Profiles on Residential Power Consumption

Phase 1 Final Report

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FOREWORD

There has been a large change in the number and nature of electrical devices in the American home since the tables used by NEC® Article 220 *Branch-Circuit, Feeder and Service Calculations,* were established more than three decades ago. These tables and requirements describe typical lighting and appliance electrical loads that may be found in residences and other occupancies. These figures form the basis for sizing services and feeders to residences. The cumulative effects of the introduction of new technologies, both positive and negative, will be a change in both the average and peak power consumption. The assumptions behind the load calculation methodology of Article 220 need to be reviewed and confirmed.

Accordingly, the Fire Protection Research Foundation undertook a study to validate the basis for the load calculation methodology of Article 220 of the National Electrical Code by developing baseline information on typical profiles of electrical loads in today's residences.

The Research Foundation expresses gratitude to the report author Justin Bishop of Exponent; the Project Technical Panelists listed on the following page; and to the National Fire Protection Association for funding the project.

The content, opinions and conclusions contained in this report are solely those of the author.

Profiles on Residential Power Consumption

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Profiles on Residential Power Consumption: Phase I Final Report

Prepared for the Fire Protection Research Foundation

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Executive Summary

The tables used by the National Electrical Code (NEC) Article 220 to calculate branch-circuit, feeder, and service loads in dwelling units have not been significantly modified for five decades. Modern technological advancements have made household devices more electrically efficient, which may have decreased the average and peak load requirements for a residential dwelling. However, this effect may be offset by an increase in number, usage, and electrical load characteristics of household devices, which, in turn, may have actually increased the average and peak load requirements. Accordingly, there is a need to evaluate the modern electrical load requirements in residences of the twenty-first century in order to validate the basis for the load calculation methodology in the tables of Article 220. Without data from a study into present day residential electricity usage, the applicability of these tables in today's dwellings cannot be confirmed.

The first time the 3 VA(watts)/ft^2 value was used to calculate the general lighting load as described in Article 220, which included general receptacles, was the 1951 NEC. Earlier values used to calculate the general lighting load was 1 Watt/ ft^2 from the 1933 NEC to the 1940 NEC and then 2 Watts/ ft^2 from 1940 NEC to the 1951 NEC when the present 3 VA(Watts)/ ft^2 was introduced. No basis was found to substantiate the values of 1, 2, or 3 VA(watts)/ft^2. It is furthermore not known how many structures are presently or were historically built to comply with this minimum standard. Its present effectiveness is therefore not known.

The 1959 NEC introduced the optional load calculation in Article 220-7. Comparison between Article 220 in the 1959 and 2008 NEC showed numerous similarities in the optional and standard load calculation methodologies and the table values. Example load calculations using both the standard and optional methods described in the 1959 and 2008 NEC were completed and showed calculated load values for 1959 and 2008 to be very similar.

Utility data was obtained from utility statistics found in the literature and available utility data for modern residential dwellings. The resulting data and electrical consumption predictions provided by the Energy Information Administration (EIA) were used to evaluate present and projected residential dwelling electricity consumption. Comparisons between available modern utility data showed conflicting trends. Based on evaluation of the limited utility data obtained, a multi-year study is advised to evaluate electricity consumption at the feeder and branch circuit level in modern dwellings to provide reasonable applicability for the table values and load calculation methodologies of Article 220 of the NEC. New construction which now requires higher efficiency lighting fixtures will also have a reduced volt-ampere requirement per m^2. It may not, therefore, be practical to create generalized code requirements to adequately address all expected situations to which this code will be applied. Additionally, modifications to Article 220 may impact other parts of the NEC. Examples of articles that reference Article 220 include Articles 210, 215, 230, and 310. Suggestions for a multi-year Phase II are discussed and a process flow for a computer model that could interpret the field measurements and residential surveys is described.

Background

Since their creation over five decades ago, the tables used by the National Electrical Code (NEC) Article 220 to calculate branch-circuit, feeder, and service loads in dwelling units have not been significantly modified. Modern technological advancements have made household devices more electrically efficient, which may have decreased the average and peak load requirements for a residential dwelling. However, this effect may be offset by an increase in number, usage, and electrical load characteristics of household devices, which, in turn, may have actually increased the average and peak load requirements. Accordingly, there is a need to evaluate the modern electrical load requirements in residences of the twenty-first century to validate the basis for the load calculation methodology in the tables of Article 220. Without data from a study into present day residential electricity usage, the applicability of these tables in today's dwellings cannot be confirmed.

The tables used in Article 220 were developed during a period when, for example, a homeowner would typically use incandescent bulbs to light the dwelling. Homeowners of the twenty-first century are now commonly converting to Compact Fluorescent Light (CFLs) or even Light-Emitting Diodes (LEDs) that will reduce energy usage. If eighteen 100-watt incandescent bulbs were replaced with eighteen 30-watt energy star CFLs[1], the lighting loads would drop by 70%. However, since the twenty-first century dwelling might have two more televisions than dwellings of the previous era, plus two computers and a microwave oven, the average and peak load requirements could be similar or higher. The characteristics of the loading such as power factor and power quality will also be quite different.

Exponent proposed to investigate, compile, and evaluate typical electricity consumption for dwellings of the twenty-first century through the use of historical utility data, published literature, and field measurements including such effects as geographical and seasonal variances made available through literature or utility data. A focus of the project was to evaluate the validity of Article 220's calculation methods. Phase I efforts included working with a National Fire Protection Agency (NFPA) representative to identify historical notes concerning iterations of the NEC and, with guidance from the technical committee, Exponent collected and evaluated available utility data for evaluation of the tables and load calculation methodologies in Article 220. Suggestions for the next phase of the project were also explored.

[1] http://www.energystar.gov/index.cfm?c=cfls.pr_cfls_lumens

Scope of Work

To answer the request for an evaluation of the validity of the load calculation methodology used in NEC Article 220, Exponent proposed to investigate, compile, and evaluate electricity consumption for dwellings of the twenty-first century through the use of historical utility data, published literature, and field measurements from utilities taking into account such effects as geographical and seasonal variances. During the kickoff meeting with the project technical panel and the project manager, the tasks from the original proposal were reevaluated and modified based on discussions during the meeting.[2] An additional discussion with the project manager was held during the project and the tasks continued to be adjusted.[3] The tasks below reflect the final agreed-upon tasks for Phase I portion of this project.

1. *Review of historical and current code requirements*
2. *Development of preliminary baseline for residential electricity consumption*
3. *Develop a detailed Phase II research plan*
4. *Complete technical reports*

Task 1: Review of historical and current code requirements

Decisions reached by the Project Technical Panel and the Fire Protection Research Foundation (FPRF) project manager focused this task in two areas. One dealt with understanding the inclusion of the "Optional Load Calculation"[4] method and the other was the choice of 3 VA(watts)/ ft^2 for general lighting[5] in the dwelling load calculations. NFPA representative, Jeffrey Sargent, provided past NEC versions and historical notes concerning changes to the NEC. The 1951 NEC was the first time the 3 VA(watts)/ft^2 value was used in the calculation for general lighting and the 1959 NEC was when the optional load calculation was introduced. Comparison between Article 220 in the 1959 and 2008 NEC showed numerous similarities. An example load calculation using both the standard and optional methods described in the 1959 and 2008 NEC were completed and showed calculated load values for 1959 and 2008 to be very similar (see Table 1).

Feeder and Service Load Calculation Methods

The Feeder and Service Load Calculation Methods in Article 220 of the NEC were meant to provide a minimum load requirement for enclosures such as single-family dwellings. There are currently two different methods of calculating the minimum load requirement for a dwelling[4]: the Standard Load Calculation[4] and the Optional Load Calculation[4]. The optional method was

[2] Teleconference on 6/15/2009

[3] Email communication from the FPRF project manager on 9/10/2009

[4] Defined in the Article 220: Branch-circuit, Feeder, and Service Calculations of the 2008 NEC

[5] Stated in Table 220.12: General Lighting Loads by Occupancy of the 2008 NEC

introduced to the NEC in 1959.[6] Based on historical notes provided by the NFPA, the Panel Comment related to including the optional method in the 1959 NEC read, "The panel accepted in general the principle that one-family dwellings served by 100 ampere (amp.) services could be permitted to use a somewhat more liberal diversity factor than now permitted. The panel did not accept the application of increased diversity to existing 60 amp. services."[7]

F. E. Sanford for EEI submitted the original proposal for the optional calculation.[8] The original proposal[9] is shown in Figure 1and the supporting documentation[10] is shown in Figure 2. The panel made minor modifications to the original proposal as seen in Figure 3.

