A Bottom-Up Engineering Estimate of the Aggregate Heating and Cooling Loads of the Entire US Building Stock

Yu Joe Huang, Lawrence Berkeley National Laboratory
Jim Brodrick, D&R International

ABSTRACT

A recently completed project for the U.S. Department of Energy‘s (DOE) Office of Building Equipment combined DOE-2 results for a large set of prototypical commercial and residential buildings with data from the Energy Information Administration (EIA) residential and commercial energy consumption surveys (RECS, CBECS) to estimate the total heating and cooling loads in U.S. buildings attributable to different shell components such as windows, roofs, walls, etc., internal processes, and space-conditioning systems. This information is useful for estimating the national conservation potentials for DOE's research and market transformation activities in building energy efficiency.

The prototypical building descriptions and DOE-2 input files were developed from 1986 to 1992 to provide benchmark hourly building loads for the Gas Research Institute (GRI) and include 112 single-family, 66 multi-family, and 481 commercial building prototypes. The DOE study consisted of two distinct tasks : 1) perform DOE-2 simulations for the prototypical buildings and develop methods to extract the heating and cooling loads attributable to the different building components; and 2) estimate the number of buildings or floor area represented by each prototypical building based on EIA survey information. These building stock data were then multiplied by the simulated component loads to derive aggregated totals by region, vintage, and building type. The heating and cooling energy consumption of the national building stock estimated by this bottom-up engineering approach was found to agree reasonably well with estimates from other sources, although significant differences were found for certain end-uses. The main added value from this study, however, is the insight it provides about the contributing factors behind this energy consumption, and what energy savings can be expected from efficiency improvements for different building components by region, vintage, and building type.

Background

Most estimates of the amount of energy used for space conditioning in the US building stock are derived through statistical analysis of energy consumption data from utility or government sources, and provide little insight in the composition of that energy use. Computer simulation is a powerful tool to disaggregate space conditioning energy use to its individual components, i.e., envelope loads, internal gains, solar, etc., but is generally done for detailed analysis of a particular building. In this study, we have combined computer simulations of prototypical residential and commercial buildings differentiated by vintage, building use, and climate, with statistical information on the amount of building floor area represented by each prototype to produce a "bottom-up" engineering assessment of the energy use characteristics of the national building stock. Although the total energy use was computed and checked to other established sources, the primary benefit of this study was to provide insight into the contributions of building components, i.e., walls, roofs, windows, HVAC systems, etc., to the aggregate heating and cooling energy bill by building type, vintage, and region. Full descriptions of this study are presented in two technical reports (Huang et al. 1999; Huang and Franconi 1999).

Representation of the U.S. residential and commercial building stock by a collection of prototypical buildings requires a major analytical effort. For this project, we were able to utilize or adapt from previous work done by the lead author at LBNL dating back as far as 1986. From 1987 to 1992, Huang was involved in several projects supported by the Gas Research Institute (GRI) to develop prototypical building descriptions and DOE-2 input files for 66 multi-family and 128 single-family buildings to represent over 70% of U.S. residential buildings (Ritschard et al. 1989, 1992). From 1989 to 1991, Huang also worked on another GRI-funded project to develop descriptions and DOE-2 input files for 481 commercial buildings covering 13 building types in 13 cities to study the market applicability of cogeneration (Huang et al. 1991). The building types and cities were selected for their favorable factors for cogeneration, e.g., constant thermal loads and high ratio of electricity to gas prices, and covered an estimated 24% of all U.S. commercial buildings.

For this project, the GRI residential prototypes were used essentially as is, with the only modifications being the deletion of some prototypes and the use of others to also represent vintages or building types not covered in the original GRI studies. For example, the results for the other single-family prototypes were also used to estimate the energy usage of single-family attached and mobile homes on the basis of floor area, and the results for the 1960's prototypes were also used to estimate the energy usage of 1950's houses.

More substantial changes were made to the GRI commercial building prototypes. Although the overall description of the prototypical buildings, including their internal conditions, operation schedules, geometry, layout, and system configuration, was retained, the building size and shell characteristics were generalized from 13 cities to 2 regions (north and south) based on data from the 1983 CBECS survey. Furthermore, several of the less important building types in the 13 were dropped, and new prototypes developed for missing building types such as small offices, small retail, and warehouses. These changes produced a set of commercial building prototypes that were estimated to cover 70% of all U.S. commercial buildings.

Statistical information on the size and energy use characteristics of the U.S. residential and commercial building stock were taken from the 1993 Residential Energy Consumption Survey (RECS) and the 1992 Commercial Building Energy Consumption Survey (CBECS), respectively (EIA 1994, 1995).

Prototypical Residential Buildings

In the 1989 and 1992 GRI projects, 16 multifamily and 45 single-family building prototypes were developed, respectively, based on housing characteristics from previous RECS surveys and other sources such as the National Association of Homebuilders Builder's Survey (Ritschard et al. 1989, 1992). Each prototypical building represents the average characteristics of the housing stock by building type (single-family, small multifamily with less than four units, large multifamily with more than 20 units, etc.), geographical area (9 Census Divisions for single-family, 4 Census Regions for multifamily buildings), and vintage (pre-1940's, 1950-59, etc.). The vintages and locations for the residential prototypes are given in the top part of Table 1. The code letters for the single-family prototypes correspond to their vintage - “A” for pre-1940s, “B” for 1950-1970s, and “C” for 1980s houses. For the pre-1970 houses, two additional prototypes, “A1” and “B1”, were developed to represent houses that have been weatherized. Lastly, two other prototypes, a “B+” prototype for a house larger than average and a “D” prototype for a 1990s “house of the future” (the study was done in the late 1980’s), were omitted as inappropriate to this study. Since the remaining three prototypes did not cover all possible house vintages, the following adjustments were made to their definitions - the “A” houses were taken to represent all houses built before 1950, the “B” houses for all houses built between 1950 and 1979, and the “C” houses for all houses built after 1979.

