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Evaluation of Electrical Feeder and Branch Circuit Loading: Phase I

FINAL REPORT BY:

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January 2017

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FOREWORD

Interest has been growing in recent years to investigate and clarify the degree to which the feeder and branch circuit load design requirements in NFPA 70, *National Electrical Code*® (NEC®) need to be adjusted based on the increasing pace of technological innovation along the entire span of the electrical power chain.

There are multiple factors driving this issue and supporting the need to address this topic. For example, today's Energy Codes are driving down the electrical load presented by end use equipment and thus load growth assumptions that justify "spare capacity" should be re-examined. In addition, larger than necessary transformers that supply power to feeder and branch circuits expose unnecessary flash hazard to electricians working on live equipment.

This report summarizes a Phase I effort to develop a data collection plan to provide statistically significant load data for a variety of occupancy and loading types to provide a technical basis for considering revisions to the feeder and branch circuit design requirements in the National Electrical Code®. This initial effort has an emphasis on general commercial (office) occupancies, and the deliverables provide a review of the literature, and clarify the key elements of a data collection plan in support of a potential second phase (not included in the scope of this effort).

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The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort. Special thanks are expressed to the following Panel members: Robert Arno, Harris Corp. & IEEE Fellow; Mark Earley, NFPA; Mark Hilbert, IAEI & CMP-2 Chair; Brian Liebel, Illuminating Engineering Society of North America; and Mark Lien, Illuminating Engineering Society of N.A. (Alt to B Liebel). Thanks are also extended to the following Sponsors: Michael Berthelsen, University of Minnesota; Brett Garrett, The Ohio State University (alternate for Bob Wajnryb); Lou Galante, University of Iowa; Jeff Gambrall, University of Iowa (Alternate to Lou Galante); Dean Hansen, University of Texas Austin; Kane Howard, Michigan State University; Michael Hughes, Michigan Association of Physical Plant Administrators; Jim Jackson, University of Nebraska (alternate for Brian Meyers); Paul Kempf, University of Notre Dame; Brian Meyers, University of Nebraska; Bob Wajnryb, The Ohio State University; and Bob Yanniello, Eaton Corporation. Gratitude is likewise expressed to three liaisons that supported this effort: Mike Anthony, University of Michigan; Jim Harvey, University of Michigan; and Richard Robben, Ann Arbor, MI.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

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Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 60,000 individuals around the world.

Keywords: electrical feeder, branch circuit, loading, transformer, NEC, National Electrical Code, NFPA 70

Report number: FRPF-2017-01

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Fire Protection Research Foundation Project

Review of Literature and Data Collection Plan
Evaluation of Electrical Feeder and Branch Circuit Loading: Phase 1

Submitted by

Tammy Gammon, Ph.D., P.E.

January 2017

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EXECUTIVE SUMMARY

The purpose of this Phase I project is to conduct a literature review and to develop a data collection plan for an ambitious Phase II study on the evaluation of electrical feeder and branch circuit loading. The intent of this research is to evaluate electrical feeder and branch circuit loading given present National Electrical Code requirements, electrical safety, energy conservation, and reduction of capital investment.

This research project focuses on commercial buildings. Report Sections 1 through 7 cover a review of related work and published data. Specifically, electricity usage and commercial building demographics are reviewed in Sections 1 and 2 to provide insight into the number of feeders and branch circuits installed in the United States and the amount of electricity supplied by them. Furthermore, Section 2 on commercial buildings and Section 3 on end-use loads have been included because the characteristics of the commercial buildings determine the electrical loads and the design of the electrical feeders and branch circuits supplying those loads. Section 4 addresses some of the factors which shape end-use equipment decisions and includes energy consumption projections for commercial buildings to the year 2040.

Commercial building energy conservation codes are covered in Section 5 with a focus on lighting and power requirements in ASHRAE 90.1. In Section 6, the following engineering practices are discussed: one utility, traditional building electrical system design, and design in federal buildings. The NEC's minimum lighting power requirements are also compared with ASRHAE 90.1 and other guidelines in Section 6.

Section 7 addresses transformer efficiency and electrical safety issues as a function of transformer loading. Section 7 contains the author's analysis regarding concern that lightly loaded transformers (supplying lightly loaded feeders) are associated with additional energy losses and increased arc flash hazards.

The data collection plan is presented in Section 8. Although included as the final section of this report, Section 8 has been written to serve as a document which can stand alone, independent of the other report sections.

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1 ELECTRICITY USAGE IN THE UNITED STATES

1.1 Electric Utility Customers and Consumption

This project addresses National Electrical Code Articles 210 – 230, specifically Article 220, which provides the requirements for branch-circuit, feeder, and service load calculations. The NEC has been adopted in 47 states[1] and applies to the vast majority of building electrical systems in this country. Although some entities generate part of or all their electric power on site, most electric power users in this country are customers of an electric power utility. Figure 1 reveals that electric utilities had close to 150 million customer accounts in June 2016. Over 131 million residential accounts provide power to the U.S. population, estimated at over 322 million. Electric utilities also had 18.3 million commercial and 827,000 industrial accounts in June 2016. Even though the number of commercial customers equals less than 14% of the number of residential customers, Figure 2 shows that the two sectors have purchased roughly the same amount of electricity over the past fifteen years. In 2015, the residential, commercial, and industrial sectors purchased 1.40, 1.36, and 0.96 trillion kW-hours, respectively.

The sheer number of electric utility customers and the amount of electricity sold in the United States attest to the importance of the National Electric Code (first printed in 1897) which applies to all new electrical installations where it is adopted and enforced. Since each electric utility customer must have at least one electrical service feeder, the number of service feeders must approach 150 million and the numbers of distribution feeders and branch circuits must exceed a billion.

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[1]As of September 1, 2016, the NEC (2008, 2011, or 2014 edition) had been adopted in all states except Arizona, Missouri, and Mississippi. Source: http://www.electricalcodecoalition.org/state-adoptions.aspx, accessed September 9, 2016. The 2017 edition of NFPA 70, *The National Electrical Code* or *NEC*, was issued by the National Fire Protection Association (NFPA) in August 2016.

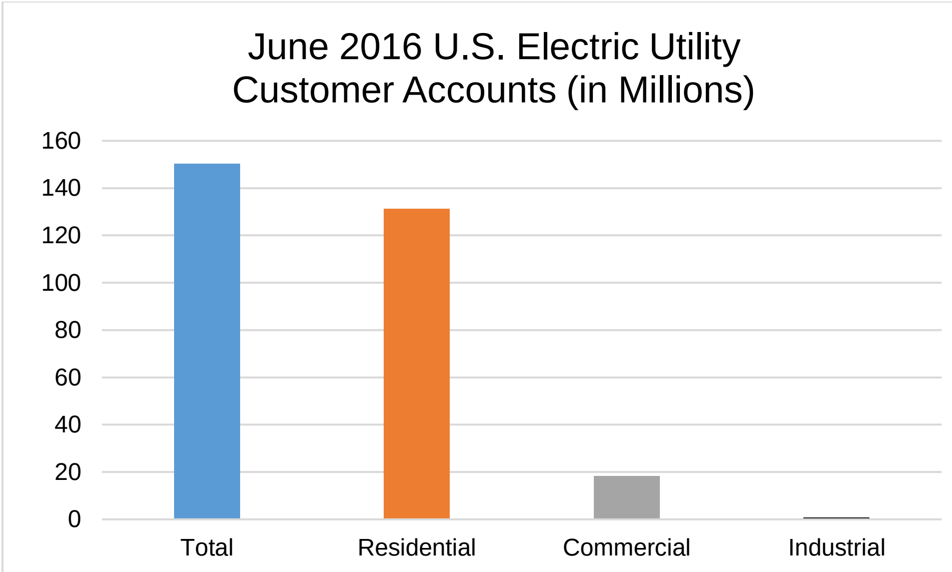

Figure 1. Numbers of U.S. Electric Utility Customers in June 2016
(Data Source: [1])

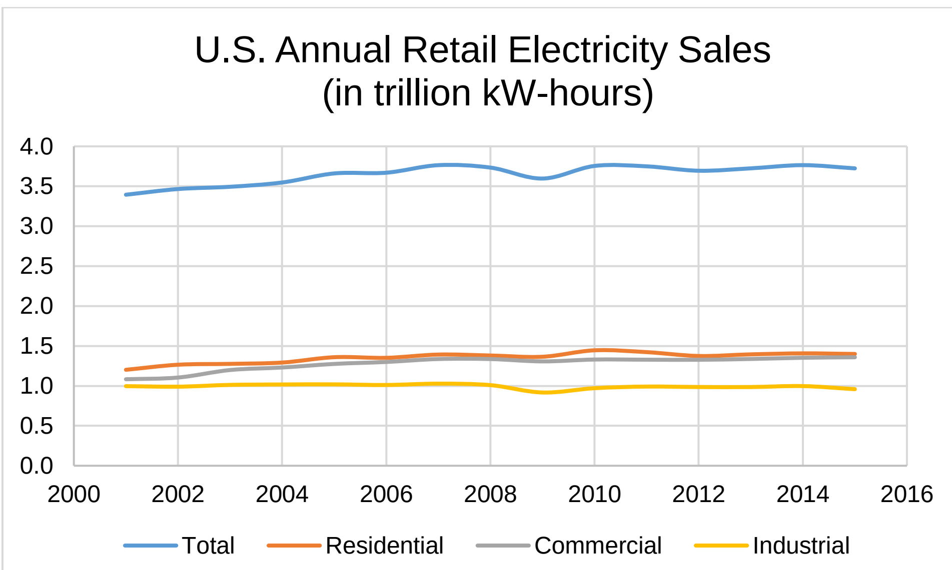

Figure 2. Annual Retail U.S. Electricity Sales from 2001 to 2015
(Data Source: [1])

1.2 Seasonal Influences and Climate

Figure 3 shows the seasonal influences of electricity purchases on commercial and residential customers. Both sectors have greater electricity demands during the summer and winter seasons. Residential customers have sharp peaks in consumption during both summer and winter months. As an aggregate group, commercial customers have a large summer peak, but the winter peak is much smaller in comparison. Individual customers that do not use electricity as the primary energy source for heating may not experience a sharp peak in electricity consumption; however, electric loads, such as lighting and receptacle (portable electric heaters if the building is not kept warm enough) may increase during winter months. In the summer, refrigeration costs may rise for cold storage warehouses and food service (grocery stores) buildings. The heat dissipated by lighting, other electrical loads, and electrical equipment may also increase the demand for air conditioning load in the summer, especially for older installations where older electrical loads and electrical equipment tend to have greater heat losses and manufactured with lower energy efficiency ratings.

Some industrial processes are greatly affected by ambient temperature and humidity; therefore, the electrical energy demanded by those processes is also dependent on the seasons.

The type of heat and the geographic location of the facility determines summer and winter electricity demand for the building. The IECC climate region map [2], developed for the U.S. Department of Energy, is included as Figure 4 and first appeared in the 2004 edition of ASHRAE 90.1. It features eight main climate zones based on temperature; the zones tend to run in east-west bands subdivided by moisture condition. [3]

Thirteen IECC climate zones are defined in Table 1. The thermal criteria for the zones are based on the number of cooling degree days over 50°F (CDD50°F) and the number of heating degree days lower than 65°F (HDD65°F). As an example, ten heating degree days is equivalent to the average outdoor temperature of 55°F for a 24-hour period[2].

In its work developing representative commercial building models for energy consumption, the Department of Energy identified three additional climate zones. The most populated city in each of these sixteen (total) zones is listed in Table 1. In the DOE modeling and simulation work, two climate regions were found for climate zone 3B and were subdivided as 3B-California coast and 3B-other for the remaining areas of the climate zone [2]. The temperature and rainfall conditions which further subdivide the climate zones are described in Table 2.

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[2] Mathematically, (65°F - 55°F) x one 24-hour period = 10 heating degree days. Another example: The average temperature is 70°F for twelve hours equates to (70°F - 50°F) x ½ of a 24-hour period = 10 cooling degree days.

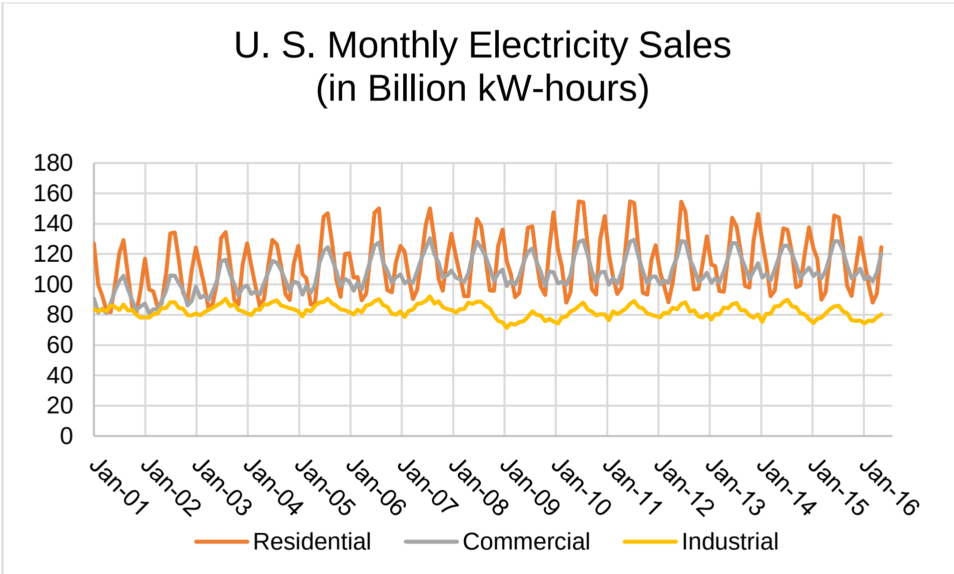

Figure 3. Monthly Electricity Sales in U.S. from 2001 to 2015
(Data Source: [1])

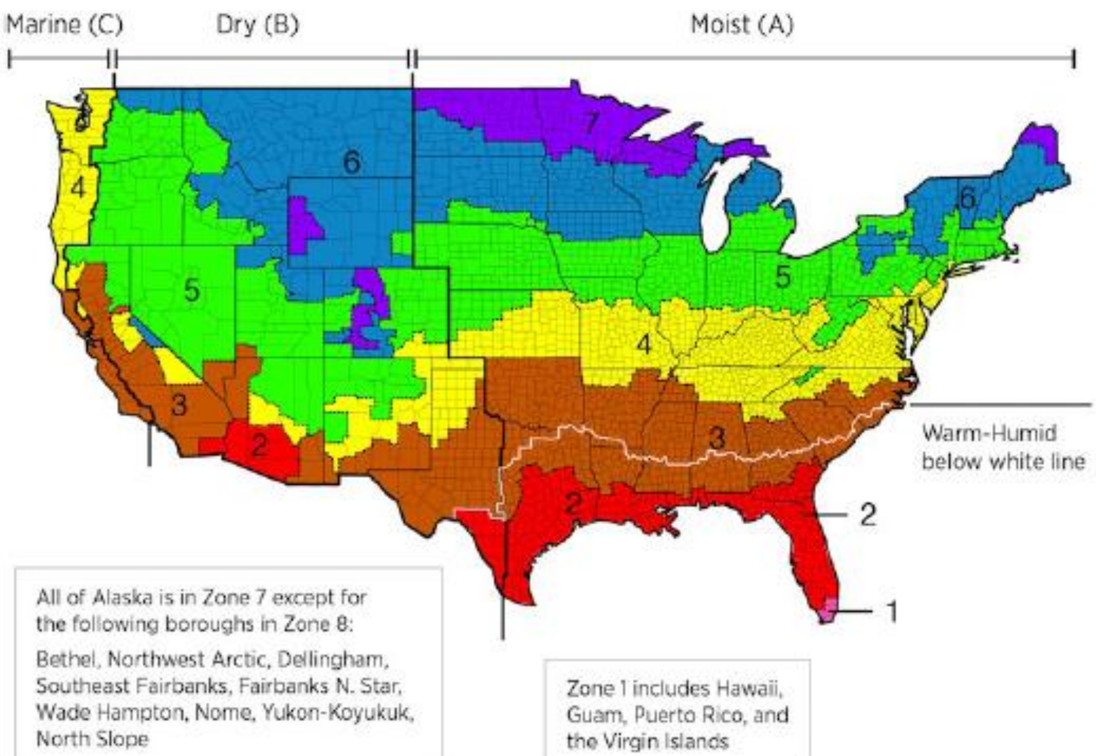

Figure 4. IECC Climate Regions in the U.S.
(Source: U.S. Department of Energy, and reference [4])

Table 1. IECC Climate Zones [2],[3],[4]

IECC	CDD50°F	HDD65°F	Temperature	Moisture	Most Populated City
1	> 9000		Hot	Humid	Miami
2A	> 6300		Hot	Humid	Houston
2B	> 6300		Hot	Dry	Phoenix
3A	> 4500	≤ 5400	Hot, Mixed	Humid	Atlanta
3B	> 4500	≤ 5400	Hot	Dry	Las Vegas (other) Los Angeles (CA coast)
3C		≤ 3600	Marine	Marine	San Francisco
4A	≤ 4500	≤ 5400	Mixed	Humid	Baltimore
4B	≤ 4500	≤ 5400	Mixed	Dry	Albuquerque
4C		> 3600, ≤ 5400	Marine	Marine	Seattle
5		> 5400	Cold		Chicago (**5A**) Denver (**5B**)
6		> 7200	Cold		Minneapolis (**6A**) Helena, MT (**6B**)
7		> 9000	Very Cold		Duluth, MN
8		> 12600	Subarctic		Fairbanks, AK

Table 2. IECC Climate, Precipitation, and Temperature Descriptions [3]

Climate Description	Precipitation, Annual (inches)	Temperature Description
Hot-Humid	> 20	During warmest six consecutive months, 67°F+ for 3000+ hours and/or 73°F+ for 1500+ hours
Hot-Dry	< 20	Monthly average > 45°F throughout year
Mixed-Humid	> 20	Monthly average < 45°F during winter months
Mixed-Dry	< 20	Monthly average < 45°F during winter months
Marine	Dry summer season Heaviest month 3+ times that of lowest	Warmest monthly mean < 72°F 27°F < Coldest monthly mean < 72°F Monthly average > 50°F at least four months

2 COMMERCIAL BUILDINGS

2.1 General Demographics for All Commercial Buildings [5]

Data collected from the Commercial Buildings Energy Consumption Survey (CBECS) provide much insight into the characteristics and energy usage of commercial buildings in the United States. A team of approximately six U.S. Energy Information Administration (EIA) employees supervises the CBECS study, which has recently been contracted out in the “tens of millions of dollars."[3] The most recent CBECS was conducted in 2013 to collect data for existing buildings and energy usage in 2012. The initial sample involved over 12,000 buildings, which was reduced to a final sample of 6,720 buildings. The final sample set was weighted to represent the total number of commercial buildings in the U.S., which the EIA estimates as approximately 5,557,000. The 2012 CBECS was based on climate zones as identified in Figure 4.

The total numbers and floor space of U.S. commercial buildings are displayed in Figure 5 based on general building size. Smaller commercial buildings (1,001 to 10,000 square feet) account for 72% of all commercial buildings, but only 19% of the total floor space. Larger commercial buildings (50,000 or more square feet) account for only 6% of all commercial office buildings, but 51% of the floor space. Figures 6 and 7 show the number of buildings and size (in mean square feet) by year of construction and region of the country. The median age of a building is 32 years ([5], Table B2). Historically speaking, it appears that as the U.S. population increases, more buildings are constructed and are larger in size. In Figure 7, the four census regions are represented by green columns and the regional subdivisions are represented by blue columns. For example, the South, which has the largest number of buildings, is subdivided into three areas: South Atlantic, East South Central, and West South Central. However, the largest commercial buildings (statistical average of floor space) are located in the Middle Atlantic area, part of the Northeast region.

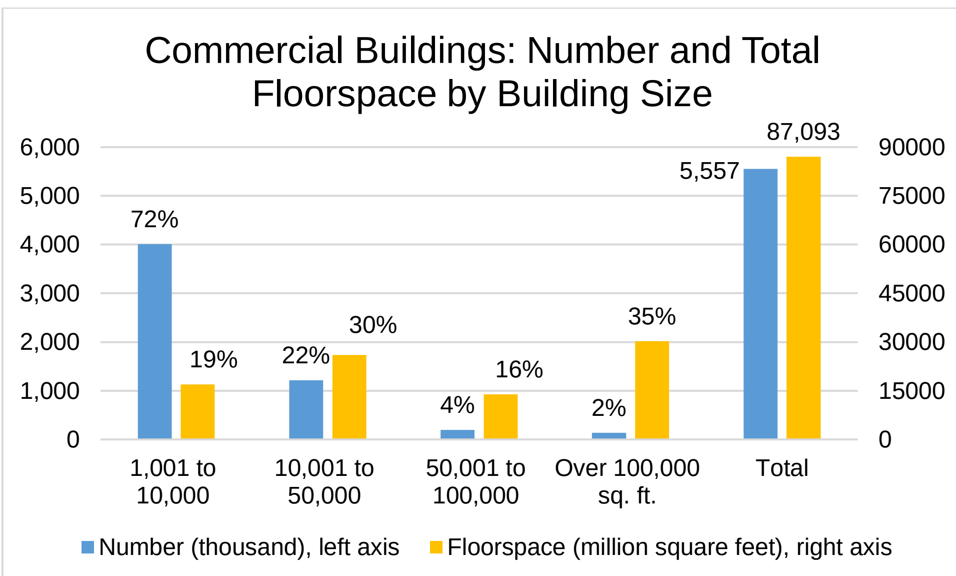

Figure 5. Commercial Buildings – Numbers and Total Floorspace Categorized by Size
(Data Source: Table B1 from [5])

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[3] September 14, 2016 email from Joelle Michaels, EIA's CBECS Survey Manager.

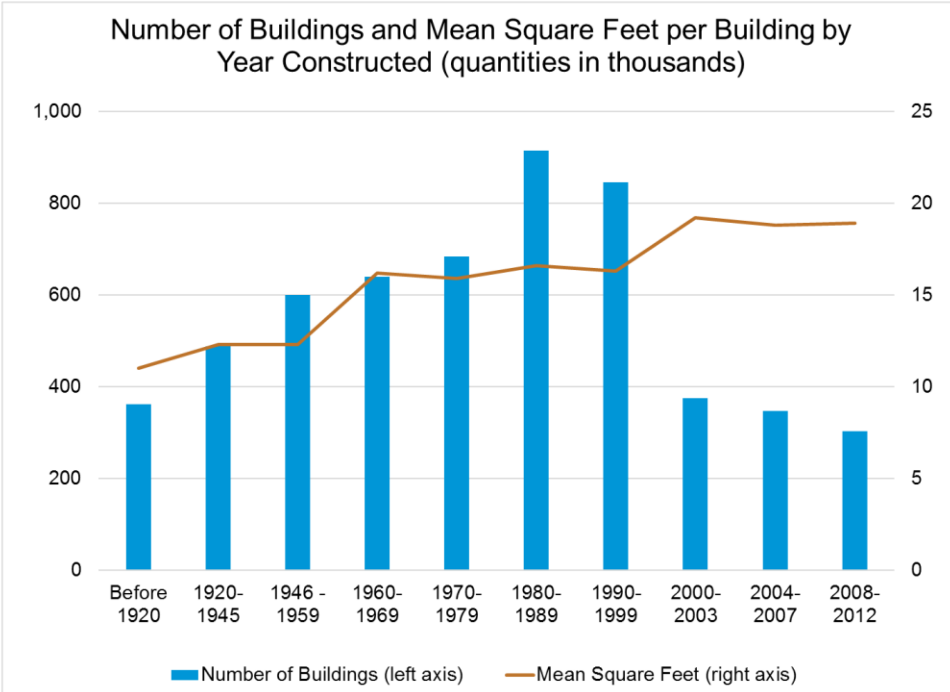

Figure 6. Commercial Buildings – Numbers and Mean Square Feet Categorized by Year
(Data Source: Table B1 from [5])

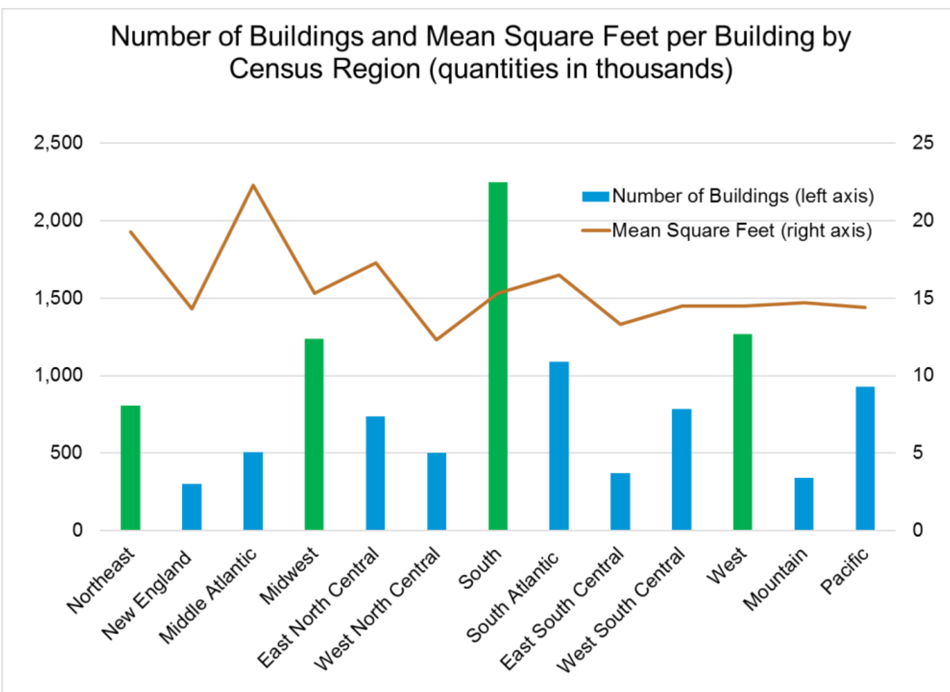

Figure 7. Commercial Buildings – Numbers and Mean Square Feet Categorized by Region
(Data Source: Table B1 in [5])

2.2 Commercial Building Types and Specific Demographics [5]

Sixteen building types have been identified by primary activity. This work will focus on five commercial building types:

- Education (e.g., K-12 schools, universities, day care, vocational training)[4]
- Healthcare, Inpatient (e.g., hospital, inpatient rehabilitation)
- Healthcare, Outpatient (e.g., medical office, outpatient rehabilitation, veterinarian)
- Lodging (e.g., hotel, dormitory, fraternity, nursing home, assisted living, shelter)
- Office (e.g., administrative, professional or government office; bank; city hall; call center)

Education buildings are used for academic or technical classroom instruction. Buildings on education campuses which are not primarily used for instruction are categorized by their primary functions; administration offices, libraries, student centers and dormitories are not identified as education buildings.

Healthcare buildings are used for patient diagnosis and treatment. If medical offices use diagnostic equipment, they are categorized as outpatient healthcare buildings; otherwise, they are categorized as office buildings.

Lodging buildings provide accommodations for short-term or long-term residents. Lodging may include simple amenities at motels or skilled nursing in nursing homes. Minimal supervision may be provided at dormitories and fraternities, while more extension supervision would be required at children's homes.

Office buildings cover a wide range of administrative, government, financial, and professional offices. They include general sales, non-profit, social service, and religious offices, as well as construction, plumbing, HVAC and other contractor offices.

Classrooms, student residence halls, offices, and even hospitals are often part of large university complexes. In fact, university complexes are communities with most, if not all, building types represented.

[4] In comments dated December 21, 2016, Mike Anthony stated, "Education facilities up to K-12 are governed by safety codes that recognize the behavioral characteristics of the occupants. Higher education facilities are governed by commercial codes. It may come as a surprise that classrooms in higher education have a 20 percent occupancy rate; and that most of the square footage in higher education is devoted to administrative activity."