The original proposal said: **"Alternate Feeder Load Computation for Residential Occupancies.** To assure reasonable operating reserve capacity this alternate method to apply only with a minimum of: on new installations, 100 amp., 240 volt feeder (or service); on existing installations, 60 amp., 240 volts. For feeders to individual occupancies (or services to single family residences) the minimum load may be calculated as follows: The sum of all air conditioning (including heat pump compressor) load 100%, the first 10 kw of all additional load 100%, all remaining load 40%. All appliances or equipment shall be taken at rating (kva for motor and other low power factor loads) except for the small appliance load which may be assumed at 1500 watts total. Lighting shall be calculated as 3 watts per square foot."

Figure 1. Mr. Sanford's original proposal for the optional calculation method.

[6] The 1956 NEC did not have an optional load calculation.

[7] From the "Proposed Amendments of the 1956 Edition National Electrical Code."

[8] From the "Proposed Amendments of the 1956 Edition National Electrical Code."

[9] From the "Proposed Amendments of the 1956 Edition National Electrical Code."

[10] From the "Proposed Amendments of the 1956 Edition National Electrical Code."

Supporting Comment: About 1000 residences, served by 21 utilities, were included in the survey and the information for each included a general description of the particular residence, a listing of the connected appliances and their ratings, the maximum demand, and the energy usage by months for a one-year period. About one-half of the residences used three or four of the following: Range, water heater, clothes drier, air conditioner, space heating or heat pump. About one-fourth of the residences had air conditioners and another one-fifth had electric space heating, not including in this category seventeen heat pump installations.

The data showed that above some minimum value, there was substantial diversity in all cases except those with a high percentage of air conditioning. It is indicated that air conditioning load may add 100 per cent, without diversity.

Analyses of these data suggest that the proposed alternate feeder load computation will assure reasonable reserve capacity for residential occupancies.

Figure 2. Optional calculation supporting comment.

In the 1959 version of the NEC, the optional calculation method for one-family residence served by a 115/230 volt, 3-wire, 100 amp. or larger service where the total load is supplied by one feeder or one set of service entrance conductors is called out in section 220-7. The calculation table and directions for the calculation from the 1959 NEC are shown in Figure 3 while the directions in the 2008 NEC are described in section 220.82 and shown in Figure 4. The calculation methods for the two years show similarities. Some examples include:

- The use a 3 watts(VA)/ ft^2 for calculating the general lighting/receptacle loads.[11]
- Require two dedicated 1500 watt 20 amp branch circuits for portable appliances/kitchen.[12]
- Cooking equipment such as ranges were taken at their nameplate rated load.[13]
- The heating/cooling equipment portion uses the highest rated value at 100% load.[14]
- Use the 40% load factor for the "Remainder of other load."[15]

[11] 1959 NEC table 220-2(a), 2008 NEC table 220.12

[12] 1959 NEC section 220-3(b), 2008 NEC section 210.11(c)(1)

[13] 1959 NEC section 220-7, 2008 NEC section 220.82 (B)(3)

[14] 1959 NEC section 220-4(k), 2008 NEC section 220.82 (C)

[15] 1959 NEC table 220-7, 2008 NEC section 220.82 (B)

Table 220-7
Optional Calculation for One-Family Residence

LOAD (in kw or kva)	Per Cent of Load
Air conditioning and cooling including heat pump compressors [see Section 220-4(k)]	100%
Central electrical space heating [see Section 220-4(k)]	100%
Less than four separately controlled electrical space heating units [see Section 220-4(k)]	100%
First 10 kw of all other load	100%
Remainder of other load	40%

All other load shall include 1500 watts for each 20 ampere appliance outlet circuit [Section 220-3(b)]; lighting and portable appliances at 3 watts per square foot; all fixed appliances, (including four or more separately controlled space heating units [see Section 220-4(k)], ranges, wall-mounted ovens and counter-mounted cooking units) at name-plate rated load (kva for motors and other low power-factor loads).

Ripped from the 1959 version of the NEC

Figure 3. Snapshot of the 1959 version of the NEC Article 220 optional load calculation for one-family residence.

(B) General Loads. The general calculated load shall be not less than 100 percent of the first 10 kVA plus 40 percent of the remainder of the following loads:

(1) 33 volt-amperes/m^2 or 3 volt-amperes/ft^2 for general lighting and general-use receptacles. The floor area for each floor shall be calculated from the outside dimensions of the dwelling unit. The calculated floor area shall not include open porches, garages, or unused or unfinished spaces not adaptable for future use.

(2) 1500 volt-amperes for each 2-wire, 20-ampere small-appliance branch circuit and each laundry branch circuit covered in 210.11(C)(1) and (C)(2).

(3) The nameplate rating of the following:

a. All appliances that are fastened in place, permanently connected, or located to be on a specific circuit

b. Ranges, wall-mounted ovens, counter-mounted cooking units

c. Clothes dryers that are not connected to the laundry branch circuit specified in item (2)

d. Water heaters

(4) The nameplate ampere or kVA rating of all permanently connected motors not included in item (3).

(C) Heating and Air-Conditioning Load. The largest of the following six selections (load in kVA) shall be included:

(1) 100 percent of the nameplate rating(s) of the air conditioning and cooling.

(2) 100 percent of the nameplate rating(s) of the heat pump when the heat pump is used without any supplemental electric heating.

(3) 100 percent of the nameplate rating(s) of the heat pump compressor and 65 percent of the supplemental electric heating for central electric space-heating systems. If the heat pump compressor is prevented from operating at the same time as the supplementary heat, it does not need to be added to the supplementary heat for the total central space heating load.

(4) 65 percent of the nameplate rating(s) of electric space heating if less than four separately controlled units.

(5) 40 percent of the nameplate rating(s) of electric space heating if four or more separately controlled units.

(6) 100 percent of the nameplate ratings of electric thermal storage and other heating systems where the usual load is expected to be continuous at the full nameplate value. Systems qualifying under this selection shall not be calculated under any other selection in 220.82(C).

Ripped from the 2008 version of the NEC

Figure 4. Snapshot of the 2008 version of the NEC Article 220 optional load calculation for one-family residence, section B and C.

The standard calculation method for the years 1959 and 2008 were also compared and example similarities and differences include:

- The general lighting load calculation for both years use 3 watts(VA)/ft^2.[16]
- The demand factors applied to "Portion of Lighting Load …" were the same for residential dwellings.[17]
- The demand loads for household electric ranges, wall-mounted ovens, counter-mounted cooking units and other household cooking appliances over 1 ¾ kw rating were the same.[18] However, differences occur in the notes to the table.

[16] 1959 NEC table 220-2(a), 2008 NEC table 220.12

[17] 1959 NEC table 220-4(a), 2008 NEC table 220.42

[18] 1959 NEC table 220-5 , 2008 NEC table 220.55

- The demand factors for the number of household electric clothes dryers up to 4 dryers were the same while factors for additional dryers were similar or were the same.[19]

- The methods call for two 1500 watt circuits for the Small Appliance load[12] but the 1959 does not specifically call out a 1500 watt circuit for laundry as the 2008 NEC does.[20]

Chapter 9 of the 1959 NEC described different examples of the standard and optional load calculations for dwellings. The examples were similar to the examples used in the 2008 version of the NEC. A difference between the examples from the two years revolved around the "Laundry Circuit." In 1959, the "Laundry Circuit" was not called out as needed for the calculations.

A comparison between the standard and optional load calculation methods from both 1959 and 2008 was completed. The example dwelling had 1500 ft^2 that was suitable for habitation, a 12 kw range and a 5.5 kw dryer. Table 1shows the calculated loads using both the standard and optional load calculation methods described in the 1959 and 2008 version of the NEC. Based on this example, the load calculation methods used in 1959 and 2008 produced load values that were similar for a given calculation method. Note, it was assumed that watts and VA were the same unit for this comparison. The difference in the calculated loads was due to the "Laundry Circuit" that was required in the 2008 NEC. Additionally, this example showed the standard and optional methods do not calculate the same minimum load value. Had different values been chosen for the dryer and range loads the optional load values could have been larger than the standard load values.

Table 1. Example dwelling load calculations based off the load calculation methods described in 1959 and 2008 NEC.

	1959	2008
Standard Load Calculation	22,075 watts	22,600 VA
Optional Load Calculation	16,000 watts	16,600 VA

General Lighting Load

The general lighting load was part of the standard and optional feeder and service load calculation methods used in the 2008 NEC. The formula for calculating the general lighting load was the square footage of a dwelling (taken from the outside dimensions and excluding porches, cellars, etc.) multiplied by 3 VA/ft^2. Three $watts/ft^2$ was introduced in the calculation

[19] 1959 NEC table 220-6, 2008 NEC table 220.54

[20] 2008 NEC section 220.52 (B)

tables of the 1951 NEC.[21] Prior versions of the NEC used 1 watt/ ft^2 (1933-1937)[22] and 2 watts/ ft^2 (1940-1947).[23] There is a footnote to the watts per square foot table in the 1940 NEC that states, "It is recommended that in occupancies used for dwelling purposes, in addition to any branch circuit supplying appliances, a 15-ampere branch circuit be installed for each 500 square feet (approximately 3 watts per square foot) of floor area."