There are 16 prototypical multifamily buildings that represent 53% of all multifamily buildings. For this study, the original GRI prototype definitions were expanded to include the full range of multifamily building types. For example, the older small 4-unit prototypical apartments (Prototypes 2, 8, 9, and 14) were used to also represent larger multifamily buildings of the same vintage in the same census region. Conversely, some of the newer large prototypical apartments (Prototypes 4, 13, 15, and 16) were used to also represent smaller buildings of the same vintage and Census Region. Lastly, the 1980s prototypes (4, 8, 13, and 16) were used to represent both the 1980-89 and Post-1989 multifamily buildings in their respective locations.

Depending on the amount of climate variation within a Census Region or Division, each prototypical building was simulated in as many as six different locations. For consistency, the same 16 locations were used for both the single-family and multifamily prototypes – Boston, New York, Minneapolis, Chicago, Kansas City, Washington, Atlanta, Miami, Fort Worth, Lake Charles, Denver, Albuquerque, Phoenix, Seattle, San Francisco, and Los Angeles. The total number of residential prototype/climate combinations simulated is 80 for single-family and 66 for multifamily buildings.

Prototypical Commercial Buildings

This project developed or modified from previous projects prototypical buildings for the following 12 commercial sectors :

Large Offices	Large Hotels
Small Offices	Small Hotels
Large Retail Stores	Fast-foods Restaurants
Small Retail Stores	Sit-down Restaurants
Schools	Food Stores (Supermarkets)
Hospitals	Warehouses

For each of these commercial building sectors, either two or four prototypical buildings were defined, depending on the quality of data in the 1989 CBECS from which the basic building characteristics were extracted. For 9 of the 12 building sectors, the interior conditions, operating schedules, thermal zoning, and even the basic DOE-2 input files, are taken from a previous project done for GRI (Huang et al. 1992). For the remaining three building sectors (small office, small retail, and warehouse), new building prototypes were defined. For each building sector, the project defined prototypical buildings representing two vintages (Pre- and Post-1980). For the following six building sectors - offices, retail stores, school, and warehouse - the project developed separate building prototypes for two broad geographical regions - North and South. For the other six building sectors – hospitals, hotels, restaurants, and food stores - single prototypical buildings were defined and used in the simulations. The general characteristics of the prototypical commercial buildings are listed in the lower half of Table 1.

Because commercial buildings are comparatively less sensitive to climate variations, simulations were done in only 5 locations (Minneapolis, Chicago, Washington, Los Angeles, and Houston), rather than the 16 used for the residential prototypes. The total number of commercial prototype/climate combinations simulated is 120 (12 building types x 2 vintages x 5 locations).

Simulated Space Conditioning Loads

The DOE-2.1E building energy simulation program (Winkelmann et al. 1993) was used to simulate the heating and cooling loads and energy usage for the 144 residential and 120 commercial prototype/climate combinations. The building loads were then disaggregated to show the separate contributions of building components such as walls, roof, window, infiltration, and internal gains. For the commercial prototypes, the contribution of outside air introduced by the HVAC system was considered as a building load. However, for the residential prototypes, natural ventilation was modeled as the standard operating condition and not considered a building load.

The component loads for the residential prototypes were estimated through regression analysis of the differences in total loads from parametric simulations where the thermal characteristics of a building component were set to zero. For opaque building surfaces such as roofs or walls, this meant a U-factor of 0; for windows, this meant that both the Solar Heat Gain Coefficient and U-factor are 0; for infiltration, this meant an Effective-Leakage-Fraction of 0, and for internal gains such as people, lights, and equipment, this meant the absence of any heat gain. In most instances, the sum of the component loads determined through this regression analysis was well within 10% of the simulated building loads. However, under low load conditions such as in Los Angeles, heating in Phoenix, or cooling in Seattle, the discrepancies can be large due to the high sensitivity of the air-conditioner or furnace run-times to changes in the building condition. In all cases, the computed component loads were adjusted to be consistent with the simulated building loads.

The intermittent hours of operation, large internal gains, and high thermal mass of the commercial prototypes necessitated a different method for computing their component loads. Initial attempts with regression analysis of parametric simulations were unsatisfactory, producing either spurious results or large unattributable loads. The selected method is more rigorous from a thermodynamic point of view, but still open to different interpretations. The method required the recording the hour-by-hour component loads calculated at a fixed temperature in DOE-2's LOADS subprogram, and then modifying these loads for the actual zone temperature in DOE-2's SYSTEMS subprogram. These component loads were then summed as either heating or cooling depending on the HVAC mode of operation for that hour. If the HVAC was off that hour, the component loads were accumulated and then assigned to the HVAC mode of operation the next time either heating or cooling was required. This was an attempt to capture the "pick-up" load and assign it to different building components. In most cases, the sum of the component loads was within 5% of the simulated building loads, but here too there were significant discrepancies under low load conditions. As with the residential runs, the component loads were adjusted to be consistent with the simulated building loads.