The other eleven commercial building types are:

- Food Sales (e.g., grocery)
- Food Service (e.g., restaurant)
- Mercantile, Retail other than mall (e.g., liquor stores, automobile dealerships, art gallery)
- Mercantile, Enclosed and strip malls
- Public Assembly (e.g., cinema, museum, sports arena, funeral home, library, health club)
- Public Order and Safety (e.g., police station, fire station, courthouse, penitentiary)
- Religious Worship
- Service (e.g., post office, gas station, dry cleaner, repair shop, hair salon, copy/print shop)
- Warehouse and Storage
- Other (e.g., crematorium, laboratory, data center, airplane hangar)
- Vacant

As shown in Figure 8, office buildings comprise the highest percentage (19%) of the number of commercial buildings by type. Figure 8 also illustrates that the total floor space (19%) and electricity consumption (20%) of office buildings account for similarly high percentages. The building type, *Warehouse and Storage*, accounts for the second highest number of commercial buildings (13%) and total floor space (15%); however, by proportion, this building type consumes much less electricity (7%). Education buildings represent the third highest percentage of total square feet (14%) and the second highest percentage of electricity consumption (11%).

Figure 9 displays the mean size and mean operating hours per week of commercial buildings. Although inpatient healthcare occupies a small percentage of the total floor space for commercial buildings, the mean size of inpatient healthcare buildings, at 247,800 square feet, dwarfs all other building types. The second largest building type is lodging at 36,900 square feet. Inpatient healthcare (168 hours) and lodging (165 hours) typically around-the-clock (i.e., 24/7 operation). Food sales (121 hours) and public order and safety (113 hours) also have a high number of operating hours.

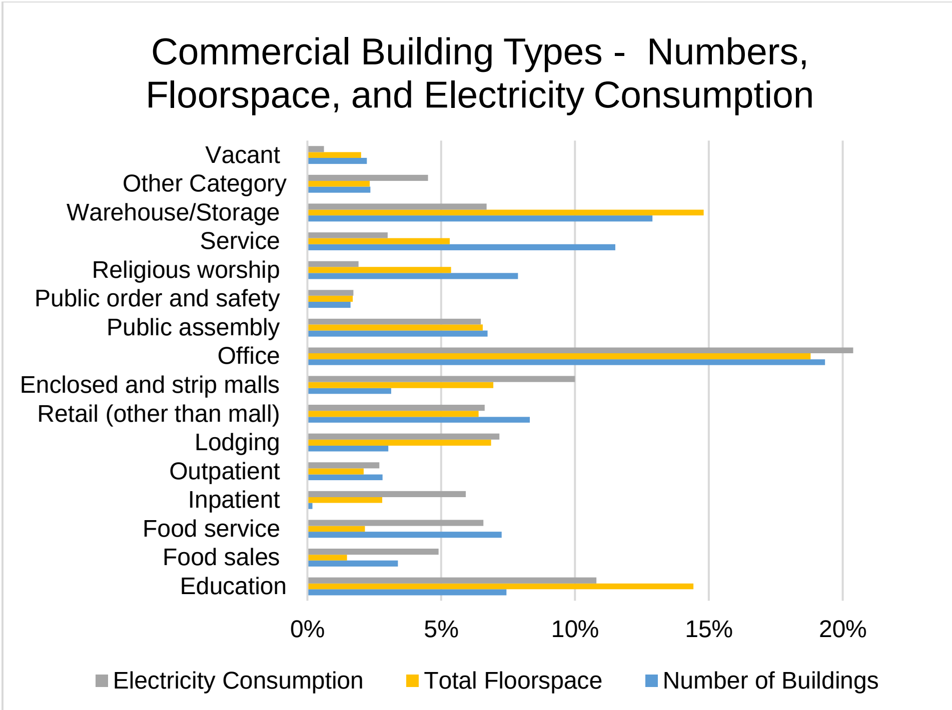

Figure 8. Commercial Building Types – Numbers, Floorspace, & Electricity Consumption
(Data Source: Table C13 in [5])

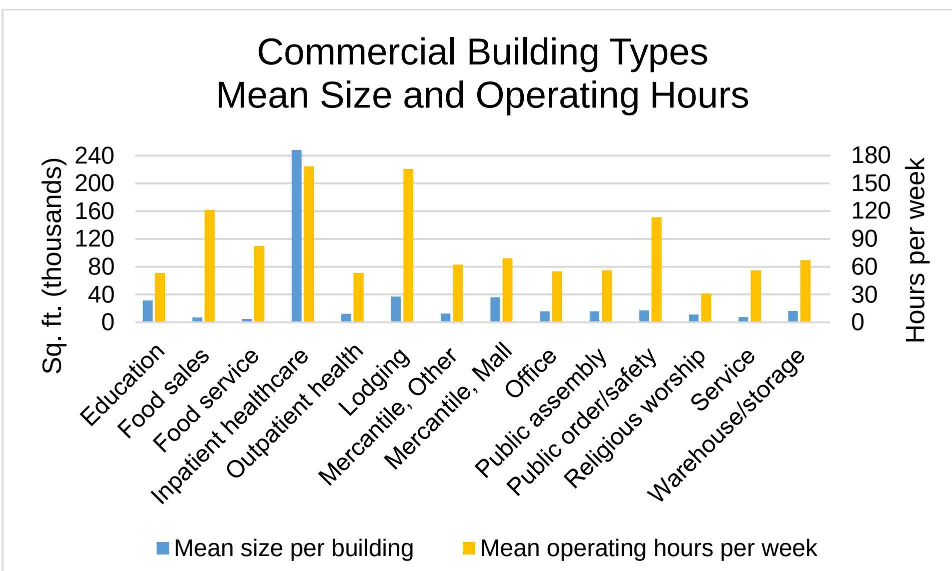

Figure 9. Commercial Building Types – Mean Size and Operating Hours
(Data Source: Table B1 in [5])

In the process of working, employees utilize electrical equipment, even if only as task lighting. Basic electrical safety in the workplace applies to all employees, not just electrical workers. Statistically speaking, as this numbers of employees increase, concern and attention to electrical safety should also increase. Therefore, a carefully designed and properly installed electrical installation is even more important when larger numbers of employees are involved. Figure 10 illustrates that education, healthcare (inpatient and outpatient), and office buildings account for 50% of the 104.9 million people working in commercial buildings. Electrical safety concerns also especially apply to lodging which provides housing for short- and long-term residents. In this research project, the commercial building category of lodging has been added to cover dormitories on university campuses, but it also addresses long-term healthcare needs provided by assisted living centers and nursing homes. Electrical safety, in the context of employee and resident safety, also covers proper operation, care, and maintenance of electrical systems and equipment. Improperly installed, operated, and maintained electrical systems and equipment could result in harmful and deadly fires.

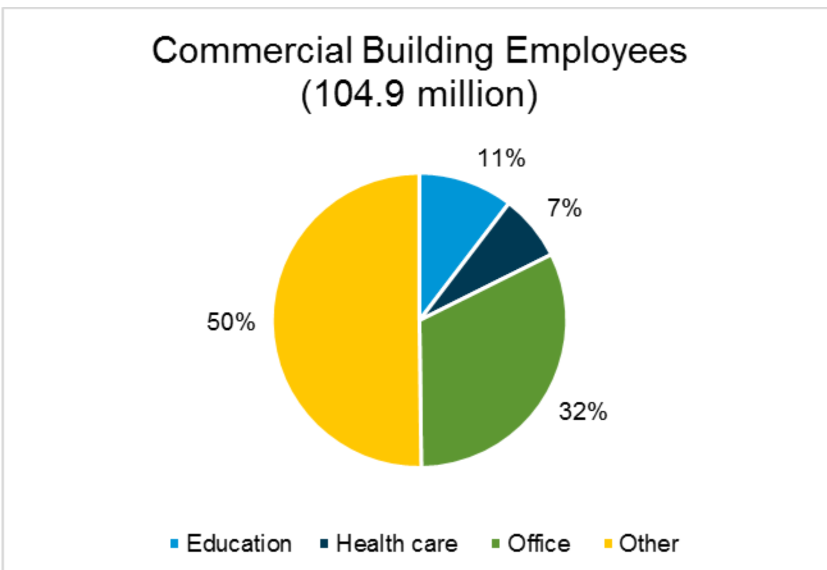

Figure 10. Percentage Employees by Commercial Building Type
(Data Source: Table B1 in [5])

2.3 Commercial Building Energy Usage by Geography [5]

As previously seen in Figure 8, the amount of electricity consumption depends on commercial building type. Figure 11 shows it also depends on climate. In hot, humid climates, the percentage of electricity consumption (18%) is notably higher than the percentage of total floor

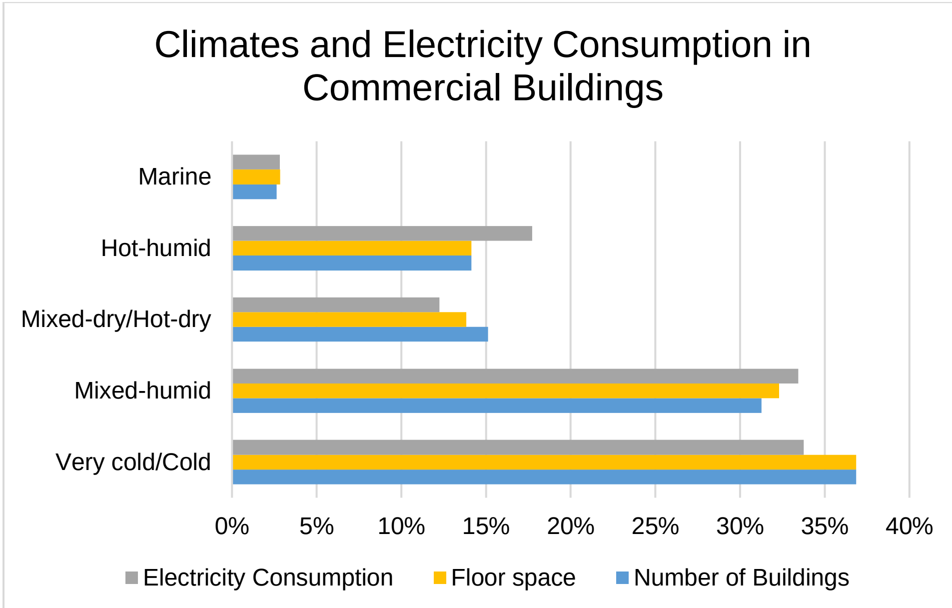

Figure 11. Electricity Consumption in Commercial Buildings Categorized by Climate
(Data Source: Table C13 in [5])

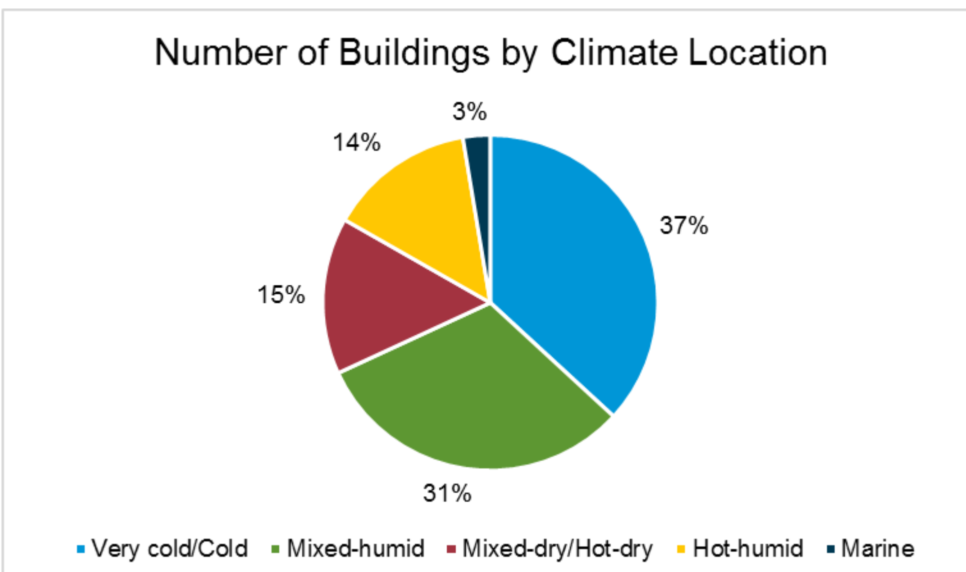

Figure 12. Number of Commercial Buildings (Percentage) Categorized by Climate
(Data Source: Table C13 in [5])

space (14%). Conversely, in cold and very cold climates, the percentage of electricity consumption (34%) is lower than the total floor space (37%). As seen in Table 1, colder climates have lower energy demands for air conditioning and have higher energy demands for heating.

The higher electricity consumption in hot, humid climates (per total floor space) in Figure 11 is likely due to the greater cooling needs in hot, humid climates; the lower electricity consumption in cold and very cold climates suggests that other energy sources, not electricity, are meeting the greater heating needs. The percentages of the total number of commercial buildings located in each climate are displayed in Figure 12. Over two-thirds of the buildings are located in mixed humid (zones 4A and part of 3A) and cold or very cold climate (zones 5, 6, and 7) zones [3].

Figure 13 shows the annual mean electric energy and power intensities for commercial buildings located in each climate. In 2012, the mean electric energy and power intensities were 14.6 kW-hour and 1.7 W per square foot for all climates represented in the study. The highest intensities were found in hot-humid climates at 18.4 kW-hours and 2.1 W per square foot. The mixed-dry and hot-dry climate region had the lowest intensities of 13.0 kW-hours and 1.5 W per square foot. The cold and very cold climate region may have been higher due to a higher electric heat load.

It must be remembered that mean power intensity differs greatly from the power intensity during peak consumption. For example, the power demand for air conditioning load is high during summer months and will peak in the afternoons especially on hot days. In climate zones with higher numbers of degree cooling days, air conditioning loads tend to have a higher power density demand. A building located in a hot climate has relatively few heating degree days; furthermore, energy for heating in any climate may be provided by another energy source, such as natural gas. A building might be designed with a high demand power density for air conditioning load with no or low electric power requirements for heating. A building in a cold climate might be designed for a low air conditioning power density but is might have no, low or high electric power requirements for heating, depending on the energy source(s) for heat.

Figure 14 shows the percentages of energy sources meeting the energy needs of commercial buildings by different census regions of the country. The South has the highest percentage of energy supplied by electricity (70%) and the lowest percentage of energy supplied by natural gas (24%). In the West, 60% of the energy is supplied by electricity, followed by 54% and 52% in the Midwest and Northeast, respectively. In contrast, the Midwest has the highest percentage of natural gas (41%), and the Northeast has the highest percentages of fuel oil (6%) and district heat (8%). In the 2012 CBECS, fuel oil is specified as distillate fuel oil, diesel, and kerosene; district heat is specified as steam or hot water from a utility or a campus central plant.

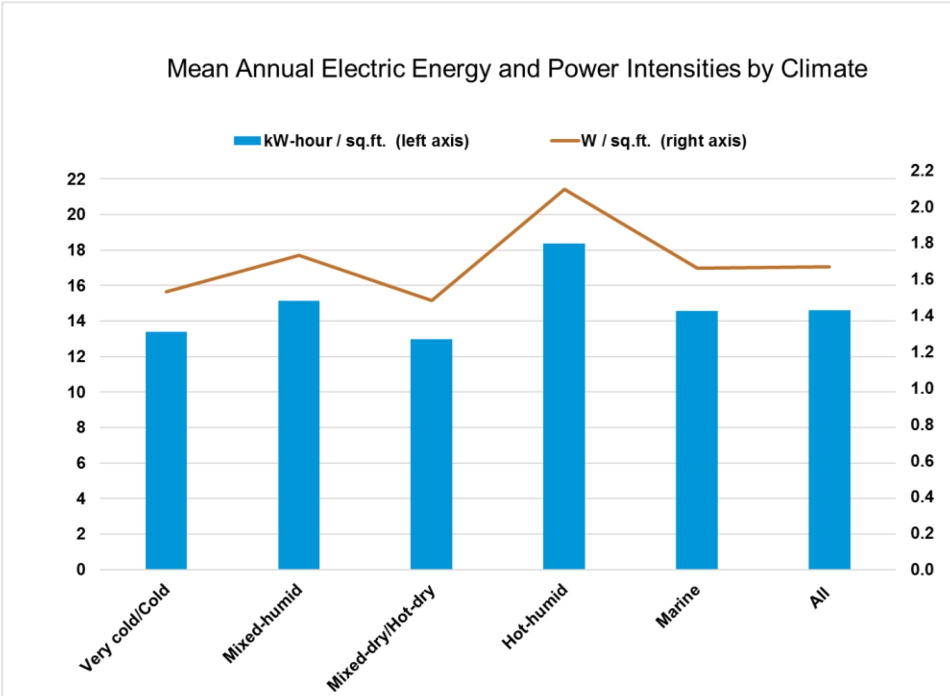

Figure 13. Mean Annual Electric Energy and Power Intensities Categorized by Climate
(Data Source: Table C13 in [5])

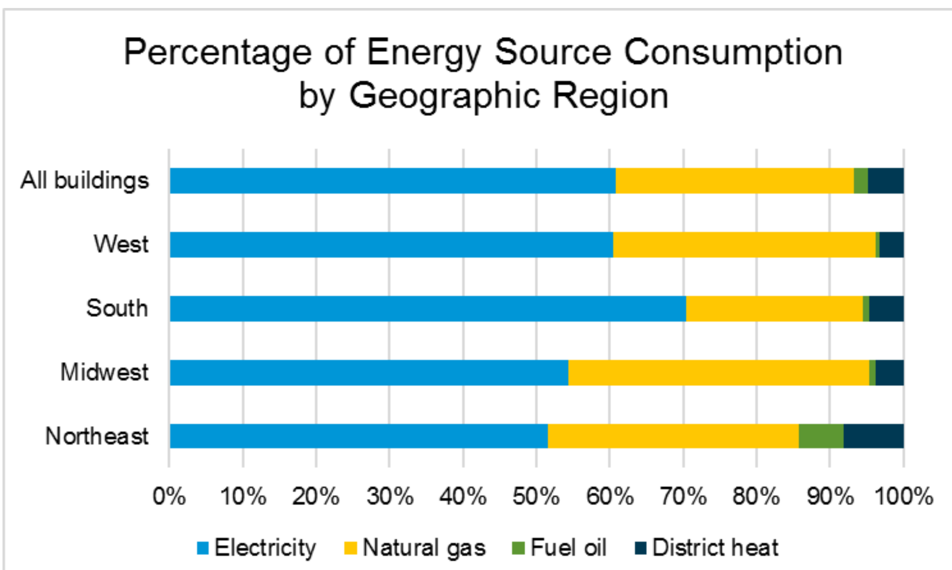

Figure 14. Percentage Energy Source Consumption Categorized by Geographic Region
(Data Source: Table C1 in [5])

Figure 15 shows that commercial buildings in the South also had the highest energy and power intensities at 16.1 kW-hours and 1.8 W per square foot in 2012. However, higher energy and power intensities do not necessarily imply that a higher percentage of the energy supplied

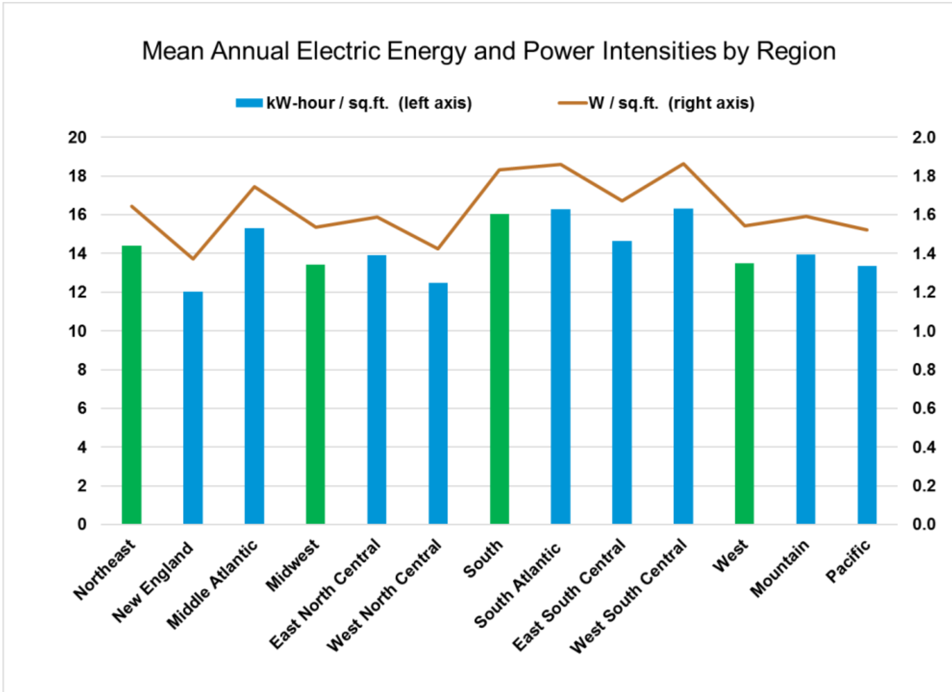

Figure 15. Mean Annual Electric Energy and Power Intensities Categorized by Region
(Data Source: Table C13 in [5])

to a building is in the form of electricity. Commercial buildings in the Northeast had the second highest electric energy and power intensities of 14.4 kW-hours and 1.6 W per square foot; in the Northeast, electricity also accounted for the lowest percentage of energy consumption by source. In Figure 15, the green columns represent the census regions and the blue columns to the right represent the subdivisions of the region.

2.4 Commercial Building Energy Usage by Building Type [5]

Figure 16 shows percentages of energy sources meeting the energy needs of commercial buildings by building type. Food sales, non-mall retail, and offices led in the highest percentage of energy needs met by electricity (79%, 77%, and 70%, respectively); not surprisingly, food sales, non-mall retail, and offices also had the lowest percentage of energy needs met by natural gas (20%, 20%, and 23%, respectively). Food sales buildings have a large refrigeration load. The highest consumers of district heat as a percentage of total energy are public assembly (13%), inpatient healthcare (11%), education (8%), office (6%), and lodging (5%).

By commercial building type, Figure 17 shows that food sales, food service, and inpatient healthcare require the most electricity per square foot of floor space. In 2012, their electric energy consumption was 48.7, 45.0, and 31.0 kW-hours per square foot, respectively. In comparison, offices consumed 15.9 kW-hours per square foot, and the electric energy intensity of all commercial building types was 18.4 kW-hours per square foot.

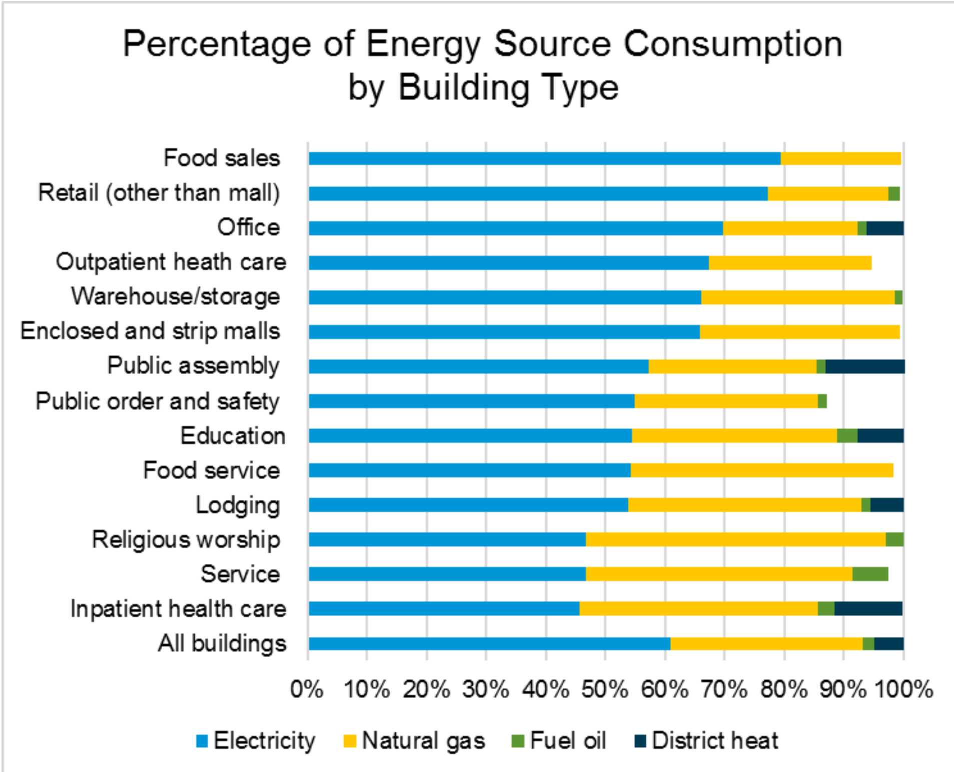

Figure 16. Percentage of Energy Source Consumption Categorized by Building Type
(Data Source: Table C1 in [5])

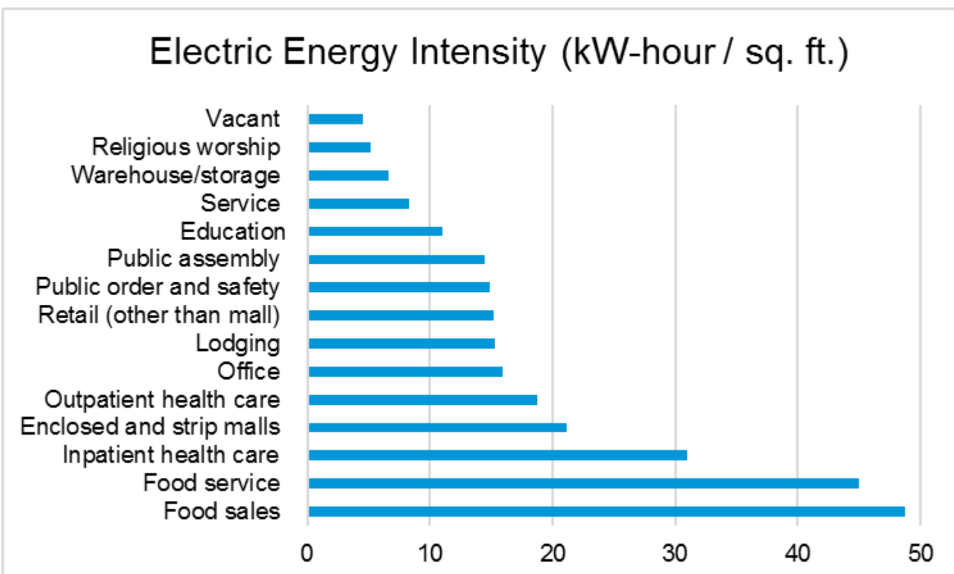

Figure 17. Electric Energy Intensity Categorized by Commercial Building Type
(Data Source: Table C13 in [5])

The mean electric power intensity for each building type in 2012 is displayed in Figure 18. As discussed earlier, the mean power intensity differs greatly from the demand power intensity; furthermore, these quantities differ from the power densities for which a building is designed. The power intensity of a building will change throughout the day to maintain thermal comfort, to adequately illuminate the spaces within the building, and to supply the electrical equipment so that employees can conduct their work activities and the building can achieve its function.

In most building types, the power intensity depends on the function of a building and the building's operating hours. The mean operating hours for the various types of commercial buildings was shown in Figure 9. Although long operating hours suggest long hours of adequate illumination and electrical equipment and device usage, long operating hours do not necessary result in high electric energy and power intensities. Figure 9 indicates that all inpatient healthcare and most lodging operate 24 hours a day, seven days a week. However, as Figure 18 shows, inpatient healthcare had a mean electric power density 3.5 W per square foot, but lodging was only 1.8 W per square foot.