Historical notes concerning modifications of the general lighting load value to 3 VA(watt)/ ft^2 were searched for in the NFPA library; however, notes concerning the value were not found. The NFPA liaison for this project suspects that the technical documentation for the value does not exist or in his opinion the notes, "do not provide anything that one can sink their teeth into." A literature search was also undertaken to find information concerning the choice of 3 VA(watt)/ft^2 used in the NEC for general lighting load calculations but supporting information was not uncovered.

Thus, there is no apparent data available or justification recorded to support the value of 3VA(watt)/ft^2.

Task 2: Development of preliminary baseline for residential electricity consumption

Decisions made by the FPRF project manager and Project Technical Panel focused this portion of the project on obtaining information concerning load demand and electricity consumption at residential dwellings. Information was obtained from utility statistics found in literature and limited available utility data for modern residential dwellings. Seven data sets, not including data from the U.S. Energy Information Administration, from specific years between 1989 to 2009 were evaluated. The data and predictions obtained from the Energy Information Administration spanned the years from 1949 to 2035. The data and predictions were used to evaluate the current and projected residential dwelling electricity consumption.

No conclusive, statistically relevant, observations regarding load calculation methodologies in Article 220 of the NEC can be made based on the data sets received and discussed below. Comparisons between the limited modern utility data sets produce contradicting trends and highlight the need for much larger scale, multi-year, field measurements that consider geographical location and season.

Data from Literature

A literature search was completed to find information that would help determine electricity usage trends in residential dwellings over past years and help in determining future residential electricity demand. A presentation titled "Electricity 101"[24] from the Edison Electric Institute

[21] The 1947 NEC did not call out the 3 watt/ft^2 value.

[22] Based on reading Article 220 of the NEC for the specified years.

[23] The 1947 NEC did not call out the 3 watt/ft^2 value.

[24] Edison Electric Institute. 2010. Electricity 101: Overview of the electric power industry. http://www.eei.org/whoweare/AboutIndustry/Documents/Electricity101.pdf. Accessed on 2/09/10.

contained information that was used in this portion of the project. Additional information was drawn from the report entitled "Review of Residential Electrical Energy Use Data"[25] and the U.S. Energy Information Administration.[26]

Past Residential Utility Data

Utility data collected between August 31, 1994 and September 1, 1995 for ten residential dwellings located in the South Atlantic[27] area of the United States showed that the average electricity consumption was 42.8 kWh/day with the peak load value occurring in the summer months.[28] Data collected at residential dwellings in the Midwest (East North Central area) of the United States during 1989 and 1994-95 suggest a 6% decrease in electricity consumption as a function of dwelling square footage[29]for dwellings defined as typical use. Dwellings that were defined as high use showed a decrease of 1% for the same years. The peak loads for this data set occurred in the winter months. Another data set collected in 1999 for residential dwellings in the Pacific West area of the United States had peak loads that occurred in the winter months.[30]

Past Utility Statistics for United States Residential Sector

The literature indicated that electricity consumption for the residential sector has been increasing.[31] Figure 5 shows the amount of electricity usage for the United States residential sector from 1949 through 2005.[32] This trend is expected to continue since the number of single family detached dwellings is expected to increase by 22% from the year 2008 to 2035.[33]

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[25] Obtained from http://www.toolbase.org/PDF/CaseStudies/ResElectricalEnergyUseData.pdf. Accessed on 2/09/10.

[26] U. S. Energy Information Administration website http://www.eia.doe.gov. Accessed on 2/09/10.

[27] The states in the regions specified throughout this report can be found at http://www.cdc.gov/niosh/images/norms/regions.gif. Accessed on 2/09/10

[28] Parker, D., Mazzara, M., Sherwin, J., 1996. "Monitored Energy Use Patterns In Low-Income Housing In A Hot And Humid Climate," Tenth Symposium on Improving Building Systems in Hot Humid Climates, Ft. Worth, TX, p. 316.

[29] Data obtained from the "Review of Residential Electrical Energy Use Data" which can be obtained at http://www.toolbase.org/PDF/CaseStudies/ResElectricalEnergyUseData.pdf. Accessed on 2/09/10

[30] Data obtained from the "Review of Residential Electrical Energy Use Data" which can be obtained at http://www.toolbase.org/PDF/CaseStudies/ResElectricalEnergyUseData.pdf. Accessed on 2/09/10

[31] Data can be found in the Annual Energy Review historical data found on the EIA website.

[32] The residential sector includes single family, multifamily, and mobile home dwellings.

[33] Data found in the Annual Energy Outlook 2010 on the EIA website.

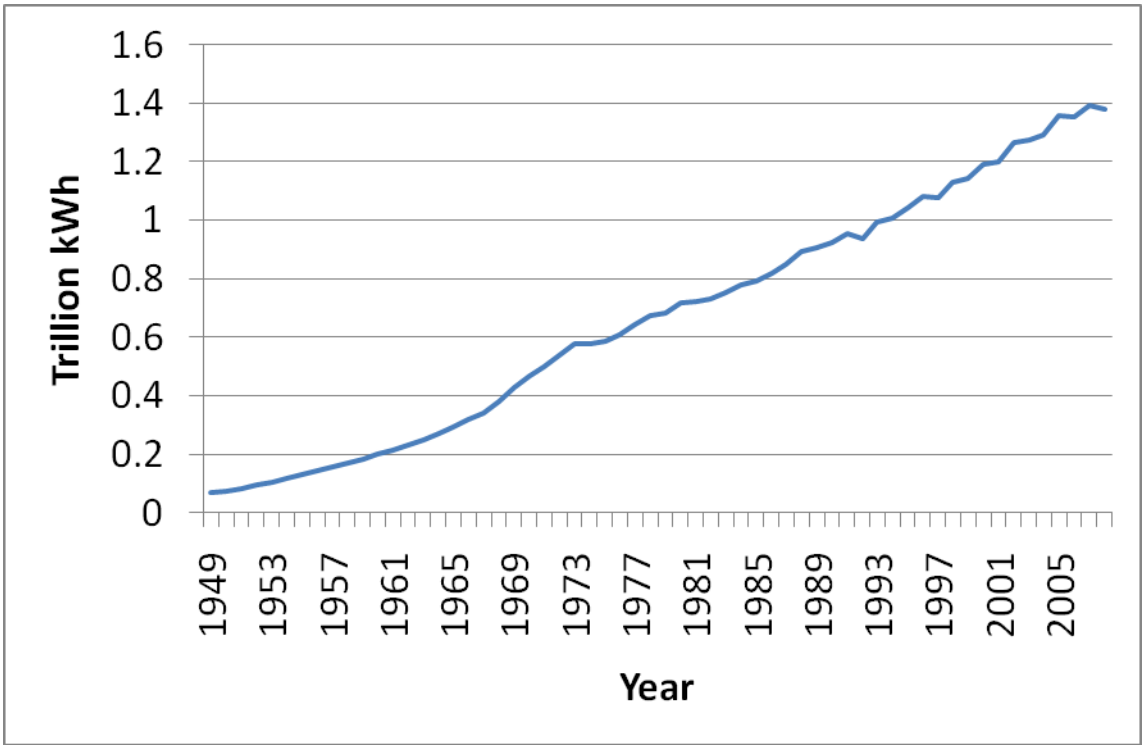

Figure 5. Electricity usage by the United States residential sector as stated by the Annual Energy Review historical data found on the EIA website.

It was suggested that the square footage of the average United States household has increased by nearly 50% since 1975.[34] Data from Residential Energy Consumption Surveys[35] for multiple years indicated that from 1993 to 2005 the per household consumption of electricity per year has increased; see Table 2. The trends shifted when the data was normalized by the average square footage for a dwelling for the corresponding year.[36] The 1993 and 2005 normalized data for electricity consumption per household per year was 4.8 kWh/ft^2. The normalized appliance and lighting data for 1993 was 2.5 kWh/ft^2 and for 2005 was 2.6 kWh/ft^2.

[34] Information obtained from "Electricity 101" which can be obtained at http://www.eei.org/whoweare/AboutIndustry/Documents/Electricity101.pdf. Accessed on 2/09/10

[35] Survey data is available to the public at http://www.eia.doe.gov. Accessed on 2/09/10

[36] Data from Residential Energy Consumption Surveys that are available to the public at http://www.eia.doe.gov. Accessed on 2/09/10

Table 2. Electricity consumption per household per year and electricity consumption related to appliances and lighting per household per year[37].