System and Plant Factors

To complete the energy analysis of the prototypical buildings, it was important to factor in the efficiencies of the space conditioning system and plant. For the prototypical commercial buildings, System and Plant Factors were calculated. Table 2 gives the average System and Plant Factors for the 12 commercial building types studied. The System Factor is defined as the ratio between the Building Load, or the amount of heating or cooling required by the building (same as the sum of the component loads), and the System Load, or the amount of heating or cooling provided by the air-handling system to meet the Building Load. System Factors for heating can vary from as low as 0.14 for a hospital that supplies 100% outside air at constant volume to over 1.00 in small offices due to "free heat" from fans. System Factors for cooling can vary from 0.51 in old large offices with constant-volume reheat systems to over 1.00 in small new commercial buildings due to "free cooling" from economizer cycles. The Plant Factor is defined as the ratio between the System Load and the amount of energy consumed by the Plant to supply that heating or cooling, and accounts for the thermal efficiencies of boilers, furnaces, chillers, and cooling towers, including the energy expended by their associated fans and pumps. Plant Factors are typically 0.60-0.70 for boilers, 3.50-4.80 for chillers, and 1.00 for pumps and fans. A Net Plant Factor is also calculated that takes into account the losses in generating electricity from fuel. These range from 0.29 to 0.57 for heating and 0.47 to 0.99 for cooling.

Since residential buildings do not have separate system and plant equipment, the System Factor is used to represent the net efficiency of the HVAC system to provide heating or cooling. Since all the residential prototypes were simulated with the same furnace/air-conditioner combination, the only variation in the System Factors are due to the effects of part-load performance and climate on air-conditioner efficiency.

Sector Sizes

To estimate the building populations represented by each prototype, we relied on the 1993 Residential Energy Consumption Survey (RECS) for residential buildings, and the 1992 Commercial Building Energy Consumption Survey (CBECS) for commercial buildings. For the residential sector, the total heating and cooling energy usages represented by each prototypical building were derived in the following manner :

(Prototypical house or apartment unit energy use) * (Fraction of floor area heated or cooled) * (No. of houses)

The 1993 RECS data base indicated that in addition to 59.2 million single-family detached and 24.1 million multi-family apartment units, there were also 5.6 million mobile homes and 7.3 million single-family attached houses. The loads and energy consumption of these two building types were estimated by adjusting the component loads of the single-family prototypes by assumed differences in wall and roof areas and house volume.

For the commercial sector, the total heating and cooling energy usages represented by each prototypical building were derived in a different manner because of the larger variations in building size :

(Prototypical building energy use per ft^2) * (Fraction of floor area heated or cooled) * (Total floor area of represented buildings)

The 1992 CBECS data base indicated that the 12 building types represented by prototypes represented 74% of the total floor area and 79% of the energy use of the entire commercial building sector. To compare the aggregated energy usage represented by the prototypical buildings to other estimates of commercial building energy use, a simple multiplier of 1.28 was applied.

Pie Charts of Aggregate Loads and Energy Usage by Building Sector

To visualize this "bottom-up" engineering estimate of the aggregated building loads and energy usage of the U.S. building stock, the results have been presented in a series of specialized pie charts. (see Figs. 1 through 5). Each pie chart consists of two pies – one for heating and the other for cooling – scaled by the magnitude of their respective loads. Component heat gains are shown as crosshatched pie slices and component heat losses as hatched pie slices. On the heating pies, the heat losses (or heat loads) are plotted on the top half and the heat gains (or "free heat") are plotted on the bottom half. These are reversed on the cooling pies, where the heat gains (or cooling loads) are plotted on the top and the heat losses (or "free cooling") are plotted on the bottom. The remaining exploded pie slide shows the imbalance between the heat gains and losses that represents the net heating or cooling load that must be met by the building's HVAC system. The concentric pie slices show the energy consumed by the HVAC system to meet the building loads, and reflect the efficiency of the system and plant, i.e., the System and Plant Factors. For cooling, a source multiplier of 3 has been added to avoid giving misleading impressions of cooling efficiency.

Figure 1 shows the total heating and cooling loads and energy use of the entire residential sector. The net national heating load is nearly 4 quads (quadrillion Btu), 5.2 quads due to heat losses minus 1.2 quads displaced by "free heat" from internal sources and solar gain through windows. Of the heat losses, infiltration and window conduction are the two largest components, each comprising roughly a quarter of the total load, followed by walls (20%), floors (15%), and roofs (10%).

The net national residential cooling load is slightly over 1 quad – 1.14 quad due to heat gains minus 0.08 quad of "free cooling" provided by ground coupling through the foundation. Of the heat gains, the largest component is solar gain through windows (32%), followed by internal gains from equipment and people (27%), infiltration (16%), roofs (14%), and walls (10%).

Figure 3 shows that for residential buildings built after 1980, improvements in the shell thermal integrity have greatly lowered heating loads, so that cooling loads have become relatively more important. In fact, the ratio of net cooling to net heating loads has doubled compared to older houses built before 1980. Moreover, the component loads for walls and roof have decreased relative to other building components such as floor, windows, and infiltration. Infiltration and window conduction compose 61% of the total heating load in post-1980s houses, compared to 52% in pre-1980s houses. Similarly, window solar gain and internal loads from equipment and people compose 60% of the total cooling load in post-1980s houses, compared to 50% in pre-1980s houses.

Figure 2 shows the total heating and cooling loads and energy use of the entire commercial sector. The net national heating load is 0.44 quad, 0.84 quads due to heat losses minus 0.4 quads displaced by "free heat" from internal sources and window solar gain. The heat losses in order of size are window conduction (22%), wall (21%), infiltration (18%), outside air (15%), roof (12%), ground (6%), and floor (2%). Compare to residential buildings, 'free heat" plays a much larger role in offsetting the heat losses, and outside air also becomes significant.

