0				
Windows (HTG)	-18.86	-28.04	-31.5	-33.61			
Windows (CLG)	-8.81	-9.49	-9.96	-10.25			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of New York, NY.

Table 17: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 3

Base Heating Load (MMBtus)	168.576						
Base Cooling Load (MMBtus)	33.18						
Ceiling Insulation (HTG)	0	-27.75	-30.71	-33.04	-33.89	-34.61	-35.06
Ceiling Insulation (CLG)	0	-4.6	-4.93	-5.21	-5.36	-5.44	-5.44
Wall Insulation (HTG)	0	-29.17	-35.39	-39.09			
Wall Insulation (CLG)	0	-2.8	-3.35	-3.73			
Foundation (HTG)	0	-7.21	-9.01				
Foundation (CLG)	0	-0.69	-0.86				
Infiltration (HTG)	0	-12.2	-24.39				
Infiltration (CLG)	-0.25	-0.13	0				
Windows (HTG)	-21.71	-31.34	-35.12	-37.43			
Windows (CLG)	-9.48	-10.03	-10.16	-10.24			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Philadelphia, PA.

Table 18: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 4

Base Heating Load (MMBtus)	69.683						
Base Cooling Load (MMBtus)	62.372						
Ceiling Insulation (HTG)	0	-15.24	-17.04	-18.41	-18.91	-19.33	N/A
Ceiling Insulation (CLG)	0	-7.44	-8.43	-9.13	-9.37	-9.5	N/A
Wall Insulation (HTG)	0	-7.33	-8.91	-9.81			
Wall Insulation (CLG)	0	-2.43	-2.84	-3.09			
Foundation (HTG)	0	-12.88	-14.67				
Foundation (CLG)	0	-7.52	-8.28				
Infiltration (HTG)	0	-4.12	-8.24				
Infiltration (CLG)	0	-1.1	-2.2				
Windows (HTG)	-4.73	-7.43	-8.46	-9.09			
Windows (CLG)	-12.59	-13.83	-14.51	-14.93			

Notes:
(1) Prototype is one-story crawlspace (1540 sf).
(2) Weather is that of Charleston, SC.

Table 19: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 5

Base Heating Load (MMBtus)	196.906						
Base Cooling Load (MMBtus)	22.437						
Ceiling Insulation (HTG)	0	-31.98	-35.41	-38.13	-39.13	-39.97	-40.51
Ceiling Insulation (CLG)	0	-3.38	-3.74	-4.03	-4.13	-4.22	-4.3
Wall Insulation (HTG)	0	-34	-41.3	-45.68			
Wall Insulation (CLG)	0	-2.36	-2.85	-3.06			
Foundation (HTG)	0	-8.4	-10.5				
Foundation (CLG)	0	-0.11	-0.14				
Infiltration (HTG)	0	-14.23	-28.46				
Infiltration (CLG)	-0.04	-0.02	0				
Windows (HTG)	-25.53	-36.21	-40.61	-43.30			
Windows (CLG)	-7.08	-7.81	-8.26	-8.54			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Chicago, IL.

Table 20: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 6

Base Heating Load (MMBtus)	60.355						
Base Cooling Load (MMBtus)	74.007						
Ceiling Insulation (HTG)	0	-16.02	-17.81	-19.21	-19.72	N/A	N/A
Ceiling Insulation (CLG)	0	-11.05	-12.55	-13.82	-14.18	N/A	N/A
Wall Insulation (HTG)	0	-7.61	-9.25	-10.19			
Wall Insulation (CLG)	0	-4.39	-5.3	-5.88			
Foundation (HTG)	0	-5.59	-7.09				
Foundation (CLG)	0	-4.51	-5.9				
Infiltration (HTG)	0	-4.36	-8.72				
Infiltration (CLG)	0	-2.3	-4.61				
Windows (HTG)	-3.48	-6.23	-7.36	-8.05			
Windows (CLG)	-13.47	-15.4	-16.4	-17.01			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Fort Worth, TX.

Table 21: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 7

Base Heating Load (MMBtus)	162.562						
Base Cooling Load (MMBtus)	50.61						
Ceiling Insulation (HTG)	0	-26.77	-29.63	-31.86	-32.67	-33.36	-33.8
Ceiling Insulation (CLG)	0	-6.28	-6.9	-7.42	-7.55	-7.71	-7.84
Wall Insulation (HTG)	0	-27.98	-33.91	-37.44			
Wall Insulation (CLG)	0	-4.56	-5.84	-6.23			
Foundation (HTG)	0	-6.75	-8.44				
Foundation (CLG)	0	-0.82	-1.03				
Infiltration (HTG)	0	-11.94	-23.89				
Infiltration (CLG)	0	-1.32	-2.64				
Windows (HTG)	-20.79	-29.67	-33.26	-35.45			
Windows (CLG)	-12.26	-13.99	-14.95	-15.54			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Kansas City, MO.

Table 22: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 8

Base Heating Load (MMBtus)	173.821						
Base Cooling Load (MMBtus)	20.023						
Ceiling Insulation (HTG)	0	-30.51	-33.74	-36.3	-37.24	-38.03	-38.54
Ceiling Insulation (CLG)	0	-4.26	-4.72	-5.03	-5.16	-5.28	-5.38
Wall Insulation (HTG)	0	-31.83	-38.66	-42.73			
Wall Insulation (CLG)	0	-2.41	-2.94	-3.08			
Foundation (HTG)	0	-7.9	-9.87				
Foundation (CLG)	-0.04	-0.01	0				
Infiltration (HTG)	0	-11.88	-23.76				
Infiltration (CLG)	0	-0.13	-0.25				
Windows (HTG)	-21.03	-31.26	-35.34	-37.83			
Windows (CLG)	-6.49	-7.3	-7.74	-8.01			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Denver, CO.

