

**Review of
Residential Electrical
Energy Use
Data**

Prepared for



451 7th Street, SW
Washington, DC
20410

Prepared by



NAHB Research Center, Inc.
400 Prince George's Boulevard
Upper Marlboro, MD
20774

July 16, 2001

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To learn more about PATH, please contact:



451 7th Street, SW
Washington, DC 20410
Fax (202) 708-5873
pathnet@pathnet.org
www.pathnet.org

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INTRODUCTION

This report summarizes electrical energy use data for single-family detached homes available from public and private sources. Data sources summarized in this report include:

- National annual data from the Residential Energy Consumption Survey (RECS) published by the Energy Information Administration (EIA),
- Monthly data from two builders,
- Hourly profiles from three utility companies, and
- Detailed energy use data from field measurements.

In this review, annual and monthly electrical energy consumption is analyzed primarily on a square footage basis. This normalization factor was selected as a means to compare different buildings. The limitation in using a per unit area basis is the assumption that all homes regardless of size have the same amount of lighting and appliances and usage patterns, which is not the case. The primary benefit in using this unit area basis is that it gives a simple, easily performed estimate of expected electrical consumption for any given home.

PURPOSE

The purpose of this research is to identify electrical energy use and demand characteristics for single-family homes. These characteristics may be used to better estimate the size required for electric generation equipment serving an individual home. The energy use data are used first to understand the annual electric energy consumption for a given home type in a particular climatic region. Secondly, using hourly and higher resolution data, a better understanding of electrical demand may be obtained. Both annual consumption and peak demand are necessary for designing and optimizing distributed electrical generation equipment for residences.

The decision on the size and design of distributed generation equipment located in homes is influenced by numerous factors such as:

- The anticipated demand of the home at any point in time.
- The intended load(s) to be served by the generation equipment.
- The desired level of independence from utility sources of energy.
- The use of other fuel sources such as fuel gas to service some of the energy requirements.
- The capability of control systems to limit demand independent of generation.
- Any combination of the above.

Manufacturers of generation, control, and large appliance equipment may use this data to design entire home energy systems that operate at higher efficiencies and reliability, and provide the homeowner with a cost-effective energy supply. Many utilities already track residential energy use data in specific regions. This data then may be used as a reference point to understand how actual energy consumption compares with known averages in a given region.

Distributed generation has been available in homes for many years. Many off-grid homes have operated successfully for years combining renewable generation, such as photovoltaics or wind, with batteries and fossil fuel generators to supply the homes' energy requirements. Typically, the energy systems in these homes are designed one at a time – paying specific attention to each appliance and load used in the home. This effort is a first attempt at supplying a rough outline of typical residential energy requirements so that whole systems may be designed that can be used in many different types of homes.

Specifically, the data may be useful in determining a variety of building generation design parameters, to:

- Size peak generation equipment to limit the peak demand of the building,
- Size base generation equipment to operate constantly at a minimum level,
- Size supplemental back-up energy storage to supply short term demand peaks in conjunction with other building generation,
- Design load-limiting equipment to reduce the building demand on the building generation equipment, and
- Provide reference points for comparison of specific homes.

ANNUAL DATA

The broadest understanding of residential electric energy consumption may be obtained from the Residential Energy Consumption Survey (RECS¹). The 1997 data reviewed here is the tenth in a series of nationwide household energy consumption surveys conducted since 1978 by the Energy Information Administration (EIA) of the U.S. Department of Energy. Nearly 6,000 households were surveyed to obtain data on the type of housing unit, size, specific construction features, energy consumption and expenditures, energy consuming appliances, and numerous other energy related issues. The survey data are considered statistically representative of approximately 101 million households nationwide. The graphs depicting the RECS data were developed from the database format of the public use data files, available from the EIA².

Figure 1 depicts the trend in annual electric consumption for the 5,900 households sampled in the RECS survey, of which 3,660 were single-family detached. The energy data are categorized by year of construction (vintage) and normalized to square footage of heated space for each home.³ The EIA recommends sample sizes⁴ greater than 10 for any level of confidence in the results; therefore, because the sample size was too small, the data for 1997 were omitted. The average size for all households across all years was 1,619 square feet with

¹ U.S. Department of Energy, Energy Information Administration, *Residential Energy Consumption Survey*.

² Data can be found at www.eia.doe.gov

³ Normalized consumption estimates were derived by averaging the individual normalized consumption for each household in the category. The normalized value is the annual consumption divided by the square footage of conditioned space.

⁴ Sample sizes refer to a specific grouping of data, by year for example, in which a number of records are available. The sample size of homes constructed in 1997 in the RECS data consists of less than 10 records and therefore is less reliable, when looking at the data based on year of construction.

a maximum of 6,598 square feet and a minimum of 127 square feet. For single family detached homes, the average is 1,975 square feet with a maximum of 6,598 square feet and a minimum of 335 square feet.

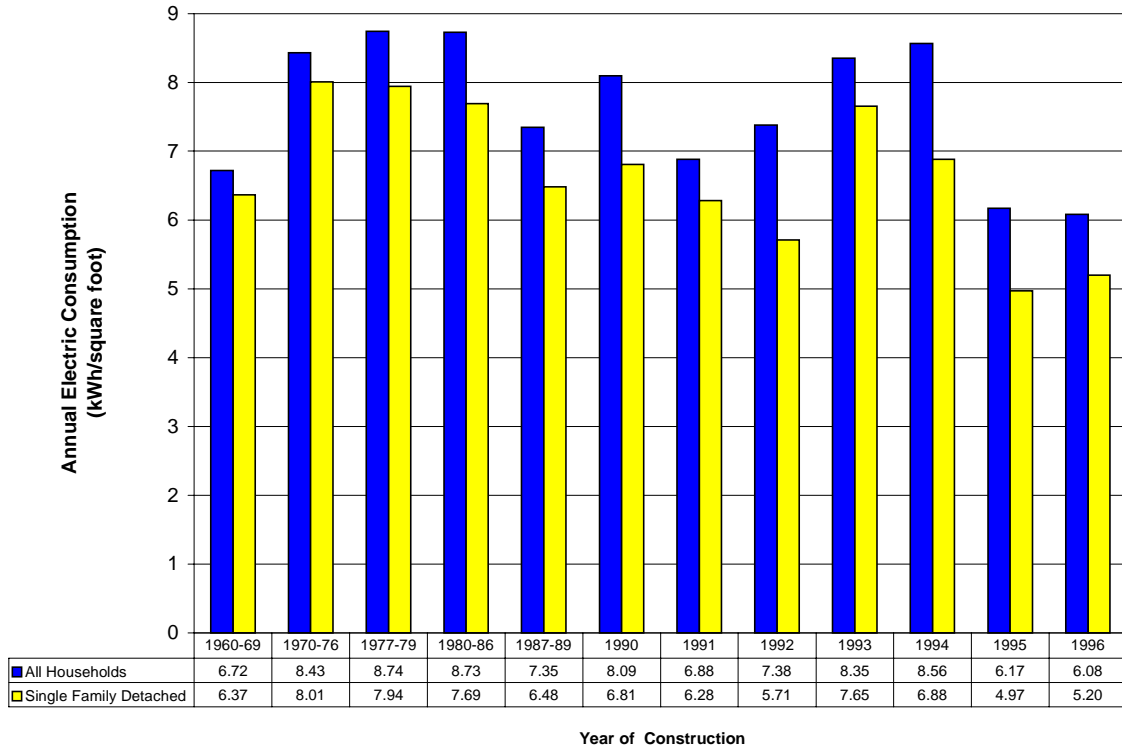


Figure 1 - Annual Electric Consumption (All Households/Single-Family Detached)

The data are representative of all U.S. households and includes all types of heating systems. Note the data are based on multi-year bins from 1960 through 1989 and is on a one-year basis for the subsequent seven years. Current trends in the data indicate that nationally, single family homes use approximately 5.0 kWh of electricity per square foot per year (10,000 kWh per year or 833 kWh per month for a 2,000 square foot home). Data analyzed on an annual basis, however, is subject to variable weather conditions in any given year. Data analyzed over multi-year periods tend to reflect weather conditions that more closely represent average conditions.

The RECS data combines the electricity used for heating and cooling equipment, appliances, and general lighting and devices. Since the 1970s, the use of air-conditioning has increased dramatically as has the use of electric appliances. However, since 1993, appliance efficiencies have steadily increased, offsetting much of the increase in number of appliances. This data set, however, analyzes only electricity use and therefore does not differentiate between homes that use gas for heating and the major appliances, and all-electric homes. In addition, the climatic differences between regions will significantly affect electric use as indicated in subsequent data analysis.

Annual electric consumption data is more meaningful by major U.S. region, because of expected differences in electricity consumption based on climate and the typical fuels used in the regions. Figure 2 shows the annual per-square-foot electric consumption for the 5,900 households sampled in the RECS survey. The sample sizes for single family detached homes are 720, 864, 1314, and 762 for Northeast, Midwest, South, and West regions, respectively. The data are normalized to the square footage of heated space for each home. The normalized consumption figures are based on the average of individual consumption records in each region (see footnote 3).

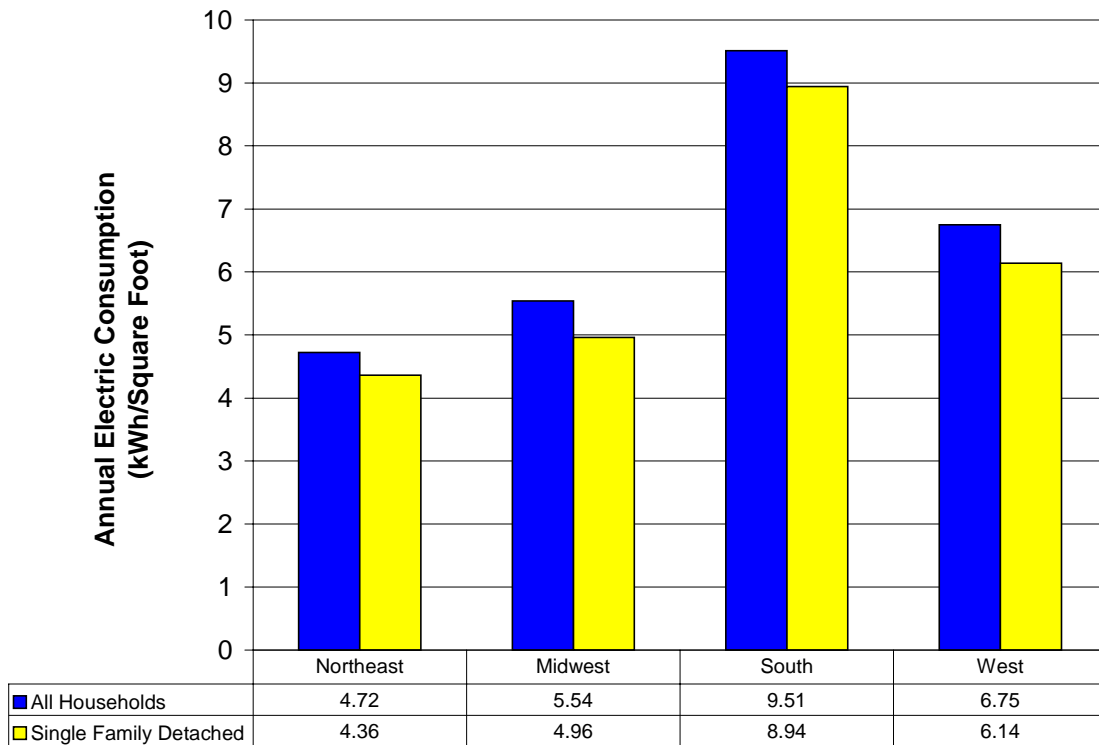


Figure 2 - Annual Electric Consumption by Region (All Households/Single Family Detached)

Most likely, the use of electricity for space conditioning is the primary driver for the large consumption of electrical energy in the South and West. The data is for all households and all years of construction.

The RECS survey is further divided into EIA division in Figure 3. The data is normalized to the square footage of heated space per home as in the previous two figures. Table 1 lists the states associated with each EIA division.