The net national commercial cooling load is about 1 quad, or very similar in magnitude to the residential cooling load – 1.2 quad due to heat gains minus 0.24 quad of "free cooling" through various parts of the building shell. It is interesting that except for the roof, the aggregate heat flows through the building shell during the cooling season are mostly negative. This implies that increasing the R-value of walls, windows, etc., would have either no or counterproductive impacts on the building cooling load. Of the heat gains, the largest components are lighting (42%), solar gain through windows (32%), and equipment (17%), with other building components not contributing much, at least at the national level.

Figures 4 and 5 shows the differences in component loads between the small and large offices. In the small offices, there are significant heating loads, although more than half of that is counteracted by "free heat" from solar gain, lights, people, and equipment.. The net heating load is roughly one-third the net cooling load. In the large offices, the relative magnitude of the heating loads is further reduced, so that the net heating load shrinks to only 1/10 the net cooling load. However, in terms of energy use, heating remains at one-third that of cooling in the large offices due to low system efficiencies.

Comparison of Aggregate Energy Use Estimates with Other Studies

When the prototypical buildings were being developed, comparisons were done against the 1982 RECS and 1989 NBECS to insure that the simulation results matched roughly the average total energy use reported by RECS and NBECS for that building sector. Outside of this check, however, no calibration has been done of the prototypes against either later versions of RECS and CBECS, or for specific end-uses such as heating or cooling. In addition, the aggregation of the prototypical building energy use to national estimates adds a further level of uncertainty. Tables 3 and 4 compare the estimated national energy consumption for residential and commercial buildings to other statistically derived estimates by DOE (RECS, CBECS, and the Annual Energy Outlook) and the Gas Research Institute (EIA 1994, 1996a, 1996b; GRI 1995, 1997). The totals for the non-space conditioning end uses (water heating, lighting, and other) were modeled very simply, but included in Tables 3 and 4 for completeness.

In the residential sector, the aggregated energy use estimates from this study are quite close to the other studies, indicating that large mistakes or missing elements are not likely. One difference, however, is that the other estimates accounted for a wider variety of fuel types, while this study assumed natural gas for heating and electricity for cooling for all buildings. The estimates for space heating are within 15% of each other, with this study being the highest by a small margin. The estimates for space cooling range from 0.46 to 0.79 quads, with this study at 0.48 quad. The estimates for total energy usage are within 12% of each other, with this study's estimate of 10.7 quads nearly identical to the DOE estimates (10.5 to 10.6 quads), but slightly higher than the GRI estimates (9.4 to 9.6 quads).

In the commercial sector, the aggregated energy use estimate for space heating is lower than in all six of the other studies, due mostly to the inclusion of other heating sources such as fuel oil and district heating. As in the residential sector, the prototypical commercial buildings were modeled with natural gas or electricity as the only fuel sources, whereas the other studies showed significant amounts of other fuel usages. The estimate of total cooling energy use is within the range of the other study results, while those for the non-space conditioning end-uses (except lighting) varied greatly among the seven different studies. Due to these variations, the estimated total energy use in commercial buildings varied by 2.3 quads, or nearly 50%, with this study being the lowest. This suggests there remains great uncertainty about the amount of commercial building energy usage, particularly of non-space conditioning end-uses other than lighting.

Conclusions

The study has shown that a bottom-up engineering approach produced aggregated estimates of residential and commercial building energy use that are generally consistent with other top-down statistical approaches. The advantage of this engineering approach relying on computer simulations of prototypical buildings is its ability to dissect in detail the energy use characteristics of each building sector, such as to calculate component loads or system and plant factors, or if needed, hourly load shapes for an entire year. This type of information can be used to assess current research, development, and deployment (RD&D) activities and prioritize future actions. The detailed hourly load shapes from this project can also be useful for evaluating energy service contracts, energy pricing alternatives, or selecting energy efficiency program needs.

Additional work is needed to 1) improve the characterization of the prototypical buildings, 2) differentiate the range of space conditioning systems and fuel types by region and building type, and 3) better calibrate the energy usage and peak demand of the prototypical buildings to measured data or utility bills. The authors are currently working on these improvements, with the Year 2000 activities to improve and calibrate the residential prototypes and system definitions, and the planned activities for the Year 2001 to do the same for the commercial building prototypes.

References

Energy Information Administration (EIA). 1994. "Commercial Building Characteristics 1992." DOE/EIA-0246(92). Washington, DC: U.S. Department of Energy.

Energy Information Administration (EIA). 1995. "Housing Characteristics 1993." DOE/EIA-0314(93). Washington, DC: U.S. Department of Energy.

Energy Information Administration (EIA). 1996a. "Annual Energy Outlook 1995", DOE/EIA-0383(95). Washington, DC: U.S. Department of Energy.

Energy Information Administration (EIA). 1996b. "Annual Energy Outlook 1997", DOE/EIA-0383(97). Washington, DC: U.S. Department of Energy.

Gas Research Institute (GRI). 1995. *Baseline Projection Data Book*, 1995 Edition, Washington, DC: Gas Research Institute Baseline/Gas Resource Analytical Center.

Gas Research Institute (GRI). 1997. *Baseline Projection Data Book*, 1997 Edition, Washington, DC: Gas Research Institute Baseline/Gas Resource Analytical Center.

Huang, Y.J., H. Akbari, L. Rainer, and R. Ritschard. 1991. "481 Prototypical Commercial Buildings for Twenty Urban Market Areas." GRI-90/0326. Chicago IL: Gas Research Institute. Also LBL-29798, Berkeley CA: Lawrence Berkeley Laboratory.