Table 23: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 9							
Base Heating Load (MMBtus)	36.517						
Base Cooling Load (MMBtus)	5.96						
Ceiling Insulation (HTG)	0	-10.65	-11.81	-12.6	-12.87	N/A	N/A
Ceiling Insulation (CLG)	0	-1.96	-2.17	-2.26	-2.3	N/A	N/A
Wall Insulation (HTG)	0	-9.47	-10.75	-10.75			
Wall Insulation (CLG)	0	-0.58	-0.66	-0.66			
Foundation (HTG)	0	-3.05	-3.76				
Foundation (CLG)	-0.22	-0.06	0				
Infiltration (HTG)	0	-2.35	-4.7				
Infiltration (CLG)	-0.13	-0.07	0				
Windows (HTG)	-0.73	-2.33	-2.91	-3.26			
Windows (CLG)	-1.84	-1.95	-2.02	-2.06			

Notes:
(1) Prototype is one-story slab (1540 sf).
(2) Weather is that of Los Angeles, CA.

Table 24: Changes in Heating and Cooling Load for Base Case Houses: Federal Region 10							
Base Heating Load (MMBtus)	194.65						
Base Cooling Load (MMBtus)	6.969						
Ceiling Insulation (HTG)	0	-28.95	-32.07	-34.56	-35.46	-36.24	N/A
Ceiling Insulation (CLG)	0	-1.12	-1.25	-1.33	-1.36	-1.39	N/A
Wall Insulation (HTG)	0	-30.9	-37.65	-41.64			
Wall Insulation (CLG)	0	-0.69	-0.83	-0.87			
Foundation (HTG)	0	-22.23	-25.45				
Foundation (CLG)	0	-0.89	-1.01				
Infiltration (HTG)	0	-12.91	-25.82				
Infiltration (CLG)	0	-0.07	-0.14				
Windows (HTG)	-22.44	-32.37	-36.44	-38.93			
Windows (CLG)	-1.82	-2.07	-2.19	-2.26			

Notes:
(1) Prototype is two-story crawlspace (2240 sf).
(2) Weather is that of Seattle, WA.

Table 25: Changes in Heating and Cooling Load for Base Case Houses: National

Base Heating Load (MMBtus)	131.703						
Base Cooling Load (MMBtus)	47.317						
Ceiling Insulation (HTG)	0	-21.89	-24.24	-26.13	-26.83	-27.42	-27.8
Ceiling Insulation (CLG)	0	-6.16	-6.76	-7.26	-7.46	-7.56	-7.7
Wall Insulation (HTG)	0	-23.02	-28.05	-31.09			
Wall Insulation (CLG)	0	-4.15	-5.06	-5.68			
Foundation (HTG)	0	-5.76	-7.19				
Foundation (CLG)	0	-0.86	-1.07				
Infiltration (HTG)	0	-10.57	-21.15				
Infiltration (CLG)	0	-0.95	-1.89				
Windows (HTG)	-15.37	-22.68	-25.66	-27.48			
Windows (CLG)	-12.05	-13.44	-14.25	-14.75			

Notes:
(1) Prototype is two-story basement (2240 sf).
(2) Weather is that of Washington, DC.

Table 26: Blown Ceiling Insulation Costs (88$/sf of Total Floor Area)

Federal Region	R11	R19	R30	R38	R49	R60
1	0.16	0.23	0.40	0.44	0.63	0.77
2	0.16	0.22	0.31	0.39	0.46	0.54
3	0.16	0.22	0.31	0.39	0.46	0.54
4	0.25	0.39	0.58	0.73	0.90	1.09
5	0.16	0.23	0.28	0.35	0.45	0.52
6	0.25	0.36	0.50	0.61	0.76	0.91
7	0.12	0.21	0.25	0.33	0.42	0.50
8	0.15	0.19	0.28	0.35	0.49	0.57
9	0.33	0.47	0.61	0.86	1.01	1.17
10	0.17	0.19	0.27	0.34	0.37	0.43
National	0.15	0.21	0.29	0.37	0.46	0.54

(1) Source: NAHB (1986), weighted by 1987 housing starts by state.
(2) Costs applicable to prototypes shown in Table 11.
Scale these costs linearly with floor area, using the ratio of prototype floor area (1540 sf or 2240 sf) to the desired floor area.

Table 27: Wall Insulation Costs (88$/sf of Total Floor Area)				
Federal Region	R0	R11	R19	R27
1	0.00	0.28	0.51	1.23
2	0.00	0.32	0.48	1.03
3	0.00	0.32	0.48	1.03
4	0.00	0.21	0.43	0.87
5	0.00	0.28	0.50	1.08
6	0.00	0.24	0.44	0.88
7	0.00	0.29	0.60	1.10
8	0.00	0.28	0.52	1.09
9	0.00	0.30	0.39	1.04
10	0.00	0.31	0.50	1.08
National	0.00	0.29	0.50	1.09

(1) Source: NAHB (1986), weighted by 1987 housing starts by state.
(2) Costs applicable to prototypes shown in Table 11.
Scale these costs using the square root of the quantity (prototype floor area (1540 sf or 2240 sf) divided by desired floor area).