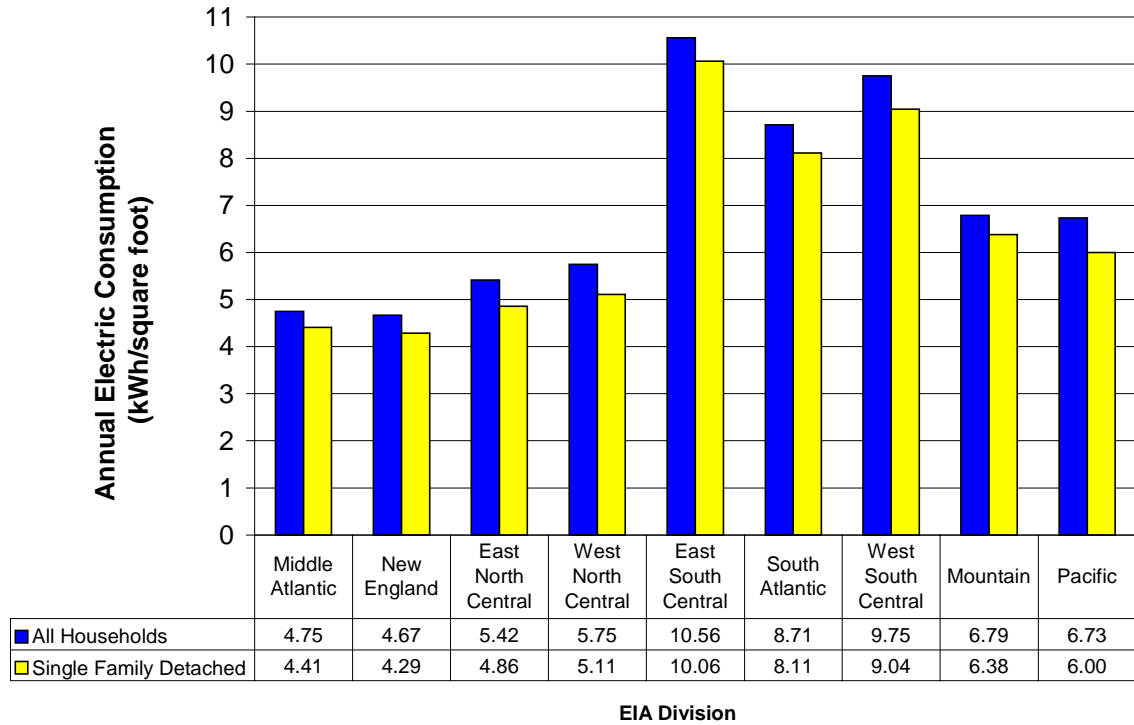


Figure 3 - Annual Electric Consumption by EIA Division (All Households/Single Family Detached)

Table 1 - States in EIA Regions and Divisions

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

Similarly, the same data are reviewed based on climate zone. Figure 4 shows the annual electric consumption for the 5,900 households sampled in the RECS survey and normalized by square footage of heated space for each climate zone as indicated in Figure 5. The consumption figures were derived in the same way as the previous three figures.

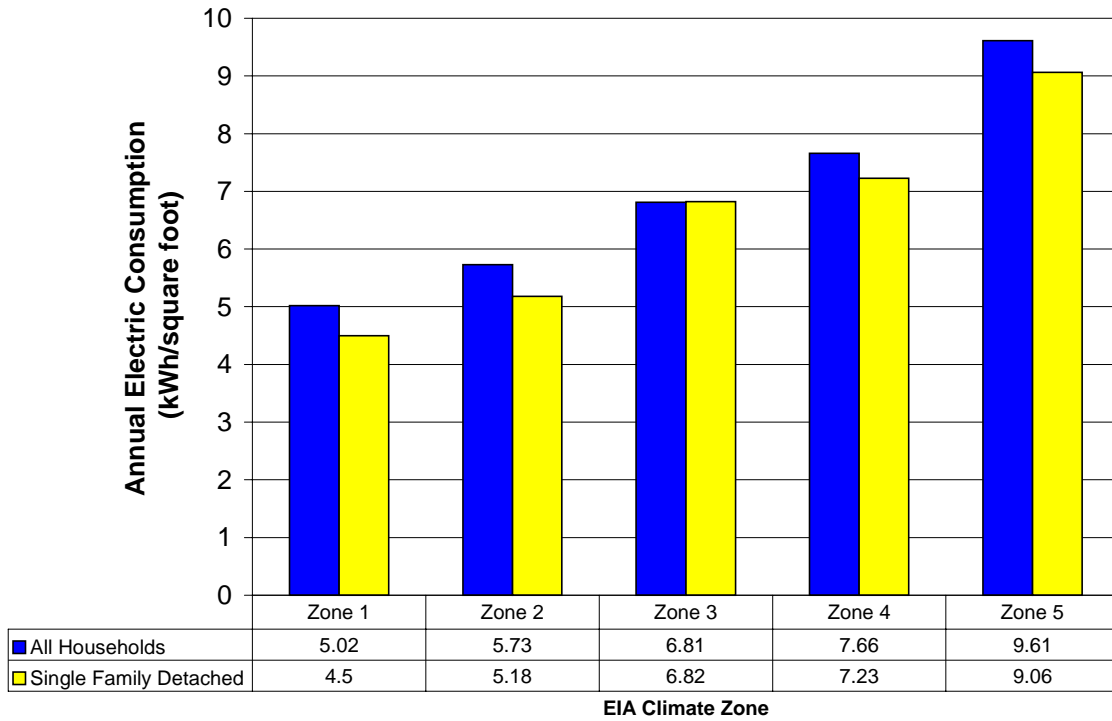


Figure 4 - Annual Electric Consumption by Climate Zone (All Households/Single Family Detached)

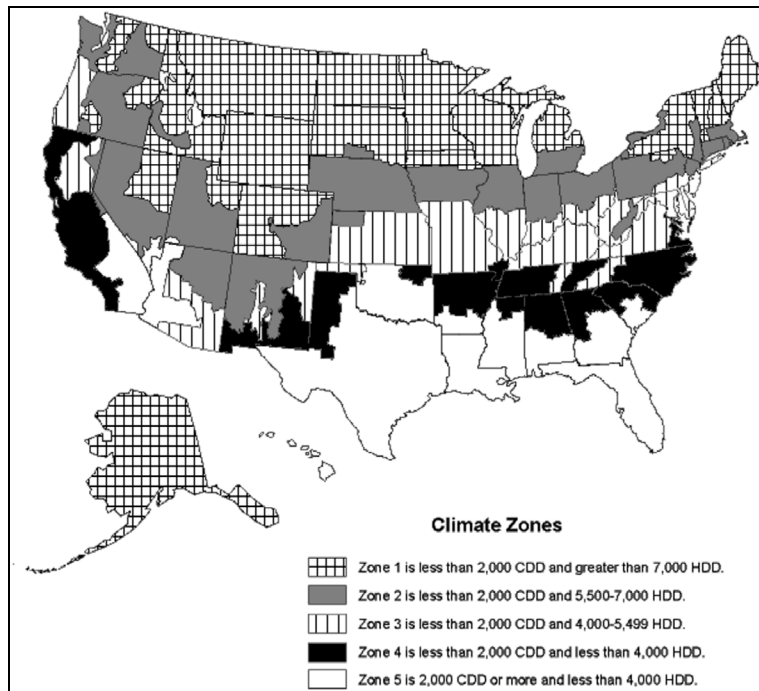


Figure 5 – Climate Zones in the United States (EIA climate zone map)

The differences in electric energy consumption by climate zone may be more readily attributed to the choice of fuel for heating rather than to other factors, except for Zone 5. Therefore, the sole use of climate zone as a predictor of electric energy use is of limited

benefit. In Zone 5, the cooling load dominates the electrical energy loads in homes with air-conditioning.

A better predictor of electric energy consumption is the fuel source used for space heating. Heating fuel type provides an indication of the fuel source available not only for space heating, but also for water heating, cooking and clothes drying. However, the use of fuel gas for heating does not necessarily mean that fuel gas-fired appliances are used. Figure 6 shows electric consumption from the RECS data according to main type of heating fuel and EIA Division. Only the data pertaining to single-family homes is considered. For homes without electric heating equipment, the areas with more cooling degree-days (CDD) use significantly more electricity than homes in climates with fewer CDD.

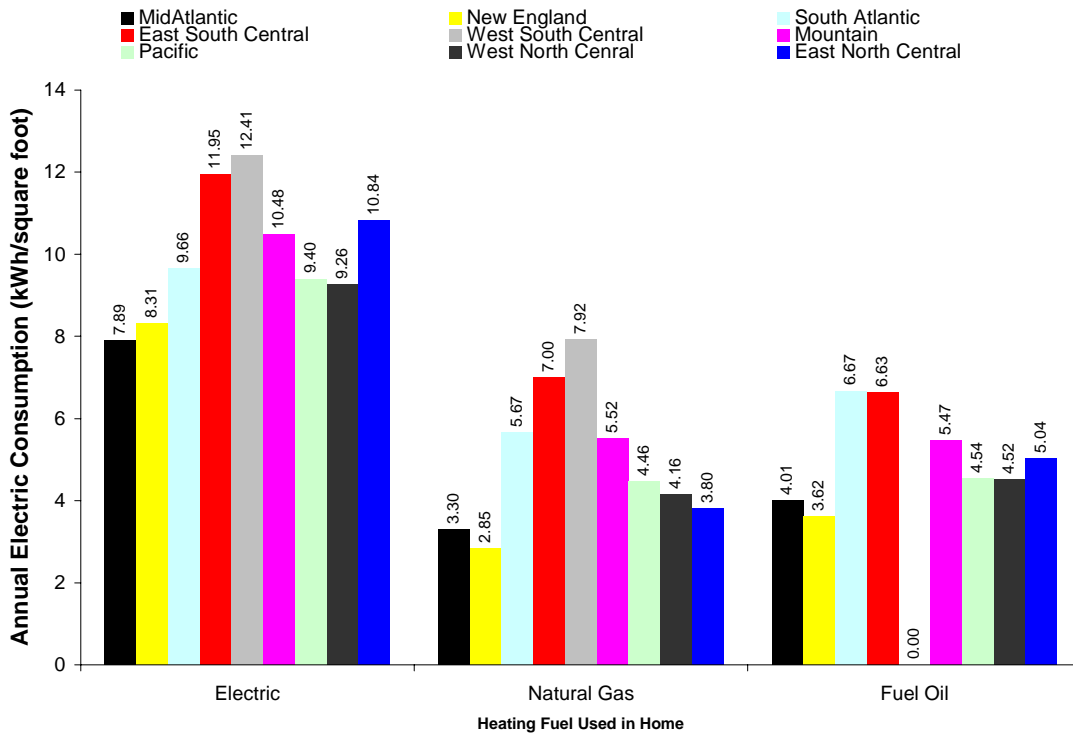


Figure 6 - Annual Electric Consumption by Heating Fuel (Single-Family Homes)

Across all years of construction, the data set does indicate the high correlation between type of heating system and annual electric consumption. For non-electric heating systems, the annual consumption ranges between 3 kWh and 8 kWh per square foot of living space. The higher estimates are presumably for areas where air-conditioning is prominent and with higher CDD. A value of "0.00" indicates that no houses heated with that fuel were identified.

The annual consumption trend for single-family detached homes that use electricity for major appliances and space conditioning is shown in Figure 7. Similarly to the previous figures, the data is normalized to square footage of heated space per home. Data are compiled in multi-year bins until 1989 and is then evaluated on an annual basis. The data for the last two available years, 1996 and 1997, are comprised of a limited data set of less than 10 records and therefore may not be representative of the entire set of homes in that year.