Huang, Y.J. and E.M. Franconi. 1999. "Commercial Heating and Cooling Loads Component Analysis." LBNL-37208. Berkeley, CA: Lawrence Berkeley National Laboratory.

Huang, Y.J., J.W. Hanford, and F.Q. Yang. 1999. "Residential Component Heating and Cooling Loads." LBNL-33033. Berkeley, CA: Lawrence Berkeley National Laboratory.

Ritschard, R.L. and Y.J. Huang. 1989. "Multifamily Heating and Cooling Requirements: Assumptions, Methods, and Summary Results." GRI-88/0239. Chicago IL: Gas Research Institute.

Ritschard, R.L., J.W. Hanford, and A.O. Sezgen. 1992. "Single-Family Heating and Cooling Requirements: Assumptions, Methods, and Summary Results." GRI-91/0236. Chicago, IL: Gas Research Institute.

Table 1. Characterization of U.S. Building Stock

Prototypical Residential Buildings

Single-family Vintages	
A (pre-1940)	A1 (retrofitted pre-1940)
B (1950-79)	B1 (retrofitted 1950-1979)
C(1980s)	

Multi-family Vintages *(varies by region)*	
small pre-1940	Large pre-1940's
Small 1950-59	Large 1960-69
Small 1960-69	Large 1970-79
Small 1980s	Large 1980s

Locations		
Northeast	*South*	*West*
Boston	Washington	Seattle
New York	Fort Worth	Denver
North Central	Atlanta	Albuquerque
Minneapolis	Miami	San Francisco
Chicago	Lake Charles	Los Angeles
Kansas City		Phoenix

Prototypical Commercial Buildings

Building Types	
Large Office (90-140,000 ft^2)	Small Office (6,000 ft^2)
	Small Retail (600-3,000 ft^2)
Large Retail (80,000 ft^2)	Small Hotel (11,000 ft^2)
Large Hotel (120-250,000 ft^2)	Hospital (66-156,000 ft^2)
	Supermarket (21,000 ft^2)
Sit-down Restaurant (5,250 ft^2)	Fast-foods Restaurant (2,500 ft^2)
School (16-47,000 ft^2)	Warehouse (130-150,000 ft^2)

Vintages	
Old shell, Old system	Old shell, New system
New shell, New system	

Locations	
Minneapolis	Chicago
Washington	Houston
Los Angeles	

Table 2. Average System and Plant Factors for Commercial Buildings

Building Type	HVAC mode	System Factor	Plant Factors * Gas	Elec	Net†	Overall Source Efficiency †
Large Office	heat	0.32	0.64	1.00	0.42	0.13
	cool	0.51	0.64	4.75	0.84	0.43
Small Office	heat	1.23	0.48	1.00	0.39	0.47
	cool	0.86		3.17	0.69	0.59
Large Retail	heat	0.22	0.63	1.00	0.43	0.09
	cool	0.62	0.63	4.65	0.89	0.55
Small Retail	heat	1.16	0.63	1.00	0.50	0.57
	cool	0.76		3.06	0.71	0.55
Large Hotel	heat	0.73	0.63	1.00	0.37	0.27
	cool	0.84		3.59	0.99	0.83
Small Hotel	heat	0.76	0.31	1.00	0.29	0.22
	cool	2.36		2.39	0.70	1.64
Fast Foods Restaurant	heat	0.29	0.62	1.00	0.52	0.15
	cool	0.66		3.09	0.76	0.50
Sit-down Restaurant	heat	1.12	0.59	1.00	0.47	0.53
	cool	0.61		3.15	0.75	0.45
Hospital	heat	0.14	0.65	1.00	0.44	0.06
	cool	1.10	0.65	4.19	0.87	0.96
School	heat	1.03	0.63	1.00	0.57	0.59
	cool	5.44		2.44	0.47	2.56
Supermarket	heat	1.66	0.49	1.00	0.33	0.54
	cool	0.82		3.11	0.56	0.46
Warehouse	heat	1.26	0.64	1.00	0.48	0.60
	cool	0.90		3.03	0.57	0.51
All Commercial	heat	0.75	0.64	1.00	0.44	0.33
	cool	0.72	0.64	3.89	0.79	0.57

* Plant Gas Factors refer to the efficiency of boilers and furnaces, Electric Plant Factors refer to the efficiency of electric resistance heating, chiller and cooling towers. Gas Plant Factors in the cooling row refer to the thermal efficiency of reheat; Electric Plant Factors in the heating row refer to the thermal efficiency of either resistance heating or heating provided by fans.

† Net Plant Factor and Overall Source Efficiency have been calculated using a multiplier of 3 to convert site electricity to source energy use.

Table 3. Comparison of Component Loads Analysis to Other National Estimates of Residential Building Energy Use (Quadrillion Btu's)