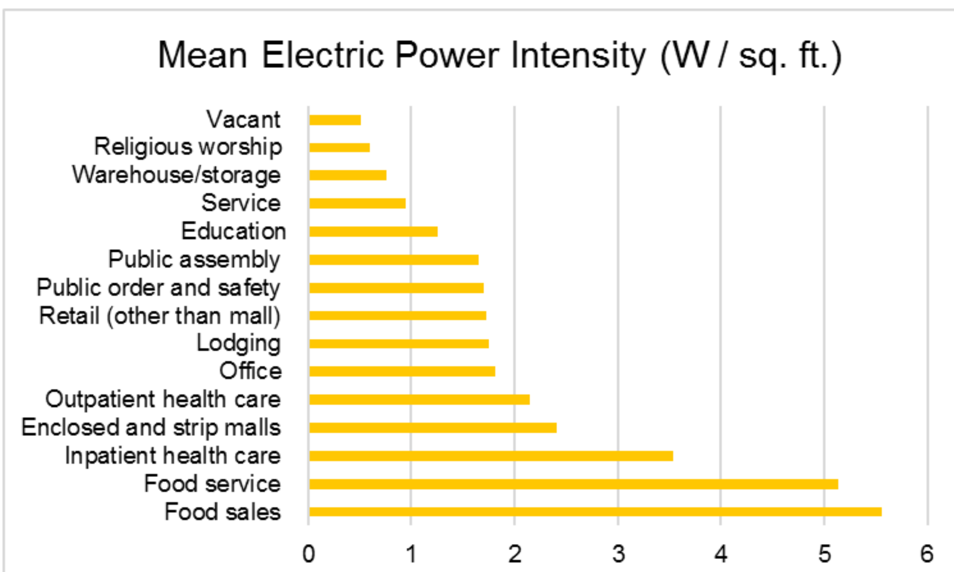

Figure 18. Electric Power Intensity Categorized by Commercial Building Type
(Data Source: Table C13 in [5], Note on terminology[5])

[5] The 2012 CBECS data and documentation classified commercial healthcare building types as "Inpatient health care" and "Outpatient health care" and the graphs in this report reflect the CBECS spelling. Various web sites delve into the correctness and usage of the terms "health care" and "healthcare." In response to a sponsor comment, the report author has used the term "healthcare" in the body of the report.

2.5 Electric Utility Commercial Building Loading

Figure 19 displays the average electric power intensity of various types of commercial buildings calculated from information released by Austin Energy in a public hearing [6]. The power intensities in Figure 19 are notably higher than those in Figure 18. One reason might be that the table produced by Austin Energy may be representative of buildings in the Austin, Texas area, a warm, humid climate with only 1,661 degree heating days in the last twelve months.[6] In Figure 19, restaurants and food stores account for the highest average loads ranging from 9.2 to 12.4 watts per square foot. Likewise, the 2012 CBECS found that food sales and food service (i.e., restaurants) had the highest mean electric power intensities, but the intensities were only 5.6 and 5.1 watts per square foot, respectively. Hospitals had the third

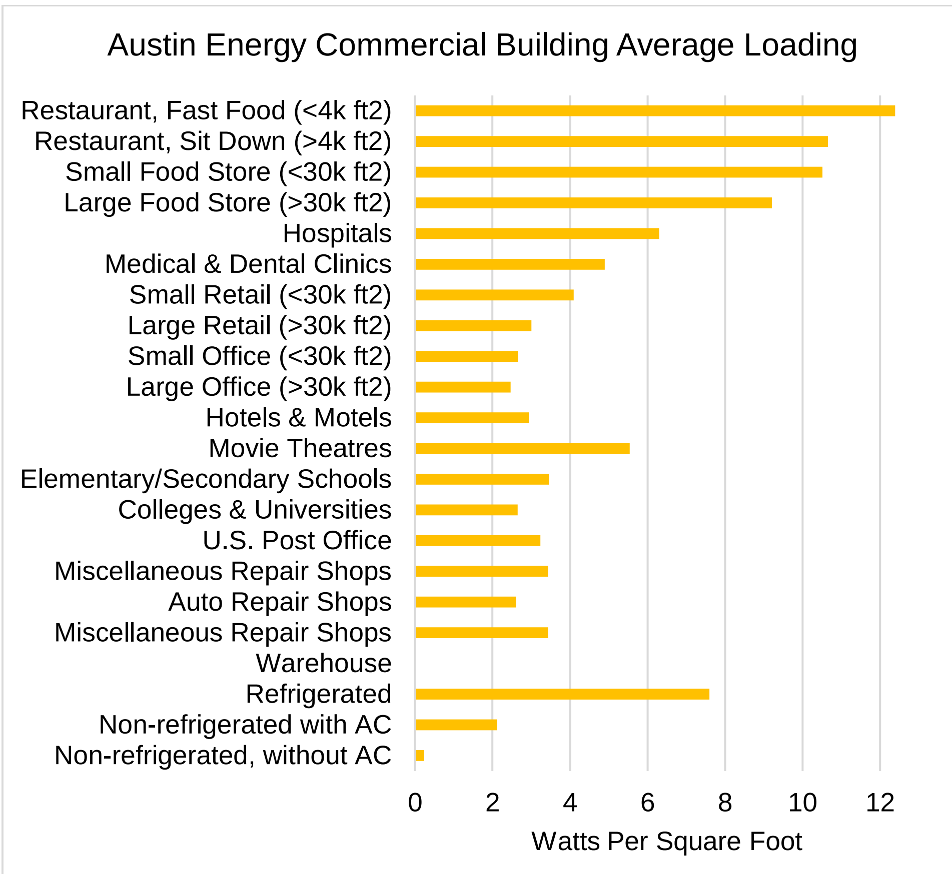

Figure 19. Austin Energy - Commercial Building Average Electric Power Intensity
(Data Source: [6])

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[6]Calculated on the website www.degreedays.net using from data taken October 1, 2015 through September 30, 2016 at the Austin-Bergstrom International Airport.

highest electric power intensities in Figures 18 and 19; the 2012 CBECS was 3.5 watts per square foot, while Austin Energy was 6.3 watts per square foot. However, there was less deviation in office buildings. Austin Energy found that office building loading was 2.5 to 2.7 watts per square foot and the 2012 CBECS was 1.8 watts per square foot.

3 BUILDING END-USE LOADS AND ELECTRICITY CONSUMPTION

3.1 End-Use Load Types and CBECS Models [5]

The 2012 CBECS included estimations of the end-use consumption by energy source, including electricity.[7] The estimations were determined from end-use models based on equations and parameters found in ASHRAE, Illuminating Engineering Society of North America (IESNA), and other standard engineering handbooks. Up-to-date parameters were also taken from large-scale field studies of commercial buildings.

The engineering estimations were calibrated by cross-section regression models where the estimations were fit based on consumption per square foot. Where possible, the regression models were reconciled with a building's known energy consumption. The reconciliation ratio was applied to the modeled end-use estimates.

- Space Heating and Cooling

The models estimated the total energy needed for space heating and cooling. The amount of electric energy required to meet the heating and cooling energy needs was determined from equipment type and estimated efficiency. The calculations account for the building heat losses and gains as a function of conductance and annual heating and cooling degree days, based on the thermal properties of the roof and wall materials. The energy models also included the ventilation heat loss or gain as a function of external air volume brought into the building daily, the temperature difference between the inside and outside air, and the heat capacity of the air.

- Ventilation

  The model estimated supply and return fan energy use based on external air ventilation volumes. Variable-air-volume factors were estimated by climate zone. Static pressure differences were accounted for by system type and by floor space.

[7] Details released on March 12, 2016 about the CBECS end-use consumption estimates are summarized in this section. The estimation models were described on the following website: http://www.eia.gov/consumption/commercial/estimation-enduse-consumption.cfm.

- Water Heating

  Water heating was estimated based on 1) equipment type and efficiency; 2) building type and size; and 3) ground water temperature.

- Lighting

  The model estimated the electric energy required to supply interior and exterior lighting fixtures. Interior lighting calculations included: 1) the efficiency (in lumens per watt) of lamp system types used in building; 2) the recommended average illuminance levels by building type; and 3) average building operating hours.

- Cooking

  The model was based on the number and types of cooking equipment reported in the CBECS and the 2005 California Commercial End-use Survey (CEuS) sponsored by the California Energy Commission.

- Refrigeration

  The model factored in the reported number of refrigeration units but was primarily based on the CEuS intensity estimates and the building type.

- Computer and Office Equipment

  Electricity consumption for office equipment in all building types was estimated. Computer equipment included personal and laptop computers, monitors, servers, and data centers. Other office equipment included copiers, printers, fax machines, cash registers, and video displays.

- Other

  “Other” end-use equipment supplied by electricity was based on floor space and CEuS intensities for miscellaneous, process equipment, motors, and air compressors.

3.2 CBECS End-Use Load Consumption [5]

Figure 20 illustrates the end-use percentages of electricity consumption in commercial buildings. Lighting, ventilation, refrigeration, and cooling loads accounted for 64% of the electricity consumed in commercial buildings. Computing and office equipment accounted for 14% of the end-use electricity consumption.

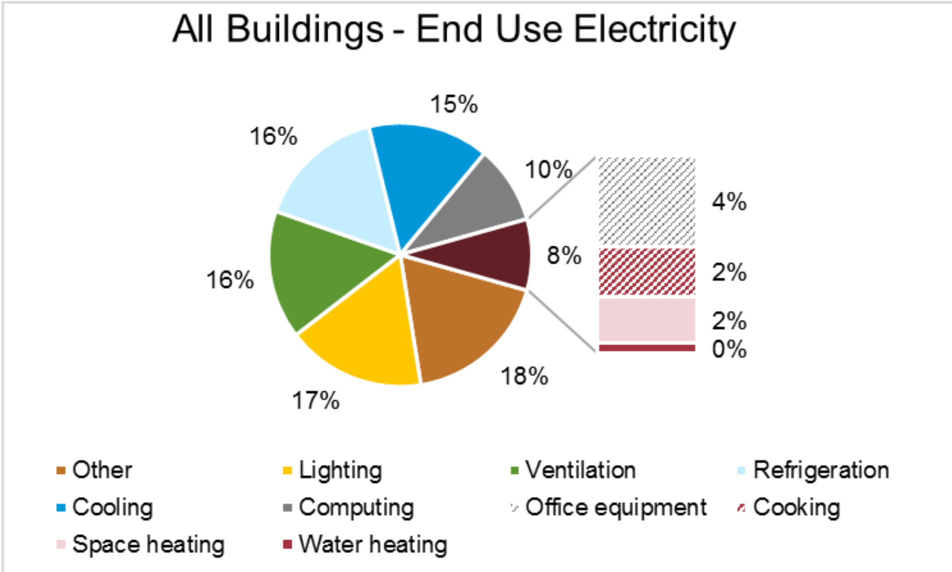

Figure 20. Percentage End-Use Electricity Consumption for All Commercial Buildings
(Data Source: Table E5 in [5])

Figures 21 and 22 show that electricity end-use consumption depends greatly on building type. At 70% and 40%, respectively, food sales and food service buildings lead in the highest percentage of refrigeration load. In contrast, refrigeration accounts for 3% of electricity consumption in office buildings. Outpatient and inpatient healthcare, public order and safety, public assembly, and office buildings have the highest percentages of air conditioning and ventilation load, ranging from 42% to 38%. In warehouse and storage and service buildings, lighting load accounts for 30% of the electricity consumption in the building; in comparison, the lighting load accounts for 16% to 18% of electricity consumption in offices, education, and healthcare buildings. Computing and office equipment account for high percentages of electricity consumption in office, education, lodging, and outpatient healthcare, at 24%, 22%, 17%, and 15%, respectively. Cooking accounts for 16% of electric energy usage in food service, followed by 5% in food sales and 3% in lodging.

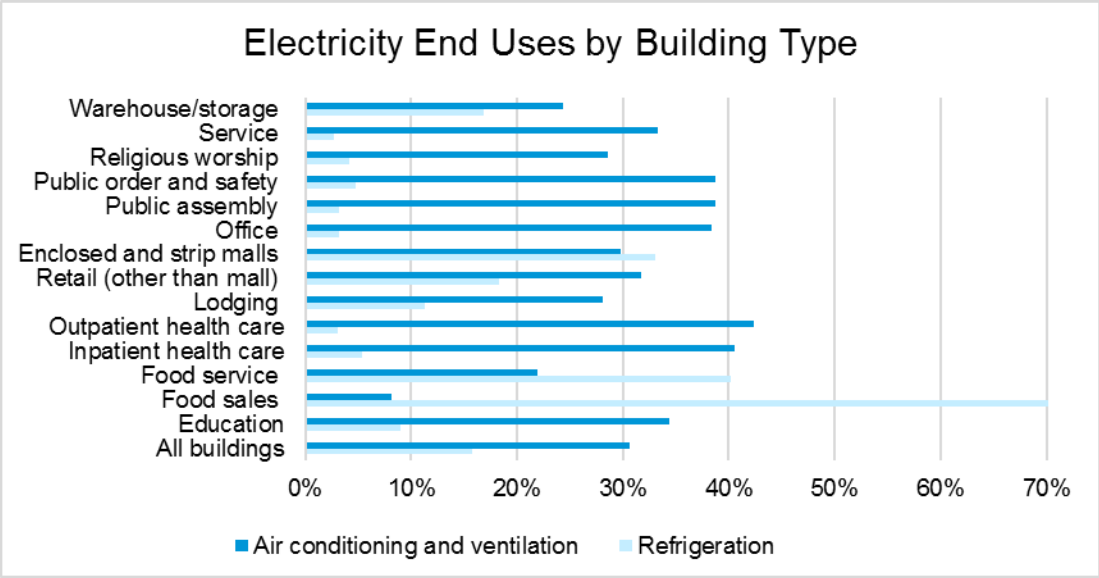

Figure 21. AC and Ventilation and Refrigeration Electricity Consumption by Building Type
(Data Source: Table E5 in [5])

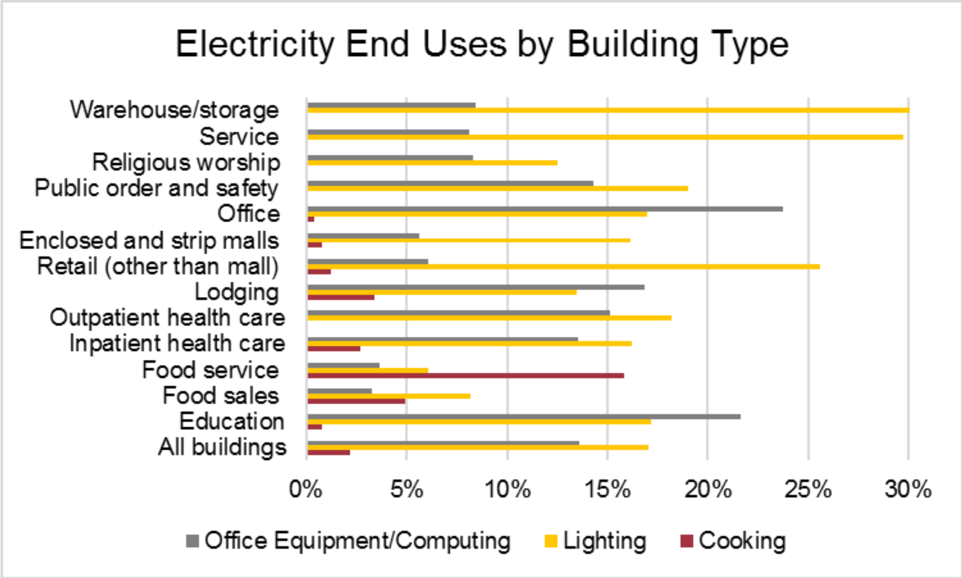

Figure 22. Office Equipment/Computing, Lighting, and Cooking Consumption by Type
(Data Source: Table E5 in [5])

The electric energy intensities for end-use equipment are shown in Figures 23 and 24 for various building types. Food sales and food service buildings had the highest intensities of refrigeration at 34.3 and 18.1 kW-hours per square foot; this is not surprising since refrigeration accounted for the highest percentage of electricity consumption (70% and 40%) in those building types. However, a high percentage of specific end-use consumption does not necessary imply a high electric energy intensity for that load. In enclosed and strip malls, refrigeration equipment accounted for 33% of electricity consumption, but its energy intensity was only 7.0 kW-hours per square foot. As shown in Figure 17, food sales and food service buildings had high electric energy intensities (48.7 and 45.0 kW-hours per square feet), but the density was much lower in enclosed and strip malls (21.1 kW-hours per square foot).

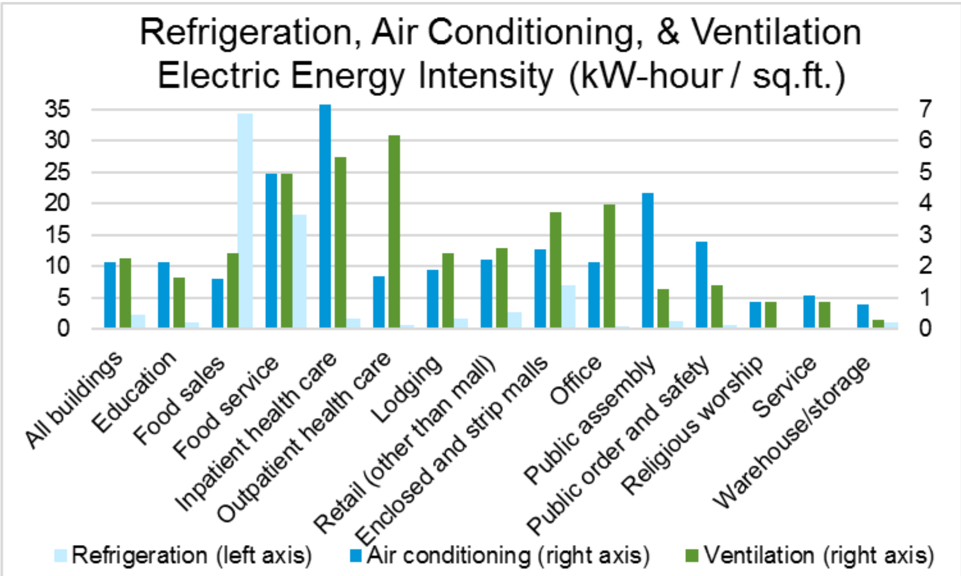

Figure 23. Refrigeration, AC and Ventilation Electric Energy Intensity by Building Type
(Data Sources: Tables C1 and E5 in [5])

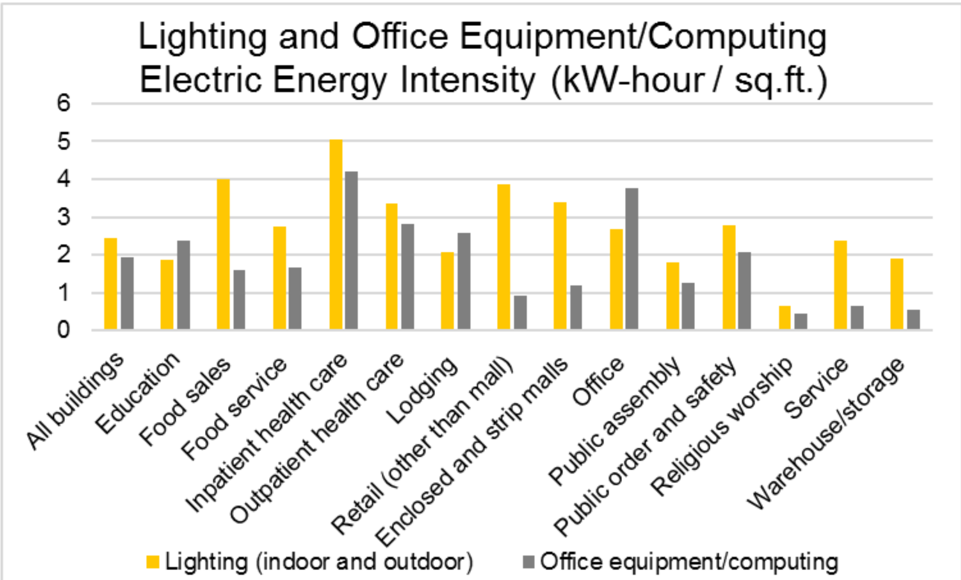

Figure 24. Lighting and Office Equipment/Computing Electric Energy Intensity by Type
Figure 24 (Data Sources: Tables C1 and E5 in [5])

Inpatient healthcare and food service had the highest air conditioning electric energy intensities of 7.2 and 5.0 kW-hours per square foot, and the second highest ventilation electric intensities of 5.5 and 5.0 kW-hours per square foot. In comparison, the air conditioning and ventilation electric energy intensities in office buildings were 2.1 and 4.0, respectively. The ventilation electric energy intensity was 2.3 kW-hours per square foot for all buildings, slightly higher than for air conditioning at 2.1 kW-hours per square foot.

The type of lighting system, illumination level required, and operating hours of the building type determined the lighting energy intensity. Inpatient healthcare and food sales had the highest electric energy intensities for lighting, 5.1 and 4.0 kW-hours per square foot. In comparison, office and warehouse/storage lighting had electric energy intensities of 2.7 and 1.9 kW-hours per square foot, which represented 17% and 30% of the building type's total electricity consumption, respectively.

With respective electric energy intensities of 4.2 and 3.8 kW-hours per square foot, inpatient healthcare and offices had the highest demand for computing and office equipment. Outpatient healthcare, lodging, and education followed with intensities between 2.8 to 2.4 kW-hours per square foot.

Refrigeration, air conditioning, and ventilation loads operate continuously, although power demand may greatly fluctuate throughout the day (and seasonally). Figure 25 illustrates the mean annual power intensities of these loads.

Power demands for indoor lighting will be high when the commercial building is operating. The indoor lighting demand is expected to be much lower when the building is not in operation, but some illumination is still required for life safety and security reasons. Outdoor lighting is more dependent on the season and will illuminate during dark hours. Power demand for computing and office equipment is high during business hours, but some computing and office equipment may be energized all the times. The mean annual power intensities of the lighting and computing and office equipment for commercial office buildings is listed in Table 3. Table 3 also displays the average power intensity if the lighting and computing and office equipment loads were energized only during building operating hours. As illustrated in Figure 9, the mean number of operating hours for office buildings was 55 hours per week in the 2012 CBECS.

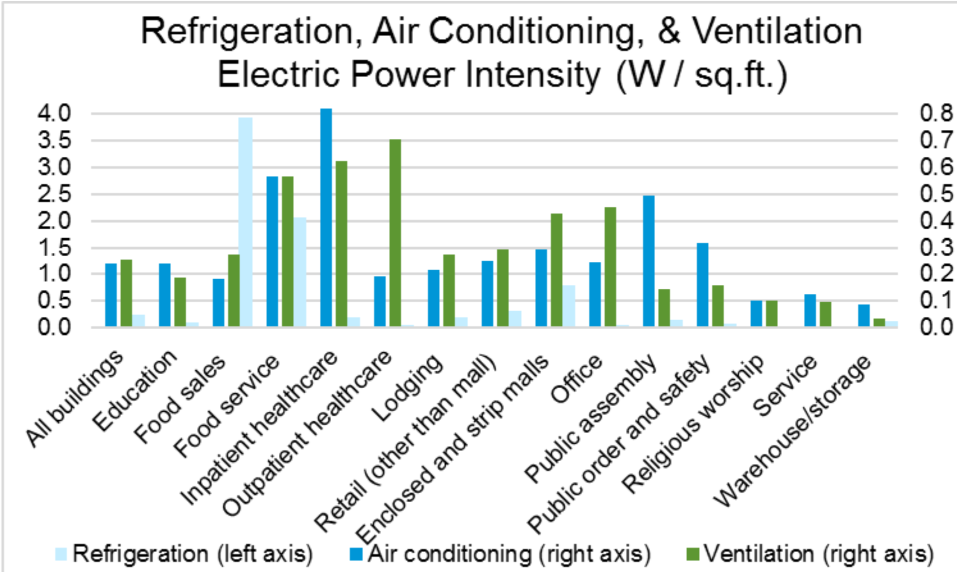

Figure 25. Refrigeration, AC and Ventilation Electric Power Intensity by Type
(Data Sources: Tables C1 & E5 in [5])

Table 3. Estimated Mean Power Intensities (W/ft^2) for Commercial Office Buildings*

End-Use Equipment	Continuous Operation	55 Hours Weekly
Lighting	0.31	0.94
Computing and Office Equipment	0.43	1.32

*Power intensities calculated from data in Tables B1, C1, and E5 in [5].

3.3 Miscellaneous Electric Loads in CDM[8] and Elsewhere

Miscellaneous electric loads (MELs) are usually defined as “the loads outside of a building’s core functions of heating, ventilating, air conditioning, lighting, and water heating…Taken across the entire commercial building sector, MELs now account for roughly 30% of total energy use [7].” Limited studies conducted by Pacific Northwest National Laboratory (PNNL) determined the energy consumption for bank branches in a cold climate was: 45% for interior and exterior lighting, 23% for HVAC, and 32% for MELs [7].

In an earlier report section, Figure 20 illustrated that computers and other office equipment and “other” loads accounted for 32% of commercial building electricity consumption. Figure 14 illustrated the electricity accounts for 61% of energy consumption in all commercial buildings. Based on the mean data from the 2012 CBECS, it might be concluded that MELs

[8] CDM is the Commercial Demand Module of the National Energy Modeling System (NEMS) used by the Energy Information Administration (EIA), a section of the U.S. Department of Energy (DOE).

account for roughly 20% (32% x 61%) of total energy consumption in commercial buildings. The PNNL findings suggest that the data produced from CBECS may underpredict the actual MEL energy consumption, at least in some building types. Although CBECS collects some information on minor end-use equipment, the survey focuses on equipment stock and energy consumption of major end-use equipment. "Given the dispersed and increasingly varied nature of this equipment and appliances [MELS], stock, usage, and consumption data can be difficult to obtain [8]." The NEMS Commercial Demand Module (CDM) projects MEL energy consumption based on unit energy consumption and total stock for each MEL.

The U.S. Energy Information Administration contracted Navigant Consulting, Inc. and SAIC to update and to project MEL energy consumption data for incorporation into NEMS. In 2013, Navigant reported on the estimated number of thirteen miscellaneous electric loads installed in the U.S. and their estimated energy consumption. Table 4 lists the thirteen MELs and the unit and total annual energy consumption for each MEL during 2011. Commercial electricity consumption was 1,319 TW-hours in 2011 [8]; therefore, the MELs selected in the Navigant study represent an estimated 15% of the total electricity consumed by the commercial sector in 2011.

The thirteen commercial miscellaneous electric loads in Tables 4 and 5 were selected in a two-stage process beginning with 173 residential and commercials MELs. The initial commercial list included:

- non-road electric vehicles coffee makers elevators escalators
- other medical equipment fitness equipment office equipment arcades
- automated teller machines (ATMs) water purification/treatment loads fume hoods

During the initial screening, 38 commercial MELs were identified that had significant energy consumption and needed better characterization. Five of these prospective MELs and their estimated energy consumption are also included in Table 4. Other miscellaneous electric loads that were not selected included kitchen equipment (ovens, steamers, griddles, fryers, and broilers) with a significant combined annual energy consumption equal to 39.1 TW-hours [8].

When data was available for the thirteen selected MELs, usage was characterized, and energy consumption was estimated based on power draw in different states (active, sleep, or off). Table 4 also lists the power drawn during the active state. Power consumption is a composite and represents average unit consumption in the U.S. For medical equipment and kitchen ventilation equipment, sub-products were analyzed individually and energy consumption for a composite unit was calculated.

Table 4. Navigant MELs - Total & Unit 2011 Energy Consumption and Active Power Draw

Selected MELs	Total Energy (TWh)	Installed Units (thousands)	Unit Energy (kWh)[1]	Per Unit Active State (W)[1]
Distribution transformers	43	5,470	7,900	
Kitchen ventilation	41	790	52,000	8,071
Desktop computers	30	74,000	400	64
Servers in data centers	29	12,200	2,400	269
Monitors for PCs & laptops	18	93,000	198	38
IT equipment (routers, hubs, switches, security)	12	487,000	25	3
Commercial security systems	7.4	11,000	2500	290
Water distribution equipment*	6.6			
Lab refrigerators & freezers	4.5	1,000	4,500	975
Medical imaging equipment	2.7	178	15,000	22,774
Laptops (including netbooks)	2.1	63,000	34	21
Large video displays (>30") for advertising/entertainment	1.7	1,600	1,084	246
Large video boards for stadiums and arenas	0.2	1	152,000	190,000
Total	198.2			
Other Prospective MELs				
Ice makers/machines	11	2,600,000		
Printers	11	34,000,000		
Vending machines	11	6,600,000		
Televisions	3.8	16,000		
Irrigation systems	3.6			
[1]Appendix G in [8]; *external to the buildings and provided by the public water distribution system.				