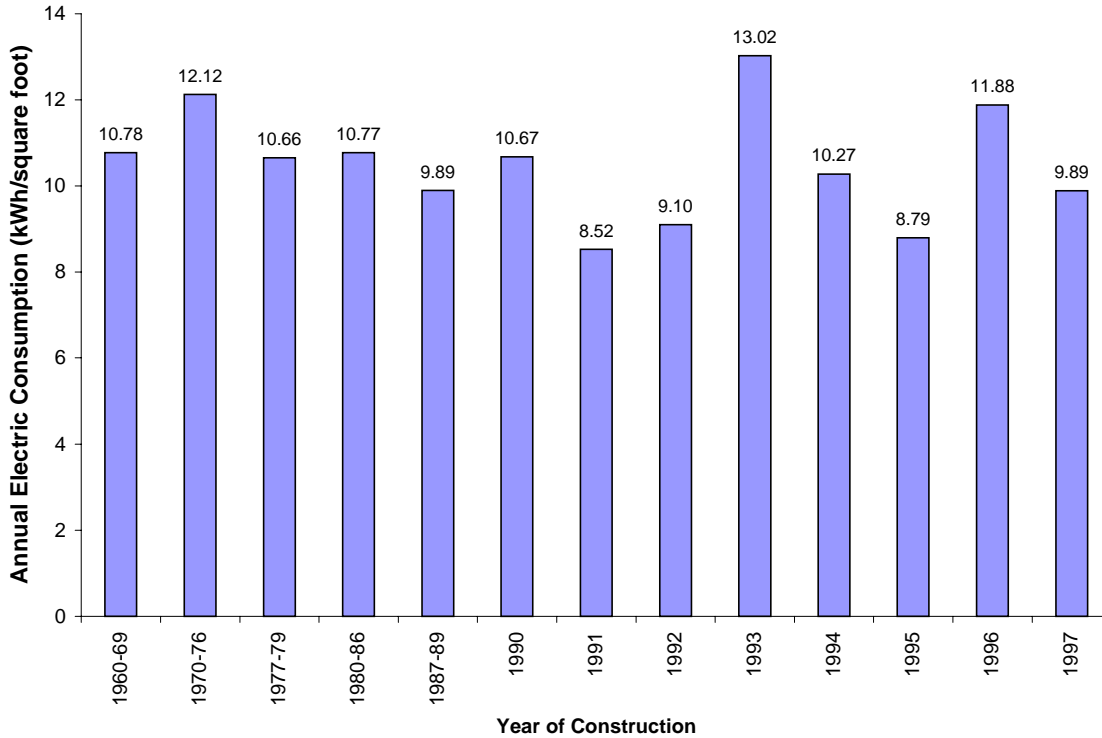


Figure 7 - Annual Electric Consumption for All-Electric Homes (Single-Family Detached)

It appears that for these particular homes the consumption trend is somewhat stable even when considering the increased efficiency of appliances. This is due, in part, to the increased frequency of air-conditioning installation and, to some extent, the greater use of electrical appliances in general. This data indicates that on average, in all-electric homes, about 20,000 kWh are consumed in a 2,000 square foot home annually (1,667 kWh per month). If this energy use were spread evenly throughout the day, it is equivalent to about 2.3 kW consumed constantly over the course of a year.

Using the same data as in Figure 7, Figure 8 depicts the annual electric consumption for single-family households that use electricity for cooking, heating, hot water and air-conditioning by EIA region. Looking at this figure, it is apparent that electric consumption is regional in nature, and that there is a correlation between energy use and expected air-conditioning use.

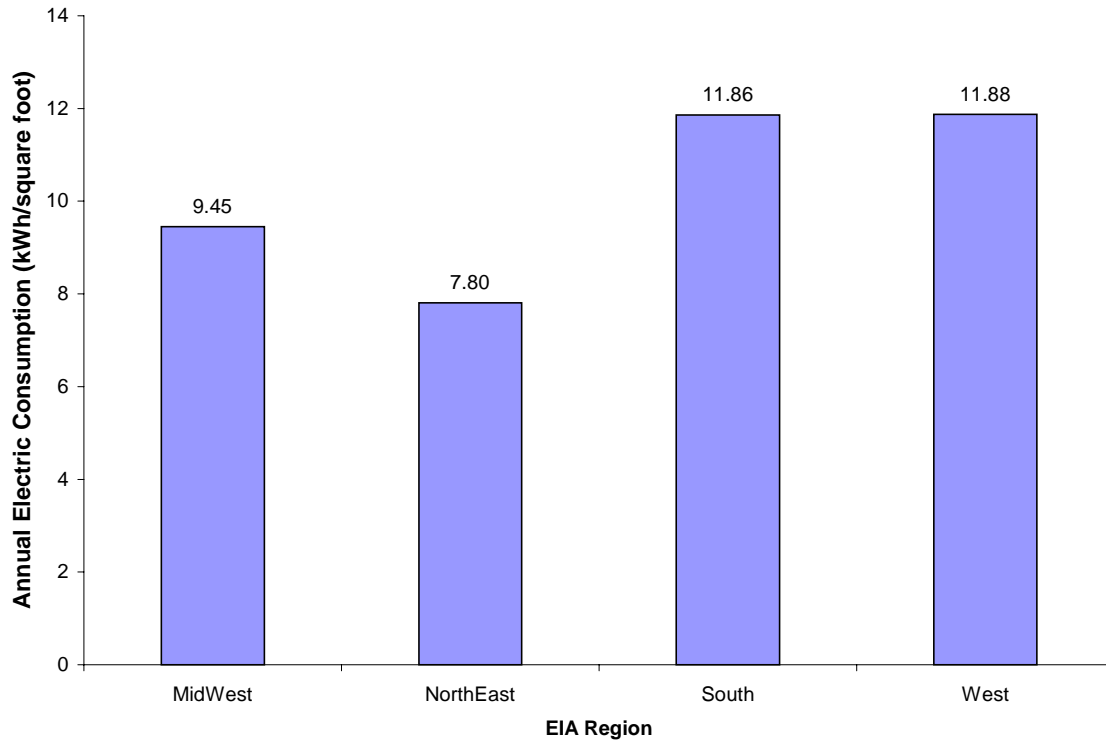


Figure 8 - Annual Electric Consumption for All-Electric Homes by Region (Single-Family Detached)

Use of the EIA data on all-electric homes are valuable in understanding the overall estimated energy use in homes. Though highly dependent on averages, the data does indicate that for all-electric homes, the average consumption ranges from about 7.8 to almost 12 kWh per square foot of living area. The higher consumption levels probably depend on the amount of cooling and, to some extent, heating, in a given climate, depending on whether heat pumps are the predominate form of space heating rather than less efficient electric resistance heating.

MONITORED HOMES

While the RECS data are a useful tool for determining annual energy consumption, a better understanding of the loads and changes in loads is necessary for evaluating the application of electrical generation to homes. A more detailed understanding of electrical energy use in homes can be gained by evaluating detailed energy consumption data from energy monitoring of single family homes. This data are valuable since it is less ambiguous and provides some level of validation to the average data. The limitation of using actual data is that the data depends highly on house construction, occupant behavior, weather, environmental conditions, and equipment performance.

Florida Solar Energy Center Study

As an example of a regional data set that may help better determine the range of expected electrical use in a given area for a given home size, data from ten homes is evaluated. The Florida Solar Energy Center (FSEC) conducted a several year study (mid-1990) of “typical”

affordable housing in the southern Florida region⁵. The three bedroom homes have a conditioned floor area of 1,030 square feet; the four bedroom models total 1,190 ft². The construction is conventional for south Florida: concrete block on an uninsulated monolithic slab with an exterior light colored stucco finish. The roofs are of standard (truss) construction with plywood decking and asphalt shingles. The concrete block walls are insulated with R-3 (hr•ft²•°F/Btu) insulation on the interior. The ceiling is insulated to R-19 with fiberglass batts. Single-hung, aluminum-framed single-glazed windows are used. The mechanical cooling system in the houses consists of 2.0-ton air conditioners in the three bedroom homes and 2.5-ton air conditioners in the four bedroom units. Both A/C units are rated at SEER 12.0. Heating is provided by 4.8 kW electric resistance elements (7.1 kW in four bedroom homes) located in the air-handling unit.

Figure 9 describes the normalized total average annual consumption for the ten homes in the study. Each total is comprised of various appliance and space-conditioning electric energy use. The homes in the study used electricity for heating, cooling, hot water production, and cooking.

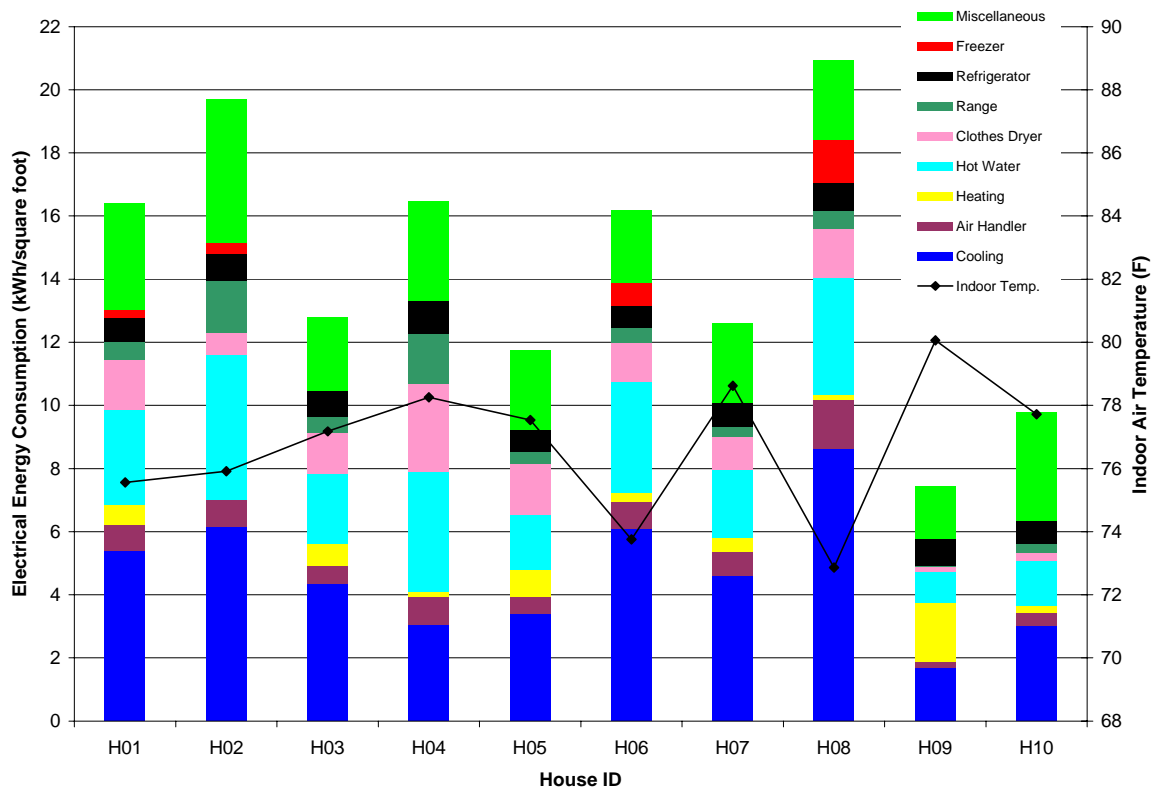


Figure 9 - Summary of Electric Energy Consumption in 10 South Florida Homes

The average annual energy use is about 14.5 kWh per square foot with a range from about 7.5 to 21 kWh per square foot. This is approximately 22% higher than the average of EIA data in the southern Region. Many differences exist especially related to the use of air-conditioning including thermostat setting, occupant use of the blower, outdoor temperature,

⁵ Monitored Energy Use Patterns in Low-Income Housing, Parker et al, Florida Solar Energy Center, 1996

house construction, and occupant behavior. Another important consideration is that the cooling energy (excluding the blower energy) accounts for about 40% of the electric energy use. From this Florida study, the average breakdown of electric consumption according to type of load shown in Table 2

Table 2 – Electric Consumption per Load Type Based on Florida Study

Electric Load	% of Total
Space conditioning	40
Domestic hot water	19
Clothes dryer	8
Range	4
Refrigerator	6
Miscellaneous	22

For these all-electric homes, energy for space conditioning and water heating accounts for approximately 60% of total energy.

New Homes in Central Ohio

Another data set based on monthly records of energy consumption is provided by a central Ohio builder. The data set includes homes ranging from 1,670 to over 3,200 square feet, with the average home just over 2,100 square feet. Most of the homes have basements or crawlspaces. Various heating and cooling systems were used including ground-source geothermal (GT) heat pumps, conventional air source heat pumps (HP), and gas furnace and conventional A/C (GAS). Two systems used an uncommon reverse cycle chiller (RCC) that heats or cools water in a storage tank to be used in an air-handler heat exchanger or radiant floor (RF) system. The variation in home sizes is shown in Table 3.