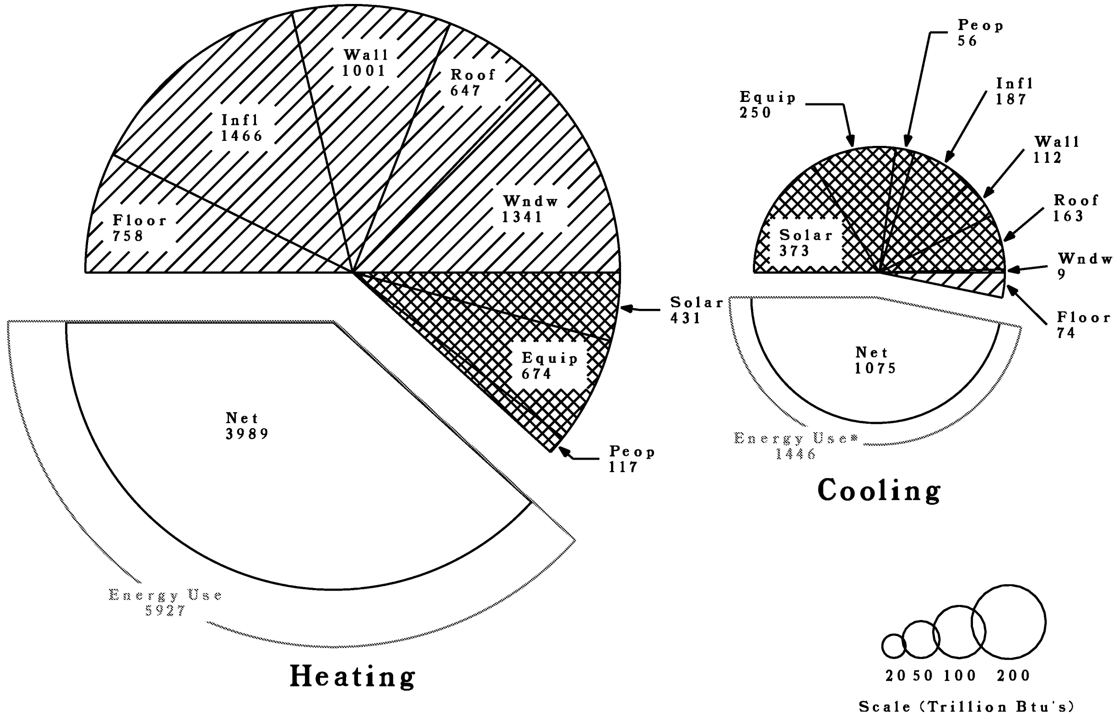
	Comp. Loads Analysis	RECS 1993	AEO 1993	AEO 1995	GRI 1993	GRI 1995
Space Heating	**5.93**	**5.32**	**5.90**	**5.65**	**5.07**	**5.31**
Natural Gas	5.93	3.67	3.68	3.48	3.56	3.39
Other Fuels		0.99	1.06	1.06	0.76	1.14
Electricity		0.41	0.37	0.43	0.75	0.79
Other, e.g. wood		0.25	0.79	0.68		
Space Cooling	**0.48**	**0.46**	**0.53**	**0.49**	**0.60**	**0.79**
Natural Gas		0.00	0.00	0.01	0.00	0.13
Electricity	0.48	0.46	0.53	0.48	0.60	0.66
Water Heating	**1.19**	**1.83**	**1.63**	**1.75**	**1.83**	**1.90**
Natural Gas	1.19	1.31	1.11	1.25	1.25	1.28
Other Fuels		0.17	0.16	0.15	0.10	0.13
Electricity		0.34	0.36	0.35	0.47	0.49
Lighting	**0.59**		**0.32**	**0.32**	**0.28**	**0.28**
Other End-Uses	**2.47**	**2.94**	**2.23**	**2.31**	**1.61**	**1.35**
Natural Gas	0.84	0.29	0.32	0.27	0.30	0.20
Other Fuels		0.29	0.05	0.04	0.02	0.10
Electricity	1.63	2.07	1.81	1.98	1.30	1.05
Total Energy Usage	**10.66**	**10.55**	**10.61**	**10.52**	**9.39**	**9.63**
Natural Gas	7.95	5.27	5.11	5.01	5.11	4.99
Other Fuels		1.45	1.27	1.25	0.89	1.38
Electricity	2.11	3.28	3.39	3.56	3.39	3.26
Other, e.g. wood		0.55	0.84	0.70		

Table 4. Comparison of Component Loads Analysis to Other National Estimates of Commercial Building Energy Use (Quadrillion Btu's)

	Comp.Loads Analysis *	CBECS 1992	CBECS 1995	AEO 1993	AEO 1995	GRI 1993	GRI 1995
Space Heating	**1.37**	**1.92**	**1.69**	**1.73**	**1.61**	**2.71**	**2.67**
Natural Gas	1.31		1.09	1.33	1.30	1.63	1.79
Fuel Oil			0.15	0.31	0.20	0.69	0.58
District Heat			0.34				
Electricity	0.05		0.11	0.09	0.11	0.39	0.30
Space Cooling	**0.42**	**0.46**	**0.34**	**0.30**	**0.61**	**0.84**	**0.92**
Natural Gas			(see Other)	0.01	0.03	0.09	0.13
Electricity	0.42		0.34	0.29	0.58	0.75	0.79
Ventilation	**0.43**	**0.17**	**0.16**	**0.30**	**0.17**	?	**0.18**
Water Heating	**0.38**	**0.86**	**0.57**	**0.41**	**0.71**	**0.66**	**0.69**
Natural Gas	0.38		0.52	0.35	0.48	0.39	0.43
Fuel Oil				0.03	0.06	0.14	0.12
Electricity			0.05	0.03	0.17	0.13	0.14
Lighting	**1.45**	**1.16**	**1.20**	**1.06**	**1.21**	**1.25**	**1.28**
Other End-Uses	**0.80**	**0.93**	**0.93**	**2.94**	**2.49**	**1.43**	**1.41**
Natural Gas	0.12		0.33	1.29	1.35	0.89	0.79
Fuel Oil			-0.15	0.46	0.15	0.00	0.05
Electricity	0.68		0.75	1.19	0.99	0.54	0.57
Total Energy Use	**4.84**	**5.49**	**4.89**	**6.75**	**7.15**	**6.90**	**7.15**
Natural Gas	1.81	2.17	1.95	2.98	3.16	3.00	3.14
Fuel Oil		0.27		0.80	0.41	0.84	0.74
District Heat		0.43	0.34	0.01	0.35		
Electricity	3.04	2.61	2.61	2.96	3.23	3.07	3.26