	1993	1997	2001	2005
Electricity consumption per household per year (kWh)	11328	11287	11965	13159
Electricity consumption per household per year normalized by the average square footage of a household (kWh/ft^2)	4.8	N/A[38]	4.7	4.8
Electricity consumption related to appliance and lighting per household per year (kWh)	5832	6198	6360	7107
Electricity consumption related to appliance and lighting per household per year normalized by the average square footage of a household (kWh/ft^2)	2.5	N/A[39]	2.5	2.6

Energy Predictions for the United States Residential Sector

The Annual Energy Outlook 2010[40] provided predictions for residential sector energy use until 2035. The residential sector includes single family detached, multifamily, and mobile home dwellings. The total delivered energy in the form of electricity to the residential sector was expected to increase by 19% from 2008 to 2035, according to the Annual Energy Outlook 2010; see Figure 6. Note this value is similar to the expected increase of single family detached dwellings of 22%. Figure 7 highlights three different areas that the electrical energy was expected to be delivered for the residential sector. The electrical energy used for lighting in the residential sector was predicted to decrease by 39% from 2008 to 2035 while the electrical energy used for computers was predicted to be fairly constant after 2011.[41] The energy for TVs was expected to increase[41] by 45% from 2008 to 2035.

[37] Data from Residential Energy Consumption Surveys that are available to the public at http://www.eia.doe.gov. Accessed on 2/09/10

[38] Data not available

[39] Data not available

[40] Annual Energy Outlook 2010 is available to the public at http://www.eia.doe.gov. Accessed on 2/09/10

[41] Based on data obtained from the Annual Energy Outlook 2010.

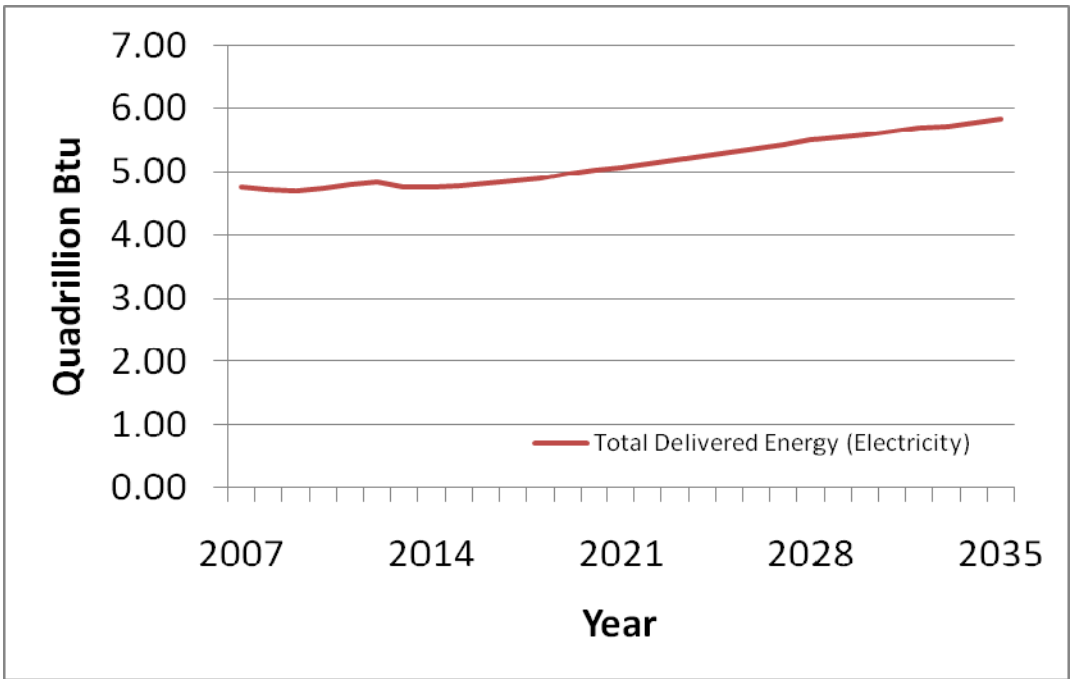

Figure 6. Residential sector energy in the form of electricity outlook. Data taken from Annual Energy Outlook 2010.

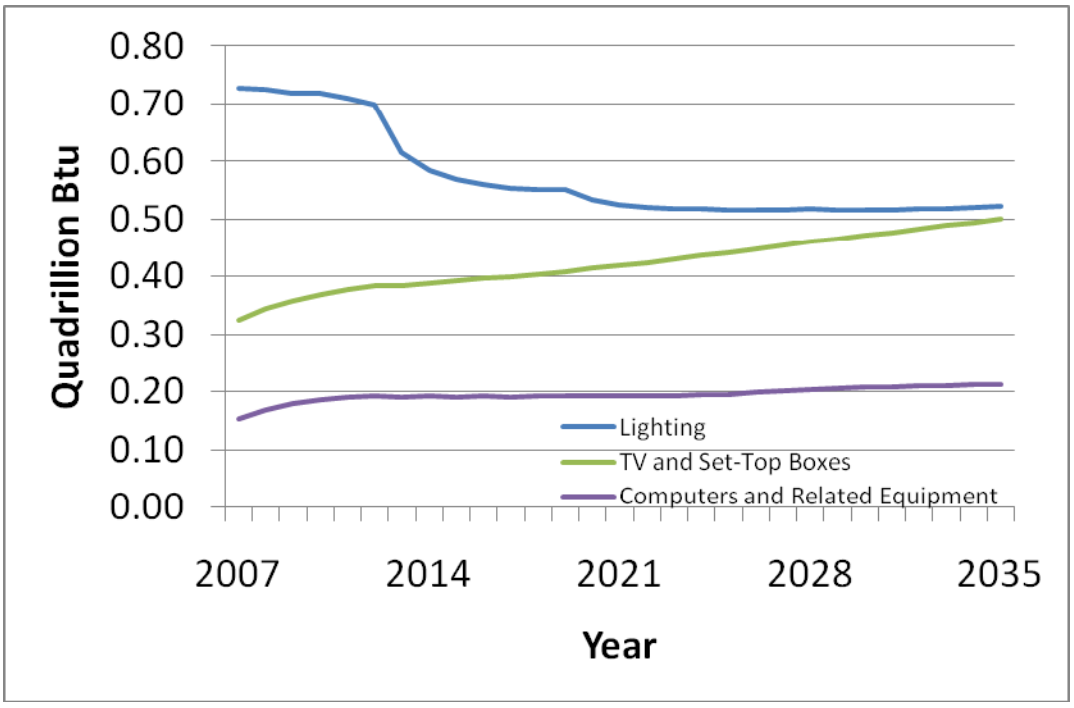

Figure 7. Residential sector energy in the form of electricity for the specified components in a dwelling. Data taken from Annual Energy Outlook 2010.

This project focuses on the electricity usage at the dwelling level. Using the data in the Annual Energy Outlook 2010 an estimate of electrical energy usage at the household level was calculated. Figure 8 shows the trend of electrical energy usage for the residential sector normalized by the number of dwellings in the residential sector and the average size of those dwellings. This calculation suggested that the average residential household energy usage in the form of electricity per square foot will decrease by 19% from 2008 to 2035.

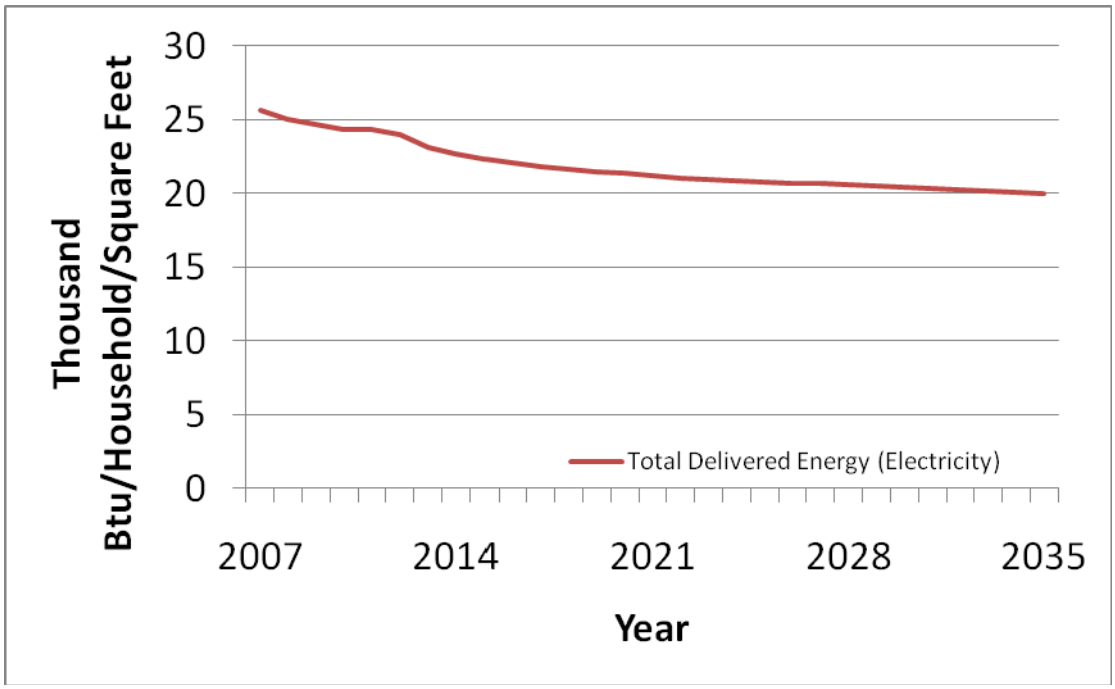

Figure 8. Residential sector energy in the form of electricity outlook normalized by the number of residential sector dwellings and the average square feet of the dwellings. Data taken from Annual Energy Outlook 2010.