Table 28: Floor Insulation Costs (88$/sf of Total Floor Area)					
Federal Region	R0	R11	R19	R5,2ft	R10,4ft
1	0.00	0.19	0.32	n/a	n/a
2	0.00	0.20	0.28	n/a	n/a
3	0.00	0.20	0.28	n/a	n/a
4	0.00	0.35	0.54	n/a	n/a
5	0.00	0.18	0.30	n/a	n/a
6	n/a	n/a	n/a	0.26	0.67
7	0.00	0.18	0.28	n/a	n/a
8	0.00	0.18	0.30	n/a	n/a
9	n/a	n/a	n/a	0.26	0.67
10	0.00	0.22	0.32	n/a	n/a
National	0.00	0.18	0.28	n/a	n/a

(1) Source: NAHB (1986), weighted by 1987 housing starts by state.
(2) Costs applicable to prototypes shown in Table 11.
Scale basement or crawl space insulation costs linearly with floor area, using the ratio of prototype floor area (1540 sf or 2240 sf) to the desired floor area. Scale slab edge insulation costs (regions 6 and 9) using the square root of the quantity (prototype floor area (1540 sf or 2240 sf) divided by desired floor area).

Table 29: Incremental Additional Window Costs (88$/sf of Total Floor Area)				
Federal Region	1 Pane	2 Panes	3 Panes	3 Panes Low E, Argon
1	0.00	0.37	0.49	0.75
2	0.00	0.38	0.50	0.78
3	0.00	0.38	0.50	0.78
4	0.00	0.40	0.52	0.80
5	0.00	0.23	0.35	0.59
6	0.00	0.23	0.30	0.50
7	0.00	0.22	0.34	0.56
8	0.00	0.36	0.48	0.76
9	0.00	0.25	0.33	0.54
10	0.00	0.38	0.54	0.93
National	0.00	0.35	0.47	0.76

(1) Source: NAHB (1986), weighted by 1987 housing starts by state.
(2) Costs applicable to prototypes shown in Table 11. Scale these costs linearly with floor area, using the ratio of prototype floor area (1540 sf or 2240 sf) to the desired floor area. Window area scales linearly with floor area because we assume that window area is a fixed percentage (10%) of floor area.

Table 30: Infiltration Reduction Costs (88$/sf of Total Floor Area)		
Federal Region	0.7 ach	0.4 ach
1	0.00	0.24
2	0.00	0.24
3	0.00	0.24
4	0.00	0.33
5	0.00	0.24
6	0.00	0.33
7	0.00	0.24
8	0.00	0.24
9	0.00	0.33
10	0.00	0.24
National	0.00	0.24

(1) Source: NAHB (1986), weighted by 1987 housing starts by state. Costs applicable to prototypes shown in Table 11.
(2) Costs applicable to prototypes shown in Table 11. Scale these costs using the square root of the quantity [prototype floor area (1540 sf or 2240 sf) divided by desired floor area].

Table 31: Current Practice - New Single-Family Detached Dwellings 1987

Ceiling Insulation (R)

Federal Region	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	23.0	32.3	31.5	13.8	27.9	19.5	22.3	31.2	38.0	33.7	23.5
Gas	22.7	24.3	29.4	25.2	29.6	23.4	27.3	28.1	24.3	28.7	26.3
Heat Pump	24.7	26.0	27.7	24.2	27.0	23.2	32.8	26.0	27.0	32.6	26.0

Wall Insulation (R)

Federal Region	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	15.9	13.5	14.7	9.4	15.7	12.0	16.2	14.1	11.0	17.0	12.7
Gas	16.1	13.3	12.9	11.4	14.0	12.3	13.7	12.9	11.7	12.7	13.0
Heat Pump	12.6	14.0	12.7	9.4	14.1	15.6	14.9	11.6	11.7	15.7	11.6

Floor Insulation (R)

Federal Region	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	15.3	15.3	15.3	15.3	15.3	3.8	15.3	15.3	3.8	15.3	15.3
Gas	11.7	11.7	11.7	11.7	11.7	1.9	11.7	11.7	1.9	11.7	11.7
Heat Pump	13.4	13.4	13.4	13.4	13.4	1.8	13.4	13.4	1.8	13.4	13.4

Infiltration (ACH)

Federal Region	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	0.51	0.65	0.44	0.60	0.56	0.49	0.60	0.66	0.68	0.55	0.54
Gas	0.49	0.59	0.62	0.67	0.53	0.50	0.65	0.65	0.62	0.46	0.59
Heat Pump	0.41	0.48	0.62	0.64	0.65	0.63	0.54	0.61	0.61	0.49	0.61

Windows (Number of Panes)

Federal Region	1	2	3	4	5	6	7	8	9	10	Nat'l.
Electric	1.94	1.93	1.87	1.47	2.17	1.56	2.01	2.03	1.54	2.01	1.62
Gas	1.95	1.94	1.82	1.60	2.00	1.48	2.01	2.06	1.84	2.01	1.82
Heat Pump	1.99	1.34	1.96	1.48	1.96	1.92	2.00	1.62	1.90	2.01	1.62

(1) Regions 6 and 9 are slab homes. Floor insulation = slab edge insulation for these prototypes.
NAHB (1989) gives no information on depth of slab insulation.
(2) HPs in Region 8 have been assigned national average values because of inadequate size of sample (two units).
(3) Source: NAHB (1989).