Most MELs listed in Table 4 were found in all the NEMS CDM building type categories identified later in Table 15. For some MELs, such as distribution transformers and security systems, MEL usage spread across all building types. For many MELs, usage predominated in a small number of building types. By definition, servers in data centers are located only in data centers. Large format video boards are only located in stadiums and arenas. Medical equipment is only located in inpatient healthcare facilities and small offices (outpatient healthcare) based on the 2003 CBECS building type definitions used in the NEMS CDM. Table 5 displays the energy consumption of each Navigant MEL in the predominant building type(s) as a percentage of the total energy the MEL consumes in all commercial building types.

Low-voltage distribution transformers (LVDT), on the customer-side of the utility meter, used 43 TW-hours of site electricity in 2011. The distribution transformer total and unit energy consumption in Table 4 is based on a composite of three transformer sizes listed in Table 6.

The number of transformers was based on the total electricity supplied to the building for other than HVAC and refrigeration loads. The analysis was based on a 1999 study done by the Cadmus group and the U.S. Department of Energy rulemaking engineering analysis[9]. Low-voltage distribution transformers topped the Navigant MEL list in energy consumption, but all transformer energy consumption represents energy loss. Unlike other MELs, transformers are not "end-use" loads; transformers are electrical equipment changing the supply voltage to a voltage that can be utilized by the end-use equipment. Navigant acknowledged that low-voltage distribution transformer losses "are highly dependent on site-specific sizing and site-specific loading profiles." [8]

Table 6 provides the energy consumption of subcategory equipment for distribution transformers, servers in data centers and medical imaging equipment. Table 6 also includes the annual per unit mean power for the distribution transformers and data center servers. Although kitchen ventilation equipment was not included in the table, it was subdivided by small, medium, and large exhaust fan capacity. Commercial security systems largely consist of video surveillance, physical access control, and intruder and fire detection. Electronic article surveillance systems are typically found in retail and some food sales stores. The power consumption of commercial security systems depends on system type and on building size and type. The subcategory equipment for these MELs was used to develop their composite profiles.

Table 5. 2011 MEL Percentage Energy Consumption by Predominant Building Category

Selected MELs	% Energy Consumption[1]	Predominate NEM CDM Building Category
Distribution transformers	28	Mercantile and service
Kitchen ventilation	84	Education, food sales, and food service
Desktop computers	68	Education; Large office; Small office
Servers in data centers	100	Other
Monitors for PCs & laptops	72	Education; Large office; Small office
IT equipment	72	Education; Large office; Small office
Commercial security systems	---	No predominant building type
Water distribution	20	Warehouse
Lab refrigerators & freezers	100	Education; Healthcare; Other
Medical imaging equipment	100	Healthcare; Small office
Laptops (including netbooks)	67	Education; Large office; Small office
Large video displays (>30")	41	Mercantile and service
Large video boards	100	Assembly
[1]Calculated from Appendix B in [8]		

[9] Federal Register / Vol. 77, No. 28 / Friday, February 10, 2012 / Proposed Rules 10 CFR Part 431, Energy Conservation Program: Energy Conservation Standards for Distribution Transformers.

Table 6. Subcategory MEL Equipment used in Composite Profile (Annual Basis for 2011)

Selected MELs	Total Energy (TWh)	Installed Units (thousands)	Unit Energy (kWh)	Annual Mean Per Unit Power (W)
Distribution transformers	43	5,470	7,900	902
25 kVA, 1 phase		600	2,200	251
75 kVA, 3 phase		4,100	6,600	753
300 kVA, 3 phase		800	19,200	2,192
Servers in data centers	29	12,200	2,400	274
Volume servers		11,800	2,000	228
Mid-range servers		340	8,000	913
High-end servers		38	50,500	5,765
Medical imaging equipment*	2.7	178	15,000	
MRI		12	111,000	
CT Scan		13	42,000	
Xray		78	9,500	
Ultrasound		75	760	
*Does not include approximately 140,000 dental X-ray and 48,000 mammography machines. Estimation based on seven days per week and may not be consistent with many locations.				

3.4 Receptacle and Plug and Process Load Studies

Different researchers use the acronym MELs in related but somewhat different contexts. "Miscellaneous electric loads" often cover a wide variety of equipment which does not fall under one of the main end-use load categories: heating, air conditioning, ventilation, refrigeration, water heating, lighting, and cooking (considered as an MEL in the Navigant study). Computer and office equipment are usually considered as an MEL, although the EIA NEMS commercial demand module (discussed in Section 4) categorizes it separately. Government sponsored research has been conducted on how to reduce the power consumption associated with receptacle load, referred to as "plug load." Unlike major end-use loads which are hard-wired, the receptacle load has not historically been regulated by building energy conservation codes. In this context, the acronym MELs refers to "miscellaneous and electronic loads," often referring exclusively to the receptacle load.

3.4.1 Lawrence Berkeley National Laboratory Office Receptacle Study

Researchers at Lawrence Berkeley National Laboratory (LBLN) conducted a study of plug-in loads in an office building on site [9]. The 89,500 square feet office building was inhabited by 450 workers. A total of 4,454 plug-loads were inventoried. From the total inventory, 455 plug-loads were carefully chosen to represent the plug-load usage in the building and were monitored for a minimum of six months, up to 16 months. The plug-loads were connected directly to meters which plugged into the receptacle outlets. Every ten seconds average power measurements were collected via a wireless metering system.

The categories for the inventoried devices and their percentage of the total 423 MW-hours estimated annual energy use is displayed in Figure 26. The *miscellaneous HVAC* category included fans and portable heaters. It is interesting to note that the *other* category, which included water coolers, accounted for 38% of the plug-in devices but less than 9% of energy use. The *imaging* category included copiers, facsimiles, printers, multi-machines, and scanners. Standard office and computer equipment categorized under *imaging*, *networking*, *displays*, and *computers* accounted for only 43% of the plug-in devices but 78% of energy use; computers alone accounted for over 50% of energy use. The *appliance* category (2.8% energy use) was included in the study because appliances are outside the business function of an office building.

The study concluded that metering for a two-month period would have provided a reasonable accurate estimate of annual energy consumption for most load categories. For categories such as miscellaneous lighting, in which usage might be impacted by seasons, longer metering periods are needed for better estimations. The LBLN study found the average power densities for the plug-loads were 1.1 W/ft^2 during the day and 0.47 W/ft^2 at night. Furthermore, the LBLN study estimates that plug loads account for 15% of building primary energy use in the United States, a much lower estimate than the PNNL study mentioned in Section 3.3.

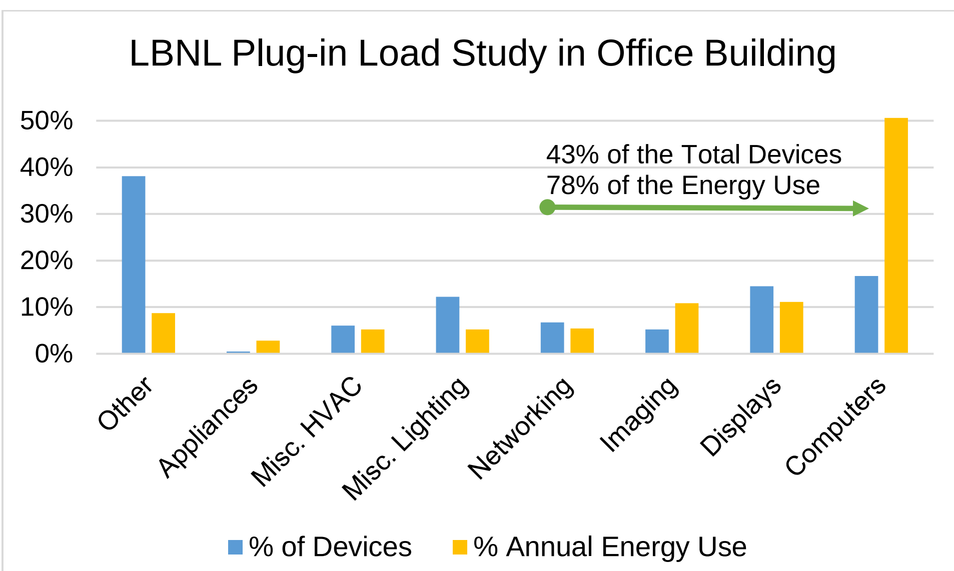

Figure 26. Plug Load Office Building Study at Lawrence Berkeley National Laboratories
(Data Source: [9])

3.4.2 University of Idaho & California PIER Studies on Receptacle Load Power

The University of Idaho conducted a study on six office buildings in Boise, Idaho to characterize the receptacle load profile and to explore the efficacy of different intervention techniques to reduce the energy consumption of plug loads [10]. Data logging equipment was placed at the panel feeders to record true power and energy consumption at fifteen-minute intervals. In panels with circuits supplying other load types, current loggers were used to record current which was subtracted from the total current load of the panel. In some panels with only a few receptacle loads, the circuits supplying the receptacles were monitored directly.

Data was collected for fifteen months, and loggers were downloaded every two to three months. The most common problem was data logger battery failure. On four sites, data was collected for three months before energy reduction interventions occurred. Baseline data was collected for twelve months before intervention on one site and the last site had no intervention.

The results of the University of Idaho study have been summarized in Table 7. Some of the less common receptacle loads included fountain pumps, handheld vacuums, massage chairs, and humidifiers. Two heaters were plugged in at one site and six at another. Fans were found on four sites.

Table 7. Summary of Results in University of Idaho's Receptacle Load Study*

Office type	Land records	World wide logistics	Architect	Elections office	Regulatory agency	Investment analytics
Square feet (ft^2)	4,544	13,688	1,288	1,550	13,072	13,688
FT employees*	31	94	6	7	49	100
FTE* / ft^2	147	146	215	221	267	137
Total plug devices	216	359	50	67	275	392
Devices / 100 ft^2	4.8	2.6	3.9	4.3	2.1	2.9
Devices / FTE	7.0	3.8	8.3	9.6	5.6	3.9
Weekdays						
Average W/ft^2	0.87	0.36	0.84	0.36	0.48	1.75
Peak Hours	6am-6pm	7am-6pm	8am-5pm	7am-5pm	8am-5pm	7am-6pm
Peak kW	6.25	10.5	1.5	1.25	9.5	28
Unoccupied kW	2.75	2.0	0.75	0.25	4.75	22
Peak* W/ft^2	1.38	0.77	1.16	0.81	0.73	2.05
Unoccupied* W/ft^2	0.61	0.15	0.58	0.16	0.36	1.61

*FTE is full-time employees. Data found in [10]. Peak and unoccupied W/ft^2 have been calculated from the peak and unoccupied kW provided in the University of Idaho report.

Other studies have found similar ranges of receptacle power density usage in office buildings. The results in Table 8 were presented by the New Buildings Institute in 2012 for the California Public Interest Energy Research (PIER) Program [11]. Table 8 includes average daytime, average night, and peak power densities for five office buildings in California and British Columbia. The peak to average daytime power density ratios varied from 1.33 (Vancouver) to 2.25 (Irvine Site 3). Average daytime lighting power densities, also included in Table 8, ranged from 0.2 W/ft^2 to 0.5 W/ft^2 and varied between average daytime receptacle power density (Rosemead) to only 20% its value (Los Angeles). The lighting power densities can also be compared with the lighting power allowances and minimum lighting power densities included in Section 5 on energy conservation codes and Section 6 on engineering practices.

Table 8. New Buildings Institute Receptacle and Lighting Load Office Study [11]

Office Location	Irvine CA Site 1	Irvine CA Site 2	Rosemead CA	Los Angeles CA	Vancouver BC
Square feet (ft^2)	8,328	1,500	16,500	8,024	9,000
Lighting Average Daytime W/ft^2	0.2	0.4	0.5	0.3	0.5
Plug Load Weekdays					
Average Daytime W/ft^2	0.8	0.8	0.5	1.5	0.6
Peak W/ft^2	1.6	1.8	0.7	2.1	0.8
Average Night W/ft^2	0.4	0.6	0.3	1.46	0.3

3.4.3 NREL Study on Plug and Process Load Power Density and Other Work

The National Renewable Energy Laboratory (NREL) conducted a study on the “plug and process” loads (“PPL”), which they defined as all loads other than heating, ventilation, air conditioning, and lighting. Buildings which had disaggregated plug and process were selected for the study. Submetering equipment was in already place for all buildings except the DOD and GSA offices. Tables 9 through 11 present the study results of plug and process load densities in buildings ranging from over 18,000 square feet to 365,000 square feet. The office power densities in Table 9 were measured from the four government offices of the Department of Defense (DOD), National Renewable Energy Laboratory (NREL), and General Services Administration (GSA). The buildings in Table 10 represent higher education buildings at Stanford University; the buildings contain classrooms, meeting areas, and faculty offices. The average ratios of peak to average power densities for the offices in Table 9 and the higher education buildings in Table 10 were 2.03 and 2.30, respectively [12].

Table 11 provides average power density of the plug and process load for ten offices. Note that the 0.64 W/ft^2 average density for the single corporate tenant with kitchen was fairly low in comparison with the two highest densities of 1.17 and 2.27 W/ft^2. The highest plug and process load power density was measured at the office of a single corporate tenant with laboratories.

It should also be noted that office buildings, as well as other buildings, house various space types. For example, the U.S. Navy office building (DOD) included in Table 9 contains a library, private offices, office areas with cubicles, two conference rooms, three kitchens, hallways, a print room, a mail room, and a reception area. The plug and process load densities in these different spaces may vary.

Table 9. Plug and Process Load Power Densities of Four Government Offices

Government Office Building	Area (square feet)	Average (W/ft^2)	Peak (W/ft^2)
DOD	18,818	0.24	0.52
GSA (with data center)	18,755	0.34	0.51
NREL	138,000	0.16	0.55
NREL (with data center)	220,000	0.77	1.25
Data center only		0.57	0.82

Table 10. Plug and Process Load Power Densities of Seven Stanford University Buildings

Number of Buildings	Area (square feet)	Average (W/ft^2)	Peak (W/ft^2)
1	115,110	0.23	0.41
1	49,360	0.30	0.64
1	83,130	0.16	0.42
1	26,326	0.40	1.08
3	113,584	0.28	0.63

Table 11. Plug and Process Load Power Densities of Ten Office Buildings

Office Building Type	Area (square feet)	Average (W/ft^2)
Multi-tenant with data center	50,725	1.17
Multi-tenant with data center	365,000	0.19
Multi-tenant with data center	191,799	0.37
Multi-tenant	173,302	0.49
Municipal	172,000	0.40
Single tenant with warehouse	94,621	0.19
Single Corporate tenant with data center	97,500	0.58
Single Corporate tenant with data center	195,721	0.36
Single Corporate tenant with kitchen	91,980	0.64
Single Corporate tenant with laboratories	222,616	2.27

Another study conducted by Baumann Consulting measured the “plug load” (i.e., receptacle load) power density of different space types located in an office occupying the fifth floor of a seven-story building in Washington, D.C [13]. The measured peak daytime demands in Table 12 are significantly higher than typical power densities listed in Tables 7 through 11 for office and higher education buildings. Table 12 is evidence that some space types might require higher receptacle demand power densities than other types and kitchens can have high demand densities. The average plug and process power density of the corporate office space with laboratory listed in Table 11 suggests that many lab spaces might also have higher power density requirements.

Table 12. Baumann Study: Plug Load Power Densities in Different Office Space Types*

Fifth-floor office in Washington, DC	Area (square feet)	Area % of 5th Floor	Average Evening (W/ft^2)	Peak Daytime (W/ft^2)
Office zones	4,890	81.6%	0.58	2.52
Conference zone	470	7.9%	0.35	1.85
Kitchen zone	246	4.1%	0.23	9.05
Other zones	384	6.4%	*Data sources: [13] and Figure 1 and Table 3 in [13]	
Fifth floor	5,990	100%		

3.4.4 Studies on Device Power Consumption

A study conducted by Ecos for the California Energy Commission (CEC) Public Interest Energy Research Program (PIER) involved inventorying the receptacle load at 47 offices, almost 7,000 plug-in devices [14]. A total of 470 plug-in devices were monitored at 25 offices for a two-week period. Data was collected at one-minute intervals. The report presented a careful analysis of the percentage of time many common device types are in active, idle, sleep, standby, and off states. The device types included: computers, monitors, imaging equipment, computer peripherals, lamps, coffee makers, and shredders. Table 13 provides the average power consumption during various states found for some common plug-in devices monitored in the study. The number of devices monitored is also included in the table.

It has been noted in various papers that device nameplate power rating is not representative of the heat that a building gains due to device operation. As Table 13 shows, a device consumes less power when it is not in the active state. The Baumann Study discussed in Section 3.4.3 also measured the power consumption of plug-in devices at 30-second intervals for at least 24-hours per device and at least three 24-hour periods on devices with highly variable usage (such as printers and copiers). The device nameplate power rating is compared with the average in-use and idle power consumption in Table 14. The number of devices represented in the study is also included in the table. It might be noted that the Baumann study involved an energy analysis simulating heat gains inside the building which rested on a lighting power density[10] of 1.1 W/ft^2 based on ASHRAE 62.1 (Table 4 in [13]). This density might be compared with the lighting power allowances and minimum lighting power densities included in Section 5 on energy conservation codes and Section 6 on engineering practices.

Table 13. Measured Power Consumption of Common Office Devices in Various States*

Device	Number	Active (W)	Idle (W)	Sleep (W)	Standby (W)
Desktop computer	61	78.9	45.6	3.2	2.2
Notebook computer	20	74.7	30.3	1.6	1.6
LCD display	84	34.2	26.4	6.2	0.9
Laser MFD	18	75.7	26.1	5.4	5.5
Laser printer	33	130.1	19.0		11.4
Inkjet printer	13	64.0	6.8	4.7	2.7
Computer speakers	18	6.0	2.4		1.7
External drive	2	28.4		10.7	1.0
Ethernet hub or switch	9	17.0	8.0	5.9	1.3
USB hub or switch	2	26.0	14.1	5.9	0.6
LCD television	2	58.2			3.1
Video projector	4	181.9		9.8	4.6
Portable CD player	7	18.0	3.0		1.3
Speakers (audio)	6	32.0	10.0		1
Coffee maker	10	464.0	40.3		1.8
Shredder	4	78.4			0.8
Space heater	4	937.7			1.0
Toaster oven	1	1057.9			0.0

*Devices and data selected from Table 11 in [14]

[10] In email dated December 5, 2016, Justin Lueker, author of [13], stated that "11.8 W/m^2, which translates to about 1.1 W/ft^2" was used. Table 4 of [13] had incorrectly included 127 W/ft^2 for the lighting power density in all occupied spaces, apparently mis-converting 11.8 W/m^2.

Table 14. Baumann Study - Device Nameplate and Idle and In-use Power Consumption*

Device	Number	Nameplate (W)	Idle (W)	In-use (W)
Laptop computer	11	80	0	40-70
Desktop computer	11	100-930	2.5	70-75
LCD display	33	25-40	0	25-40
LED lamp	11	11	0	7.6
Printer	1	1584	15	780 printing 130 scanning
Shredder	1	800	0	200
Server rack	1	--	1175	1175
Conference system	1	--	92.5	543
Refrigerator	1	180	0	100-105
Coffee machine	1	1250	3.3	1300
Toaster	1	1000		765
Microwave	1	1700	0.05	1540
Water cooler	1	700	0	130-160 chilling 553 heating

*Data sources: Tables 1 and 3 in [13]

3.4.5 Receptacle Load Power Densities in Real Estate and Building Design

In the abstract of [12], it is stated: "Tenants [of commercial buildings] require that sufficient electrical power is available for PPLs [plug and process loads] to meet the maximum anticipated load. Lease language often dictates a value of 5 to 10 W/ft^2 for PPLs….Overestimating PPL capacity leads designers to oversize electrical infrastructure and cooling systems."

Cooling requirements in buildings are partially determined by the heat generated by the lighting and electrical equipment, including receptacle load. The receptacle load can also influence peak heating loads. According to [13], the standard practice for HVAC sizing calculations is to assume a plug load density of 1 W/ft^2, published in ASHRAE Research Project RP-1055 (1999) for offices. According to [15], the 2009 ASHRAE Handbook – Fundamentals "states that a 'medium density' office building will have a plug load of 1 W/ft^2." Based on an analysis of results published in ASHRAE-sponsored research project RP-1482 (2010), "Update to Measurements of Office Equipment Heat Gain Data," reference [15] further asserts that peak plug loads as low as 0.25 W/ft^2 are possible. This assertion seems to be based on plug loads consisting of light usage of notebook computers with speakers and one printer per ten workstations.

What is not stated in papers addressing the receptacle demand power density required by tenants is that the estimated power density of a building may be based on the total receptacle load calculated from National Electrical Code Article 220 which requires 180 VA for single or duplex receptacles on one yolk. Furthermore, the power density required by tenants may also, in a sense, be expressing a need to have a space populated with an adequate number of receptacles.

4 EIA MODEL AND PREDICTIONS FOR COMMERCIAL BUILDINGS

4.1 NEMS Commercial Demand Module

The CBECS provides data for the Commercial Demand Module (CDM) of the National Energy Modeling System (NEMS) [15]. As part of NEMS, the CDM generates projections of the commercial sector energy demand for the nine Census division levels identified in Figure 7. Equipment purchases for the major end-use loads in a commercial building are based on a life-cycle cost algorithm which incorporates consumer behavior and time preference premiums. Equipment selection factors are also based on major energy source, such as electricity, natural gas, or distillate fuel oil. The seven major end-use loads in the CDM are heating, cooling, water heating, ventilation, refrigeration, cooking, and lighting. The CDM has also incorporated the three minor end-use loads: personal computers, other office equipment, and miscellaneous end-use loads (MELS). Miscellaneous end-use loading is represented in the “other” category in Figure 20, which illustrated that MELS (excluding computers and other office equipment) were attributed to 18% of the electrical energy consumption in all commercial buildings. Minor and renewable energy sources, as well as district energy services, are also included in the CDM.

The CDM defines eleven building categories based on the 2003 CBECS. Table 15 includes the building categories and ownership since projections for equipment decisions are impacted by these factors. The model is also used to assess how changing energy markets, building and equipment technologies, and regulatory initiatives impact the energy consumption of the commercial sector. The base year for the current CDM is 2003, corresponding to the 2003 CBECS.

The total building “service demand” depends on the building type, size, and location. The CDM models energy-consuming “service demands” because consumers do not directly utilize energy. End-use equipment is purchased to meet service demand for 1) new construction; 2) replacement of equipment at the end of useful life; and 3) retrofit of equipment with useful life remaining, but at the end of economic life. The total energy consumption depends on the average efficiency of the equipment supplying the service demand.

Table 15. Commercial Demand Module Building Categories, Floorspace, and Occupancy*

CDM Building Category	2003 CBECS Building Type	Total Floorspace (million ft^2)	% Govt. Owned	Non-Govt. % Owner Occupied	Non-Govt. %Non-owner Occupied
Assembly	Public assembly Religious worship	7,693	23	52	25
Education	Education	9,874	79	13	9
Food sales	Food sales	1,255	1	43	56
Food services	Food services	1,654	7	30	64
Healthcare	Inpatient healthcare	1,905	18	48	34
Lodging	Lodging	5,096	7	32	61
Mercantile/ Service	Mercantile	15,242	7	34	59
Office	Office	13,466	14	47	40
Two office types: Large (>50,000 ft^2) & small (≤ 50,000 ft^2), includes outpatient healthcare					
Warehouse	Warehouse	10,078	7	37	56
Other	Other	5,395	26	21	53
TOTAL		71,658	21	35	44

*Data Sources: Tables 1, E-4, and 8 in [15]

4.2 EIA 2015-2040 Projections for Commercial Buildings

The EIA projects that floor space and delivered energy consumption in commercial buildings will increase by 1.1% and 0.6% per year respectively from 2015 to 2040. The net result is a decrease in energy intensities due to higher efficiency lighting, heating, cooling, and ventilation systems; it is also due to more stringent building codes. The EIA reports an expected 0.3% per year reduction of electric energy intensity. However, the energy intensity of miscellaneous electric loads is expected to increase by a total of 11.5% [16].

5 COMMERCIAL BUILDING ENERGY CONSERVATION CODES

5.1 U.S. Department of Energy (DOE) Commercial Buildings Models

The DOE building models [2] aid in the development of energy codes and standards. Sixteen reference building energy models, listed in Table 16, have been developed for the U.S. Department of Energy in collaboration with the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Lawrence Berkeley National Laboratory (LBNL). The fifteen commercial buildings models (excluding the midrise apartment building model) represent over 60% of the commercial buildings in the United States. Table 16 provides the floor space and the number of floors for each reference model; the corresponding CBECS building type is also included. The remaining percentage of commercial buildings (less than 40%) may be similar to one or more of the reference models, but are not as easy to characterize by a representative type [2].

The building models were developed from the 2003 CBECS, which collected data on 5,215 buildings. The fifteen commercial building models represent 3,279 of the 2003 CBECS buildings with a floor space of 44 billion square feet (62% of the total floor space of the buildings in the study). The buildings used to develop the reference models accounted for 65% of the total energy consumption in the 2003 CBECS.

A version of the reference model for each building has three vintages: buildings constructed before 1980, buildings constructed after 1980, and new construction. About 78% of the U.S. population lives in five of the climate zones identified in Table 1. Population is an indication of geographic building distribution. But reference models have been developed for each of the sixteen climate zones discovered by the DOE; the most populated city in each of these zones appears in Table 1. The DOE developed 768 models to represent each unique combination of commercial building type, vintage, and location [2].

Table 16. DOE Reference Building Models and Equivalent CBECS Building Type

DOE Reference Building	Equivalent CBECS Building Type	Floor Area (in thousand ft^2)[1]	Floors[1]	Parking Lot Area (in thousand ft^2)
Large office	Office	498.6	12	8.9
Medium office	Office	53.6	3	86.8
Small office	Office	5.5	1	325.1
Primary school[a]	Education	74.0	1	14.7
Secondary school[b]	Education	210.9	2	59.3
Stand-alone retail	Retail, other than mall	25.0	1	35.0
Strip mall	Enclosed & strip malls	22.5	1	42.4
Supermarket	Food sales	45.0	1	63.8
Quick service restaurant	Food service	2.5	1	10.1
Full-service restaurant	Food service	5.5	1	22.3
Small hotel[c,d]	Lodging	43.2	4	33.7
Large hotel[d]	Lodging	122.1	6	88.5
Hospital[e]	Inpatient healthcare	241.4	5	77.5
Outpatient health care	Outpatient healthcare	41.0	3	82.9
Warehouse	Warehouse & storage	52.0	1	20.0
Midrise apartment	--	33.7	4	28.6

[a]650 students, [b]1200 students, [c]77 rooms, [d]1.5 occupants each room at 65% occupancy, [e]250 bed; Data Sources: [2] & [1]http://energy.gov/eere/buildings/commercial-reference-buildings

The models consider the following: building occupancy and operating hours; ventilation requirements and air infiltration; and construction materials. The models incorporate the energy requirements of heating; air conditioning; ventilation; refrigeration; elevators; hot water service demand; commercial kitchens; plug and process loads; and lighting. Data in ASHRAE standards were used for many of the model parameters. The power densities of interior and exterior lighting loads were taken from ASHRAE 90.1-1989 for existing building stock and from ASHRAE 90.1-2004 for new construction. Energy demands for exterior lighting considered building type and specific lighting levels required for façade, main entry and other doors, canopies with heavy and light traffic, drive-throughs, and parking lots. ASHRAE 90.1-1989 and 90.1-2004 set parking lot power requirements at 0.18 and 0.15 W/ft^2 ([2], Table 27), respectively. Parking lot sizes for the reference building models ([2], Table 28) are also included in Table 16.

Based on an office occupancy rate of 200 square feet per person ([2], Table 4), it might be estimated that small, medium and large office buildings have 2493, 268, and 28 employees, respectively. The "plug and process loads" for office buildings were determined based on engineering judgment.