An approximation of the general lighting and receptacle load described in Article 220 of the 2008 NEC was attempted by normalizing the summed categories[42] of Lighting, TV and Set-Top Boxes, Computers and Related Equipment, and Other Uses[43] by the predicted dwelling square footage for the specified year. Figure 9 shows the energy trend. There was a downward trend till around 2015 then the calculated prediction suggests a constant energy usage through 2035. The total decrease in the calculated prediction for dwelling electrical energy usage per square foot for the summed categories was 10% from 2008 to 2035.

[42] Defined in the Annual Energy Outlook 2010.

[43] Defined as small electric devices, heating elements, and motors not listed.

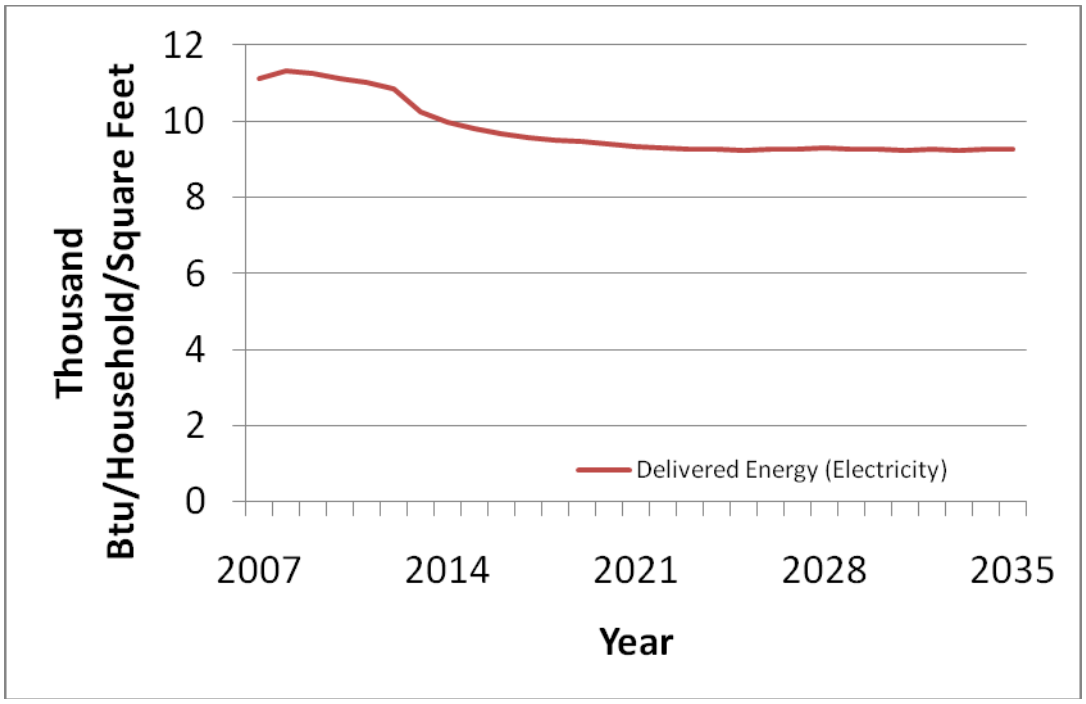

Figure 9. Residential sector energy in the form of electricity for the categories of lighting, TVs and set-top boxes, computers and related equipment, and other uses normalized by the number of residential sector dwellings and the average square feet of the dwellings. Data taken from Annual Energy Outlook 2010.

Modern Residential Utility Data

Utility Data Acquisition Efforts

Exponent worked with the Project Technical Panel appointed by the Fire Protection Research Foundation (FPRF) to develop an approach to collecting current available utility data. It was decided by the FPRF project manager and Project Technical Panel that the utilities represented at the Edison Electric Institute (EEI) conference on August 3 through August 5, 2009 would be asked to provide utility information to Exponent. Exponent gave a presentation at the EEI conference concerning the Residential Power Consumption project. After the conference surveys requesting information on the available utility data were emailed to the 24 attendees on August 6, 2009 (see Appendix B: Survey Sent to EEI Conference Attendees). The request ultimately generated ten returned surveys that were analyzed. The variety of possible data that would be available from their utilities was estimated by each attendee (see Table 3) and this was communicated to the project manager and project technical committee.

Table 3. Number of survey responses corresponding to the utility data requested

Yes	Maybe	No	Data Requested
5	2	3	Average 1 hr. Peak Demand vs. Month (any time between 1990-present)
2	4	4	Average 1 hr. Peak Demand vs. Geographical Location (any time between 1990-present)
2	2	6	Average 1 hr. Peak Demand vs. Square Footage of Dwelling (any time between 1990-present)
3	2	5	Are the Average 1 hr. Peak Demand values grouped into categories such as dwellings that use electric heat and electric water heater; electric heat and gas water heater, gas heat and gas water heater? If other please describe: _____
3	4	3	Are Average 1 hr. Peak Demand values for residential dwellings available in any format? Please describe: _____

The FPRF project manager and Project Technical Panel decided, based on the results of the survey request, that the project should continue. Upon this decision, Exponent formally requested utility data using letters sent to the six most likely utilities to have usable data, a representative letter is shown in Appendix C: Representative Letter Sent to Utilities. Each letter was modified to request the specific sets of data that the utility member had specified in the survey as having or possibly having. A summary of the responses to the request for data via letters are shown in Table 4.

Table 4. Summary of data received from utility companies after the letter request.

Number of Letters Sent Out	6
Number of Letter Responses	4
Number of Responses with Raw Data Spanning Multiple Years	1
Number of Responses with Estimated Data Spanning Multiple Years	1
Number of Responses with One Year of Raw Data	1
Number or Responses with One Year of Averaged Data	1

Acquired Modern Residential Utility Data

The data received were in different formats but the majority of the data had units of kWh. Since the load calculations of Article 220 were used to specify a minimum service value for a residential dwelling, the maximum kWh per day values were used to make comparisons between the data received to ensure this minimum was met. The maximum kWh per year for each data set was presented to show an upper limit of electrical consumption. An average of the maximum kWh per day in a year was completed for each dwelling. Each dwelling average was then averaged to create one average maximum kWh/day for a given year. The same procedure was used to calculate a median maximum kWh/day for each year available.

One data set received was the kWh per hour for every day from 2004 through 2009[44] for approximately 100 residential dwellings located in the South Atlantic area of the United States. These dwellings used electric heating and electric water heating. No information was given on the square footage of the dwellings. The raw data was analyzed by finding the maximum kWh for every day of the year for each dwelling. The daily maximum kWh values for all dwellings were averaged creating an averaged maximum kWh/day. The median of the daily maximum kWh values for all dwellings per year was also calculated. Figure 10 shows the trends over the five year time span available concerning the average and median maximum kWh/day values for a given year and the maximum kWh/day for each year. The maximum kWh/day of each year occurred between the months of November and March. Linear trend lines were added to the graph to show the general decrease in the kWh/day values in the three categories plotted.

[44] The data for 2009 went from 1-01-2009 through 8-31-09.