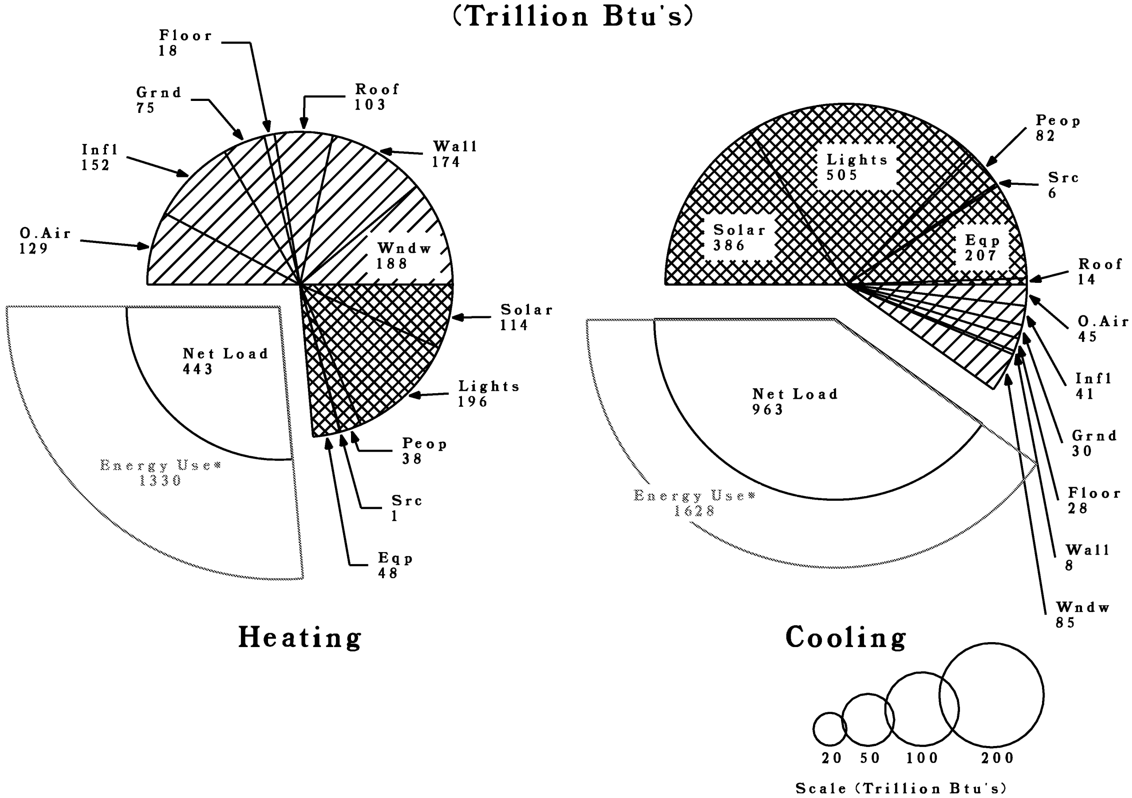
* scaled by 1.28 to account for building types not included based on energy use ratio from 1992 CBECS.

Figure 1. Aggregate Component Loads for All Residential Buildings (Trillion Btu's)



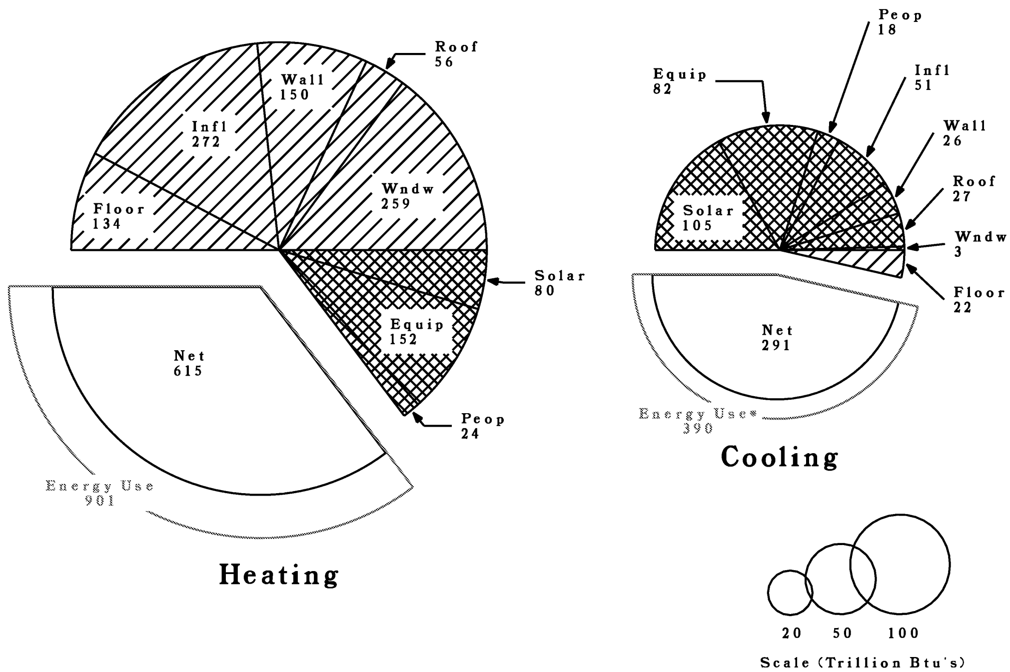
* Source multiplier of 3 used for electricity