Table 3 – Conditioned floor area and Type of Mechanical System for 17 Monitored Homes in Ohio

Home ID	Sq. Ft.	HVAC	Home ID	Sq. Ft.	HVAC
1	2000	GAS	10	1719	GAS
2	3250	RCC/RF	11	2067	GT
3	1685	GAS	12	2561	GAS
4	1992	GAS	13	1670	GT
5	2897	GT	14	2200	GT
6	2100	GT	15	1315	GT
7	2192	RCC	16	1942	GT
8	1705	GAS	17	2500	HP
9	2023	GT			

GAS – Furnace with conventional A/C
RCC – Reverse chiller, /RF – with radiant floor system
GT – Ground-source heat pump

The normalized annual energy use for each of the central Ohio homes is shown in Figure 10. The months are summed to an annual total. The type of space conditioning system is included with acronyms from Table 3.

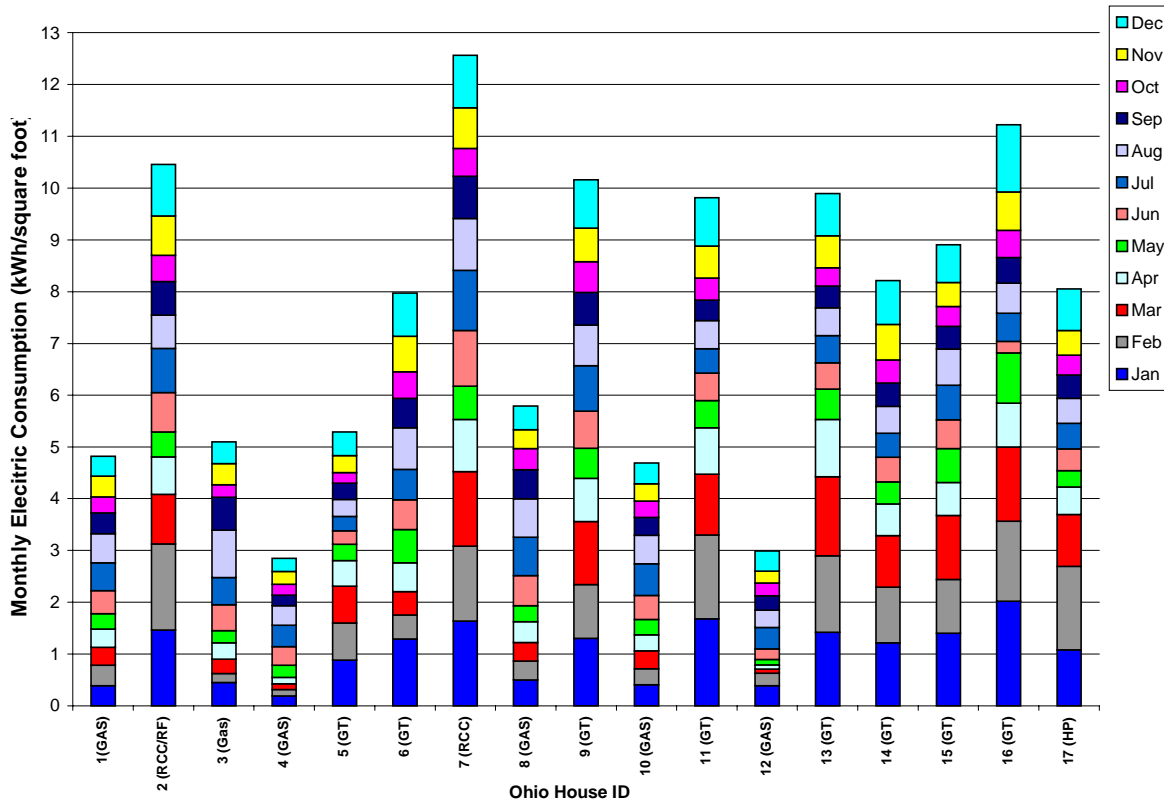


Figure 10 - Normalized Annual Electric Consumption, Ohio Homes, by Month

Average annual electricity consumption is about 7.5 kWh per square foot, including both electric and gas heating systems. For electrically heated homes, the average is 9.3 kWh per square foot; the average for gas furnace homes is 4.4 kWh per square foot. These averages are similar to EIA data for the region.

All-Electric Homes in Northern Ohio

A summary of the energy use of homes constructed primarily in northern Ohio is shown in Figure 11.

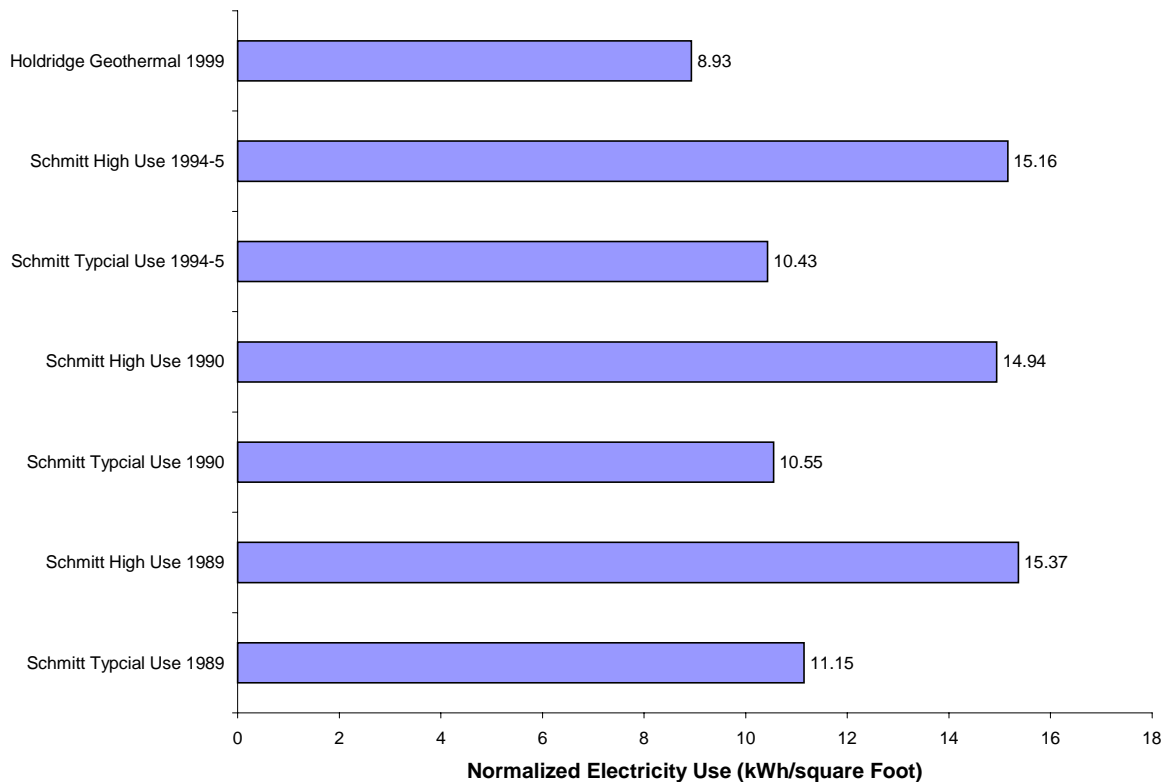


Figure 11 - Normalized Electric Use for All-Electric Homes in Ohio

The data in Figure 11 indicates clearly the range of usage between different households, even with similar type appliances for heating and cooling. A high use home is defined as one using more than 13.5 kWh per square foot.⁶ There is a 50% difference in the average annual consumption between the categories indicating the wide range to be expected. About 20% of the homes fell into the high-use category.

Implications for Residential Distributed Generation – Annual Data

Annual data describes the expected range of electrical consumption for homes in the United States. The data may be analyzed to highlight differences according to year of construction, region, climate etc.

For homes that use non-electric energy sources for heating, the annual range of electric consumption is between 3 and 8 kWh per square foot. The average of 5 kWh per square foot is a suitable reference point for these homes. The higher end of this range is primarily for homes in the southern part of the U.S., and is most likely due to the use of air-conditioning.

When electricity is used for heating, the electric consumption estimates range from 8 to 12.5 kWh per square foot. The higher portion of this range is again for homes in the southern

⁶ In compiling the data, the builder selected the cut-off point, which has not been adapted for this analysis.

U.S. with the upper northeast also reaching the high end of the range due to the extremely cold and long winters.

When actual data are reviewed as with the data set from Florida, these ranges were exceeded on average by about 25%. The data sets from Ohio however are similar to the expected consumption identified by the EIA data with the exception of the higher consumption (high-use) for about one-fifth of the homes analyzed.

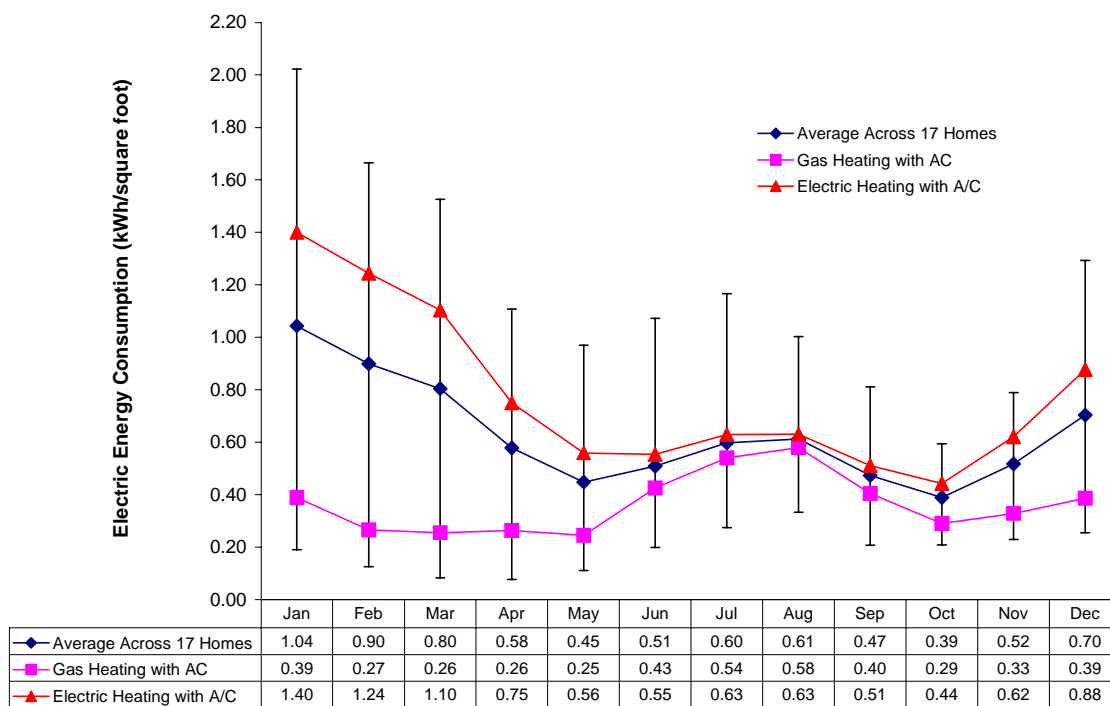
MONTHLY DATA

A search for publicly available monthly residential energy use data was performed to determine the seasonal variation in electric energy use. Two specific data sets were supplied by builders from Ohio (the same data used above); other data sets were obtained from various reports or studies.

Monthly electric consumption data provides a greater level of detail than annual consumption and may be used for sizing electrical generation equipment for homes. The data reported here are specific to a set of homes constructed from the mid- to late-1990s. The limitation of this data is that its applicability may be location specific, for central Ohio for example. The advantage is that the data show the realistic variation in electric consumption as well as a close relationship with seasonal variation in outdoor temperature.

New Homes in Central Ohio

Figure 12 shows average electric consumption for 17 homes in central Ohio. The bar lines represent the maximum and minimum for each month. A detailed description of the size of each home and type of heating and cooling system is found in the previous section. The average electric use for all homes in this study is highest in the winter for electrically heated homes (ground- or air-source heat pump or reverse cycle chiller). The homes with gas furnaces have the highest electric use in the summer because homes with gas furnaces probably use gas for other appliances as well—making summertime electric use driven mainly by cooling loads.



1999 Data

Figure 12 - Monthly Normalized Electric Consumption for 17 Homes in Central Ohio

The range of monthly electric use for all hours ranges from less than 0.1 to over 2 kWh per square foot (200 to 4,000 kWh for a 2,000 square foot home). The summer consumption is very consistent across all homes that have central air-conditioning.