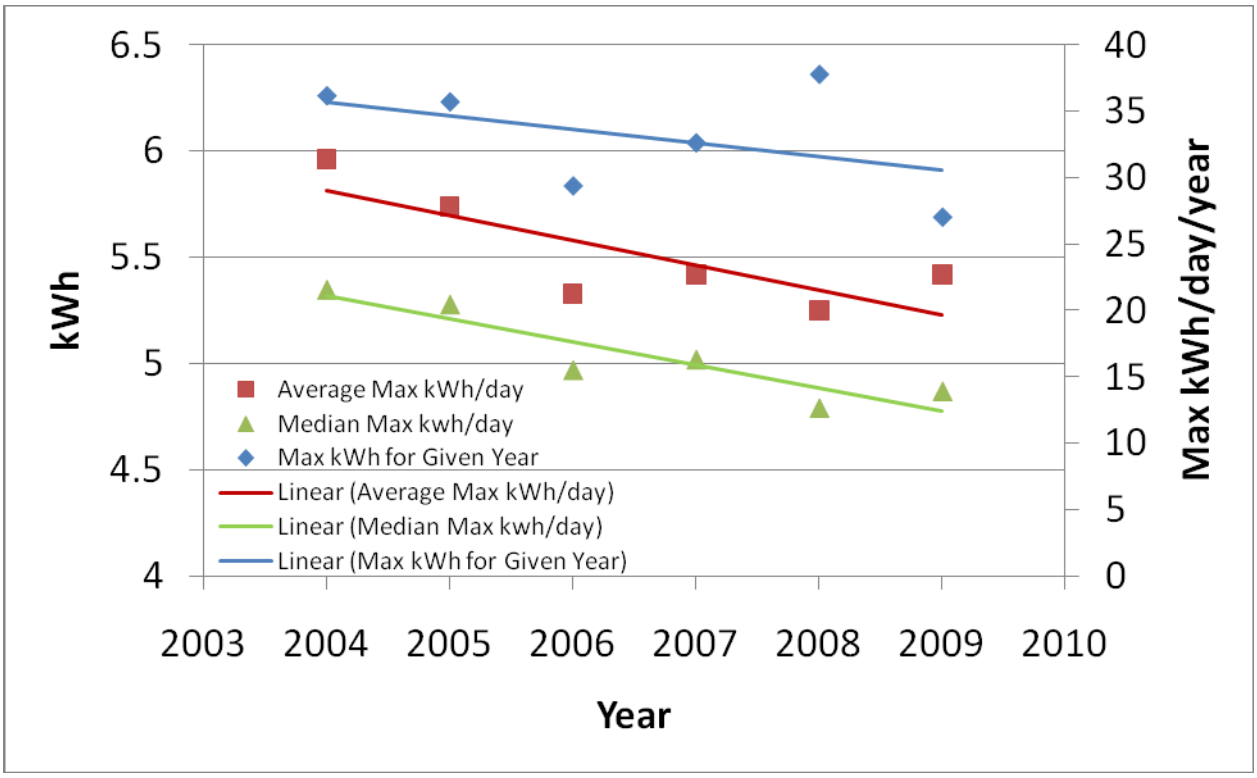

Figure 10. Analyzed raw hourly load data from approximately 100 dwellings with electric heating and water heaters. The dwellings were located in the South Atlantic part of the United States.

Two utilities provided data for a one year period. One utility provided information for dwellings located in the South Atlantic area of the United States. The information was for approximately 60 residential dwellings that were all electric homes with a square footage between 2000 ft^2 and 3000 ft^2. The data was analyzed using the same procedure as discussed above. For these dwellings, the average maximum kWh/day was 10.93 kWh, the median maximum kWh/day was 10.67 kWh, and the maximum kWh/day for the year was 26.57. The maximum kWh/day for the year was recorded in January. Additionally, the utility representative indicated that he believed the "peak demands have decreased from what they were 20 years ago on all electric homes due to higher efficiency home construction, and higher efficiency appliances." [45]

The other utility provided information from dwellings located in the Middle Atlantic portion of the United States. The number of residential dwellings, the square footage of the dwellings, and the specific year of the measurements were not available. It is believed the data was collect sometime between 2001 and 2005.[46] The utility did not provide raw data; they provided averaged kVA per customer on a monthly basis. The data was divided into three categories: all electric dwellings (AE), dwellings with gas heat and electric water heaters (WWH), and dwellings with gas heat without electric water heaters (WOWH). The data was analyzed by

[45] Based on email communication on 10/18/2009

[46] Based on the dates on the document

calculating the average and median of the kVA values in each category (12 values per category). Table 5 shows the results of the analysis for all three dwelling categories. The maximum kVA per customer for the year for the AE and WWH categories occurred in January and February while the maximum in the WOWH category occurred in July.

Table 5. Analyzed electricity demand data for a year from residential dwellings in the Eastern portion of the United States.

Dwelling Category	Average maximum kVA per customer over the year	Median maximum kVA per customer over the year	Maximum averaged kVA per customer over a month
AE	8.62 kVA	8.56 kVA	10.7 kVA
WWH	6.68 kVA	6.64 kVA	7.59 kVA
WOWH	4.90 kVA	4.93 kVA	5.35 kVA

The final responding utility provided estimates of the amount of electricity the average customer uses each hour of the year. Based on the documentation supplied with the data, the estimates for the residential dwellings were based on data collected from statistically valid samples. The residential dwellings were located in the New England portion of the United States. The number of dwellings, the square footage of the dwellings, and the appliances used in the dwellings were not available. The estimated data was analyzed by finding the maximum kWh for every day of the year. The daily maximum kWh values were averaged creating an averaged maximum kWh/day. The median of the daily maximum kWh values per year was also calculated. The plots shown in Figure 11 and Figure 12represent analyzed estimated hourly load data for residential dwellings in two different areas in the New England portion of the United States. The figures show that the maximum estimated hourly load has an increasing trend in both areas. In Area One (see Figure 11) the average and median estimated hourly load per customer is relatively constant while in Area Two (see Figure 12) the average and median estimated hourly load per customer is increasing. The maximum estimated hourly load values per customer for each year were projected to occur primarily between the months of June and August in Area One and during the months of July and August in Area Two.

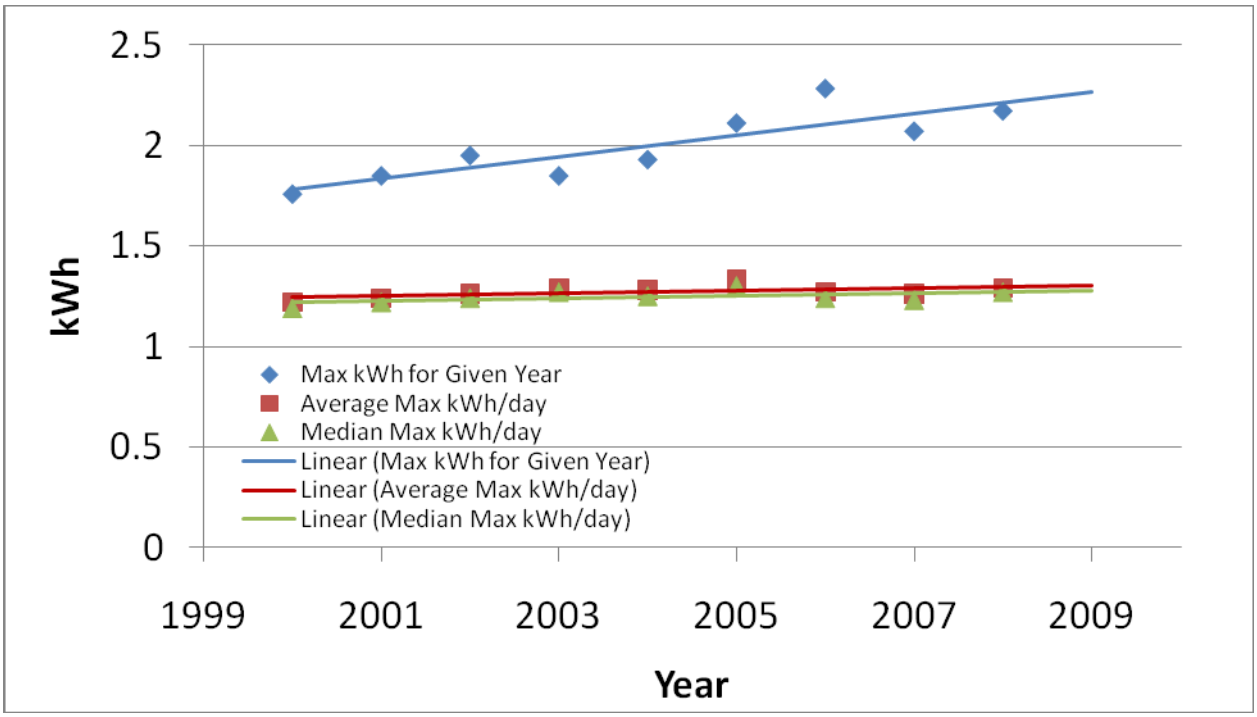

Figure 11. Analyzed estimated hourly load data per residential customer located in Area One of the New England part of the United States.