Figure 2. Aggregate Component Loads for All Commercial Buildings (Trillion Btu's)



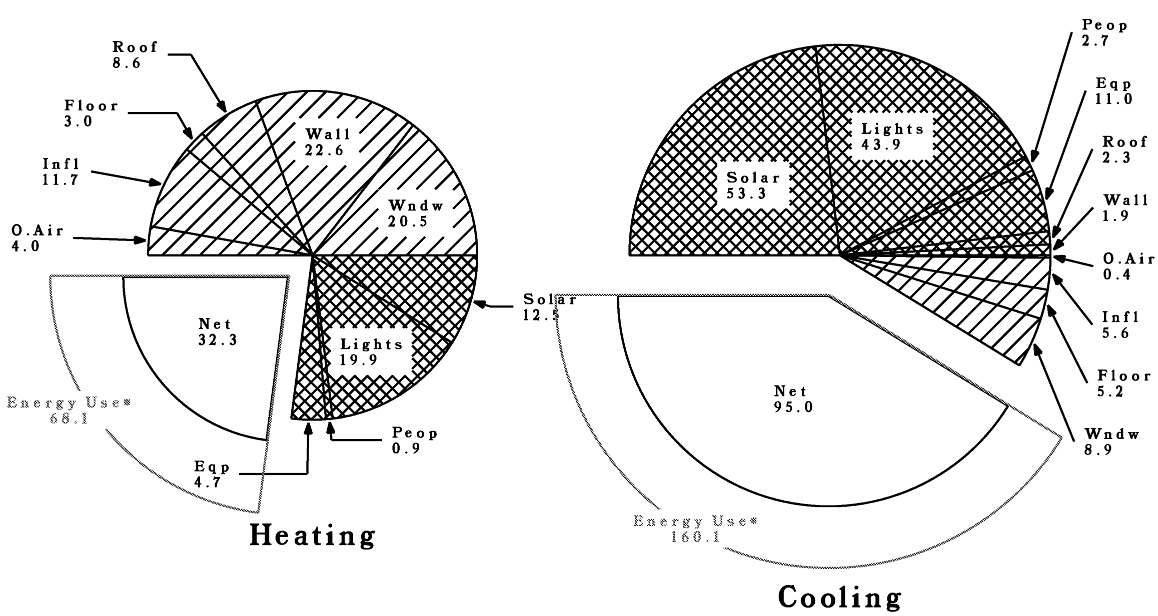
* Source multiplier of 3 used for electricity

Figure 3. Aggregate Component Loads for New Residential Buildings (Trillion Btu's)



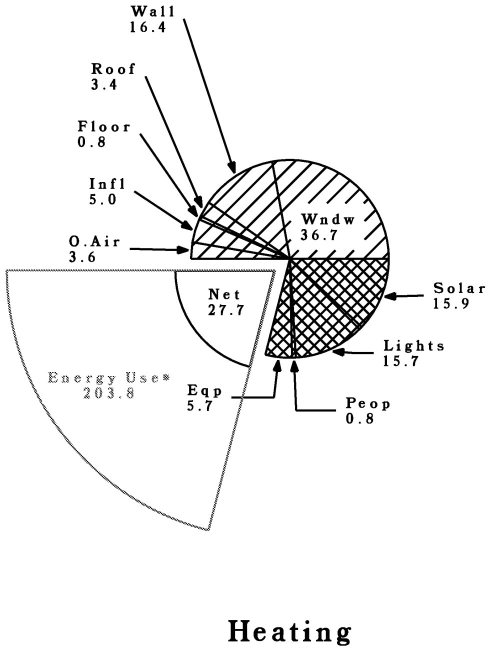
* Source multiplier of 3 used for electricity

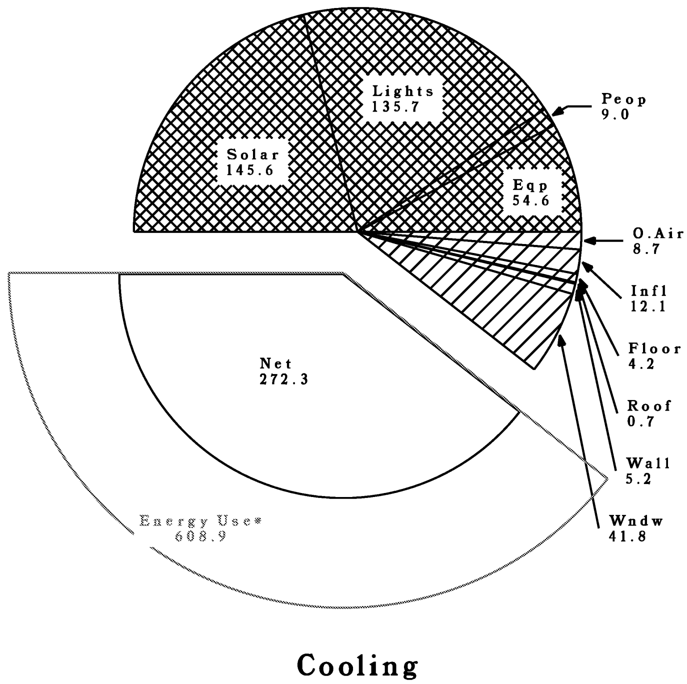
Figure 4. Aggregate Component Loads for Small Offices (Trillion Btu's)



* Source multiplier of 3 used for electricity

Figure 5. Aggregate Component Loads for Large Offices (Trillion Btu's)





* Source multiplier of 3 used for electricity