The annual mean energy intensities for new DOE reference model[11] office buildings in Miami are displayed in Figure 27; these intensities represent the total energy supplied by all energy sources, which includes electricity, natural gas, and other sources. For informational purposes in this report, Miami was selected because it had only an annual average of 124 heating degree days from 2011 to 2015 and, therefore, a low demand for heating, which might be supplied by natural gas or another non-electric source. Water heating and kitchen equipment (possibly supplied by natural gas or another source) do not account for a large percentage of energy consumption in office buildings. Therefore, the energy and power intensities displayed in Figure 27 should largely represent electric energy and electric power intensities with a low contribution from other energy sources.

The mean annual energy and power intensities for the DOE "small office" reference model in Miami are 12.9 kW-hours and 1.5 W per square foot. Based on the 2012 CBECS data, Figure 13 illustrates that the mean annual electric energy and power intensities of a commercial building (all building types) located in a hot, humid climate are 18.4 kW-hours and 2.1 W per

[11] New construction annual energy use intensities in kBtu/ft^2 for each of the 16 DOE reference models for each of the 16 reference cities is provided in [18].

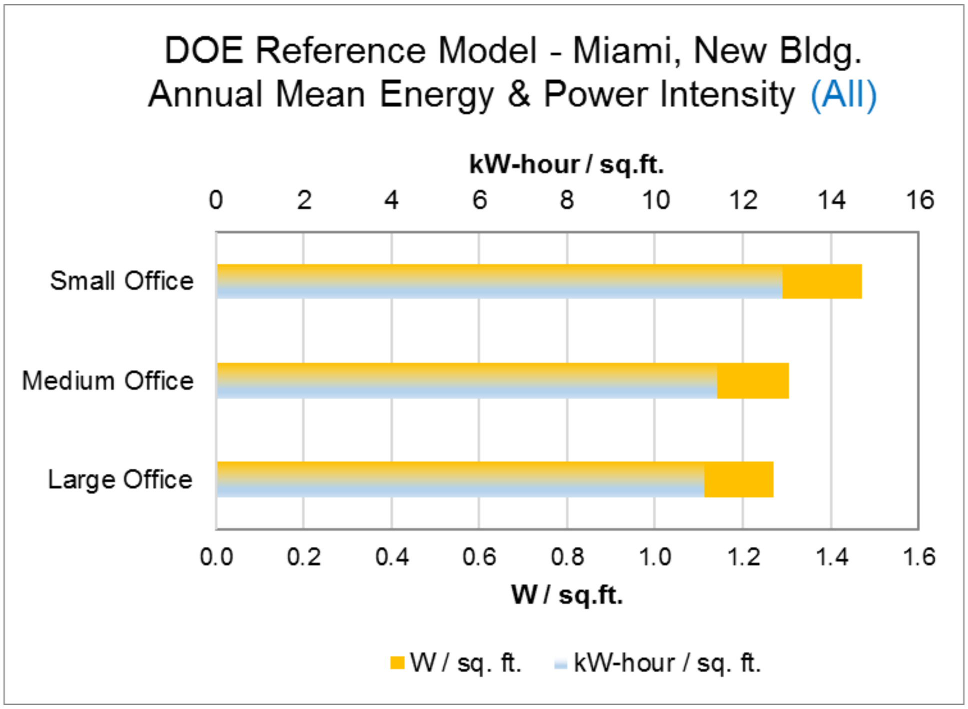

Figure 27. Energy & Power Intensities for DOE Reference Office Buildings in Miami
(Based on data provided in [18] obtained from http://cms.ashrae.biz/EUI)

square foot, respectively. Similarly, Figures 17 and 18 illustrate that the mean annual electric energy and power intensities of a commercial office building are 16.0 kW-hours and 1.8 W per square foot, respectively. When the differences between the data sets represented in the figures are considered, the intensities for new construction in Figure 27 correlate well to the intensities for all building types represented in Figure 13 and to the intensities for the CBECS 2012 office building category (all sizes) in Figures 17 and 18.

5.2 Historical Perspective, Energy Savings, and Coverage

The federal government passed the first energy conservation act in 1975. In 1978, the DOE was given the authority to establish mandatory minimum energy performance standards for appliances. Mandatory minimum energy performance standards have expanded, and coverage includes commercial appliances, lighting systems, motors, transformers, and HVAC equipment efficiencies established in 10 CFR §431. Since the Energy Policy Act of 1992, the U.S. Department of Energy (DOE) has taken an active role in the development, adoption, and impact analysis of model building energy conservation codes for residential, commercial, and federal buildings. [19], [20], [21] Building codes address the energy efficiency of the building envelope regarding fenestration, insulation, air barriers, and air leakage. Building codes address mechanical systems, specifically space and water heating, cooling, ventilation, refrigeration, and exhaust fan requirements. Building codes also address motor and transformer efficiency requirements, electric power and lighting systems, including automatic dimming (lighting) and shut-off requirements. [22], [23], [24]

The estimated site energy savings attributed to the adoption of residential and commercial building energy codes from 2011 to 2015 is 122 TBtu (all energy sources) with a cost savings of $3.0 billion [25, Table 9]. Data in [25, Table B.1] was used to calculate the projected electricity site energy savings for commercial buildings from 2010 to 2030 at 0.27 trillion kWh.

First published in 1975 as ASHRAE 90, ANSI/ASHRAE/IES Standard 90.1-2016, *Energy Standard for Buildings Except Low-Rise Residential Buildings* [22], provides the minimum requirements for commercial buildings. First published in 2000, the 2015 *International Energy Conservation Code* (IECC) [23] provides minimum energy conservation requirements for new commercial and residential buildings. The differences between the commercial building requirements for earlier editions of the ASHRAE 90.1 and IECC are covered in depth in [26]. Since ASHRAE 90.1 is the latest energy code standard released and probably considered more of a benchmark standard for commercial buildings than IECC, ASHRAE 90.1 will be briefly covered in this report.

5.3 ASHRAE 90.1 – General, Power, and Lighting Requirements

ASHRAE 90.1 [22], first published in 2001, establishes the minimum energy efficiency requirements for building design and construction and for maintenance and operation plans. It covers new construction and new systems and equipment in existing buildings except for low-rise residential buildings. The 90.1 standard covers hot water heating, elevators, and escalators. It specifies nominal efficiency levels for low-voltage distribution transformers in accordance with 10 CFR §431.

The standard requires installing energy measurement devices to monitor the total building load and the following building load categories: HVAC, interior lighting, exterior lighting, and receptacle circuits; however, other electrical load categories may account for up to 10% of each monitored load category. Energy usage must be recorded every 15 minutes, and the monitoring system must be able to store data for 36 months.

Automatic receptacle control is also required in at least 50% of general purpose receptacles (125 V, 15 and 20 A) in private offices, conference rooms, print/copy rooms, break rooms, classrooms, and individual workstations. Automatic receptacle control is required on at least 25% of branch circuit feeders installed for modular furniture not shown on construction documents. The control device should turn receptacles off at specifically programmed times or 20 minutes after the space becomes unoccupied.

ASHRAE 90.1 specifies lighting power densities (W/ft^2) for interior and exterior building spaces. Two methods are provided for interior lighting power allowance: a simple building area method and a more flexible space-by-space method. The installed lighting system should not exceed the total power allowed for illuminating the building. Space interior lighting should have a manual control and should be dimmable with at least one intermediate light level. Automatic partial or full shutoff is also required for most spaces 20 minutes after they become unoccupied.

With the building area method, the lighting power densities in Table 17 are used to determine the allowable lighting power for the building [22, Table 9.5.1]. If the building consists of one than one type listed in the table, then the total allowable lighting power is the sum of the lighting power for each area of the building.

The space-by-space method is similar but is a more detailed method of calculating and summing the allowable lighting power for all space types within the building. For example, office buildings might have open or closed offices. Office buildings often contain conference rooms, break rooms, restrooms, storage areas, stairwells, corridors, and other spaces. Furthermore, spaces like corridors require different illuminations levels depending on the building type and purpose. Table 18 includes a few select lighting power allowances for spaces commonly found in office buildings, including laboratories, computer rooms, and workshops [22, Table 9.6.1] sometimes found in engineering and research office buildings. Table 18 also displays the lighting power allowance for corridors in different building types. When the space-by-space method is employed, additional lighting power allowance is permitted for exhibits, retail areas, spaces using non-mandatory lighting controls, and certain room geometries.

For comparison purposes, the lighting power density allowances listed in IECC 2015 [23] Tables C405.4.2(1) and C405.4.2(2) have been included in Tables 17 and 18. The lighting power densities of IECC 2015 and ASHRAE 90.1-2013 are identical except as noted with yellow highlighting.

Table 17. ASHRAE 90.1 & IECC Building Area Method Lighting Power Density Allowances

Building Area Type	90.1-2016 (W/ft^2)	90.1-2013 (W/ft^2)	IECC 2015 (W/ft^2)
Automotive Facility	0.71	0.80	0.80
Convention Center	0.76	1.01	1.01
Courthouse	0.90	1.01	1.01
Dining: Bar Lounge/Leisure	0.90	1.01	1.01
Dining: Cafeteria/Fast Food	0.79	0.90	0.90
Dining: Family	0.78	0.95	0.95
Dormitory	0.61	0.57	0.57
Exercise Center	0.65	0.84	0.84
Fire Stations	0.53	0.67	0.67
Gymnasium	0.68	0.94	0.94
Healthcare Clinic	0.82	0.94	0.90
Hospital	1.05	1.05	1.05
Hotel/Motel	0.75	0.87	0.87
Library	0.78	1.19	1.19
Manufacturing	0.90	1.17	1.17
Motion Picture Theatre	0.83	0.76	0.76
Multi-Family	0.68	0.51	0.51
Museum	1.06	1.02	1.02
Office	0.79	0.82	0.82
Parking Garage	0.15	0.21	0.21
Penitentiary	0.75	0.81	0.81
Performing Arts Theater	1.18	1.39	1.39
Police Stations	0.80	0.87	0.87
Post Office	0.67	0.87	0.87
Religious Buildings	0.94	1.00	1.00
Retail	1.06	1.26	1.26
School/University	0.81	0.87	0.87
Sports Arena	0.87	0.91	0.91
Town Hall	0.80	0.89	0.89
Transportation	0.61	0.70	0.70
Warehouse	0.48	0.66	0.66
Workshop	0.90	1.19	1.19

Table 18. ASHRAE 90.1 & IECC Lighting Power Allowances for Selected Space Types

Common Space Types	90.1-2016 (W/ft^2)	90.1-2013 (W/ft^2)	IECC 2015 (W/ft^2)
Classroom/Training Room	0.92	1.24	1.24
Conference Room	1.07	1.23	1.23
Copy/Print Room	0.56	0.72	0.72
Computer Room	1.33	1.71	1.71
Electrical/Mechanical Room	0.43	0.42	0.95
Laboratory	1.45	1.81	1.81
Office – enclosed	0.93	1.11	1.11
Office – open	0.81	0.98	0.98
Restroom	0.85	0.98	0.98
Stairwell	0.58	0.69	0.69
Storage - < 50ft^2	0.97	1.24	0.63
Storage - > 50ft^2	0.46	0.63	0.63
Workshop	1.14	1.59	1.59
Corridor			
…in a facility for visually impaired	0.92	0.92	0.92
…in a hospital	0.92	0.99	0.99
…in a manufacturing facility	0.29	0.41	0.41
…all other corridors	0.66	0.66	0.66

5.4 Development of ASHRAE 90.1 Lighting Power Allowances[12]

The ASHRAE lighting power densities (LPD) have been developed by the 90.1 Lighting Subcommittee with support from a team at Pacific Northwest National Laboratory (PNNL). The LPDs are developed using spreadsheet models based on the IES recommended illumination levels for visual tasks required in specific building spaces. The models incorporate source efficacy data from efficient lighting products, typical light loss factors, and coefficient of utilization values for applicable luminaire types. Light loss factors represent the amount of light lost due to lamp and room surface depreciation and dirt accumulation.

[12] The first three paragraphs of this section were initially drafted by the report author based on [27], but were revised by Eric Richman at PNNL on October 27, 2016. In conversation with Eric Richman on September 8, 2016, he remarked that LED lighting systems had been added to the lighting sources represented in the model used to develop the lighting power allowance in ASHRAE 90.1-2016.

The coefficient of utilization represents the amount of the total lamp lumens which will reach the work plane in a specific room configuration (room cavity ratio) with specific surface reflectances. For the interior space models, ceiling, wall, and floor reflectances were selected as 70%, 50%, and 20% to represent most common building design practices. For each specific space type, appropriate room cavity ratios were chosen from 2 to 10 to represent common geometries for that space type.

Lumen power densities were developed for over 100 different space types and applications. Professional lighting designers on the subcommittee provided additional model input and oversite for design related issues such as task versus general lighting in spaces, appropriate lighting systems, and appropriate room cavity ratios for specific building areas. The ASHRAE space type power densities represent the power needed to illuminate typical spaces using reasonable efficient lighting sources and good effective design. Whole building LPD values are also developed using weighted averages of space LPD values and the mix of spaces in typical building types.

The following simple equations are not part of the ASHRAE 90.1 design process for lighting power allowance. They are general lighting design equations used in the zonal cavity method [28]. They are included here to help clarify the basic process of determining the total luminous flux (lumens), the number of luminaires (i.e., lighting fixtures), and the electric power needed to illuminate a space. Lighting design rests on providing adequate illumination (in lumens) for a space. Different spaces in a building (with different visual tasks) require different levels of illumination.

$$Luminous\ Flux\ (total) = \frac{Illuminance\ required\ for\ task\ (in\ fc\ or\ lux) \cdot floorspace}{coefficient\ of\ illumination \cdot light\ loss\ factor}$$

$$Number\ of\ luminaires = \frac{Luminous\ flux\ (total)}{Lumens\ per\ selected\ luminaire}$$

$$Electric\ Power\ (total\ in\ watts) = Number\ of\ luminaires \cdot Power\ required\ per\ luminaire$$

The placement of the luminaires must also meet certain spacing criteria [28].

6 ENGINEERING PRACTICES

6.1 Electric Utility Demand Load and Transformer Sizing for Commercial Buildings

Austin Energy released employee reference materials on evaluating customer demand load in a 2012 suit filed with the Public Utility Commission of Texas. The Austin Energy material included a table on commercial building demand in VA/ft^2, power factor, and load factor. Figure 28 displays the demand load per square foot in volts-amperes (VA) and watts, and the loading factor expressed as a percentage. Figure 19, developed from the Austin Energy table, shows that restaurants had the highest average power consumption.

As shown in Figure 28, fast-food and sit-down restaurants also have the highest demand load (32 and 25 VA/ft^2, respectively), but their load factors are less than 50%. Large and small food stores, refrigerated warehouses, and hospitals (with demand loads of 13.1, 20,6, 17.8, and 14.5 VA/ft^2, respectively) are the only occupancy types with load factors exceeding 50%, perhaps due to high refrigeration load and long operating hours. The 79% load factor of large food stores accounts for its relatively high average load of 9.2 watts per square foot (shown in Figure 19) even though the demand load is about average. Some occupancy types, including schools (17.5 VA/ft^2), have higher demand loads but only restaurants and small food stores have higher average power densities (shown in Figure 19).

The Austin Energy manual recommends several methods of estimating the demand load for commercial customers. The preferred method is estimating demand based on a similar customer, such as another business of the same franchise, comparable size, and located in the same climate zone. If this method is not feasible, the VA demand load is determined from the demand estimation per square foot for a similar occupancy type as shown in Figure 28. An estimated demand load is also calculated using the demand factors in Table 19 with the connected load, listed on the electrical plans submitted for the building. Depending on the proximity of the estimations, the demand load is assigned to equal the lesser demand or the demand based on occupancy type and building size.

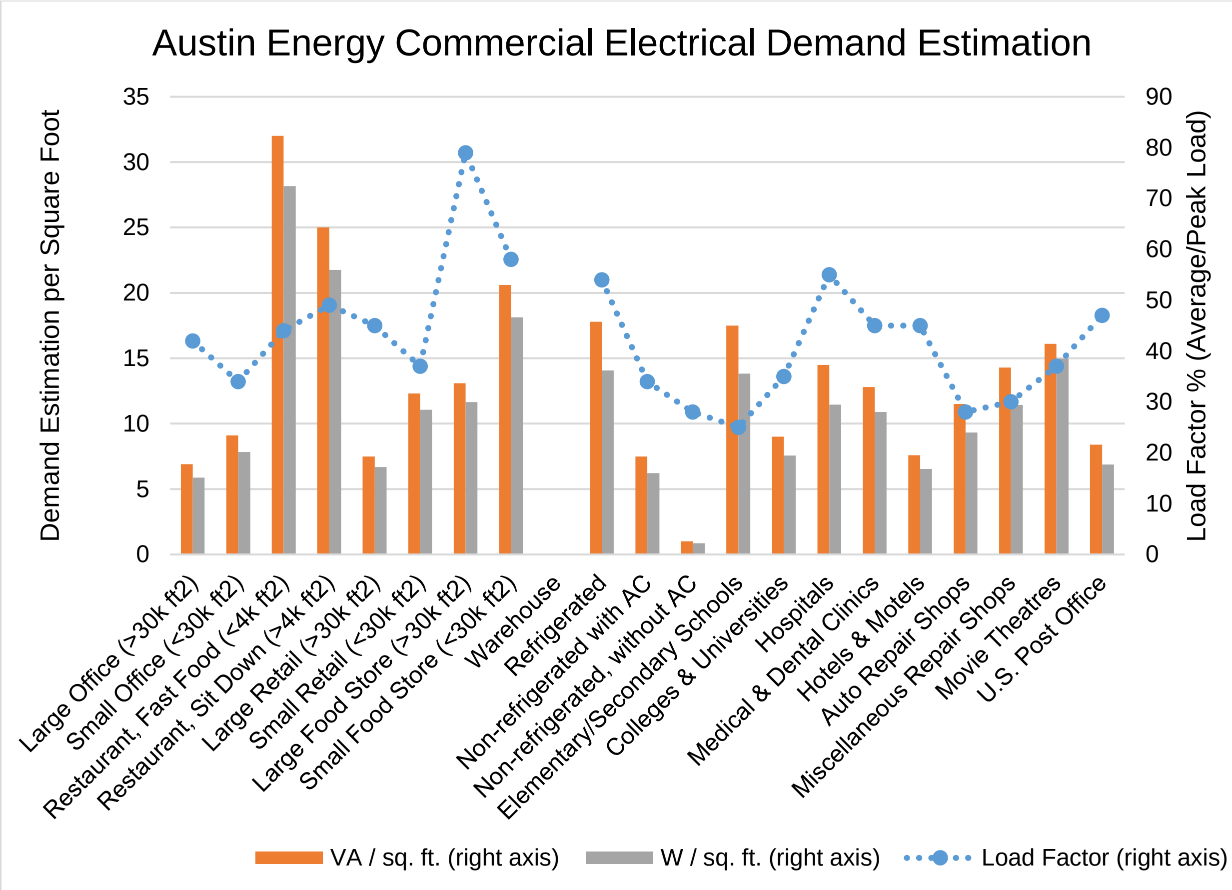

Figure 28. Austin Energy – VA and Power Demand Load in Commercial Buildings
(Data Source: [6])

Table 19. Austin Energy Demand Factors for Connected Commercial Loads

Austin Energy Demand Factors for Connected Commercial Loads			
General Lighting[a]	General Receptacles	Air Conditioning[b]	[a]May be adjusted based on application and hours of usage
0.8	0.1	0.8-1.0	[b]1.0, 0.9, or 0.8 for 1, 2-5, or 5+ units
General Power	Laundry	Water Heaters	
0.3	0.5-0.8	0.2	
Cooking	Refrigeration	Air Compressors	
0.3-0.5	0.5	0.2-0.5	
Elevators[c]	Escalators	Motors[d]	[c]Most operate less than 15 minutes
N/A	0.6	0.3-0.5	[d]Largest + 50% remaining motors

Austin Energy also provided guidelines for transformer loading. Table 20 includes some of the recommended loading ranges for three-phase, pad-mounted transformers based on a maximum load factor of 60% and a balanced three-phase load. A transformer secondary voltage of 208Y/120 V is available with transformer ratings from 75 to 750 kVA. A transformer secondary voltage of 277Y/480 V is available with transformer ratings from 75 to 2500 kVA.

Table 20. Austin Energy Three-Phase Pad-mount Transformer Loading Guidelines[a,b,c]

Transformer Nameplate kVA	Initial kVA Loading Range	kVA Loading Change-out Point
75	0-85	100
150	85-175	200
225	175-275	300
300	275-350	400
[a]For 61-75% load factor, limit initial loading to 75% nameplate, change out at 110%		
[b]For 76-90% load factor, limit initial loading to 70% of nameplate, change out at 100%		
[c]For 90-100% load factor, install next size and limit initial loading to 80%, change out at 100%		

6.2 Traditional Design Practices for Electrical Systems in Buildings

6.2.1 Building Demand Load, Panel, and Feeder Sizing

Consulting engineers and electrical system designers determine building loads by applying demand load factors to connected loads in a similar manner to Austin Energy's guidelines for their employees. In the design process, the first step is to identify (or estimate) the major equipment loads: heating, ventilating, air conditioning, electric water heaters, elevators (if any), and any other owner or tenant equipment. The engineer determines the lighting and receptacle load. The total demand load on the main panel or a sub-panel is based on the connected loads and the category demand factor for each type of connected load. The demand load on a panel might be calculated by organizing the connected loads into categories and the applying demand factors displayed in Table 21. [28]

It has been noted in [29] that the listed ampere requirements on packaged HVAC units are lower than NEC Article 440 requirements for calculating the ampacity of the multiple motors found in field installed air conditioning equipment. Comparisons of the power requirements of packaged HVAC equipment with the total ampacity that would be required to supply all the motors packaged inside the equipment validate this assertion.[13]

The National Electrical Code is a standard which specifies the minimum requirements for electrical installations. The National Electric Code is adopted (with or without amendments) by states. Final approval of the design and installation of an electrical system in a building rests on

[13] Based on the report author's experience reviewing the electrical and mechanical plans of several commercial buildings.

the authority having jurisdiction. In some circumstances, engineers may find it prudent to exceed code guidelines or comply with local regulations. [28]

The demand load at the main panel may be less than the sum of the demand loads on each panel. For example, the summer air conditioning load may be larger than the winter heat load. Rooftop air conditioning units are likely to be connected directly to the main panel, but electric resistance heat is likely to be connected directly to subpanels. Furthermore, the total receptacle demand load calculated at the main panel will be less than the sum of the receptacle demand loads on the subpanels. Consider three panels supplying connected receptacle loads of 10, 10, and 20 kVA with demand loads of 10, 10, and 15 kVA (summing to 35 kVA). The receptacle demand load on the main panel is 25 kVA.[14]

Table 21. Traditional Engineering Demand Factors for Building Loads*

Load Category	Demand Factor	Comments
Air conditioning	0 or 1	If heating and ac do not operate at the same time, the larger load has demand factor of 1.
Resistance heat & motors for heating	0 or 1	
Water heating	1	
Lighting	1.25	"Continuous," circuit loading cannot exceed 80%
Receptacle	1 x 1st 10kVA, 0.5 x remainder	180VA per receptacle is general minimum standard, see NEC 220.14 and 220.44
Motors	1	See NEC 430.24
Largest motor	0.25	See NEC 430.24
Other loads	1 or 1.25	1.25 for continuous, 1 otherwise
Kitchen	0.65 – 1.0	Depending on number of items, see NEC 220.56
Spare capacity	1	

*Demand factors from [28]

6.2.2 Branch Circuit Sizing and Protection

Branch circuits are directly connected to the end use equipment, including resistance heating, water heaters, motors (such as elevators), lighting fixtures, and receptacle load. Circuit breakers are not allowed to continuously carry 100% of their current loading. Therefore, for non-motor loads, the overcurrent protective device is the next standard size higher than 1.25 times the required load current. Wire size selection is based on the rating of the overcurrent protective device. [28]

[14] Correct use of receptacle demand factor in NEC Table 220.44 verified through email with Derek Vigstol, Senior Electrical Specialist at NFPA, October 14, 2016.

Determining the appropriate branch circuit wire size and overcurrent device is more complex for motor loads. For branch circuits supplying a single motor, the wire size should be selected as the next standard size higher than 1.25 times the motor's full load amp (FLA) rating. The sizing of the overcurrent protective device depends on the delay-time characteristics of the protective device. The appropriate sizing for a thermal-magnetic circuit breaker would be next standard size higher than 1.75 times the motor full load amps. For an overcurrent protective device such as a time-delay fuse, the device rating should be higher than 1.25 times the FLA. When a branch circuit serves several motors, the wire size is based on 1.25 times the FLA of the largest motor plus the sum of the FLAs of the smaller motors. The calculation is identical for time-delay overcurrent protective devices. For molded case circuit breakers, the calculation is similar except the largest motor FLA is multiplied by 1.75. [28]

Wiring sizing for feeders and branch circuits must also comply with voltage drop requirements.

6.2.3 In-House Transformers and Connecting Equipment Selection

Step-down transformers in building electrical systems are based on the demand load being supplied. The next size transformer higher than the calculated demand is selected. The size of the overcurrent protection device on the secondary must not exceed 1.25 times the rated secondary current. The size of the overcurrent protection device on the primary is selected as the next standard size higher than 1.25 times the rated primary current. The primary and secondary conductors are based on the overcurrent protective device ratings. [28]

6.3 NEC Lighting Requirements and Other Lighting Guidelines

6.3.1 NEC and NEC Comparison with ASHRAE Requirements

Interior and exterior lighting systems for buildings are designed to ensure adequate levels of illumination to meet the visual tasks required in a space. Appropriate selection and placement of lighting fixtures are equally important in the design process. Table 220.12 of the 2017 National Electrical Code specifies the minimum lighting load (in VA/ft^2) for specific occupancy types with two permitted exceptions. The first exception, added to the 2014 edition, allows the lighting load to comply with the energy code adopted by the authority having jurisdiction if a monitoring system is installed and the demand factors in Table 220.42 (applicable to dwelling units, hospitals, hotels, and warehouses) are not applied. The second exception, added to the 2017 edition, allows the minimum lighting power density to be reduced by of 1 VA/ft^2 for office and bank areas in a building which complies with an adopted energy code.

Table 22 shows that the minimum NEC lighting power densities (in VA/ft^2) have changed little since 1968, yet lighting technologies have advanced and have become much more energy efficient in the last fifty years. Also included in Table 22, the lighting power allowances (in W/ft^2) in ASHRAE 90.1, even the 2004 edition, are considerably lower than those in the NEC for most occupancy types. Furthermore, the commercial reference building model for new construction developed for the U.S. Department of Energy uses the lighting power allowances in ASHRAE 90.1-2004; this suggests that power requirements of modern lighting systems to provide adequate illumination are more in alignment with ASHRAE 90.1-2004 than the 2017 NEC.

It must be remembered that the minimum lighting power density requirements were likely included in the NEC to ensure that adequate illumination was provided for the visual tasks of the space. In the last half century, the light output efficiency (lumens per watts) has increased significantly. The U.S. Department of Energy has set minimum lamp efficiency requirements on some types of linear fluorescent and halogen lamps.[15] It should also be noted that at one time, office tasks included reading from paper and required higher illumination levels than current office tasks which focus on computer interaction and reading some higher quality printed material. Consequently, overhead lighting systems that were once designed to produce between 750 to 1000 lux can now be designed to produce between 300 and 500 lux [30].

[15] Effective July 14, 2012 40-205W Halogen PAR lamps and some linear T12, T8 and T5, and U-bend fluorescent lamps must meet 2009 DOE regulations established in Federal Register Vol. 74, No. 133, Part II Department of Energy 10 CFR Part 430 Energy Conservation Program: Energy Conservation Standards and Test Procedures for General Service Fluorescent Lamps and Incandescent Reflector Lamps; Final Rule, July 14, 2009.