New Homes in Northern Ohio

Bob Schmitt Homes, Inc., a builder in Ohio, amassed and tabulated monthly electric consumption data for houses that his company has constructed. The data represents the monthly average electric consumption for all the homes in a particular year. The average is weighted for high use and typical use with the high use homes using more than 13.5 kWh per square foot annually. The data was compiled and aggregated by Bob Schmidt Homes and represents an enormous effort on the part of the builder to monitor the energy use of his homes consistently over a period of years. The data presented is for a select set of years, 1989, 1990, and 1994-1995. The heating degree-days in 1989 was calculated at 6,324, and in 1990, 5,264. For the winter period 1994-1995, the heating degree-days were calculated at 5,449.

A large data set containing monthly electric consumption for homes that are heated and cooled with heat pump units is charted in Figure 13. The seasonal change in electric use is clearly visible as well as the spikes in energy use due to severe weather conditions. As with other similar data, there is a period of moderate use with other periods of high to very high use. The high use periods may extend to four or five months depending on the temperature. It is also clear that for electric homes the consumption exclusive of heating and cooling is

relatively modest, about one-quarter to one-third of the peak in high use periods. The "Hi-Lo Range" data represent the ratio of the highest monthly use to the lowest monthly use across the annual periods considered.

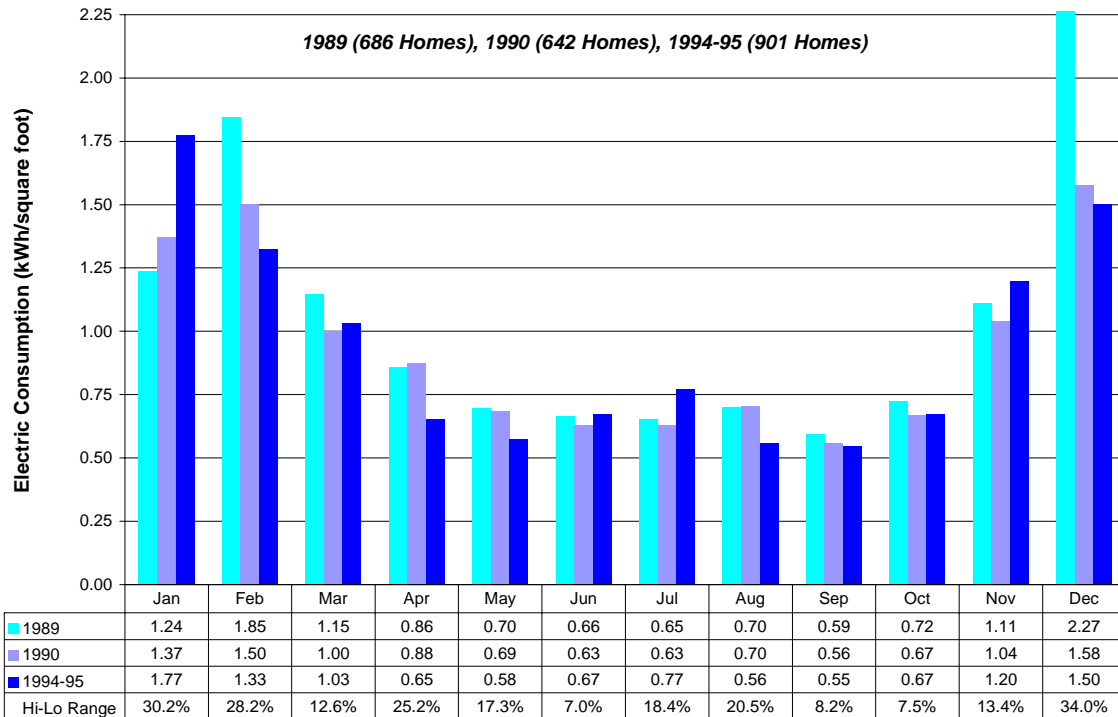


Figure 13 - Normalized Monthly Electric Use in North Central Ohio Homes

With electric space heating, the peak winter months' consumption exceeds the summer months' consumption by at least 50%. The variation from year to year however ranges from 7 to 34 percent, primarily attributed to the severity of the climate in any one period.

Southern California Edison (SCE) Residential Monthly Load Profile Data

A very different monthly consumption pattern from the Ohio homes is evidenced in the Southern California Edison's Residential Load Profile data for 1999. Figure 14 shows monthly consumption, calculated from hourly data, for 1999. The data has not been normalized on a square foot basis. However, when using an average square footage from EIA data for single- and multi-family residences in the Pacific region of 1441 square feet, the normalized consumption is between 0.30 and 0.43 kWh per square foot per month. The SCE consumption profile is also much closer to a flat line over the course of the year, indicating either a temperate climate zone or one that requires similar space conditioning year-round. The change in monthly use from the highest month to the lowest is about 30%. This flat profile lends credence to the assumption that heating and cooling loads are the primary driver for large monthly variations in energy consumption.

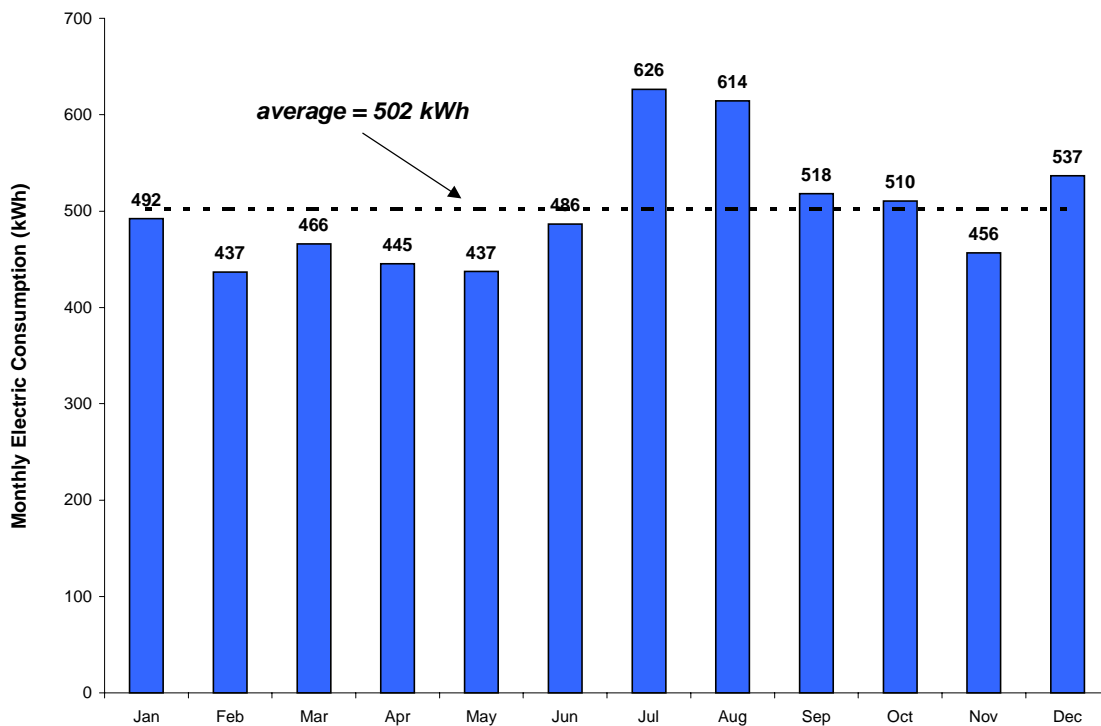


Figure 14 – Southern California Edison Residential Load Profile

The data, when compared to the Ohio data, are quite consistent. The months when space-conditioning energy is (assumed) low may be representative of the estimated “base” load of the home—the load for all appliances except heating and cooling. This assumption depends on the consistent use of appliances such as the range, hot water heater, entertainment equipment, etc. For Ohio homes that use fuel gas for heating and at least some appliances, the base electric load is similar to the base load for the SCE territory. The base load for the Ohio homes that are all-electric, or nearly so, is about twice that of the fuel-gas-supplied homes. These estimates are not conclusive but, rather, show general consistency from one location to another and between primary energy sources used in the home.

Implications for Residential Distributed Generation – Monthly Data

The monthly analysis describes the expected range of electrical consumption for homes in selected regions of the United States. The data is analyzed primarily to highlight differences in monthly consumption across the year, accounting for heating and cooling system use. In the “swing” months, where the largest portion of the load is attributed to normal electrical use, rather than heating or cooling system operation, a base use may be identified. This monthly base use is approximately 0.25 kWh per square foot for homes with gas appliances and about twice that (0.50 kWh/ft²) for homes that use electricity for all appliances.

The demand on a distributed power system for the home may be expected to see a large monthly variation across the seasons, especially when electricity is used for heating. The design of a system to supply the base load may be appropriate for homes that use gas for heating and water heating, with a greater reliance on battery storage or the utility connection.

For electric homes however, the design of a system that is much larger and capable of supplying a large portion of the load may be appropriate. However, due to the actual variation in consumption, as high as 50% or more, a load-limiting design may be necessary to achieve higher generation equipment efficiencies. Higher equipment efficiencies may be extracted when the generation equipment operates at more of a constant rate rather than experiencing large swings in output due to variable demand.

DAILY DATA

Daily energy use data give further insight for sizing and designing residential distributed generation equipment. The daily, hourly and demand data presented in the following sections are simple energy data and are not normalized on a square footage basis. This is convenient since at this resolution, it is advantageous to evaluate the actual energy being used rather than a general annual or monthly consumption. In addition, the maximum and minimum consumption for the day or hour is analyzed so that a degree of confidence in sizing the distributed generation equipment is possible.

The information on daily consumption contained here was obtained from utility supplied residential electric energy use profiles. These data sets represent a statistically determined profile for the particular utility, in this case, residential single- and multi-family. The user profiles are in effect dynamic, taking into account varying demand based on real-time conditions such as weather patterns⁷. Using one year of hourly data, the maximum, minimum and average hourly demand for any 24-hour period of the year was determined.

Southern California Edison Load Profile Data

Figure 15 shows the daily average, maximum and minimum demand for each day in 1999 for a typical residential unit in the Southern California Edison territory. This graph shows how the demand varies throughout a single day by a factor of two to three. The daily data is summarized from hourly data.

⁷ For a more complete description of the data set and its applicability, refer to Southern California Edison's web-site - <http://www.sce-esp.com>.

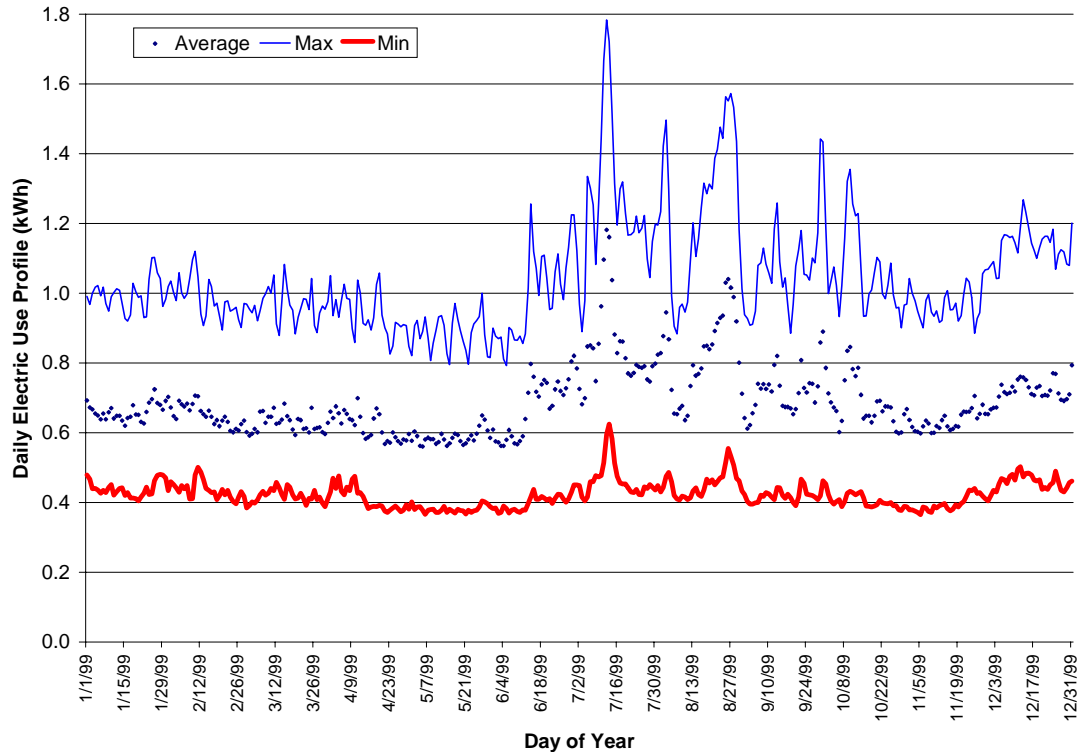


Figure 15 - Residential Load Profile in Southern California Edison Territory - 1999

The data from Figure 15 has a number of implications for the design of distributed generation systems in southern California:

- The maximum peak energy use for any hour of any day across the year is about five times that of the minimum use for any hour of any day,
- The average consumption for any hour ranges from less than 600 watts to about twice that for all days during the year, and
- The average energy use profile is somewhat constant for about eight months of the year.