Table 32: Heating and Cooling Loads of New Single-Family Houses 1987							
Federal Region	Fuel Type	Heating Load MMBtu/yr	Heating Load kBtu/sf/yr	Index	Cooling Load MMBtu/yr	Cooling Load kBtu/sf/yr	Index
1	Electric	42.46	19.24	1.31	6.15	2.79	0.28
	Gas	46.28	21.04	1.27	6.51	2.96	0.31
	HP	42.49	21.11	1.26	6.46	3.21	0.33
2	Electric	42.29	23.45	1.60	10.70	5.94	0.60
	Gas	41.83	18.72	1.13	10.87	4.86	0.51
	HP	37.30	12.92	0.77	10.94	3.79	0.39
3	Electric	32.80	18.34	1.25	12.64	7.07	0.71
	Gas	50.38	20.71	1.25	14.17	5.82	0.61
	HP	62.56	27.90	1.66	16.02	7.15	0.74
4	Electric	17.95	9.07	0.62	26.53	13.40	1.35
	Gas	21.62	9.85	0.59	30.18	13.75	1.43
	HP	20.97	11.32	0.67	29.17	15.75	1.62
5	Electric	67.86	32.89	2.24	9.18	4.45	0.45
	Gas	73.84	37.62	2.27	9.91	5.05	0.53
	HP	69.62	34.67	2.07	8.90	4.43	0.46
6	Electric	15.01	8.57	0.58	32.78	18.71	1.89
	Gas	14.86	6.78	0.41	32.53	14.83	1.55
	HP	15.94	8.85	0.53	33.15	18.42	1.90
7	Electric	53.40	26.88	1.83	23.56	11.86	1.20
	Gas	68.33	35.33	2.13	27.57	14.25	1.49
	HP	49.08	20.36	1.21	23.09	9.58	0.99
8	Electric	42.43	28.03	1.91	4.39	2.90	0.29
	Gas	43.16	22.56	1.36	4.47	2.34	0.24
	HP	55.81	27.73	1.65	5.57	2.77	0.28
9	Electric	4.80	2.64	0.18	0.93	0.51	0.05
	Gas	6.03	3.38	0.20	1.03	0.58	0.06
	HP	6.07	3.40	0.20	1.01	0.57	0.06
10	Electric	57.78	37.11	2.53	1.82	1.17	0.12
	Gas	56.84	29.00	1.75	1.91	0.97	0.10
	HP	55.51	30.75	1.83	1.83	1.02	0.10
Natl	Electric	27.13	14.68	1.00	18.33	9.92	1.00
	Gas	33.96	16.61	1.00	19.61	9.59	1.00
	HP	33.80	16.79	1.00	19.56	9.72	1.00

(1) Index is relative to National average heating or cooling load (kBtus/sf) for a building with the same fuel type.
(2) Heating and cooling loads calculated using house characteristics from Table 31, interpolated total loads from Tables 15-25, floor area multipliers from Appendix D, and floor areas by region and heating fuel from Table 12.

Table 33: Heating and Cooling Site Energy Use of New Single-Family Houses 1987

Federal Region	Fuel Type	Heating Energy MMBtu/yr	Heating Energy kBtu/sf/yr	Heating Index	Cooling Energy MMBtu/yr	Cooling Energy kBtu/sf/yr	Cooling Index
1	Electric	42.46	19.24	1.31	2.08	0.94	0.28
	Gas	56.79	25.81	1.27	2.20	1.00	0.31
	HP	19.76	9.82	1.26	2.18	1.08	0.33
2	Electric	42.29	23.45	1.60	3.62	2.01	0.60
	Gas	51.33	22.97	1.13	3.67	1.64	0.51
	HP	17.35	6.01	0.77	3.70	1.28	0.39
3	Electric	32.80	18.34	1.25	4.27	2.39	0.71
	Gas	61.82	25.41	1.25	4.79	1.97	0.61
	HP	29.10	12.98	1.66	5.41	2.41	0.74
4	Electric	17.95	9.07	0.62	8.96	4.53	1.35
	Gas	26.53	12.08	0.59	10.20	4.64	1.43
	HP	9.75	5.27	0.67	9.85	5.32	1.62
5	Electric	67.86	32.89	2.24	3.10	1.50	0.45
	Gas	90.60	46.16	2.27	3.35	1.71	0.53
	HP	32.38	16.13	2.07	3.01	1.50	0.46
6	Electric	15.01	8.57	0.58	11.08	6.32	1.89
	Gas	18.24	8.32	0.41	10.99	5.01	1.55
	HP	7.41	4.12	0.53	11.20	6.22	1.90
7	Electric	53.40	26.88	1.83	7.96	4.01	1.20
	Gas	83.84	43.35	2.13	9.31	4.82	1.49
	HP	22.83	9.47	1.21	7.80	3.24	0.99
8	Electric	42.43	28.03	1.91	1.48	0.98	0.29
	Gas	52.96	27.68	1.36	1.51	0.79	0.24
	HP	25.96	12.90	1.65	1.88	0.94	0.28
9	Electric	4.80	2.64	0.18	0.31	0.17	0.05
	Gas	7.40	4.15	0.20	0.35	0.19	0.06
	HP	2.82	1.58	0.20	0.34	0.19	0.06
10	Electric	57.78	37.11	2.53	0.61	0.39	0.12
	Gas	69.75	35.58	1.75	0.64	0.33	0.10
	HP	25.82	14.30	1.83	0.62	0.34	0.10
Natl	Electric	27.13	14.68	1.00	6.19	3.35	1.00
	Gas	41.67	20.38	1.00	6.63	3.24	1.00
	HP	15.72	7.81	1.00	6.61	3.28	1.00

(1) Index is relative to National average heating or cooling site energy (kBtus/sf) for a building with the same type.
(2) Source: Table 32, for heating and cooling loads.
(3) Electric resistance efficiency = 100% (assumes electric baseboard); Gas efficiency = 81.5% AFUE; HP SPF = 7.32 (COP = 2.15); HP SEER = 10.1 (COP = 2.96).
(4) Cooling efficiency assumed to be that of Central Air Conditioner meeting 1992 Standards, SEER =10.1; COP = 2.96.