Table 22. NEC (VA/ft^2) and ASHRAE 90.1 (W/ft^2) Lighting Power Density by Occupancy

Type of Occupancy	NEC 1968	NEC 1971	NEC 1981	NEC 2017	90.1-2004	90.1-2013
Armories and auditoriums	1			1		
Banks	2	5	3½	3½		
Barbershops & beauty parlors	3			3		
Churches	1			1	1.3	1
Clubs	2			2		
Courtrooms	2			2	1.2	1.01
Dwelling Units	3			3		
Garages – commercial (storage)	½			½		
Hospitals	2			2	1.2	0.94
Hotels, motels & apts. (no cooking)	2			2	1	0.87
Industrial commercial (loft) bldgs.	2			2		
Lodge rooms	1½			1½		
Office buildings	5		3½	3½	1	0.82
Restaurants	2			2	1.4	0.9
Schools	3			3	1.2	0.87
Stores	3			3	1.5	1.26
Warehouses (storage)	¼			¼	0.8	0.66
Assembly halls, & auditoriums*	1			1		
Halls, corridors, closets, & stairways*	½			½		
Storage spaces*	¼			¼		
***Except in individual dwelling units, See Table 18 for 90.1-2013 and 90.1-2016 allowances**						

6.3.2 IEEE, IES, and Federal Lighting Recommendations

A joint IEEE I&CPS and IES committee[16] has been tasked with drafting a new IEEE Technical Book 3001.9 *Recommended Practice for Industrial and Commercial Lighting Systems*. The initial draft was rescinded and is under revision. When released, the IEEE Technical Book 3001.9 will not overlap with the IES Handbook contents and IES recommended practices; it will refer the reader to the appropriate work published by IES. The initial draft copyrighted in 2012 included the design lighting power densities and required illumination levels for federal buildings from the 2003 and 2005 PBS-P100, *Facilities Standard for Public Service Buildings* [31], released by the U.S. General Services Administration.

Table 23 lists the nominal average recommended illumination levels for various space types within a building as specified in the 2003 PBS-P100. Table 23 includes the lighting

[16] The committee is composed of members from the IEEE Industrial and Commercial Power Systems group and from the Illuminating Engineering Society of North America. Steven Townsend, 3001.9 Working Group Chair, responded to inquiry about technical book status in an email dated October 21, 2016, and attached rescinded draft standard to the response email.

demand load for building areas published in the 2005 PBS-P100; the estimated demand load did not stipulate maximum design values. Also included in Table 23 are the lighting power allowances calculated to comply with the 2014 PBS-100, which states that the lighting load must use 30% less energy than required by the ASHRAE 90.1-2007 space-by-space method. The 2014 PBS-P100 does recognize that the actual lighting power density demanded by a space is reduced when lighting controls are used to reduce the illumination levels. Lighting controls might be employed due to: partial illumination provided by daylight, lack of occupancy, or reduced light levels desired [31, 2014 ed., pg. 136].

Table 23. Recommended Illumination Levels and Lighting Densities in PBS-P100

Building Area	PBS-P100 2003 (Lux)	PBS-P100 2005 (VA/ft^2)	ASHRAE 90.1-2007 (W/ft^2)	PBS-P100 2014 (W/ft^2)
Office: Enclosed 1	500	1.5	1.1	0.77
Office: Open1	500	1.3	1.1	0.77
Conference/Meeting/Multipurpose	300	1.5	1.3	0.91
Classroom/Lecture/Trainings	500	1.6	1.4	0.98
Lobby	200	1.8	1.3	0.91
Atrium: first three floors	200	1.3	0.6	0.42
Atrium: each additional floor		0.2	0.2	0.14
Lounge/Recreation		1.4	1.2	0.84
Dining Area	150-200	1.4	0.9	0.63
Food Preparation	500	2.2	1.2	0.84
Restrooms	200	1.0	0.9	0.63
Corridor/Transition	200	0.7	0.5	0.35
Stairs	200	0.9	0.6	0.42
Active Storage		1.1	0.8	0.56
Inactive Storage		0.3	0.3	0.21
Electrical, Mechanical, and Telecommunication Rooms	200	1.3	1.5	1.05

6.4 Federal Recommendations in Building Electrical System Design

6.4.1 GSA's PBS-P100, Facilities Standards for the Public Buildings Service

The Public Buildings Service (PBS) of the U.S. General Services Administration (GSA) provides a workspace for 1.1 million federal civilian employees and is one of the top real estate holders in the United States. Most of the buildings are courthouses, land ports of entry, and federal office buildings. The PBS-P100, *Facilities Standards for the Public Buildings Service,* is a mandatory standard which covers the design and construction of new federal buildings and major renovations to existing buildings. [31, 2014 ed.]

The General Services Administration (GSA) tends to own and operate buildings longer than the private sector. Buildings may undergo major or minor renovations as the building function changes. "Electrical and communication systems should provide ample capacity for increased load concentrations in the future and allow modifications to be made in one area without causing major disruptions in other areas of the building [31, 2003 ed., pg.181]." GSA buildings are generally constructed to more exacting specifications, but all buildings should be designed and constructed with the life cycle of the building in mind.

6.4.2 PBS-P100 Advanced Building Metering and Control

New federal buildings must install advanced electric metering equipment. Meters must be capable of monitoring phase voltages, phase current, demand power consumption, power factor, and reactive power. Meters must communicate via MODBUS/TCP/IP. [31, 2014 ed]

6.4.3 PBS-P100 Demand Load Calculations

In PBS-P100 2014, the demand power requirements for the following connected load categories are established:

- Motor and equipment loads*
- Elevator and other vertical transportation loads*
- Lighting
- Receptacle
- Miscellaneous*
    - Security, communication, alarm, and building automation systems
    - Heat tracing
    - Kitchen equipment
    - Central computer servers and data centers
    - Uninterruptible power supply (UPS) and battery rooms
- *Must comply with power requirements and full-load efficiencies in ASHRAE 90.1-2004.

The lighting load requirements in PBS-P100 have been addressed in the Section 6.3.2. The minimum receptacle load power densities for typical installations is included in Table 24. Circuits for 120-V convenience receptacles must be limited to 1,440 VA (180 VA each).

Electrical systems are sized according to the total demand load from the load categories included in the bullet-point list and the spare capacity listed in Table 25. However, the 2014 PBS-P100 cautions:

Before adding the spare equipment ampacity to account for future load growth, it is important that the load study reflects actual demand loads rather than connected loads. The designer must apply realistic demand factors by taking into account various energy-conserving devices such as variable frequency drives applied to brake horsepowers, energy-efficient motors, occupancy sensors, and so on. The designer must also avoid adding the load of standby motors and must be careful to distinguish between summer and winter loads by identifying such “noncoincidental” loads. A “diversity factor” must be applied to account for the fact that the maximum load on the elevator system, as a typical example, does not occur at the same time as the peak air conditioning load. [31, 2014 ed., pg.153]

Table 24. 2014 PBS-P100 Minimum Receptacle Load Power Density

Building Area	Service Equipment W/ft^2	Distribution Equipment W/ft^2
Office: Enclosed	1.30	2.50
Office: Open	1.30	3.25
Non-workstation areas	0.50	1.00
Core and public areas	0.25	0.50
Technology/server rooms	50	65

Table 25. 2014 PBS-P100 Additional Spare Capacity

	Spare Ampacity	Spare Circuit Capacity
Panelboards for branch circuits	50%	35%
Panelboards – lighting only	50%	25%
Switchboards & distribution panels	35%	25%
Main switchgear	25%	25%

6.4.4 PBS-P100 Treatment of Harmonics

The branch circuit distribution system supplies equipment which generates harmonics. Harmonic loads include:

- Computers Laser printers Copiers Fax machines File servers
- Variable Frequency Drives Electronic ballasts Telecommunication equipment

Harmonic distortion can cause overheating in transformer and conductor neutrals, motor failure, false tripping of protective devices, computer operational problems, and hardware component failures. K-rated transformers (K13 or higher) with a 200% neutral can be used to dissipate the additional heat generated by harmonic distortion. However, the 2014 PBS-P100 states that harmonic mitigating transformers are preferred since they cancel the harmonic frequencies. Panelboards supplied by K-rated or harmonic-mitigating transformers must be provided with a 200% neutral. [31, 2014 ed.]

7 OVERSIZING AND "RIGHTSIZING" TRANSFORMERS

A corollary of this project on evaluating the electrical feeder and branch circuit loading is the loading level of transformers. Previous work suggests that oversizing transformers results in increased transformer energy losses and greater arc flash hazards. One objective of addressing transformer efficiency in this section is to illustrate the importance of "right selecting" transformers to reduce transformer energy losses.

7.1 1999 Cadmus Transformer Loading Study [32]

A 1999 study on 89 low-voltage dry-type distribution transformers with three-phase 480-V primaries[17] and capacity ratings between 15 and 300 kVA determined that the average RMS load factor was approximately 16% of the transformer rating. Only 14% of the transformers had RMS average loads greater than 35%.

Table 26 illustrates that the group of twelve transformers rated 15 to 30 kVA had the highest average and maximum RMS load factors. The average and maximum RMS load factors increased as transformer capacity decreased in the four lower capacity groups (i.e., 15 to 30, 45, 75, and 112.5 to 150 kVA). The two largest capacity transformer groups (112.5 to 150 and 225 to 300 kVA) had maximum RMS load factors at approximately 35%; however, the average RMS load factors for the two groups deviated by about 8%. This deviation was attributed to the relatively small sample number and the diversity in the building operations (building types, hours, etc.).

Table 26. Measured Transformer Load Factor in 1999 Cadmus Study

RMS Load Factor	15-30 kVA	45 kVA	75 kVA	112.5-150 kVA	225-300 kVA
Average	23.4%	15.6%	14.0%	12.3%	19.9%
Maximum	62.4%	50.0%	40.2%	34.3%	35.6%
Minimum	1.3%	1.1%	0.9%	0.0%	11.0%
Number of Transformers (89 Total)	12	28	34	10	5

Transformer loading is expected to fluctuate; one or two phases may even be more heavily loaded. Transformer selection is usually based on the demand load with spare capacity for future load built into the calculation. The average peak loading factor of the transformers studied was only one-third of transformer capacity.

[17] Dave Korn, a principal investigator in the study, confirmed in email on October 17, 2016 that the transformers were three-phase 480 V on the primary, and "All or nearly all secondaries were 208V/120V."

The transformers were evenly selected from five building types: office, manufacturing, healthcare, school and institutions, and retail. Some buildings operated with one shift of workers and other buildings operated with two or three shifts. However, different building types and operating hours were found to cause little change in transformer loading. The transformers mainly served general lighting and receptacle load, which consisted primarily of office equipment and task lighting. Other loads included small water heaters, pumps, exhaust fans and other HVAC equipment, low-voltage manufacturing equipment, forklift battery chargers, and sign lighting.

All buildings had been constructed or modified in the last ten years. Most transformers had also been manufactured in the last ten years, but all were less than fifteen years old. In the initial phase of the study, 353 transformers in 43 buildings were observed. Nameplates on some were missing or inaccessible; 335 transformers were surveyed, and loading data was collected on 89 of those for a two-week period. Roughly 50% of the transformers surveyed were rated 45 or 75 kVA. By rise type, 80% of the transformers surveyed were 150°C temperature rise.

The transformers were between 90 and 98% efficient in power delivery. Winding losses are proportional to the square of the current flowing through the windings. The core losses are relatively constant and independent of transformer loading. Core losses account for a significant percentage of transformer losses when transformers are lightly loaded (0 to 30%); on the other hand, winding losses account for a significant percentage of transformer losses when transformers are heavily loaded (65 to 100%).

Spot measurements of power factor, total harmonic distortion and K-factor were taken when the transformer monitoring equipment was installed and removed. The roughly 80% of the measured K-factors (estimation based on Figure 4-5 in [32]) were 4 or less. K-factor is a metric of a transformer's ability to withstand harmonics. Higher harmonics are associated greater heat losses. A K-factor equal to 4 corresponds to a non-linear loading of 50% [33].

Table 27. 1999 Cadmus Study – Power Factor, Total Harmonic Distortion, and K-Factor

Spot Measurement	Power Factor	Total Harmonic Distortion	K-Factor
Average	0.87	21	2.7
Median	0.91	12	1.4

7.2 Transformer Loading and Efficiency

The U.S. Department of Energy mandates efficiency requirements and defines test procedures for measuring distribution transformer energy loss in the Code of Federal Regulations.

Transformer efficiency is a function of transformer loading; 10 CFR §431.196 specifies the evaluation of transformer load losses at 35% of rated load with an operating temperature of 75°C (55°C temperature rise above a 20°C ambient temperature). The regulation does not explain why 35% is the reference load level, although other work has suggested that the origin is a 1997 report which states: "…most low-voltage dry distribution transformers have a peak load of only about 50-60% of their rated capacity." It further states, "A per unit RMS load of 0.35 is a reasonable assumption." [34] As shown in Figure 29, maximum transformer efficiency also occurs in the vicinity of 35% loading.

Furthermore, Figure 30 shows that the power losses as a percentage of power supplied increase when transformers are more lightly and heavily loaded. The power lost as a percentage of power supplied to the EL-6 amorphous core is lowest from 10% to 40% of the rated load; furthermore, the losses are lower than the traditional core materials EL-4 and EL-5 for loading of 50% and less. The EL-5 standard core transformer has lower losses than the EL-4 and EL-6 at 60% the rated load and higher. However, the power loss as a percentage of power supplied for the EL-5 is lowest from 30% to 60% loading. Figures 29 and 30 use efficiency data for Eaton 45 kVA transformers with 480Δ-208Y V windings and 115°C rise type, but constructed using three different core materials.[18]

Transformers loaded close to the transformer rating are associated with higher power losses as a percentage of the power supplied. Power loss and supply calculations in Figures 30, 31, and 32 are based on loading at a 0.95 power factor, real power losses (W), and real power supplied (W). In Figure 31, real power losses are calculated for Eaton 480Δ-208Y V, 115°C rise, EL-5 (23QGD080) transformers rated at 30, 45, and 75 kVA supply loads ranging from 7.5 to 45 kVA.[19] The 30 kVA transformer does supply the 7.5 kVA load with the lowest power losses, 9 W in comparison with 15 to 16 W. However, Figures 31 and 32 illustrate that power losses for the transformers at these loading levels generally decrease as the transformer kVA rating increases. In Figure 32, Eaton 480Δ-208Y V, 150°C rise transformers with aluminum windings rated from 75 to 300 kVA supply loads from 75 to 225 kVA.[20]

[18] Robert Yanniello, Vice President of Engineering & Technology, Eaton's Electrical Systems & Services Group, provided the transformer efficiency data at loading levels of 10 to 100%, in 10% increments attached to email dated October 21, 2016.

[19] Robert Yanniello, provided the transformer efficiency data at loading levels of 10 to 100%, in 10% increments attached to email dated November 15, 2016. The efficiencies were linearly interpolated to determine the efficiencies at other loading levels.

[20] Robert Yanniello, provided a pdf file "DOE 2016 Tech Data 3-28-2016," attached to email dated October 21, 2016. The file contained efficiency data at 25, 50, 75, and 100% loading levels for Eaton

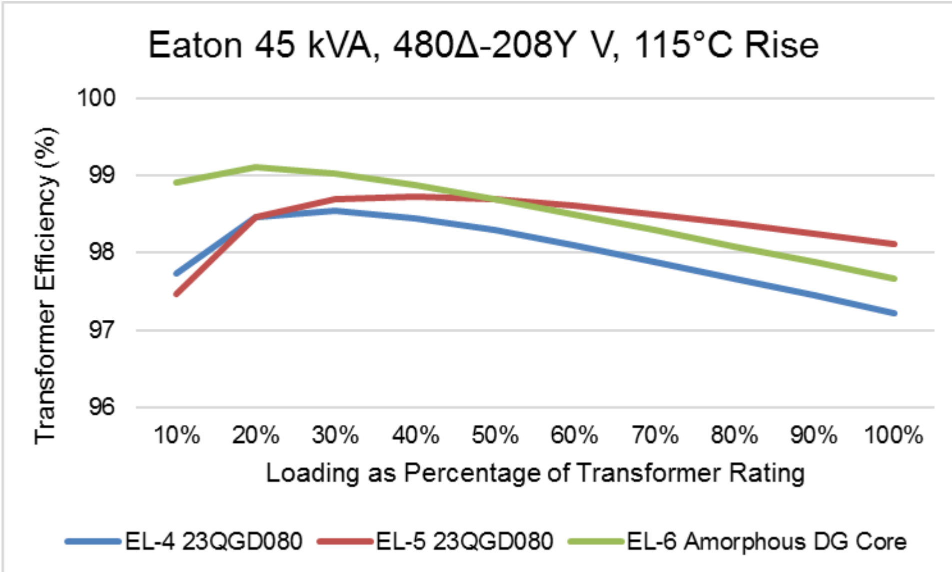

Figure 29. Efficiency Curves for Three Eaton 45 kVA, 480Δ-208Y-V Transformers

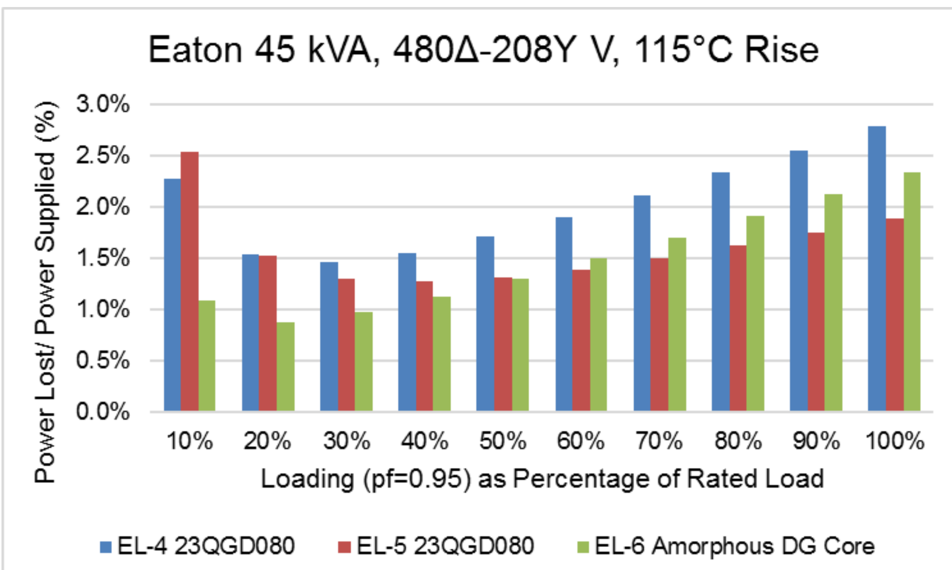

Figure 30. Power Losses as Percentage of Power Supplied for Three Eaton Transformers

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transformers, including the three-phase 480Δ-208Y/120V, 150°C with aluminum windings (model V48M28T…) in Figure 32. Again, linear interpolation was used to determine other efficiency values.

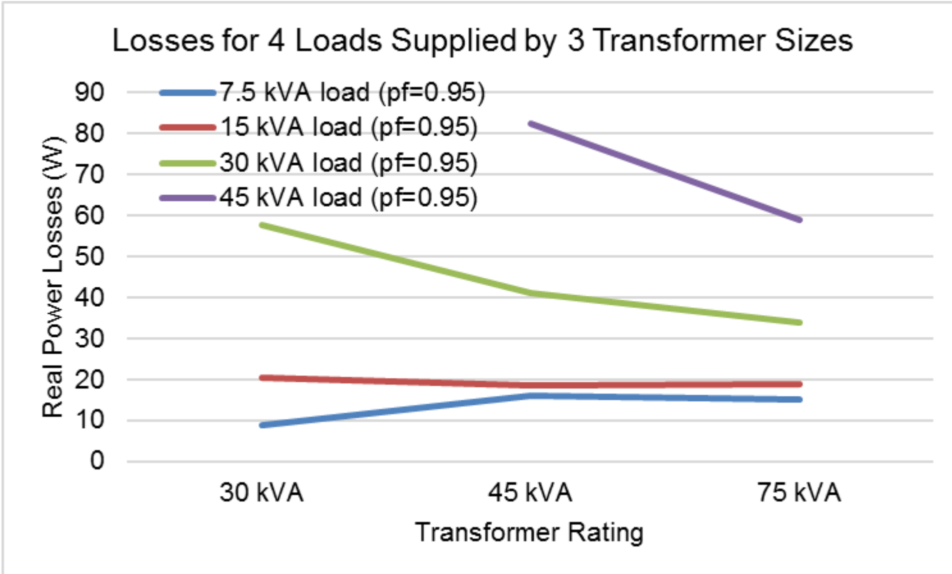

Figure 31. Power Losses: 7.5 to 45 kVA Loads Supplied by 30 to 75 kVA Transformers

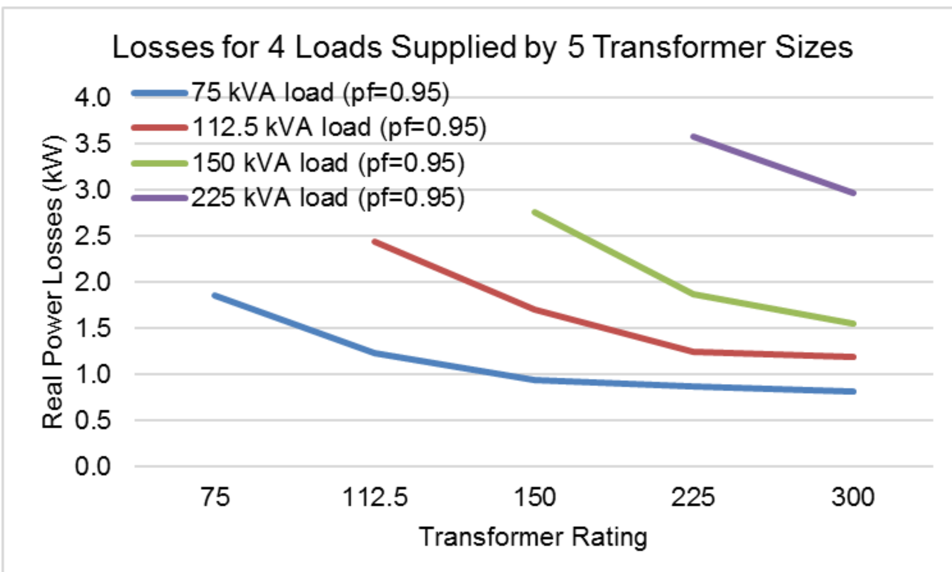

Figure 32. Power Losses: 75 to 225 kVA Loads Supplied by 75 to 300 kVA Transformers

Figures 29 and 30 illustrate that transformer efficiency is dependent on the core material. Transformer efficiency is also dependent on temperature-rise type. Figures 33, 34, and 35 show that transformer types with lower rather than higher rise temperatures are more efficient for all three Eaton 45 kVA, 480Δ-208Y V transformers in Figures 29 and 30 with traditional EL-4 and EL-5 refined steel cores, as well as the amorphous core EL-6. Transformers with a 150°C

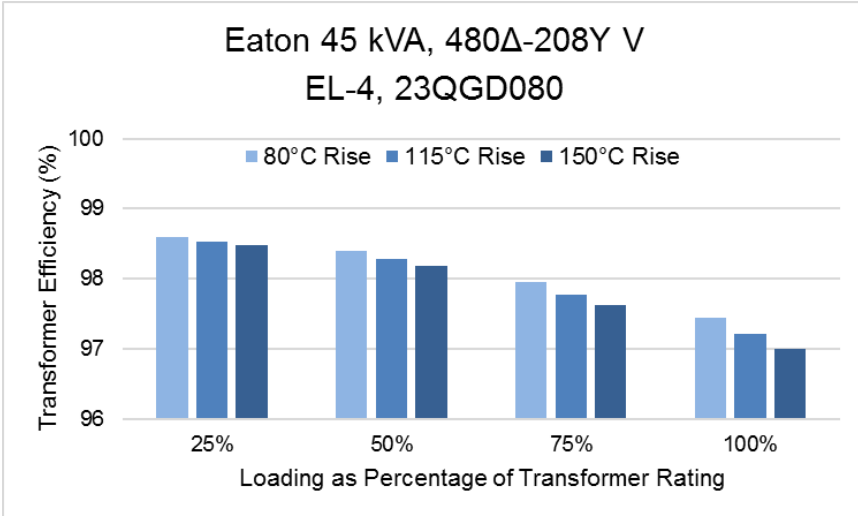

Figure 33. Efficiency as Function of Rise for 45 kVA, 480Δ-208YV, EL-4 Core Transformer

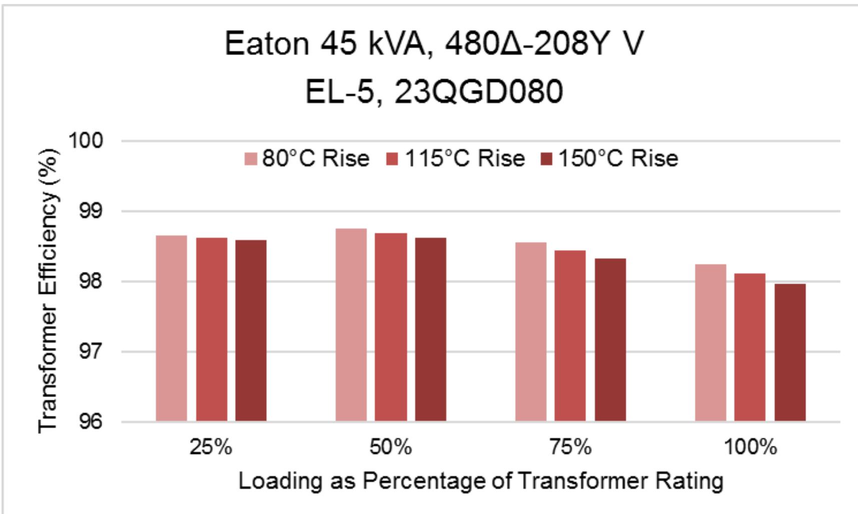

Figure 34. Efficiency as Function of Rise for 45 kVA, 480Δ-208YV, EL-5 Core Transformer

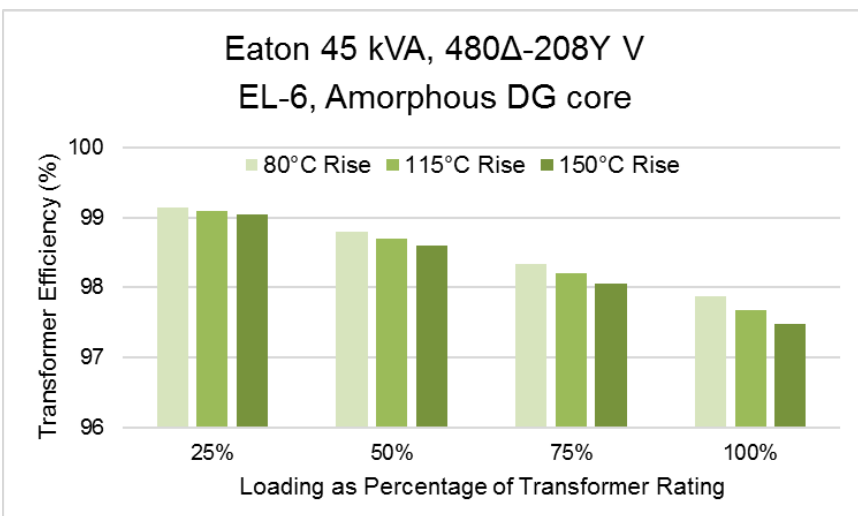

Figure 35. Efficiency as Function of Rise for 45 kVA, 480Δ-208YV, EL-6 Amorphous Core

temperature rise is the standard selection, but temperature rise specifications of 80°C and 115°C are also common. A temperature rise specification of 150°C allows the transformer temperature to rise 150°C (302°F) above the ambient temperature (20°C), so a fully loaded commercial transformer can exceed 300°F [35]. Data provided by Eaton on the percentage of three-phase transformers manufactured in 2016 by rise type is included in Table 28.[21] Single-phase transformers have similar percentages. Other manufacturers are expected to sell similar relative percentages.