Public Service Electric and Gas Data

Where the daily data from SCE is for all homes within the load profile, a more detailed division between homes with electric heat versus homes with other types of heating is shown in Figure 16 and Figure 17. The data from Public Service Electric and Gas (PSE&G), located in New Jersey, represents hourly demand for the residential sector of PSE&G territory.⁸ The data set in Figure 16 charts the daily average, minimum, and maximum electric energy consumption of homes that do not use electricity for heating.

⁸ This data obtained from <http://web3.pseg.com>, with further processing used to develop charts.

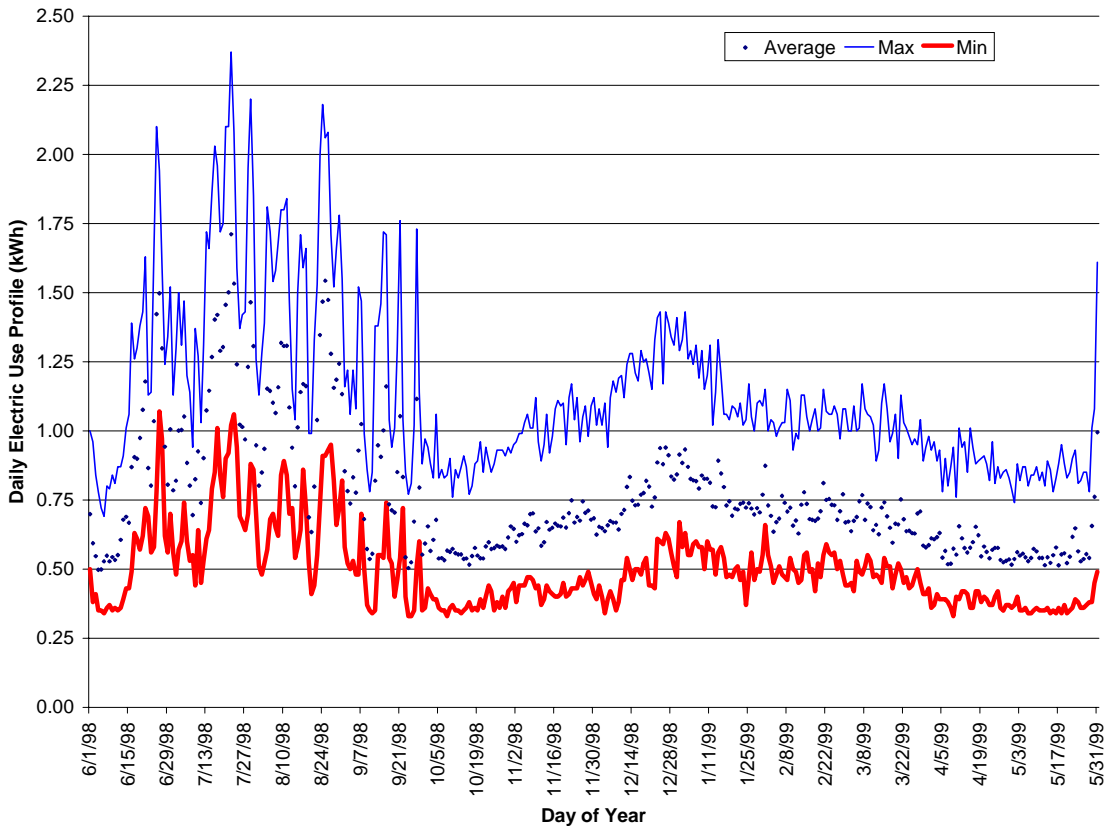


Figure 16 - Residential Load Profile in Public Service Electric & Gas Territory (other than Electric for Space Heating)

Like the previous chart in SCE territory, the data from PSE&G in Figure 16 has a number of implications for the design of distributed generation systems in this territory and in homes that do not use electric for space heating:

- The maximum peak energy use for any hour of any day across the year is over seven times that of the minimum use for any hour of any day,
- The average consumption for any hour ranges from just over 500 watts to as high as about 1,750 watts for all days during the year, and
- The average energy use profile is somewhat constant for about eight months of the year.

These implications are very similar to SCE except for the ratio of peak to minimum use.

Figure 17 shows data for the same period for homes that use electricity for space heating. The data displayed is again the average, maximum, and minimum demand for each day of the year.

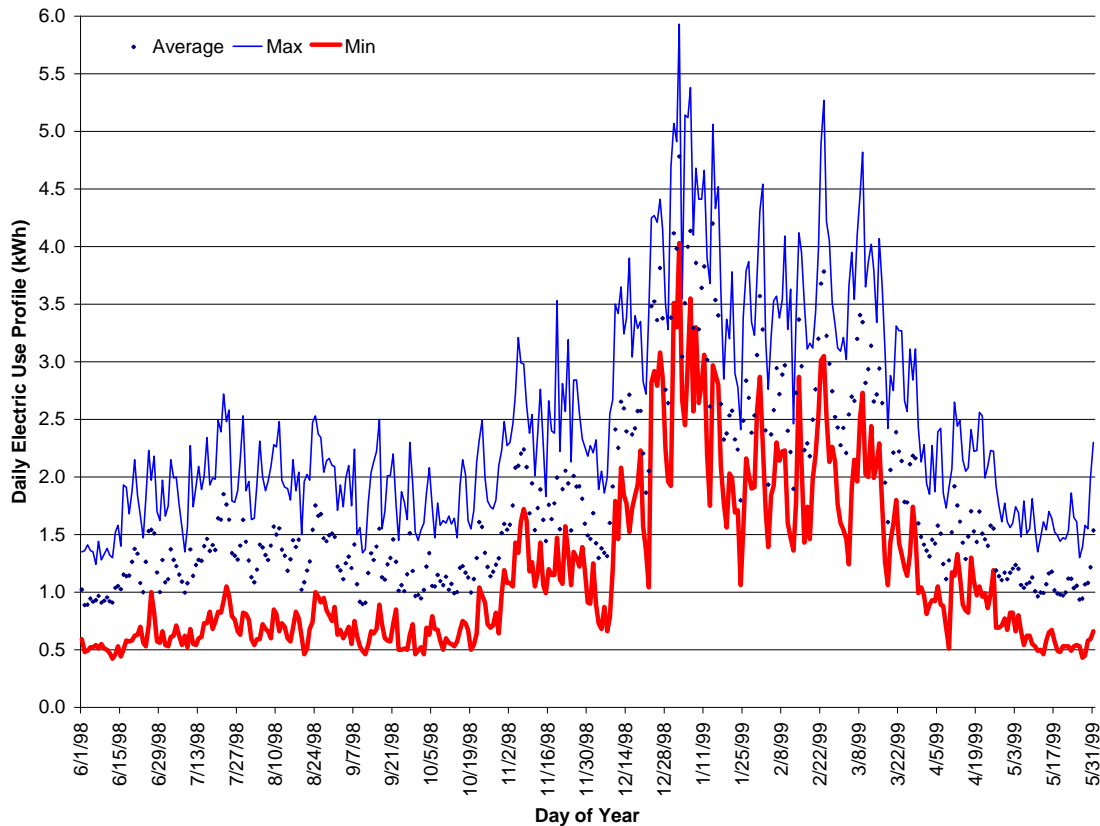


Figure 17 - Residential Load Profile in Public Service Electric & Gas Territory (Electric for Space Heating)

In the PSE&G territory, a mixed climate with significant heating, the average electric use ranges by a factor of five, from about 1 kWh/hr to almost 5 kWh/hr. In addition, the period when the use is generally flat is decreased from eight months (for Southern California Edison) to about five months and there is much greater variation from day-to-day in this same period.

For this particular profile in the PSE&G territory and in homes that use electric for space heating, Figure 17 has a number of implications for the design of distributed generation systems:

- The maximum peak energy use for any hour of any day across the year is over fourteen times that of the minimum use for any hour of any day,
- The average consumption for any hour ranges from about 1,000 watts to almost five times that for all days during the year, and
- The average energy use profile is somewhat constant for about five months of the year but with much greater variation from day-to-day.

These implications are very different from the previous two examples and present a much larger design problem for distributed generation applications in these particular home configurations.

Baltimore Gas and Electric

For another utility in a mixed climate,⁹ Figure 18 shows similar results as the PSE&G data but with lower peaks. Figure 18 shows residential electric load profile for homes without electric heat followed by the load profile for homes with electric heat in Figure 19.

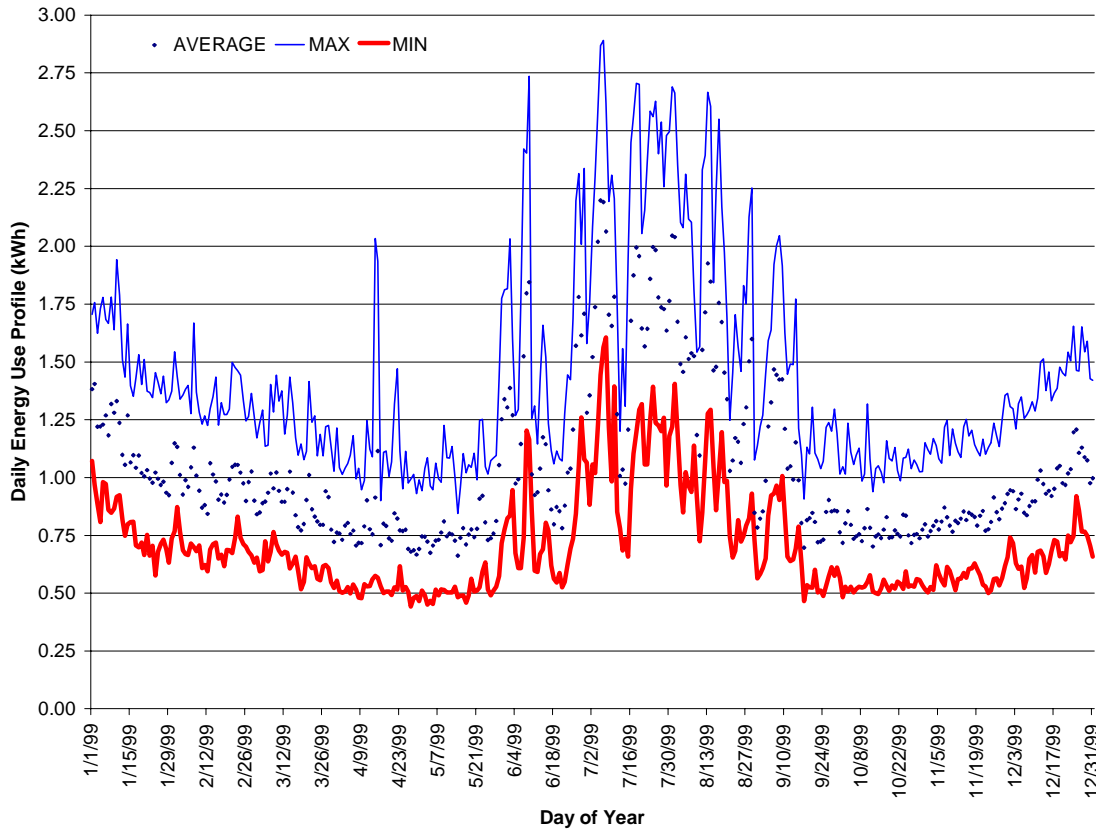


Figure 18 - Residential Load Profile in Baltimore Gas and Electric Territory (other than Electric for Space Heating)

For this particular profile in the BG&E territory and in homes that do not use electric for space heating, Figure 18 has a number of implications for the design of distributed generation systems:

- The maximum peak energy use for any hour of any day across the year is almost six times that of the minimum use for any hour of any day,
- The average consumption for any hour ranges from about 720 watts to about three times that for all days during the year, and
- The average energy use profile is somewhat constant for only about five months of the year.