Table 34: Heating and Cooling Energy Costs of New Single-Family Houses 1987

Federal Region	Fuel Type	Heating Cost 1988$	Heating Cost 1988 ¢/sf/yr	Index	Cooling Cost 1988$	Cooling Cost 1988 ¢/sf/yr	Index
1	Electric	1133	51.3	1.55	55	2.5	0.33
	Gas	402	18.3	1.60	59	2.7	0.36
	HP	527	26.2	1.48	58	2.9	0.39
2	Electric	1324	73.4	2.21	113	6.3	0.83
	Gas	353	15.8	1.38	115	5.1	0.70
	HP	543	18.8	1.07	116	4.0	0.54
3	Electric	754	42.1	1.27	98	5.5	0.72
	Gas	379	15.6	1.36	110	4.5	0.62
	HP	669	29.8	1.69	124	5.5	0.75
4	Electric	376	19.0	0.57	188	9.5	1.25
	Gas	159	7.2	0.63	214	9.7	1.33
	HP	204	11.0	0.62	206	11.1	1.50
5	Electric	1633	79.2	2.38	75	3.6	0.48
	Gas	477	24.3	2.12	81	4.1	0.56
	HP	779	38.8	2.20	72	3.6	0.49
6	Electric	316	18.0	0.54	233	13.3	1.76
	Gas	93	4.2	0.37	231	10.6	1.44
	HP	156	8.7	0.49	236	13.1	1.77
7	Electric	1201	60.5	1.82	179	9.0	1.19
	Gas	390	20.2	1.76	209	10.8	1.48
	HP	513	21.3	1.21	175	7.3	0.98
8	Electric	862	57.0	1.72	30	2.0	0.26
	Gas	258	13.5	1.18	31	1.6	0.22
	HP	528	26.2	1.48	38	1.9	0.26
9	Electric	117	6.4	0.19	7.6	0.4	0.06
	Gas	40	2.2	0.20	8.5	0.5	0.06
	HP	69	3.9	0.22	8.4	0.5	0.06
10	Electric	795	51.1	1.54	8.5	0.5	0.07
	Gas	380	19.4	1.69	8.9	0.5	0.06
	HP	355	19.7	1.11	8.5	0.5	0.06
Natl	Electric	614	33.2	1.00	140	7.6	1.00
	Gas	234	11.4	1.00	150	7.3	1.00
	HP	356	17.7	1.00	149	7.4	1.00

(1) Index is relative to National average heating or cooling energy costs (cents/sf/yr) for a building with the same fuel type.
(2) Source: Table 33, for heating and cooling energy, Table B-1 for energy prices.

Table 35: Allowable Increase in Heating System Capital Costs Compared to Electric Resistance System in New Single-Family Houses 1987

Federal Region	Heating Fuel Type	Present Value Heating Cost 1988$/sf	Index	Allowable Increase in Heating System Capital Cost 1988$/sf	Allowable Increase in Heating System Capital Cost 1988$/House
1	Electric	5.44	1.00	0.00	0
	Gas	1.94	0.36	3.50	7702
	HP	2.77	0.51	2.66	5360
2	Electric	7.78	1.00	0.00	0
	Gas	1.67	0.21	6.11	13647
	HP	1.99	0.26	5.79	16702
3	Electric	4.46	1.00	0.00	0
	Gas	1.65	0.37	2.82	6853
	HP	3.16	0.71	1.31	2927
4	Electric	2.01	1.00	0.00	0
	Gas	0.77	0.38	1.24	2732
	HP	1.17	0.58	0.84	1561
5	Electric	8.39	1.00	0.00	0
	Gas	2.57	0.31	5.81	11408
	HP	4.11	0.49	4.27	8582
6	Electric	1.91	1.00	0.00	0
	Gas	0.45	0.24	1.46	3208
	HP	0.92	0.48	0.99	1788
7	Electric	6.40	1.00	0.00	0
	Gas	2.14	0.33	4.27	8250
	HP	2.26	0.35	4.15	10002
8	Electric	6.03	1.00	0.00	0
	Gas	1.43	0.24	4.61	8811
	HP	2.78	0.46	3.26	6557
9	Electric	0.68	1.00	0.00	0
	Gas	0.24	0.35	0.45	793
	HP	0.41	0.60	0.27	487
10	Electric	5.41	1.00	0.00	0
	Gas	2.05	0.38	3.36	6582
	HP	2.09	0.39	3.32	6002
Natl	Electric	3.52	1.00	0.00	0
	Gas	1.21	0.34	2.31	4715
	HP	1.87	0.53	1.65	3315

(1) Index is relative to present value of electric resistance energy costs in each region. (present value calculation assumes that electric and gas prices remain constant or escalate at the same rate).
(2) Real discount rate = 7%, and heating system lifetime is assumed to be 20 years.
(3) for heat pumps the allowable additional capital cost is the cost over and above the cost of a central air conditioner.
(4) Sources: Table 34 for heating energy costs, and Table 12 for floor areas by region and heating fuel.

APPENDIX A: NATIONAL DATABASE

This is the database derived using a two-story basement prototype (2240 square-feet) and Washington, DC weather. Capital costs are in 1988$/square-foot of total floor area. These costs should be scaled either linearly with the floor area (for ceiling insulation, crawl space or basement floor insulation, and window measures) or with the square root of the floor area (for slab edge insulation, wall insulation, and infiltration measures). See main text (Section III.B.1) for more details.