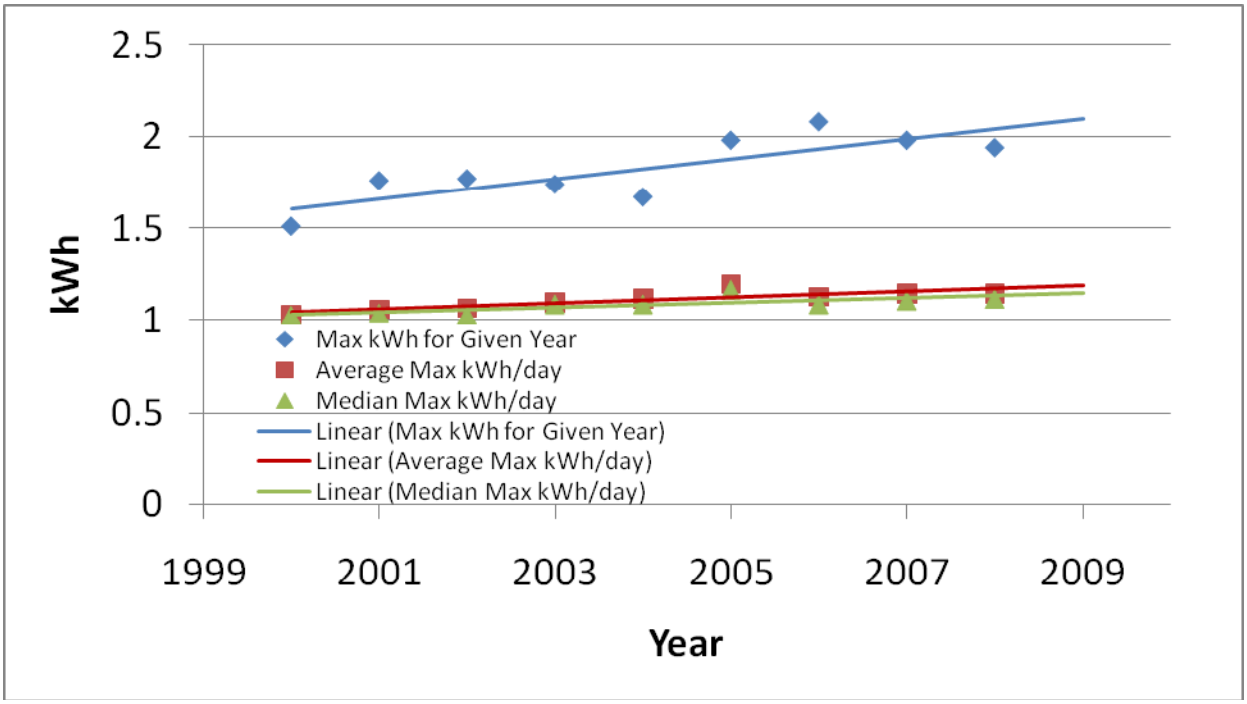

Figure 12. Analyzed estimated hourly load data per residential customer located in Area Two the New England part of the United States.

The analysis of the data supplied by the utility companies indicated that additional information was needed to provide clear insight into the electrical load seen or expected at residential dwellings. The analyzed raw load data (see Figure 10) and the analyzed estimated load data, (see Figure 11 and Figure 12) for residential dwellings located in the South Atlantic and New England portion of the United States show contradicting trends. The time of year that the peak load occurred for the analyzed raw load data from one utility was during the winter months while for the analyzed estimated load data from another utility the peak occurs in the summer months. For the estimated load data, the use of electric heat and/or electric water heaters was unknown. The peak load data from the all electric dwellings, dwellings with an electric water heater, or dwellings with electric heat and water heating occurred during the winter months.

While it is expected that climate and location will affect utility peaks and the time of year when they occur, the code must be comprehensive such that the diversity inherently present in the US is addressed.

Task 3: Develop a detailed Phase II research plan

Phase II was expected to be a multi-year process to evaluate the electricity consumption for residential dwellings at the branch circuit level. Field measurements in modern dwellings need to be compared to the results found in Task 2 to assess the validity of the table values of Article 220. The use of Smart Meters, which are currently being installed at residential dwellings across the United States, are expected to play a critical role in this portion of the project along with branch circuit measurement techniques. Additionally, surveys of home owners were suggested. The lists below represent suggestions for the next phase of the Residential Power Consumption project.

Partners

- U.S. Energy Information Administration
- Edison Electric Institute
- Electric Power Research institute
- Partnership for Advancing Technology in Housing
- Utility Companies
- NEMA
- Companies developing energy efficiency equipment for residential dwellings

Variables to Consider Include

- Age of dwelling
- Size of dwelling

- Location of dwelling
- Dwelling heating styles
- Electric vs. non-electric appliances

Locations and Time Frame

- Monitor residential dwellings across the United States
- Multiple dwellings in each region of the United States
- Monitor dwellings at least three to five years
- Monitor dwellings year round

Data Collection

- Hourly load demand for dwelling
- Hourly load demand on each branch circuit
- Use equipment/analysis software to determine/estimate which appliances are being used

Household Information to Collect/Consider

- Location of dwelling
- Square footage
- Year dwelling was built
- Number of branch circuits
- Number of appliances
- Nameplate rating on appliances
- What equipment is generally on each circuit
- What type of appliances are used (i.e., electric heating, electric water heater, air conditioning, etc.)
- Number of lights
- Type/Wattage of light bulb used

A statistically relevant sample size is of importance for this portion of the project. As discussed above, there are numerous variables that may be investigated during the field evaluations. A

statistical analysis was completed to determine the number of dwellings needed to achieve a reasonable confidence interval. Twenty-five samples per category of dwellings was determined to be an adequate sample size to produce a reasonable confidence level for the resulting data. Assuming that the dwelling data was to be separated into 25 regions and use three dwelling square footage ranges, the total number of dwellings for this example would be 25 regions times 3 square footage ranges times 25 dwellings for a total of 1,875 dwellings.

While the original focus of Phase II was on Article 220, other parts of the NEC could benefit from this large scale survey. Potential NEC Articles such as 210, 215, 225, 240, 250, 300, 310, 404 and 406 may benefit from additional evaluations or from information gained as part of this large scale survey.

Verification of Article 220 Table Values

Data collected during Phase II of the project should be analyzed and compared to current Article 220 table values and calculation methodologies. A computer model may be appropriate for this portion of the project. The intent of Article 220 was to provide a minimum load demand for a given dwelling size. Using the data obtained through surveys and field measurements, the model would be able to compare actual load demands for the dwelling participating in the project and the load demand calculated using the current load calculation methods. Figure 13 represents a model process flow.

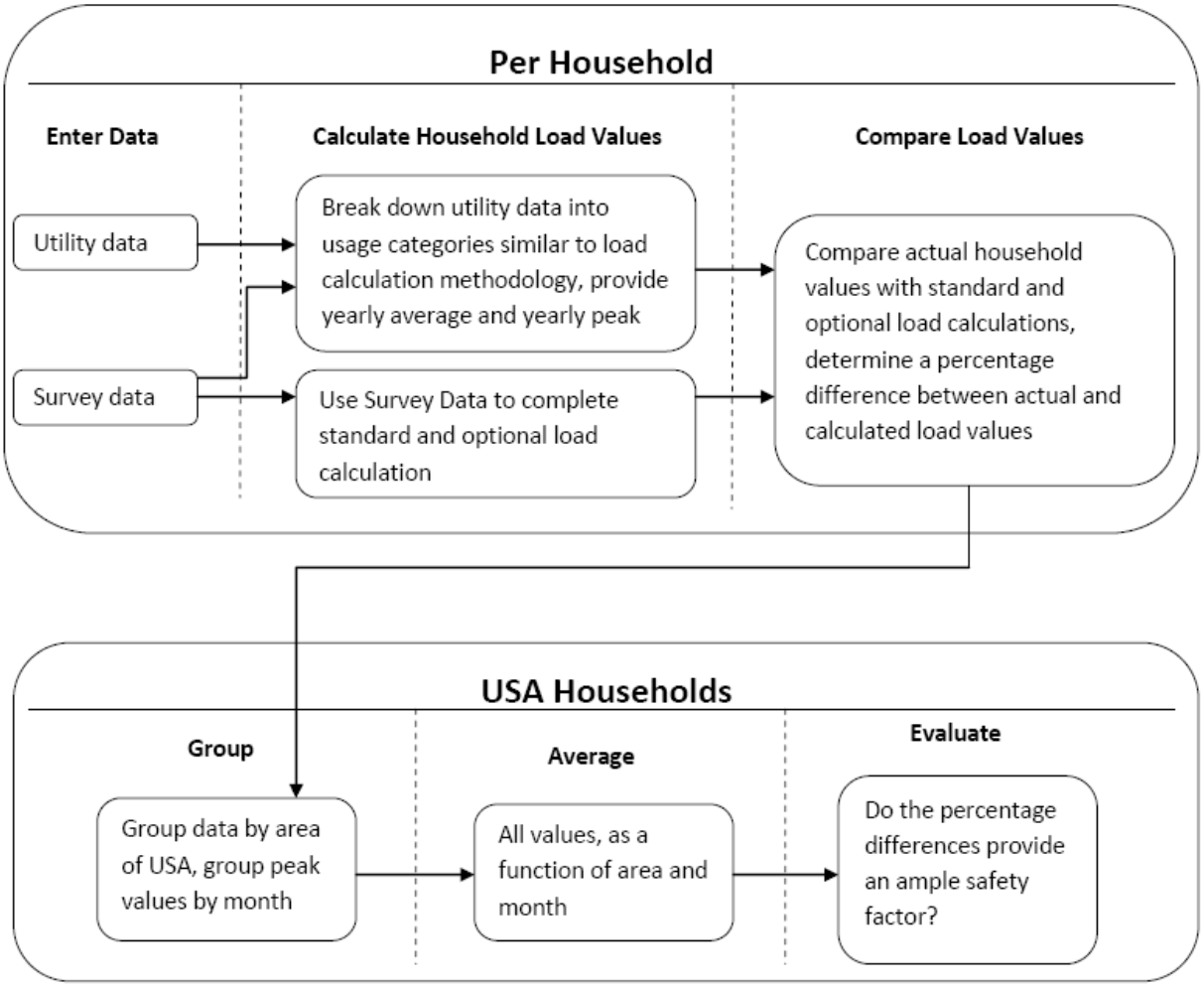

Figure 13. Example model process flow for Article 220 table value verification.