⁹ Raw data obtained from <http://supplier.bge.com>, and processed further in this analysis.

These implications again are very different from the previous examples. While the minimum-to-peak ratio is not as significant as other utilities, it is still large. The period of time when the load is somewhat level is also limited with a much more varied use throughout the year. The design issues associated with a distributed generation application in these particular home configurations are also substantial.

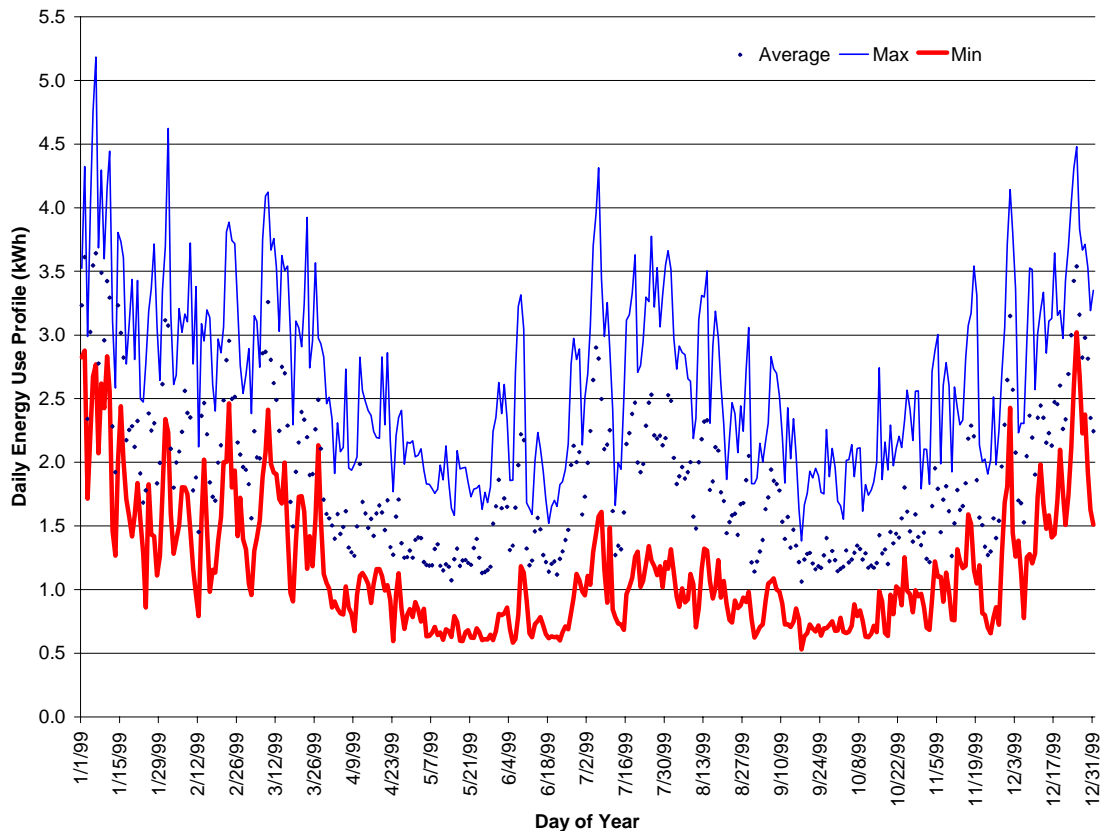


Figure 19 - Residential Load Profile in Baltimore Gas and Electric Territory (Electric for Space Heating)

As in the previous analysis in the BG&E territory and in homes that use electric for space heating, Figure 19 has a number of implications for the design of distributed generation systems:

- The maximum peak energy use for any hour of any day across the year is almost ten times that of the minimum use for any hour of any day,
- The average consumption for any hour ranges from about 1,000 watts to almost 3.5 times that for any day during the year, and
- The average energy use profile is somewhat constant for only about four to five months of the year with a large variation from day-to-day.

These implications again are similar to the previous BGE example, however, the minimum-to-peak ratio is more severe. The period of time when the load is fairly level is also limited with a much more varied use throughout the year. The design issues associated with a

distributed generation application in these particular home configurations are again significant.

Implications for Distributed Generation Equipment – Daily Data

The available utility data of daily consumption for residential buildings provides more detail for determining a suitable application for distributed generation equipment. In some climates, and especially those where electricity is not used for heating, there is a rather flat energy use profile for a large portion of the year. However, there is also a large spike in energy use during the cooling season. A distributed generation system in these homes would need supply between 600 and 1,000 watts on average. A system that would supply all of the electricity needs of the home would need to peak between 2 and 3 kilowatts depending on the climate. These averages do not represent actual demand at any time during the hour.

For homes that are electrically heated and, most likely all-electric, the average consumption is from 1,200 to 1,500 watts during any hour and peaking between 4 and 6 kilowatts. There is a much larger variation from day-to day as well, in both the minimum and average use profile in all-electric homes.

HOURLY DATA

In addition to understanding average daily residential electricity use, it is useful to understand average hourly electricity use. The hourly change in electrical demand provides a snapshot of what may be expected of the distributed generation equipment through a diurnal period. Using the previously considered utility residential load profile data, the data are analyzed for each hour of the day across all days in the year. Figure 20 shows the average hourly use from SCE's residential load profile data, and including the median, maximum and minimum for each hour.

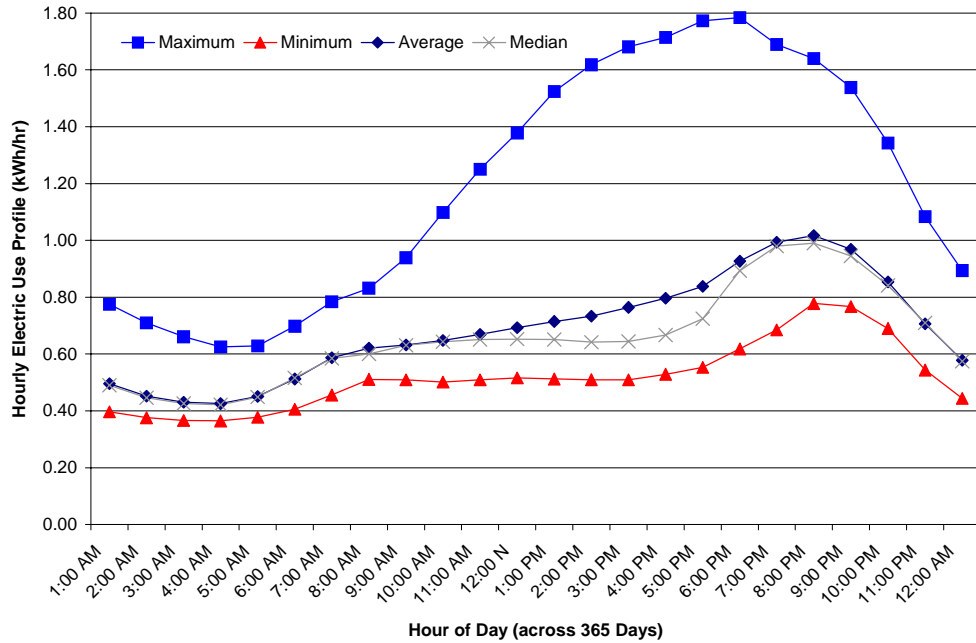


Figure 20 - Hourly Average Residential Load Profile (Southern California Edison Territory)

For the PSE&G residential load profile data, Figure 21 and Figure 22 show the hourly load profile for homes without electric space heating and homes with electric space heating, respectively. Hourly average, median, maximum and minimum loads are included.

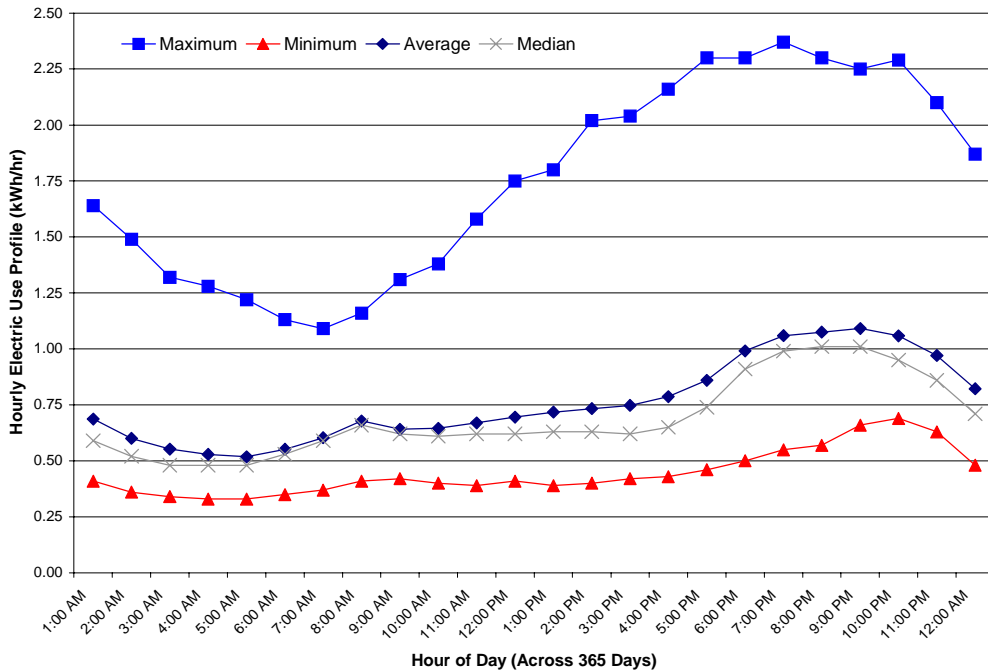


Figure 21 - Hourly Residential Load Profile (Public Service Electric & Gas Territory, Non-Electric Space Heating)

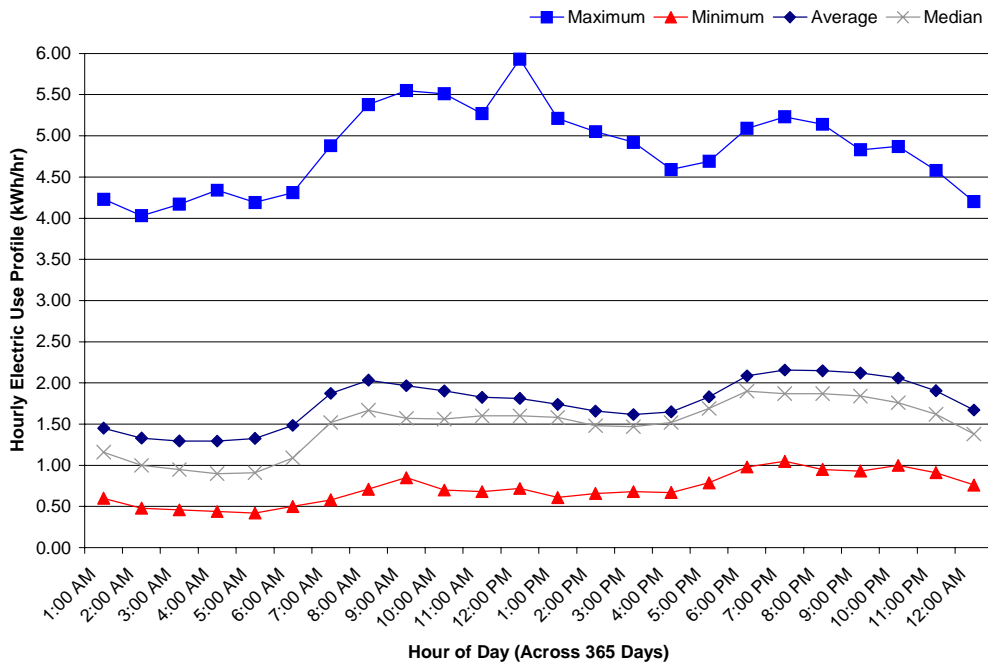


Figure 22 - Hourly Residential Load Profile (Public Service Electric & Gas Territory, Electric Space Heating)

Similar hourly data for the BGE residential electric load profile is shown in Figure 23 and Figure 24. The data is also divided according to homes that do not use electricity for heating and those that do.