When transformers with no K-factor rating (i.e., K-factor = 1) supply non-linear loads, the harmonics generated by nonlinear loads reduce expected transformer efficiency and can reduce transformer life. Harmonics increase transformer load and no-load losses, but the increase in eddy current losses is the most significant. Transformers with K-factors higher than one are specially designed to reduce eddy current losses in the windings. Core laminations may be individually insulated, and the size of the transformer core and windings may be increased [36]. K-factor, a weighting of the harmonic load current, is defined by the following equation, where n is the harmonic number and i_n is the magnitude of the harmonic current.

$$K - factor = \sum i_n^2 n^2 \ / \ \sum i_n^2$$

Pure linear loads have a K-factor of one. Higher harmonics are associated with greater heat losses.

Harmonics are commonly generated in building systems, and transformers are sometimes de-rated and oversized to compensate for the presence of harmonic current. However, selecting the appropriate K-factor transformer may be more economical [37] and is a better approach to reducing power losses. Data provided by Eaton on the percentage of three-phase transformers (115°C rise type) manufactured in 2016 by K-factor is included in Table 29. Single-phase transformers have similar percentages. Furthermore, other manufacturers are expected to sell similar relative percentages.

Table 28. Eaton Percentage of Transformers Manufactured in 2016 by Rise Type

150°C Rise	115°C Rise	80°C Rise
82%	14%	4%

[21] Robert Yanniello provided the data in Tables 28 and 29 in email dated October 21, 2016. The data represent ventilated, dry type distribution transformers with low-voltage primary and secondary windings. Mr. Yanniello provided clarification on the data in email dated November 21, 2016.

Table 29. Eaton Percentage of Transformers Manufactured in 2016 by K-Factor Rating

K-Factor = 1	K-Factor =4	K-Factor = 13	K-Factor = 9 OR K-Factor = 20
94%	2%	4%	<1%

7.3 Transformer Sizing and Arc Flash Hazards in Building Systems

The Request for Proposal soliciting contractors for this Phase I research project stated: "In addition, larger than necessary transformers that supply power to feeder and branch circuits expose unnecessary flash hazard to electricians working on live equipment." The author of this report does not necessarily agree that this statement is true for dry-type distribution transformers in building systems with low-voltage primary and secondary windings. This section provides the results of sample calculations for three typical 480 V building systems[22] listed in Table 30. The systems represent low-, medium-, and higher- capacity systems with available three-phase, RMS short-circuit currents ranging from over 14 kA to over 50 kA at the main distribution panel. Certainly, there are some "high capacity" systems with higher available fault currents, but a representative system has not been developed for this work.

Transformers which step down 480 V to 208Y/120 V are used in buildings systems to supply lower-voltage mechanical loads, including water heaters, various fans, sump pumps and ductless heat pumps, as well as other specialized equipment and receptacle load. Feeders supplying transformers with different ratings are sized according to transformer capacity and any overcurrent protective devices present. Feeder lengths are determined by the physical layout of the electrical system in the building.

Since feeder impedance is a function of length, shorter feeders, supplying in-house distribution transformers located near the main switchgear or main switchboard, tend to have less impedance than longer feeders. Feeders with larger ampacities supplying transformers with higher kVA ratings have less impedance per unit length than those supplying transformers with lower kVA ratings. None the less, the feeder impedance further decreases the available fault current at the transformer. For illustration purposes, the impedances of the feeders supplying the transformers have been neglected, so that the direct impact of different transformer ratings on potential arc current is not obscured by different feeder impedances.

Figures 36 and 37 display the faults currents calculated at the secondary of 480-208Y/120 V transformers rated from 15 to 300 kVA supplied by "low," "medium," and "higher"

[22] The three typical systems were developed for use in [38] and later used in [39].

Table 30. Three Typical 480-V Building Systems

Capacity	Low	Medium	Higher
Utility System kVA and X/R	100,000kVA X/R=6	250,000kVA X/R=8	500,000kVA X/R=10
Utility Transformer kVA and X/R (%Z = 5.32)	750 kVA X/R=5.7	1,500 kVA X/R=8.1	2,500 kVA X/R=8.3
Main Feeder (40') Conductor Size and Conduit	4 sets 4 #350 kcmil, 3" conduit	6 sets 4 #400 kcmil, 3" conduit	11 sets 4 #500 kcmil, 3" conduit
Service Entrance Rating (A)	1,200	2,000	4,000
Service Entrance Impedance	19.1mΩ, X/R=5.3	9.37mΩ, X/R=7.1	5.51mΩ, X/R=7.5
Available 3-phase RMS Isc (A)	14,528	29,578	50,304
IEEE 1584-2002 Iarc (A) [a]	8,610	15,575	24,249

[a] 1584 Iarc based on arcing in an enclosure and an arc gap width of 1.25".

capacity systems. The available three-phase, RMS short-circuit currents are determined from the following equations:

$$Isc_{secondary} = \frac{120}{Z_{secondary}}$$

$$Z_{transformer} = \left(\frac{208^2}{VA\ Rating}\right) \cdot \left(\frac{\%Z_{transf}}{100}\right) \cdot \left(\cos\left(\arctan\left(\frac{X}{R}\right)_{transf}\right) + j\sin\left(\arctan\left(\frac{X}{R}\right)_{transf}\right)\right)$$

$$Z_{secondary} = Z_{up\ to\ transformer} \cdot \left(\frac{208}{480}\right)^2 + Z_{transformer}$$

Some values associated the transformer impedance calculation are included in Table 31, based on Eaton 480Δ-208Y V, 150°C rise transformers[23] with aluminum windings rated from 15 to 300 kVA.

The impedance of the transformer has a far more limiting effect on the available fault current than the impedance of the electrical system up to the location of the transformer for the three typical systems in Table 30. (The system impedances referred to the transformer secondary are 3.58, 1.76, and 1.03 mΩ, respectively.) For the transformers rated up to 112.5 kVA, the available three-phase, short-circuit current does not even reach 7 kA. At higher transformer ratings (150 kVA and higher) in Figure 36, the transformer impedance decreases and the limiting effect of the electrical system impedance on the available short-circuit current becomes more evident in lower and medium capacity systems.

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[23] In email dated November 29, 2016, Robert Yanniello attached excel file "Tech Data as 06-06- 2016," providing Eaton transformer %Z, X, and R (all at Trise +20°C) data.

Table 31. Impedance for 480Δ-208Y/120 V, 150°C Rise, 15 – 300 kVA Transformers

kVA Rating	%Impedance	X/R	Impedance (mΩ)*	Catalog Number
15	3.74	0.50	107.9	V48M28T15EE
30	2.44	0.48	35.2	V48M28T30EE
45	3.51	0.97	33.7	V48M28T45EE
75	3.61	1.31	20.8	V48M28T75EE
112.5	4.37	1.92	16.8	V48M28T12EE
150	3.46	1.72	10.0	V48M28T49EE
225	4.29	2.86	8.2	V48M28T22EE
300	4.45	2.62	6.4	V48M28T33EE

*The magnitude of the transformer impedance is with respect to the secondary winding.

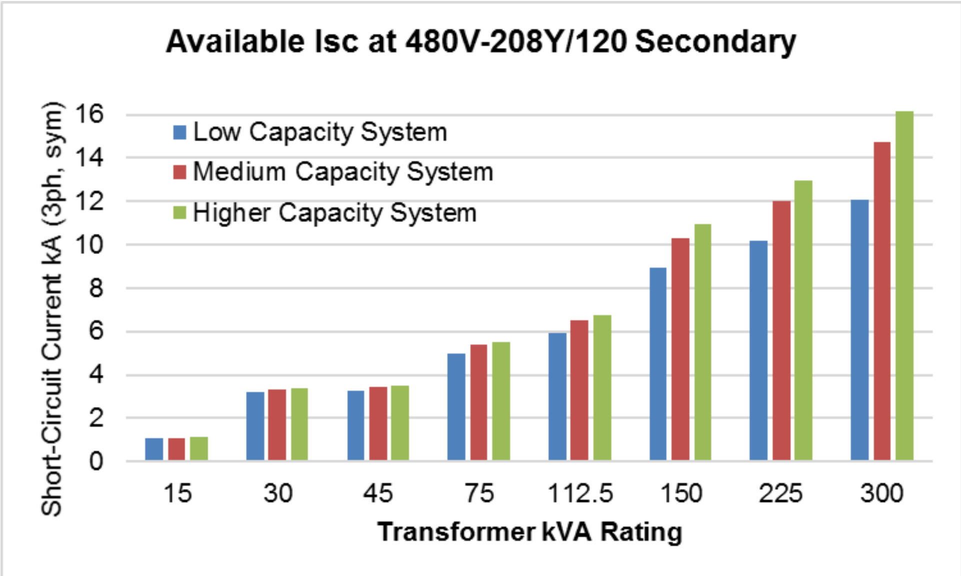

Figure 36. Available Short-Circuit Current at Transformer Secondary in Typical Systems

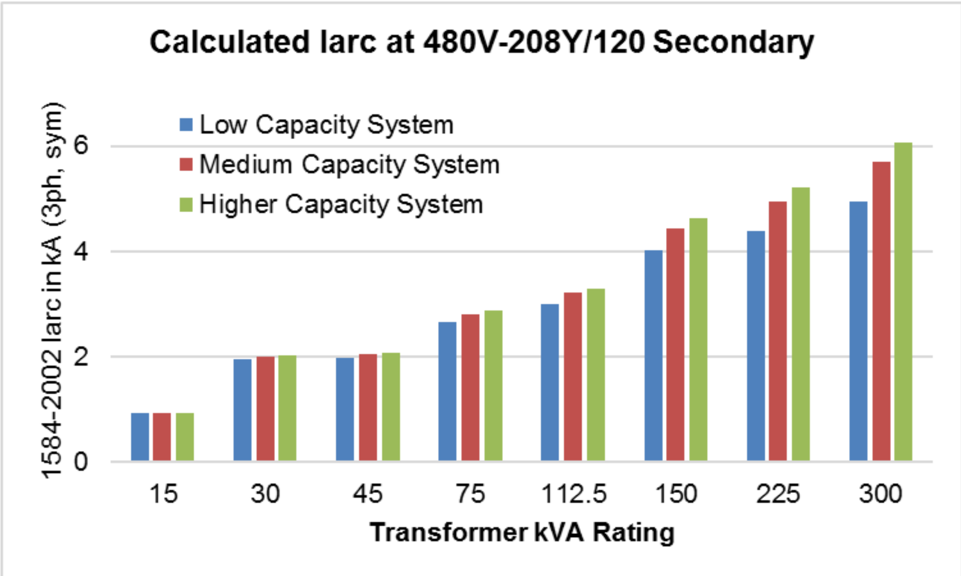

Figure 37. 1584-2002 Arc Current at Transformer Secondary in Typical Systems

The three-phase arc currents have been calculated using the IEEE 1584-2002 [40] arc current model based on a three-phase voltage of 208 V and a gap width of 1 inch in an enclosure. The calculated arc current at the transformer secondary only exceeds 6 kA (6,075 A) for the 300 kVA transformer in the higher capacity system. Furthermore, the 1584-2002 arc current equation tends to overpredict low-voltage, low-magnitude arcing faults currents. In addition, it is difficult to sustain arcing at 208 V (three-phase), especially for lower-magnitude short-circuit currents, wider gaps (including 1 inch), and equipment configurations which do not create a protected space that can be easily ionized.

Moreover, the greatest threat posed by electrical arc flash hazards is burn injury. Burn injury not only depends on the total incident energy but also depends on the rate of heat transfer. The heat flux of lower-magnitude arc currents is less intense, and heat is lost in the vicinity of the arc. The 1584-2002 calculated incident energies after 100 ms are displayed in Figure 38. The calculated incident energies at a distance of 18” are based on a panel configuration in a grounded electrical system. The calculated incident energies (which inherently assumes a sustainable arc) do not reach 2 cal/cm^2 even for a 300 kVA transformer in a higher capacity system.

Figures 37 and 38 demonstrate that “oversizing” in-house 480-208Y/120 V transformers one size higher does not pose a significant risk of the arc flash hazard generated at the transformer secondary. For electrical systems in commercial buildings, the service transformer size is typically determined by or negotiated with the electric utility provider. Tables 19 and 20

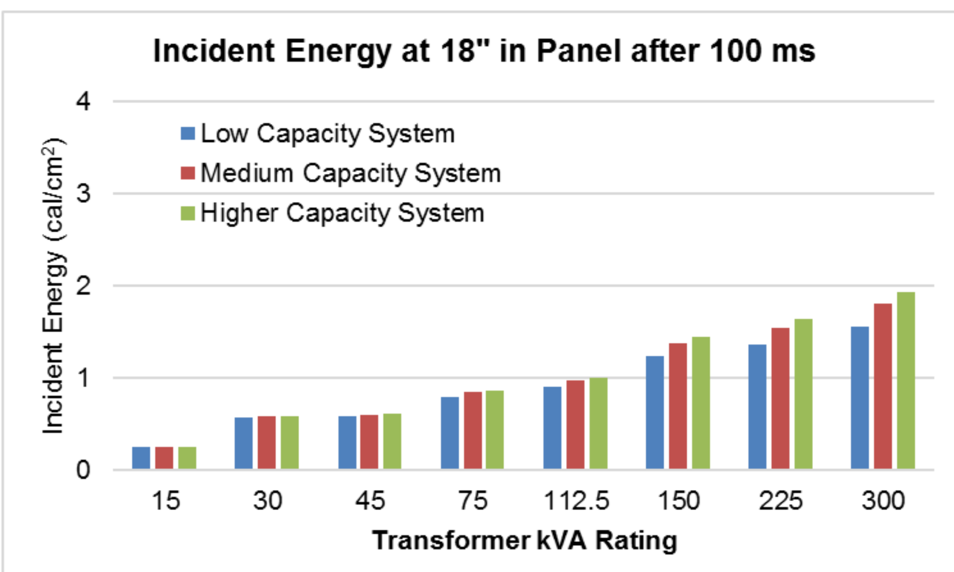

Figure 38. 1584-2002 Incident Energy after 100 ms at Secondary in Typical Systems

illustrated that electric utilities may size transformers based on different capacity requirements and different demand factors than established in the National Electrical Code.

8 DATA COLLECTION AND ANALYSIS PLAN FOR EVALUATION OF ELECTRICAL FEEDER AND BRANCH CIRCUIT LOADING PROJECT PHASE II

8.1 Motivation for Project

Although electrical systems are utilized from the bottom up, they are designed from the top down. When a building is constructed, the transformer supplying the main feeder is installed before the procurement of all electrical equipment serving the building. Engineers determine the building power requirements based on the connected and demand load calculations subdivided into the following (or similar) categories:

- Receptacle Lighting Heat Cooling Motor Other Spare

The "Heat" load might consist of electric heating elements in the HVAC system, permanent space heating, and water heaters. In a commercial building, the "Motor" load might include elevators, exhaust fans, and pumps required for building function. The "Other" load might consist of any dedicated building equipment identified early in the design process. The "Heat," "Cooling," "Motor" and "Other" loads are based on known building service demands. The power required for these loads may be determined from the specified equipment or estimated from other equipment capable of meeting the service demand.

Spare capacity may be added to one or all building panels to accommodate both anticipated and unforeseen additional load growth. Panel and feeder sizing are based on the demand power requirements and often include spare capacity.

Branch circuit requirements for receptacle load power density are specified in NEC 220.14. The receptacle load is calculated at 180 VA for each single or multiple receptacles on one yolk. Equipment with four or more outlets is calculated at a minimum of 90 VA per receptacle. For feeder and service-load calculations, NEC 220.44 permits that the receptacle demand load may be calculated as 100% of the first 10 kVA plus 50% of the remaining kVA. Many practicing engineers question the 180 VA design requirement in today's changing technology market and with changing receptacle usage. Moreover, the NEC 180 VA requirement dates back 1937. The National Electrical Code has been adopted statewide in 47 states, and its enforcement lies upon the authority having jurisdiction. However, even engineers in areas with statewide adoption have been known to not always adhere to the NEC. A review of a few sets of electrical plans uncovered three variations of the NEC feeder and service-load receptacle calculations, in addition to engineering judgment in the branch circuit design.

Like heat, cooling, motor, and other loads, lighting fixtures are fixed loads with specific power requirements. The Illumination Engineering Society has set guidelines on the illumination levels required to adequately light a space for specific work tasks. Engineers and lighting designers design fixture layouts to provide adequate illumination levels. But it has also been estimated that up to 40% of all lighting projects are designed by electrical contractors.[24] The NEC specifies the minimum lighting load power density by occupancy type in Table 220.12 and included as Table 32 here.[25] As Table 32 illustrates, the load requirements have largely been in effect since at least 1968 with few modifications, yet lighting technologies have advanced and become much more energy efficient in the last fifty years.

Table 32. NEC (VA/ft^2) and ASHRAE 90.1 (W/ft^2) Lighting Power Density by Occupancy

Type of Occupancy	NEC 1968	NEC 1971	NEC 1981	NEC 2017	90.1-2004	90.1-2013
Armories and auditoriums	1			1		
Banks	2	5	3½	3½		
Barbershops & beauty parlors	3			3		
Churches	1			1	1.3	1
Clubs	2			2		
Courtrooms	2			2	1.2	1.01
Dwelling Units	3			3		
Garages – commercial (storage)	½			½		
Hospitals	2			2	1.2	0.94
Hotels, motels & apts. (no cooking)	2			2	1	0.87
Industrial commercial (loft) bldgs.	2			2		
Lodge rooms	1½			1½		
Office buildings	5		3½	3½	1	0.82
Restaurants	2			2	1.4	0.9
Schools	3			3	1.2	0.87
Stores	3			3	1.5	1.26
Warehouses (storage)	¼			¼	0.8	0.66
Assembly halls, & auditoriums*	1			1		
Halls, corridors, closets, & stairways*	½			½		
Storage spaces*	¼			¼		
***Except in individual dwelling units**						

[24] Statement made in email from Mark Lien, Illumination Engineering Society (IES) Industry Relations Manager, September 9, 2016.
[25] Table 32 is identical to Table 22. Section 8, the data collection plan, has been written as a separate document which can be reviewed independently of earlier report Sections 1 – 7.

The commercial reference building model for new construction, developed for the U.S. Department of Energy, uses the lighting power densities of ASHRAE 90.1-2004. Lighting power densities for ASHRAE 90.1 building area types equivalent to NEC occupancy types are listed in Table 32 for comparison purposes. The lighting power densities of ASHRAE 90.1-2013 and even 90.1-2004 differ significantly from the 2017 NEC.

Two exceptions to the NEC lighting power density requirements are permitted. The 2014 edition permitted an exception if the building complies with local energy codes and a monitoring system is installed. In the 2017 NEC, the lighting load specified by Table 220.12 for office and bank areas may be *reduced by* 1 VA/ft^2 when the local authority has adopted an energy code specifying an overall lighting density less than 1.2 VA/ft^2. At least 45 states have energy conservation codes in effect. California has its own state code, and part of Hawaii has a locally adopted code. Other states except Vermont have adopted ASHRAE 90.1-2004 or a later edition. In many states, the adopted energy codes are not enforced. However, even before state adoption of NEC's 2014 edition, engineers in various areas nationwide have based lighting power density requirements on local energy conservation codes (and therefore likely lower than NEC requirements).

The National Electrical Code may be considered the Gold Standard for the design and installation of electrical equipment. For the NEC to remain the unrefuted standard nationwide, the requirements of the NEC must be well-founded and up-to-date with today's technology and building design. At one time, the NEC focused exclusively on the design and installation of electrical equipment. Today it also encompasses safety issues addressed by NFPA 70E, *Standard for Electrical Safety in the Workplace*; these issues include electric shock, arc flash hazards, and other forms of electrical injury. Recent NEC 2017 exceptions in Section 220.12 demonstrate that the NEC is also becoming responsive to growing national concern for energy conservation.

U.S. government passed its first energy policy act in 1975. Since the Energy Policy Act of 1992, the U.S. Department of Energy (DOE) has taken an active role in the development, adoption, and impact analysis of model building energy conservation codes. The DOE also establishes minimum efficiency standards for appliances and equipment, which includes mandating greater efficiency requirements for transformers effective January 2016. For several years, government entities and electric utility providers have publicized the energy saving benefits of replacing older electrical equipment, including transformers and lighting fixtures, with new more energy efficient equipment. Financial incentives are often given.

There has been recent interest in "rightsizing" transformers to reduce energy losses associated with older oversized transformers. A 1999 Cadmus study of in-house low-voltage dry-type transformers found the average RMS loading of transformers at 16% of capacity [32]. A Navigant study on miscellaneous electric loads (MELs) estimated 43 TW-hours of energy loss generated by low-voltage dry-type transformers in commercial buildings in 2011 [8]; this transformer energy loss was higher than the energy consumption of any of the other thirteen MELs in the study.

Environmental science focuses on the importance of sustainability in new building construction. Sustainability is becoming a more important issue in the electrical system design in buildings. Specifying oversized electrical equipment might be viewed as wasteful of national and planetary resources. "Rightsizing" equipment may save in capital investment. Excess capacity may lead to higher available fault current and concern has been expressed about the potential for greater electrical safety hazards, including arc flash hazards.

The intent of this research study is to evaluate electrical feeder and branch circuit loading given present NEC requirements, electrical safety, and energy conservation and sustainability issues.

The lighting and receptacle loads are of particular interest because of the long-standing minimum power densities established by the NEC. The lighting and receptacle load power densities in new building construction need to be measured to ensure that the NEC requirements reflect today's technology and usage in building spaces. However, design requirements for receptacle power density (which is not a "fixed" load) also need to accommodate the anticipated future growth in plug-loads and the development of unforeseen new types of plug-loads over the life cycle of the building.

Finally, many commercial buildings are provided 480 V which is stepped down to 208Y-120 V by in-house transformers. The research project recommends monitoring load levels on all transformers within the building and supplying the main service.

8.2 Relevance of Project Focus

In June 2016, electric utilities had close to 150 million customer accounts, including 18.3 million commercial accounts. Assuming each customer has at least one electrical service feeder, the number of service feeders must be close to 150 million and the numbers of distribution feeders and branch circuits must exceed a billion. Feeders and branch circuits might be considered pipelines for electricity. In 2015, residential, commercial, and industrial sectors purchased over 3.7 trillion kW-hours of electricity.

The U.S. Energy Information Administration (EIA) estimated that, in 2012 in the United States, there were close to 5.6 million commercial buildings with a total floor space over 87 billion square feet. The EIA also estimated that lighting accounted for 17% of all electricity consumption; furthermore, miscellaneous electric loads including computing and office equipment accounted for 32% of the total electricity consumption. In the 2012 Commercial Building Energy Consumption Survey (CBECS) funded by the EIA, office buildings alone accounted for 19% of the total number of commercial buildings, 19% of the total floor space, and 20% of electricity consumption.

A study on the electrical feeder and branch circuit loading in commercial buildings will provide substantive data, more valuable than estimation, on the major and minor end-use loads in commercial buildings in the U.S. The average age of a commercial building is 32 years. The results of this project may also serve as an impetus for retrofitting equipment to realize energy savings and quality enhancements. In addition, new data on transformer loading and measured power losses of working transformers might warrant a reassessment of the transformer efficiency test procedures specified by the U.S. Department of Energy. The results from this project will provide NEC code-making panels data to reassess current NEC branch-circuit, feeder, and service load calculations, particularly for lighting and receptacle load. The results of this project may stimulate additional national, standards, and professional group discussion on energy conservation and sustainability, specifically regarding building electrical systems.

8.3 Selection of Study Type and Participating Study Buildings

8.3.1 Objective

The objective is to locate fifty[26] commercial buildings where electrical feeder loading can be monitored for one calendar year. Previous studies in the reliability of electrical equipment found that at least forty samples were needed for the results to be statistically meaningful [41]. Ten additional office buildings have been added to enhance the statistical value and to compensate

[26] In December 21, 2016 email, Bob Arno stated: “I do have one concern minor in nature, I would target double the facilities for data collection in the anticipation of achieving solid data on 50. I know this will add additional cost but anticipating equipment failure, facility pullout, Murphy’s law, this is an effort you will want to do only once with positive results.” The report author agrees that monitoring additional sites will enhance the value of the data collected. It will be left to Phase II project personnel to double the sites monitored if resources are available.

for any sites withdrawing, data being lost, or any unforeseen event which might reduce the value of the building's contribution to the study.

8.3.2 Types of Commercial Buildings

Three potential groups of commercial buildings have been identified for study. The group selected for study may depend on budget, interest, and Phase II sponsorship.

8.3.2.1 Commercial Building Type Option 1 Study

- Fifteen of the Sixteen Commercial Building Types as identified in the 2012 CBECS
  - 192 buildings total -- 12 for each of type except offices and none for vacant
  - 12 for office buildings up to 50,000 ft^2 and 12 for those over 50,000 ft^2

An electrical feeder and branch circuit loading study is needed for different types of commercial buildings. The 2012 CBECS, costing in the tens of millions, collected detailed information about 6,720 commercial buildings to project the energy consumed by major and minor end-use loads in all commercial buildings. Although the study collects information about building electricity usage, the specific energy consumption of end-use loads is not measured; it is estimated based on survey information about building HVAC equipment, lighting types, general numbers of computer and office equipment, etc.

The U.S. Department of Energy has developed its Commercial Building Reference Models from the 2003 CBECS and information found in ASHRAE standards. The U.S. Department of Energy, the U.S. Energy Administration (a sector of the DOE), and standards need data on the electricity consumption of specific load types in all commercial building types. The U.S. government might use this information to help shape energy policies and to develop more accurate models for electricity consumption. Consumption data on heating, cooling, ventilation, and refrigeration equipment would shed light on demand and mean power consumption with respect to "nameplate" requirements, building needs, and electrical system design requirements. Inventory information and nameplate power requirements for lighting and receptacles would shed light on usage and power demand requirements.

Furthermore, the U.S. Department of Energy mandates efficiency requirements and defines test procedures for measuring distribution transformer energy loss in the Code of Federal Regulations. Transformer efficiency is a function of transformer loading; 10 CFR §431.196 specifies transformer loading during the testing at 35% of rated load. If 35% loading is not representative of transformer loading, the DOE test procedure may not provide a good assessment of energy loss in working transformers.

Different building types may have different load profiles and transformer loading.

8.3.2.2 Commercial Building Type Option 2 Study

- Large University Campuses
  - 137 commercial buildings, with a focus on 50 office buildings as follows:
  - 25 offices up to 50,000 ft^2 and 25 offices over 50,000 ft^2
  - 25 residence halls, 25 education buildings, 25 laboratories, 12 hospitals

Large university complexes might benefit from this study on electrical feeder and branch circuit loading because the results might help bring about changes in standards which might ultimately reduce capital investment in new construction. Results may also provide evidence for realizing energy savings through decisions to retrofit older, lossy equipment. Older equipment also has a higher probability of failing, interrupting service, and even starting a fire; furthermore, it is more likely to pose an electrical hazard not only to maintenance workers but also to end users, including students. New equipment may also bring additional benefits such as improved lighting quality.

8.3.2.3 Commercial Building Type Option 3 Study

- Fifty Commercial Office Buildings
  - 25 offices up to 50,000 ft^2, ideally equally divided into three groups: 1,000-10,000 ft^2, 10,000-25,000 ft^2, and 25,000-50,000 ft^2
  - 25 offices over 50,000 ft^2, ideally with 10 offices over 100,000 ft^2 and 5 over 200,000 ft^2

The Request for Proposal issued by for the Fire Protection Research Foundation stated the initial focus was commercial office occupancies.

8.3.3 Geographic Distribution of Study Buildings

The monitoring sites should be selected to represent different climate zones, time zones, and Census regions. Many aspects of climate can influence daily power requirements, including temperature, humidity, precipitation, cloud cover, and winds. In offices conducting interstate business, time zones might influence operating hours. In different regions of the country, building construction and engineering design practices may differ due to climate differences and local building and energy conversation codes.

Site locations should be selected to represent each IECC climate region shown in Figure 39[27], but a higher percentage of monitoring sites should be concentrated in climate zones with higher population densities which also have greater building densities. A population density map produced by the United States Census Bureau has been attached as Appendix A.