Table A-1: Thermal Integrity Database for New Single-Family Detached Dwellings

CE	WA	FL	IN	WI	HTG LOAD kBtus/sqft	CLG LOAD kBtus/sqft	CAP COST 88$/sqft
0	0	0	0.7	1	47.22	15.32	0.00
11	0	0	0.7	1	37.45	12.57	0.15
11	11	0	0.7	1	27.17	10.72	0.44
11	11	11	0.7	1	24.60	10.34	0.62
11	11	11	0.4	1	19.88	9.92	0.86
11	11	11	0.4	2	16.61	9.30	1.21
19	11	11	0.4	2	15.56	9.03	1.27
19	19	11	0.4	2	13.32	8.62	1.48
19	19	19	0.4	2	12.68	8.52	1.58
19	19	19	0.4	3	11.35	8.16	1.70
30	19	19	0.4	3	10.50	7.94	1.78
38	19	19	0.4	3	10.19	7.85	1.86
49	19	19	0.4	3	9.93	7.80	1.95
49	27	19	0.4	3	8.57	7.52	2.54
49	27	19	0.4	4	7.76	7.30	2.83
60	27	19	0.4	4	7.59	7.24	2.91

(1) CE = ceiling R value; WA = wall R value; FL = floor R value; IN = infiltration rate (ACH); and WI = # of window panes.
(2) When WI = 4 it signifies triple pane argon-filled glass with one Low-E film.
(3) Capital costs are in 1988$ per sqft of TOTAL floor area.

APPENDIX B: DETAILS OF ASSUMPTIONS AND CALCULATIONS

1. NAHB Regions

The NAHB cost data are reported by regions that are not defined in the report. Koomey called NAHB and spoke with Mr. Lee Fisher, who was in charge of producing this report. He could not remember how the regions were defined, and could not easily extract those assumptions. We used his best estimates and our best judgement to fill in the states for the Mid-Atlantic and Mid-South Regions, as shown in Table 1. The 1987 Builder Survey does not include data for Alaska or Hawaii, and we assumed they are also ignored in the cost data. We assigned these two states the national average costs for purposes of aggregating to Federal Regions.

2. Procedure for Calculating Low-E, Argon Window Energy Savings

The PEAR database does not include heating and cooling load savings from advanced window technologies, such as triple-paned, Low-E, argon-filled windows. Since we are assuming that heating and cooling load savings from thermal integrity measures are independent, we can use simple uA calculations to estimate energy savings. We have estimates for the U-improvements and costs for Low-E and argon-filled windows, and we can use the PEAR simulation database to estimate the changes in space conditioning loads caused by these improvements, since we know the U-values assumed in calculating these numbers.

After examining Gilmore (1986) and discussing the issue with Susan Reilly of LBL's windows and daylighting group, we assumed that triple-paned, Low-E, argon-filled windows would achieve U-values of 0.2. This value was then used to estimate the changes in heating and cooling loads relative to standard triple-paned windows. Switching from double- to triple-paned windows results in a change in U-value of 0.18 (0.49 - 0.31), while switching from triple-paned to triple-paned, Low-E, argon-filled windows, results in a change in U-value of 0.11. The ratio of these changes is 0.611 (0.11/0.18). The change in heating or cooling load of going from two panes to three panes is then multiplied by 0.611, and the result is subtracted from the heating or cooling load of triple-paned windows to calculate the heating or cooling load for triple-paned, Low-E, argon-filled windows.

This method is admittedly imperfect. A computer program now in beta-test version (RESFEN 1.0), recently developed by Lawrence Berkeley Laboratory's Windows and Daylighting Group, should be used in the future to do such calculations (see Sullivan 1991 for details).

2. Energy Prices in 1987

Table B-1 shows regional average residential natural gas and electricity prices in 1987. Weighted average prices have been calculated for each Federal Region from U.S. DOE (1989 and 1990). No correction factors have been included to account for differences in electricity prices for space heating and cooling customers relative to the regional average fuel prices.

Table B-1: Energy Prices for Space Conditioning - 1987.

Federal Region	Residential Average Natural Price 88$/MMBTU	Residential Average Electric Price 88$/kWh
1	7.078	0.091
2	6.873	0.107
3	6.124	0.078
4	5.998	0.071
5	5.263	0.082
6	5.101	0.072
7	4.658	0.077
8	4.870	0.069
9	5.399	0.083
10	5.444	0.047
National	5.617	0.077

(1) Weighted average residential prices for each federal region were derived from data in US DOE (1989b and 1990).

APPENDIX C: MORE DETAIL ON FOUNDATION TYPES

Table C-1: Electrically-Heated Single-Family Detached Buildings by Foundation Type

	Federal Region 1	2	3	4	5	6	7	8	9	10	Nat'l.
One-Story											
Units Built	27	103	486	1225	67	342	22	93	194	138	2697
Basement	18	3	375	6	40	16	20	29	0	8	517
Crawl Space	4	6	110	55	17	28	2	37	8	130	397
Slab	3	94	1	1164	10	298	0	27	186	0	1783
Two-Story											
Units Built	90	78	584	444	25	249	17	88	50	40	1665
Basement	83	40	541	18	15	44	16	27	1	5	790
Crawl Space	3	36	43	16	4	42	1	1	5	34	185
Slab	4	2	0	410	6	163	0	60	44	1	690
Bi-Level											
Units Built	22	26	187	3	3	80	1	16	6	7	351
Split-Level											
Units Built	6	0	67	2	6	42	1	32	0	10	166
Total	145	207	1324	1674	101	713	41	229	250	195	4879

(1) Source: Survey responses from NAHB (1989).