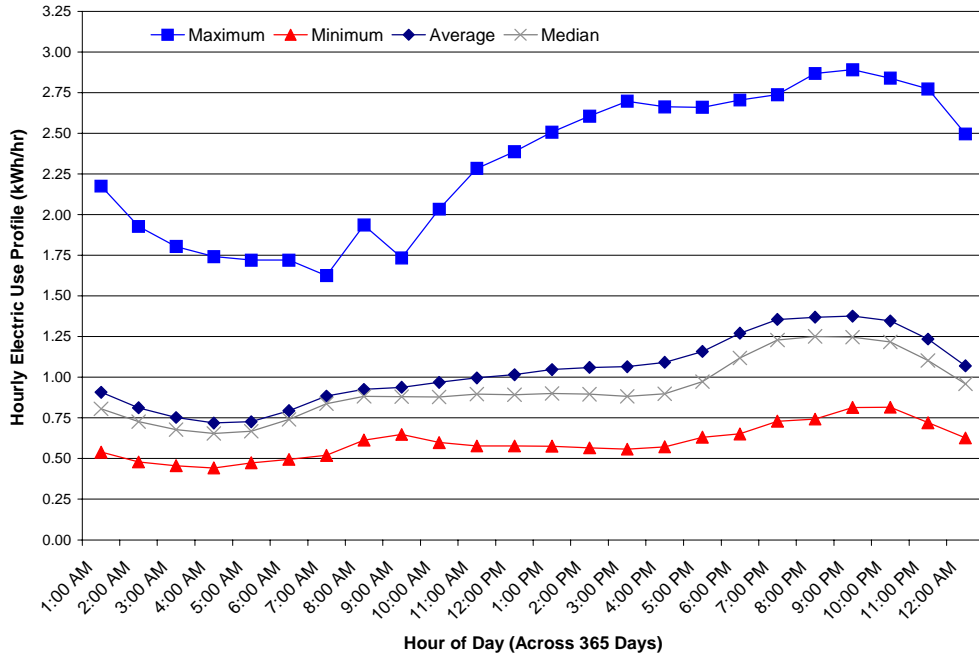


Figure 23 - Hourly Residential Load Profile (Baltimore Gas and Electric Territory, Non-Electric Space Heating)

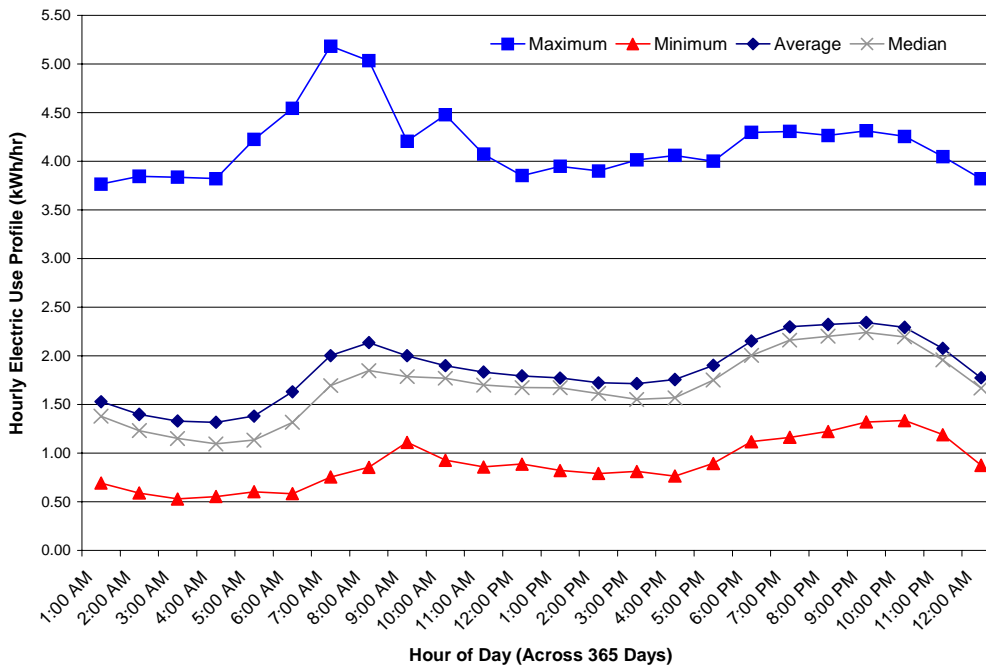


Figure 24 - Hourly Residential Load Profile (Baltimore Gas and Electric Territory, Electric Space Heating)

Implications for Residential Distributed Generation – Hourly Data

The hourly data, which spans all hours of the year, represents the range of change in electrical use for each hour of the day throughout the year. The average, median maximum and minimum are shown for each hour across the year. Most notable from the data is the difference from the minimum to the average relative to the difference between the average and the maximum for each hour. The difference between the maximum and the average is about three times more than the difference between the average and the minimum. This implies that the data is skewed towards the minimum level of consumption for each hour of the day and throughout the year. This appears to be consistent for all locations analyzed.

ELECTRICAL DEMAND DATA

A more thorough understanding of residential electrical demand is determined from actual consumption data for specific homes. Demand data is useful for evaluating the size of a distributed energy generation system such as fuel cells, especially where the generator is required to supply the entire load. As opposed to hourly data, demand data provides an indication of the required energy for brief periods of time, in this case for 15 minutes. Higher levels of energy may be necessary for brief periods on the order of seconds to a few minutes.

An example of demand data is shown in Figure 25 for an occupied residence. The data resolution is on a 15-minute basis. Daily consumption along with the maximum 15-minute demand for any period in the day is recorded. The 15-minute demand period is important because it provides a framework for designing supplemental storage that will supply a large amount of energy for a short period. This in turn can lower the cost of the distributed generation system since the increased capacity for storage is less expensive than installing a larger generation system that will be used at its peak only rarely. The data summary is for more than a year of monitoring.

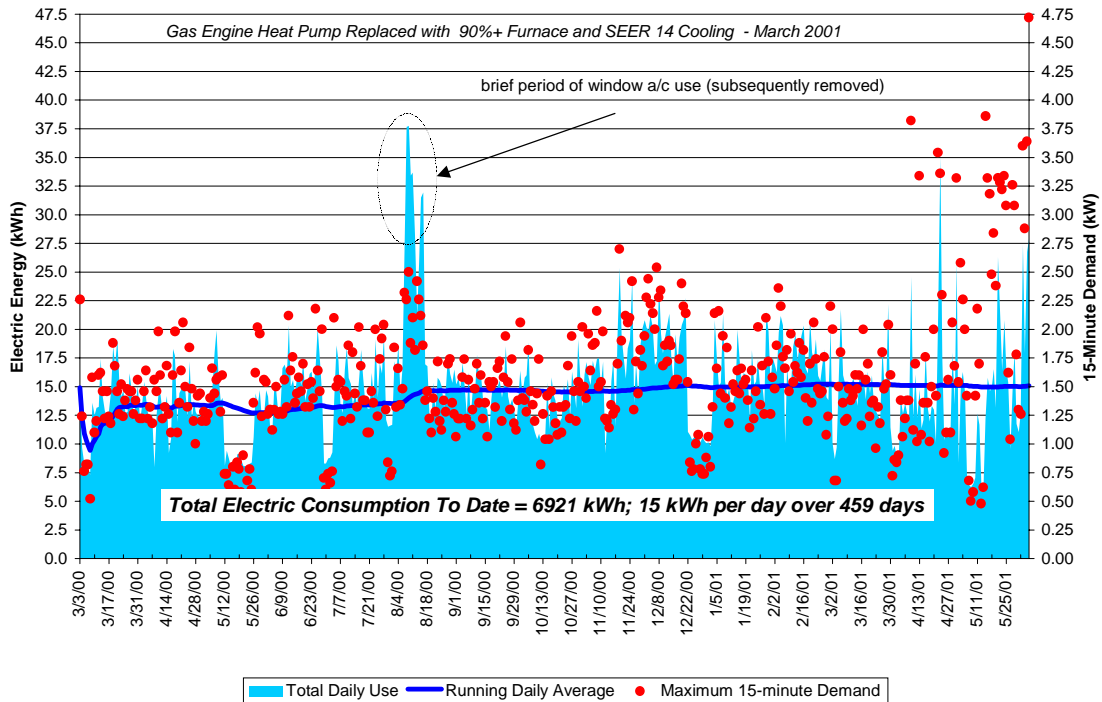


Figure 25 - Actual Energy and 15-Minute Demand Data for Proposed Fuel Cell Site

The 15-minute demand is shown on the right axis and peaks at almost 5.0 kW. The home uses gas for all of the major appliances. Over the summer, a gas-engine heat pump was used for cooling until the March of 2001 when the gas-engine heat pump was replaced with a gas furnace and electric air-conditioner.

The 15-minute **clock** demand is very near the **floating** 15-minute demand, to within about 360 watts. The floating demand is based on 180, 5-second increments¹⁰. The maximum 15-minute demand is approximately 4,000 watts for this home. On a one-minute basis, the maximum demand is approximately 5,100 watts, and the maximum 5-minute demand is about 4,920 watts.

The minimum demand for any 5, 10, and 15-minute period is 120 watts. The minimum 1-minute demand is 0.0 watts.¹¹ This result indicates that the generator has a turndown ratio, the ratio of the maximum 5-minute to the minimum 5-minute demand, of nearly 41. A generator would theoretically need to respond to this wide range of demand, instantaneously, unless a limitation on the demand was utilized or a storage system like a battery was used to supply intermediate power for a short period.

¹⁰ In 15 minutes, there are 180, 5-second readings. The floating 15-minute demand monitors the new demand calculation made on the previous 179 readings and the latest new reading.

¹¹ The 0 watt 1-minute demand is more a function of the resolution of the power monitoring device than the home actually using zero watts at any point.

SUMMARY

This report summarizes an available body of data to describe energy use in homes. The data is evaluated on an annual, monthly, daily, and hourly basis. Demand data, on a 15-minute resolution are also included for one sample home. A brief outline of implications for distributed generation equipment for use in the home is provided at the end of each section.

The data is available for use as a basis for comparison of the energy use in different homes. New home designs that seek to achieve goals of energy efficiency may be compared to homes in a given area. This application will be more valuable as the database expands to many regions across the U.S.

The data also serve as a design reference when implementing distributed generation systems for use in homes. Home generation systems serve the home electrical loads. Loads are the sum of all electrical demand required to operate any electrical device that is turned on. On-site generation in homes may take many approaches including:

- Systems that supply the entire home load independent of the traditional utility,
- Systems that serve a specific load only,
- Utility-interconnected systems that seamlessly function in conjunction with a utility supply,
- Multi-source systems that rely on numerous generating or energy storage devices to supply the total house load, and
- Systems that rely on a combination of demand limiting and generation to serve the home electrical needs.

The entire home energy supply may involve various sources of supply including fuel gas, oil, and electricity. The home electrical use data is primarily divided according to homes that do not use electricity for heating and those that do use electricity for heating. The prevalent fuel for cooling is electricity. When electricity is used for heating, it may be used in a home that uses fuels other than electricity for water heating or cooking for example, although this is not considered typical. On an annual basis, homes that use electricity for heating generally have at least twice the electricity consumption than homes that do not use electricity for heating. On a monthly basis, however, the electricity use may be very similar in all homes in a given climate regardless of the fuel used for heating.

This data, while limited in sample size on other than an annual basis, may be used to support changes in home electrical and energy systems. These changes may focus on one or more specific areas such as:

- Appliance designs that deactivate based on an external signal (the signal may be generated based on total electrical demand, electricity costs, or consumer interaction),
- Automatic-off controls that deactivate devices based on non-use,
- Design of renewable generation equipment that rely on a variable supply such as solar or wind,
- Design of distributed generation equipment,

- Design of neighborhood power systems,
- Consumer energy-use education and awareness, and
- Achieving long-range goals such as net-zero energy consumption.

Distributed generation specifically, but also the entire electrical system of the home generally, is emerging to a unique point in development. Well developed, residential electrical systems are now sophisticated, reliable, easily installed and, for the most part, durable. New technologies continue to drive the opportunities to use the electrical system to its fullest, while decreasing the amount and cost of using electricity.