Findings

The standard and the optional load calculation methodologies in the 2008 NEC were similar to the calculation methodology described in the 1959 NEC. A difference between the two years was the inclusion of a laundry circuit in the 2008 NEC. A similarity was the use of 3 VA (watts)/ ft^2 in calculating the general lighting and receptacle demand. In fact, the 3 VA (watts)/ft^2 value had been used in the NEC since 1951. The standard and optional calculation methods were shown to produce different minimum load values for the example dwelling. This difference is due to the more liberal diversity factor allowed in the optional calculation method.

The load calculations in Article 220 were meant to provide a minimum load value for sizing the feeder entering a dwelling such as a single-family detached house. The example calculation showed the two calculation methodologies may not provide the same or similar minimum load values with the optional method often providing a lower minimum load value. This was due primarily to the more liberal diversity factor used in the optional load calculation. It has been stated[47] that the choice of methods was to be determined by the user. Article 220.82 (A) of the 2008 NEC states, "It shall be permissible to calculate the feeder and service loads in accordance with this section instead of the method specified in Part III of this article." However, no guidance was given in the NEC to help the user determine the choice of calculation method to use. Since the two load calculations can differ significantly, recall in the example used above the differences were ~33%, the user is left with a decision as to which minimum to use that can notably affect their cost. More significantly, one method may result in code-compliant though undersized service that is inadequate for the known needs.

Electrical energy consumption was predicted in the Annual Energy Outlook 2010[48] to increase by 19% for the residential sector[49] over the length of the estimated time (2035). However, the data in the Annual Energy Outlook 2010 also predicted that the number of single-family detached dwellings would increase by 22%[50] from 2008 to 2035. The current project focused on electrical consumption and demand at the household level related to the load calculation methodologies. The load calculations in the NEC were based largely on the square footage of a dwelling. Using this guidance, the predications for future electrical energy usage at a household for a given year were normalized to the average square footage of households for that year.[51] This calculation, based on data in the Annual Energy Outlook 2010, predicted a 19% decrease in electrical energy consumption between 2008 and 2035 for average residential sector households may occur.

The limited available utility data both in the form of actual and estimated electrical consumption data per household along with estimates of future electricity consumption provided guidance for

[47] W. A. Werning, "House Divided," IAEI News, July-August 2009.

[48] Annual Energy Outlook 2010 is available to the public at http://www.eia.doe.gov. Accessed on 2/09/10

[49] Data obtained from the "Review of Residential Electrical Energy Use Data" which can be obtained at http://www.toolbase.org/PDF/CaseStudies/ResElectricalEnergyUseData.pdf. Accessed on 2/09/10

[50] Information obtained from "Electricity 101" which can be obtained at http://www.eei.org/whoweare/AboutIndustry/Documents/Electricity101.pdf. Accessed on 2/09/10

[51] Data can be found in the Annual Energy Review historical data found on the EIA website.

future Phases of this project. Though limited, data suggested that electrical consumption and demand was geographically and seasonally dependent. The data sets received for the South Atlantic and New England area of the United States showed differing trends for electrical consumption. This difference highlights the need for large scale field measurements that consider geographical location. The peak demand in the few reporting areas differed between winter and summer seasons. This result confirms the need for monitoring electricity demand throughout the whole year. Based on evaluation of the limited utility data, a multi-year process to evaluate the electricity consumption at the feeder and branch circuit level in modern dwellings should be accomplished to provide high engineering certainty for the table values and load calculation methodologies of Article 220.

Exponent's findings are based on current information and observations. Exponent reserves the right to supplement these findings should additional information become available.

Sincerely,

Justin Bishop, Ph.D.
Associate

Appendix A: Data Collection Efforts

Energy Management System

- Five companies that develop residential energy managements systems were contacted
- Phone calls and email every two to three weeks were made trying to contact the companies and obtain support for the project.
- The companies either did not have the data, the data was proprietary, did not want to participate, or did not answer their phone or respond to emails.
- Observation: there were only a few residential energy management system companies as this type of system was generally focused on the commercial industry.

Collecting Survey and Letter Responses

- Contacted individuals who received a survey or letter every two to four weeks by phone or email.
- Some individuals said it was too much work while others did not respond.
- Some utilities said the raw data was proprietary and it could not be provided.
- Some utilities did not have the data that was requested.

Others Contacted

- The survey was sent out to individuals in EEIs Load Forecasting Group
- Request for contact information regarding individuals showing interest in the survey was made but contact information was not provided.
- The contact for the Load Forecasting Group did not expect surveys to be returned.

Appendix B: Survey Sent to EEI Conference Attendees

Subject

The subject of this survey is to obtain contact information and gauge existence of data that may be used in validating the load calculation methodology of Article 220 of the NEC

Background

The Fire Protection Research Foundation is the research arm of the National Fire Protection Association, the organization which facilitates the development of the National Electrical Code © (NEC) and other consensus fire and electrical safety codes and standards. The Foundation has initiated a program, at the request of the code making Panels of the NEC, to validate the basis for the load calculation methodology of Article 220 of the NEC by developing baseline information on typical profiles of electrical loads in today's residences.

We are seeking a broad set of data from utilities and other organizations across the country and invite you to contribute to the project by completing the survey below concerning contact information and existence of data that may be helpful to the project. We will work with companies to facilitate the provision of the data in whatever form is most convenient. All individual data provided will be held confidential to the program; only aggregate data will be used for analysis and published in the Foundation's report of the project.

Survey

Name:_____ Company:_____

Contact Information:_____

_____

Are you the correct person in your company to address this survey? □ NO □ YES

If NO can you provide the contact information for the appropriate person within your company? □ NO □ YES

If YES please provide their contact information: Name:_____

Contact Information:_____

_____

Please check the boxes beside the data descriptions that may be obtainable through your company

YES	MAYBE	NO	
			Average 1 hr. Peak Demand vs. Month (any time between 1990-present)
			Average 1 hr. Peak Demand vs. Geographical Location (any time between 1990-present)
			Average 1 hr. Peak Demand vs. Square Footage of Dwelling (any time between 1990-present)
			Are the Average 1 hr. Peak Demand values grouped into categories such as dwellings that use electric heat and electric water heater; electric heat and gas water heater, gas heat and gas water heater? If other please describe: _____ _____
			Are Average 1 hr. Peak Demand values for residential dwellings avaliable in any format? Please describe: _____ _____

Please describe any other data that your company may have that you feel may be helpful to this project. Information concerning number of TVs, Refrigerators in a dwelling; type of stove and dryer in a dwelling (gas or electric) are of interest.

Other information that may be available and of interest:

Appendix C: Representative Letter Sent to Utilities

DATE

NAME
ADDRESS

Subject: Residential Power Consumption

Dear NAME

The Fire Protection Research Foundation is the research arm of the National Fire Protection Association, the organization which facilitates the development of the National Electrical Code © (NEC) and other consensus fire and electrical safety codes and standards. The Foundation has initiated a program, at the request of the code making Panels of the NEC, to validate the basis for the load calculation methodology of Article 220 of the NEC by developing baseline information on typical profiles of electrical loads in today's residences.

This information includes specific information on electrical loads from residential structures as shown below. We are seeking a broad set of data from utilities and other organization across the country and invite you to contribute to the project by providing us with the data requested below. We are willing to work with you to facilitate the provision of the data in whatever form is most convenient for you . All individual data provided will be held confidential to the program; only aggregate data will be used for analysis and published in the Foundation's report of the project.

Data from January 1990 to present

- Average 1 hr Peak Demand vs. month
- Average 1 hr Peak Demand vs. geographical location
- Average 1 hr Peak Demand vs. Square footage of dwelling

For Communities/Subdivisions/Dwellings that have not had additional construction projects like adding new homes to a subdivision or added square footage to a dwelling.

Average 1 hr Peak Demand vs. month over the stable period for either a specific dwelling or subdivision

If you have additional information that you are willing to share which you feel may be helpful to the fulfillment of this project please do not hesitate to provide it and suggest its inclusion. If you are capable of providing any of the requested data, please send it to Kathleen Almand, Fire Protection Research Foundation, 1 Batterymarch Park, Quincy, Massachusetts 02169, or you may email it to me at kalmand@nfpa.org.

Our consultant will follow up shortly by telephone to answer any questions you may have. Thank you in advance for your cooperation.

Sincerely,

Kathleen H. Almand
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Fire Protection Research Foundation
1 Batterymarch Park
Quincy, MA 02169
(617) 984-7282
kalmand@nfpa.org