Table C-2: Gas-Heated Single-Family Detached Buildings by Foundation Type

	Federal Region										
	1	2	3	4	5	6	7	8	9	10	Nat'l.
One-Story											
Units Built	49	393	56	1131	1479	1236	403	449	2074	135	7405
Basement	43	63	33	245	972	28	379	280	20	7	2075
Crawl Space	1	18	17	340	257	48	22	161	644	126	1634
Slab	0	312	6	546	250	1160	2	8	1410	2	3696
Two-Story											
Units Built	309	869	1423	1990	2715	1309	436	556	2045	344	11996
Basement	296	529	1292	961	2095	65	435	489	2	20	6193
Crawl Space	4	126	25	853	229	73	1	41	727	320	2399
Slab	0	214	106	176	391	1171	0	26	1316	4	3404
Bi-Level											
Units Built	111	39	64	137	335	126	70	103	28	43	1056
Split-Level											
Units Built	8	12	135	174	702	73	68	360	138	100	1770
Total	477	1313	1678	3432	5231	2744	977	1468	4285	622	22227

(1) Source: Survey responses from NAHB (1989).

Table C-3: Heat-pump Heated Single-Family Detached Buildings by Foundation Type											
	Federal Region										
	1	2	3	4	5	6	7	8	9	10	Nat'l.
One-Story											
Units Built	0	825	473	6510	199	480	21	0	2395	100	11003
Basement	0	414	240	105	25	52	21	0	0	3	860
Crawl Space	0	124	190	698	44	196	0	0	308	95	1655
Slab	0	287	43	5707	130	232	0	0	2087	2	8488
Two-Story											
Units Built	23	309	3769	1574	167	46	24	0	430	55	6397
Basement	23	2442	3176	168	125	1	24	0	202	82	3993
Crawl Space	0	20	291	705	40	4	0	0	9	20	1089
Slab	0	47	302	701	2	41	0	0	219	3	1315
Bi-Level											
Units Built	0	6	161	37	4	55	4	0	21	7	295
Split-Level											
Units Built	0	9	281	50	10	1	3	0	29	6	389
Total	23	1149	4684	8171	380	582	52	0	2875	68	18084

(1) Source: Survey responses from NAHB (1989).

APPENDIX D: FLOOR AREA ADJUSTMENT FACTORS

The factors in this appendix should be used when adjusting the prototype loads in Tables 15-25 to floor areas that are different than those of the DOE-2 prototypes (1540 sf or 2240 sf). These numbers have been taken directly from the PEAR database. They should be treated as an approximation to the complicated effects captured by DOE-2 or the PEAR model itself. In doing runs in the future, it is preferable to use these models instead of using the approximate method for floor area correction from this Appendix. When these models are unavailable, however, or if somewhat less precision is needed than these models provide, the method outlined in these tables will suffice.

Table D-1: Heating floor area adjustment factors

Prototype	2S BSMT	2S BSMT	2S BSMT	2S BSMT	1S CRWL	2S BSMT	1S SLAB	2S BSMT	2S BSMT	1S SLAB	2S CRWL
Federal region	National	1	2	3	4	5	6	7	8	9	10
Floor area											
1000					0.661		0.658			0.593	
1100					0.725		0.722			0.666	
1200					0.789		0.787			0.740	
1300					0.852		0.851			0.817	
1400					0.915		0.914			0.896	
1500					0.978		0.978		*0.692*	0.977	*0.692*
1600					1.038		1.039		*0.734*	1.047	*0.734*
1700				*0.776*	1.098		1.099		*0.776*	1.117	*0.776*
1800	0.816	0.819	0.817	0.818	1.157	0.819	1.159	0.818	0.818	1.188	0.818
1900	0.858	0.860	0.859	0.860	1.216	0.861	1.218	0.860	0.860	1.259	0.860
2000	0.900	0.902	0.901	0.902	1.274	0.902	1.277	0.901	0.901	1.331	0.902
2100	0.942	0.943	0.942	0.943	1.334	0.943	1.337	0.943	0.943	1.402	0.943
2200	0.984	0.984	0.984	0.984	1.394	0.984	1.398	0.984	0.984	1.474	0.984
2300	1.025	1.024	1.025	1.025	1.453	1.024	1.458	1.025	1.025	1.546	1.025
2400	1.066	1.065	1.066	1.065	1.512	1.065	1.517	1.065	1.065	1.618	1.065
2500	1.107	1.105	1.106	1.106	1.571	1.105	1.577	1.106	1.106	1.691	1.105
2600	1.147	1.145	1.146	1.146	1.628	1.145	1.635	1.146	1.146	1.760	1.145
2700	1.187	1.184	1.186	1.185	1.686	1.184	1.693	1.185	1.185	1.829	1.185
2800	1.227	1.224	1.226	1.225	1.743	1.223	1.751	1.225	1.225	1.898	1.224
2900	1.267	1.263	1.266	1.264	1.799	1.263	1.808	1.265	1.264	1.968	1.264
3000	1.307	1.302	1.305	1.303	1.855	1.302	1.865	1.304	1.304	2.037	1.303
3100	1.346	1.341	1.344	1.342		1.340		1.343	1.343		1.342
3200	1.385	1.379	1.383	1.381		1.379		1.381	1.381		1.380
3300	1.424	1.418	1.422	1.419		1.417		1.420	1.420		1.419
3400	1.463	1.456	1.461	1.458		1.455		1.459	1.458		1.457
3500	1.502	1.494	1.499	1.497		1.493		1.497	1.497		1.495
3600	1.540	1.532	1.538	1.535		1.531		1.535	1.535		1.533
3700	1.579	1.570	1.576	1.573		1.569		1.573	1.573		1.571
3800	1.617	1.608	1.614	1.610		1.606		1.611	1.611		1.609
3900	1.655	1.645	1.651	1.647		1.643		1.648	1.648		1.646
4000	1.692	1.682	1.689	1.685		1.680		1.685	1.685		1.683
	Average floor areas (from Table 12)										
Electric	1848	2207	1803	1788	1980	2063	1752	1987	1514	1817	1557
Gas	2045	2200	2235	2433	2196	1963	2193	1934	1913	1782	1960
HP	2013	2013	2887	2242	1852	2008	1800	2411	2013	1783	1805
	Adjustment factor										
Electric	0.836	0.987	0.818	0.813	1.262	0.928	1.130	0.896	0.698	1.200	0.716
Gas	0.919	0.984	0.998	1.079	1.392	0.887	1.394	0.874	0.865	1.175	0.885
HP	0.905	0.907	1.261	1.001	1.188	0.905	1.159	1.070	0.906	1.176	0.820

(1) source: PEAR database of DOE-2 runs.
(2) adjustment factors are approximate. Multiply the load for the prototype house (either 1540 or 2240 square feet in area) by the appropriate adjustment factor to get the heating load for a house of a given floor area.
For example, the load for a house of 1848 square feet in region 1 would be multiplied by 0.836 to account for the difference in floor area between the prototype house and the average house.
This method is more accurate than scaling linearly by floor area.
(3) numbers in italics for regions 4, 8, and 10 are estimated by continuing the absolute decline from 1900 sf to 1800 sf.

Table D-2: Cooling floor area adjustment factors

Prototype	2S BSMT	2S BSMT	2S BSMT	2S BSMT	1S CRWL	2S BSMT	1S SLAB	2S BSMT	2S BSMT	1S SLAB	2S CRWL
Federal region	National	1	2	3	4	5	6	7	8	9	10
Floor area											
1000					0.758		0.749			0.877	
1100					0.811		0.803			0.918	
1200					0.860		0.854			0.950	
1300					0.906		0.901			0.973	
1400					0.947		0.944			0.988	
1500					0.984		0.983		*0.894*	0.994	*0.894*
1600					1.030		1.030		*0.912*	1.022	*0.912*
1700				*0.864*	1.073		1.075		*0.930*	1.046	*0.930*
1800	0.877	0.931	0.905	0.892	1.113	0.921	1.117	0.874	0.948	1.065	0.948
1900	0.908	0.952	0.931	0.920	1.152	0.944	1.157	0.906	0.966	1.080	0.966
2000	0.937	0.970	0.955	0.946	1.187	0.964	1.195	0.926	0.980	1.089	0.980
2100	0.965	0.985	0.975	0.970	1.229	0.981	1.238	0.964	0.991	1.108	0.991
2200	0.990	0.996	0.993	0.992	1.270	0.995	1.280	0.990	0.998	1.125	0.998
2300	1.018	1.012	1.015	1.016	1.308	1.013	1.321	1.018	1.010	1.137	1.010
2400	1.047	1.031	1.038	1.042	1.346	1.034	1.360	1.048	1.026	1.147	1.026
2500	1.074	1.047	1.060	1.067	1.381	1.052	1.398	1.076	1.039	1.153	1.039
2600	1.101	1.061	1.080	1.090	1.422	1.069	1.440	1.103	1.049	1.172	1.049
2700	1.126	1.074	1.098	1.111	1.462	1.083	1.482	1.125	1.058	1.189	1.057
2800	1.152	1.087	1.118	1.134	1.501	1.099	1.523	1.155	1.067	1.205	1.066
2900	1.178	1.102	1.138	1.157	1.539	1.116	1.562	1.183	1.078	1.218	1.077
3000	1.204	1.115	1.157	1.179	1.575	1.131	1.601	1.209	1.087	1.229	1.086
3100	1.229	1.126	1.175	1.201		1.145		1.235	1.094		1.093
3200	1.253	1.136	1.191	1.220		1.158		1.259	1.099		1.099
3300	1.272	1.134	1.200	1.234		1.160		1.280	1.091		1.090
3400	1.287	1.119	1.199	1.241		1.151		1.296	1.067		1.066
3500	1.300	1.102	1.196	1.245		1.139		1.311	1.040		1.039
3600	1.312	1.081	1.191	1.248		1.125		1.325	1.010		1.009
3700	1.323	1.058	1.184	1.250		1.108		1.337	0.977		0.975
3800	1.332	1.032	1.175	1.249		1.088		1.349	0.940		0.938
3900	1.340	1.003	1.163	1.247		1.066		1.358	0.900		0.897
4000	1.346	0.971	1.149	1.242		1.042		1.367	0.856		0.853
	Average floor areas (from Table 12)										
Electric	1848	2207	1803	1788	1980	2063	1752	1987	1514	1817	1557
Gas	2045	2200	2235	2433	2196	1963	2193	1934	1913	1782	1960
HP	2013	2013	2887	2242	1852	2008	1800	2411	2013	1783	1805
	Adjustment factor										
Electric	0.892	0.997	0.906	0.889	1.180	0.975	1.097	0.923	0.897	1.068	0.904
Gas	0.950	0.996	1.001	1.050	1.268	0.957	1.277	0.913	0.968	1.062	0.974
HP	0.941	0.972	1.135	1.002	1.133	0.965	1.117	1.051	0.981	1.062	0.949

(1) source: PEAR database of DOE-2 runs.
(2) adjustment factors are approximate. Multiply the load for the prototype house (either 1540 or 2240 square feet in area) by the appropriate adjustment factor to get the heating load for a house of a given floor area.
For example, the load for a house of 1848 square feet in region 1 would be multiplied by 0.892 to account for the difference in floor area between the prototype house and the average house.
This method is more accurate than scaling linearly by floor area.
(3) numbers in italics for regions 4, 8, and 10 are estimated by continuing the absolute decline from 1900 sf to 1800 sf.