[27] Figure 39 is identical to Figure 4. See footnote 26.

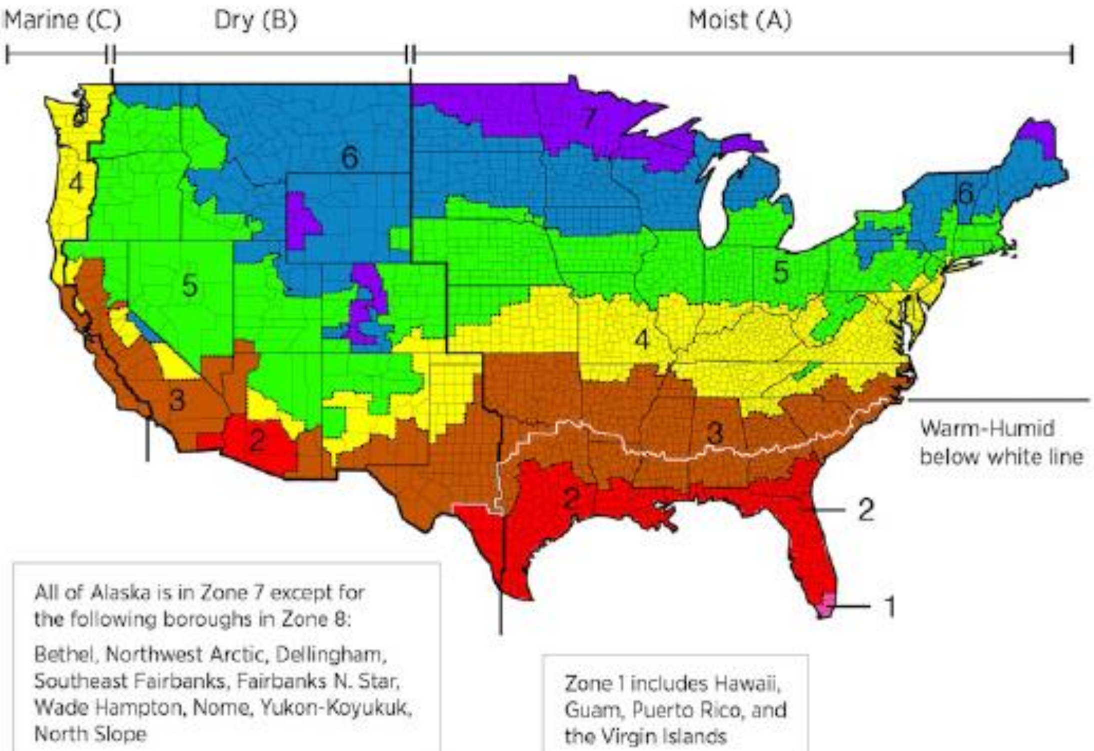

Figure 39. IECC Climate Regions in the U.S.
(Source: U.S. Department of Energy, and reference [4])

Table 33. Geographic Selection and Number of Monitoring Sites

	13 IECC Zones	3 DOE Added	Most Populated City	Office	Residence Halls	Education	Labs	Hospitals
1	1		Miami	1				
2	2A		Houston	5	4	4	4	2
3	2B		Phoenix	2				
4	3A		Atlanta	5	3	3	3	1
5	3B	Other	Las Vegas	3				
6	3B	CA-coast	Los Angeles	3	4	4	4	2
7	3C		San Francisco	3				
8	4A		Baltimore	7	4	4	4	2
9	4B		Albuquerque	1	2	2	2	1
10	4C		Seattle	3				
11	5	5A	Chicago	7	4	4	4	2
12	5	5B	Denver	4	2	2	2	1
13	6	6A	Minneapolis	3				
14	6	6B	Helena, MT	1	2	2	2	1
15	7		Duluth, MN	1				
16	8		Fairbanks, AK	1				
			Total	50	25	25	25	12

The distribution of site selection is suggested in Table 33, modeling a study focusing on university campuses (Building Type Option 2). If all major commercial building types (Building Type Option 1) are selected for study, the geographic distribution for each building type should be similar to the distribution for the hospital geographic distribution in the table. If the commercial office building study (Building Type Option 3) is conducted, office buildings should be selected as in Table 33. Ideally, site selection for the two main groups of 25 office buildings (based on size) should be distributed as residence halls, education, or laboratories in the table.

8.3.4 Criteria for Building Selection

Prospective buildings should be less than three years old (preferably two) with all equipment installed and operating. The building should be functioning at designed capacity (regarding building function, the number of employees, etc.). Prospective buildings should submit electrical plans, including panel schedules and riser diagram.

Site selection should be based on the disaggregation of loads so that the power consumption of different load types can be determined. Figure 40 illustrates feeder monitoring when load types are disaggregated at the main switchboard (a site ranked “optimal”). Buildings with electrical system riser diagrams similar to Figure 40[28] are likely to be equipped with building automation systems and advanced metering systems to monitor power requirements and energy consumption. Figure 40 is the ideal candidate for System Monitoring Option 1 or 2, discussed in Section 8.4. System Monitoring Option 1 or 2 may also be feasible for an electrical system with a riser diagram similar to Figure 41, which may be ranked “optimal” or “good.” However, monitoring and personnel resources for data collection will be more intensive and expensive.

Sites with a riser diagram similar to Figure 42 may be ranked “acceptable.” For illustration purposes, Monitoring System Option 3, monitoring receptacle and lighting loads, is shown in Figures 41, 42, and 43. Prospective buildings with riser diagrams similar to Figure 43 do not rank “optimal,” “good,” or “acceptable.” Ideally, such buildings should not be selected for monitoring. However, such buildings may provide some limited data as shown in Figure 43, if building owners are willing to provide it and research funding is limited. However, metrics such as average or demand lighting or receptacle power density for the building cannot be determined from partial building data and utilization levels in specific building zones vary.

[28] In reviewing the draft report, Bob Wajnryb, Senior Electrical Engineer at The Ohio State University, stated in an email dated December 16, 2016: “Based on personal experience, Figure 40 does not often occur.” The report author agrees.

8.3.4.1 Ranking Prospective Sites

- Optimal – All lighting and receptacle loads on dedicated panels
- Good – 90% of all lighting and receptacle loads in building are on dedicated panels
- Good – Panels with receptacle and lighting loads are 90% dedicated to respective load
- Acceptable – 80% of all lighting and receptacle loads in building are on dedicated panels
- Acceptable – Panels with receptacle and lighting loads are 80% dedicated

8.3.4.2 Additional Consideration Factors in Site Selection

- Building size
- Building service voltage
- Monitoring resources (number, type, and cost) required for building study
- Number of in-house transformers and their rating
- Primary energy sources for heating, cooling, and hot water

Ideally, selected buildings will have management and contact personnell interested in participating in the project and willing to assist.

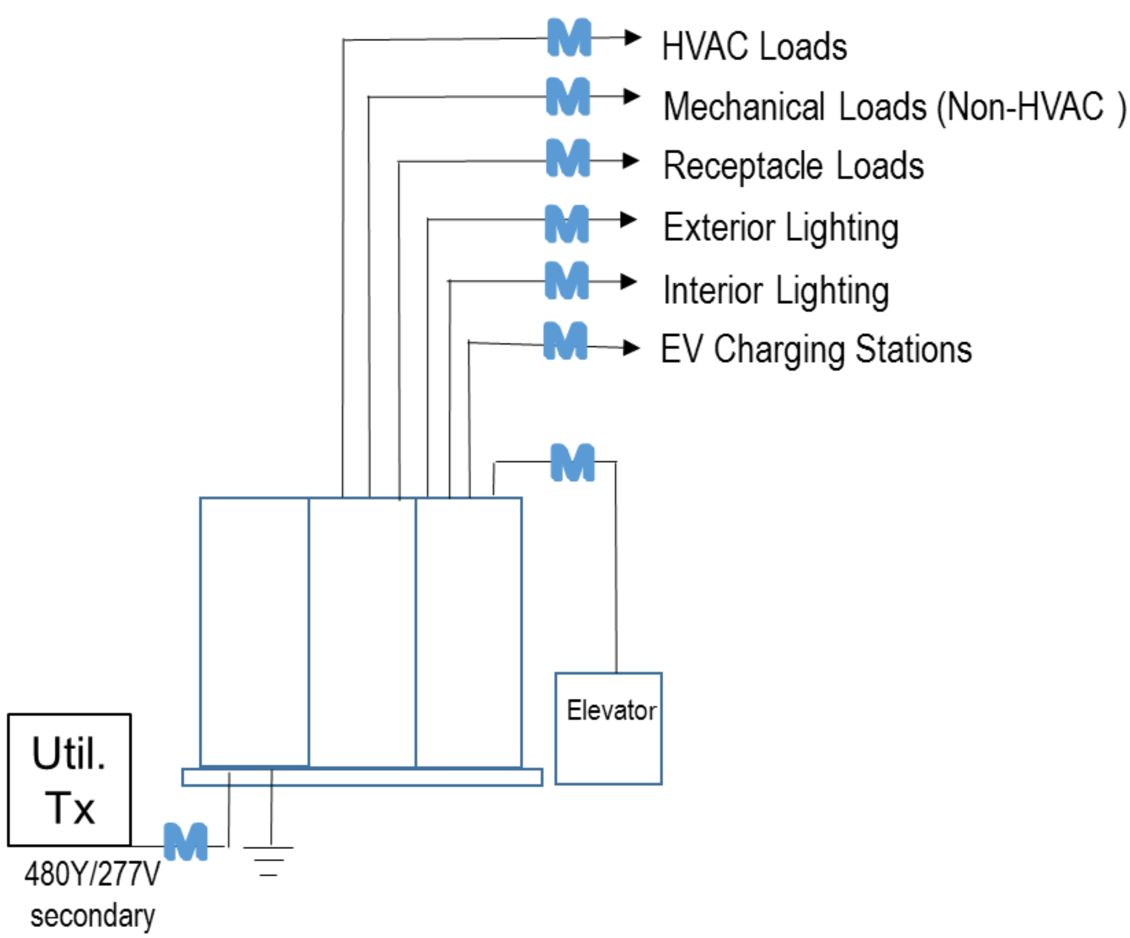

Figure 40. Monitoring Optimal Site with Load Separation

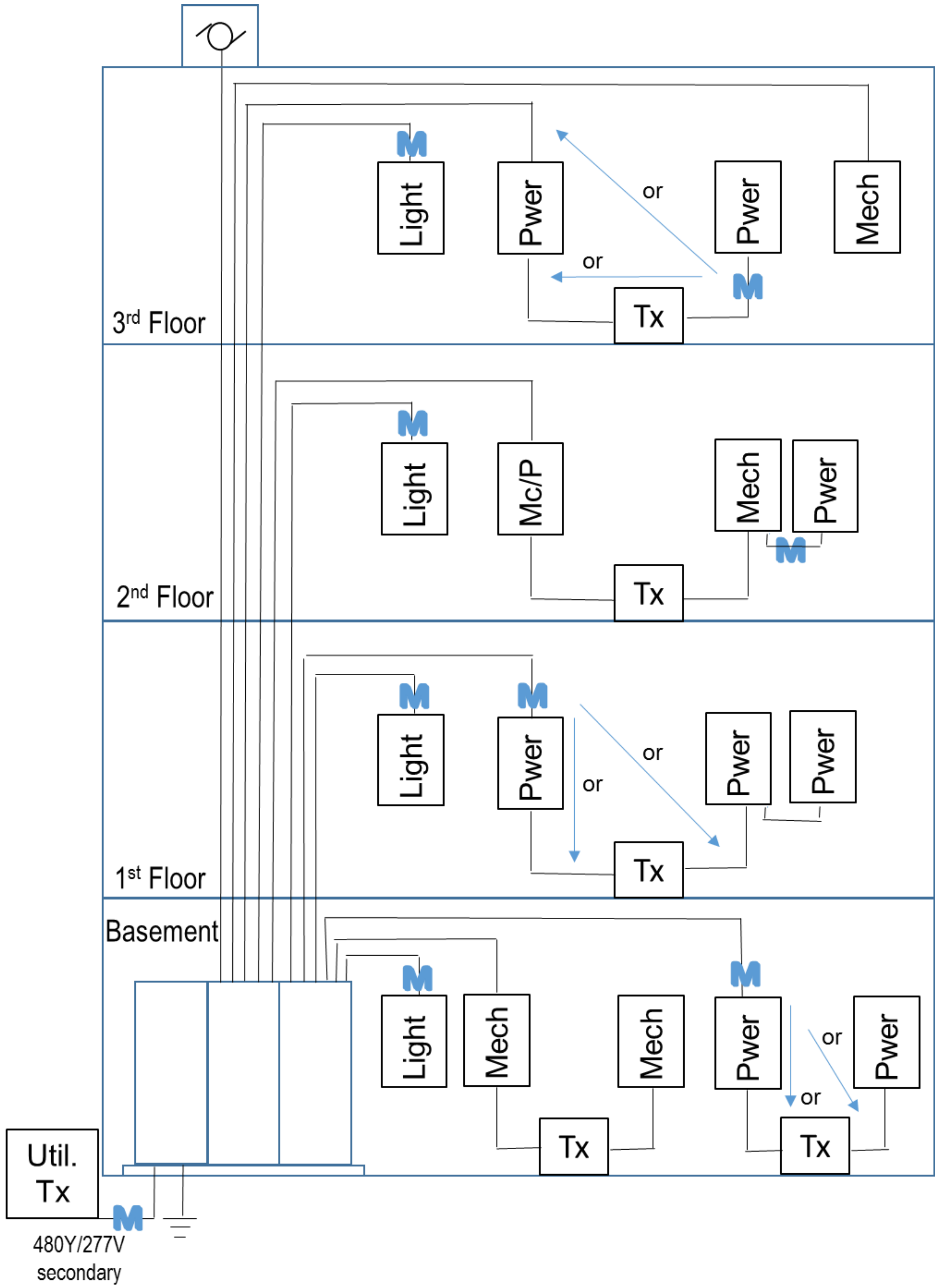

Figure 41. Monitoring "Good" or "Optimal" Site

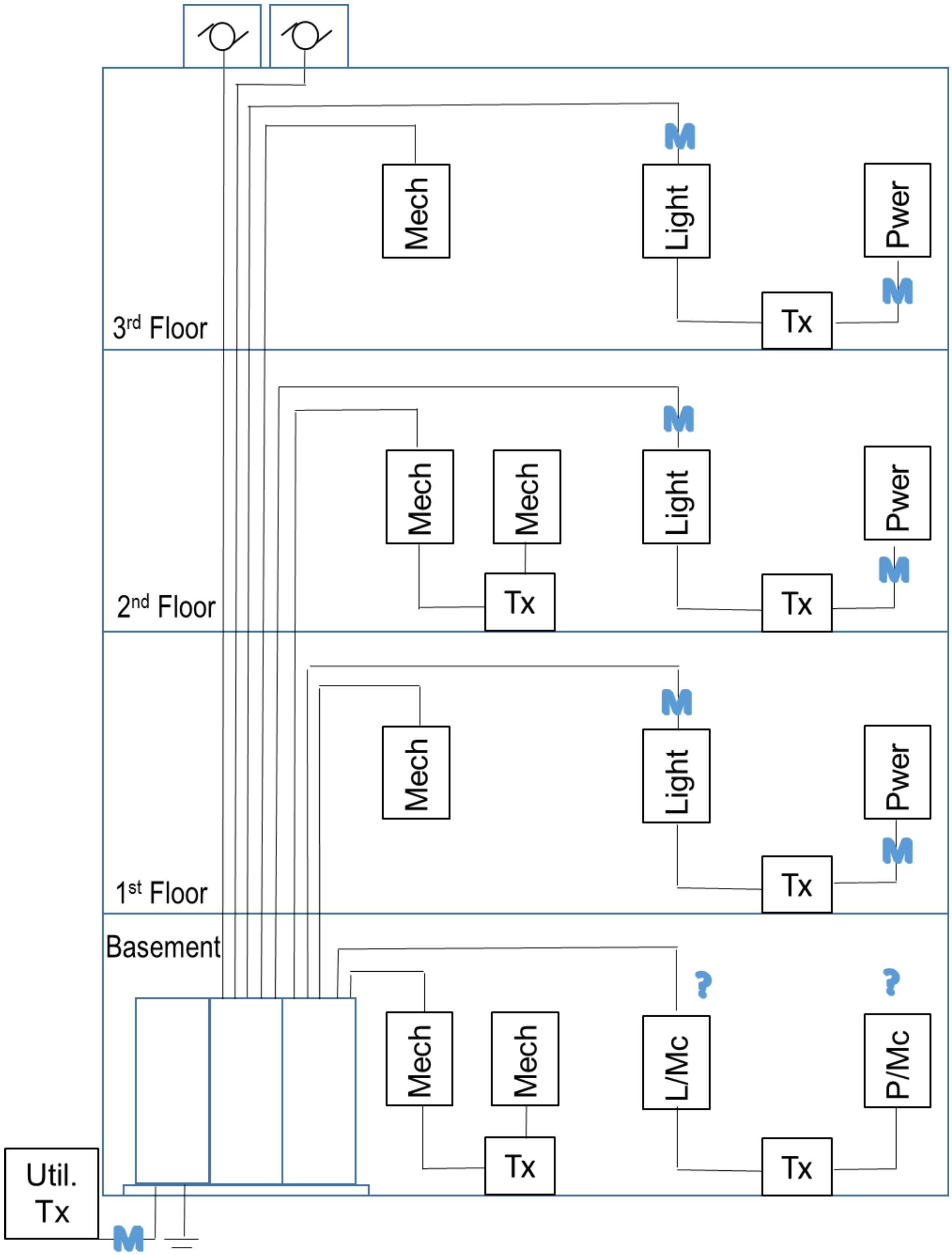

Figure 42. Monitoring Acceptable Site

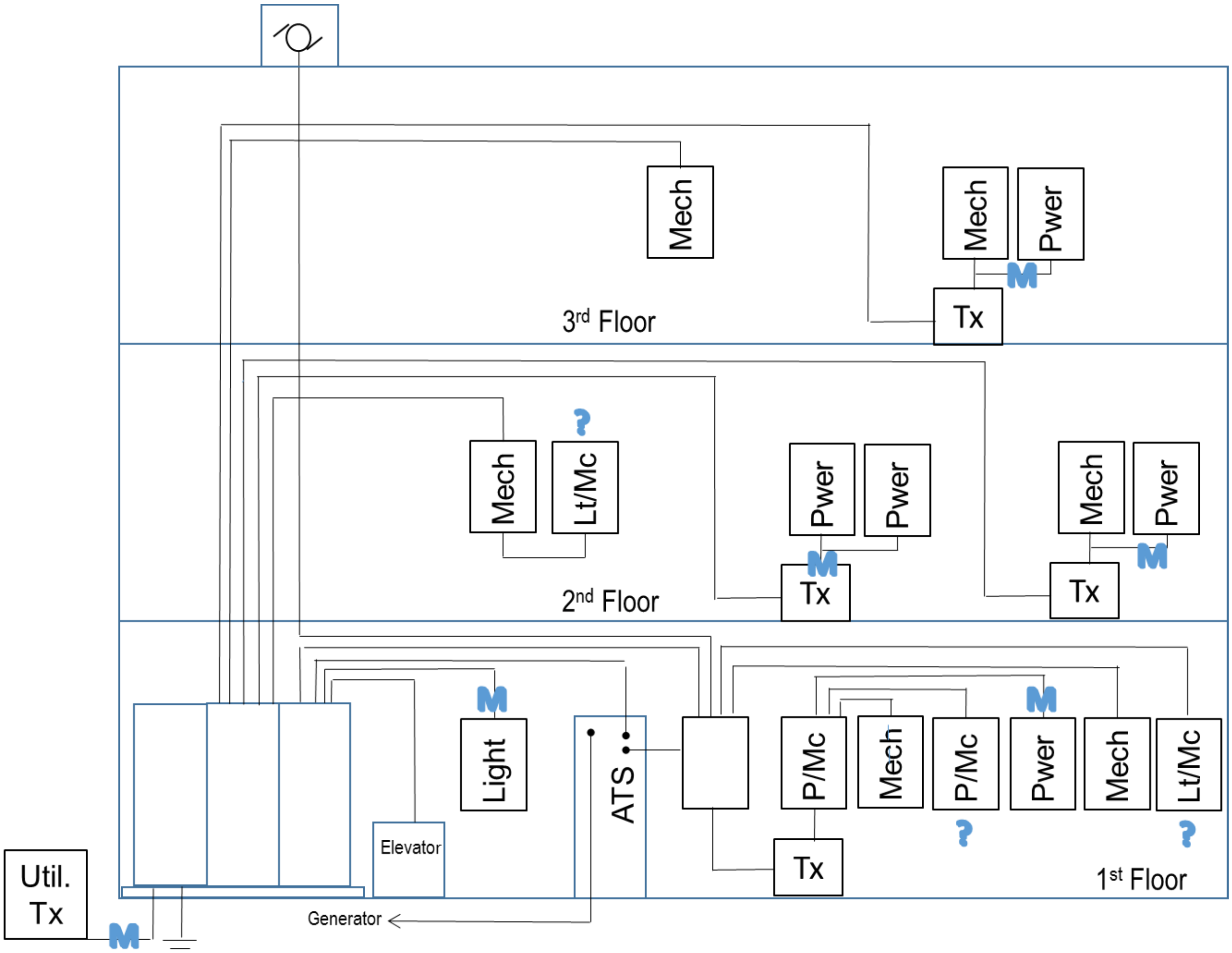

Figure 43. Monitoring a Site Not Meeting "Optimal," "Good," or "Acceptable" Ranking

8.3.5 Required Building Documents and Information[29]

1. Electrical plans, including outdoor lighting plan and lighting fixture schedule
2. For all on-site transformers, the following nameplate information: manufacturer name, model, and date; capacity; type (temperature rise); impedance; K-factor rating; primary and secondary voltages (and currents where specified); primary and secondary winding connection type
3. Mechanical plans with detailed HVAC and other mechanical equipment load information (including manufacturer and model information) for mechanical loads powered by electricity

[29] Bob Yanniello commented in December 15, 2016 email: "This is certainly a very inclusive list. Upon seeing it, I question if we could ever afford to capture it for the number of sites we felt were needed for a statistically accurate sample size." The report author has attempted include as much detail as possible. Phase II project personnel should omit details which are not considered essential at that time.

4. Two-years of utility load data (including the year which monitoring takes place)
5. Building size (should be included on drawings)
6. General description of building function and how employees carry out work (in an office building, if work primarily conducted through telephone and computer use, do employee tasks involve engaging with the general public, etc.)
7. Photos of the building, representative interior spaces, and major equipment including the parking lot, main entry, office areas, reception area, breakroom or kitchen, corridor, server/IT room, mechanical and electrical room, RTUs, transformers, etc.
8. Numbers of full-time and part-time employees and the target number of employees (with quarterly updates during the monitoring period). Additional employee demographics on age, gender, and race desirable if available.
9. If other buildings in addition to offices are selected for study, additional building benchmark information will need to be provided. For example, hospitals would need to provide the number of beds and monthly reports on utilization. Educational buildings would need to provide student capacity and utilization.
10. Building operation and maintenance manuals
11. General building operating schedule and fixed or flex employee work hours on weekdays and weekends
12. General building schedules for heating, cooling, and ventilation (automatic, occupancy sensing or manual, location specific; fixed by time of day, day of week, season; determined by employee comfort or directly controlled by employees)
13. Schedule for lighting operation (automatic, occupancy sensing, or manual, fixed by time of day, day of week, season)
14. Schedule and response time of any automatic or occupancy sensor controlled receptacles
15. Any building policies for turning off office equipment, computers, and monitors during weekdays, evenings, or weekends
16. Inventory of items connected to receptacles (including manufacturer name and year, model, power requirements if available). Receptacle inventories should be labeled by building floor and space areas (as can be identified on building plans). Inventories can be self-reported by employees (including cleaning and maintenance staff) and updated or verified quarterly. The inventory list should also contain corded-equipment or tools (such as vacuum cleaners and drills) which are connected to receptacles on an as-need basis.
17. Any energy conservation codes or standards to which building was constructed (should be included in drawings)

8.3.5.1 Collection of Building Information

Project management will generate form documents to collect building information from building contact personnel. Preferred document form is an Excel file for easy organization and analysis. Excel files might also be transformed for use in Access.

8.4 Site Monitoring

The request for proposal stated: "The goal of this project is to develop a data collection plan to provide statistically significant load data for a variety of occupancy and loading types to provide a technical basis for considering revisions to the feeder and branch circuit design requirements in the National Electrical Code." A large-scale project to evaluate electrical feeder and branch circuit loading would be significantly enhanced by expanding the study to include harmonics, power quality, power reliability, and voltage stability issues.

8.4.1 System Monitoring Options

The extent of electrical system monitoring in the buildings selected to participate in the Phase II research project depends on the interests of the sponsors and funds raised. It also depends on the level of load disaggregation in the buildings selected for site monitoring and the presence of existing advanced metering systems. Five options for monitoring the electrical systems in the study buildings are presented in Table 34.

The subsequent paragraphs in this section discuss the data to be collected for System Monitoring Option 1, which will facilitate the greatest gain in knowledge for undertaking a research project of this magnitude. If one of the lesser monitoring options is selected, the extent of monitoring should be cut back as appropriate to the selected monitoring option and the capabilities of the monitoring equipment used in the study. Similarly, the discussion of

Table 34. System Monitoring Options for Study Buildings

	Five Options for System Monitoring
1	Monitor all loads, harmonics and neutral current measurements (at least spot) on transformers and receptacle panels; continuous or two-month monitoring or spot measurements on receptacle branch circuits; obtain detailed service data (power quality and reliability and voltage stability)
2	Monitor all loads
3	Monitor lighting and receptacle loads
4	Monitor receptacle (or lighting) load
5	Monitor receptacle load, including branch circuits, no restriction on building age

data analysis in Section 8.5 addresses System Monitoring Option 1. If one of the lesser monitoring options is selected, the data analysis will be more limited, based on the monitoring option selected and the data available for analysis.

The following require continuous one-year monitoring[30] of current, voltage, and power. Some project sponsors like government agencies may prefer monitoring all sites during a single calendar year beginning on January 1 and ending on December 31. Otherwise, it may be easier to begin monitoring once a suitable monitoring site has been identified and the site is ready to participate; conducted in this manner, the window of data collection for all sites should be 18 months or less.

- Main service feeder (may be provided as electric utility data, but need current and voltage harmonic content)
- All feeders supplying panels (will also provide information about transformer loading)
- All motor control centers
- All individual loads rated over 10 kVA, including any RTUs, elevator motors, dock equipment, water heaters, and large pumps. Exception: When HVAC equipment such as fan powered terminals and fixed space heating equipment are fed from a dedicated panel, monitoring the panel is sufficient.
- Also, current harmonics and power may be monitored on all feeders supplying transformers. (Power loss may be calculated as power supplied to feeder supplying transformer subtracted from power supplied to downstream feeder supplying panel.)

Ideally, the lighting panels would be dedicated to the lighting load. However, if other loads are fed from lighting panels, they should be continuously monitored individually, unless they represent less than 20% of the panel's demand load.

In larger buildings supplied by 480 V service equipment, 208 V panels primarily serve receptacle load. However, a wide range of miscellaneous equipment may also be served; these loads include ductless air conditioners and heat pumps, water heaters, low-voltage lighting, and smaller mechanical loads including dock equipment, pumps, fans, and electric vehicle charging stations. Ideally, the building will have low-voltage panels dedicated to receptacle load.

However, monitoring dedicated receptacle panels does not provide sufficient information about the power requirements of receptacle branch circuits. Receptacles are placed throughout buildings to provide convenient and easy access to electric power. In office buildings, receptacle locations include office areas, conference rooms, break rooms, kitchens, restrooms, hallways, reception areas, filing and storage rooms, server/IT rooms, and exercise rooms. Receptacle

[30] Robert Arno, Project Technical Panel member, believes one year of monitoring is required for scientifically valid data. Mr. Arno, a manager at Harris Corporation, is an IEEE Fellow and Chairman of the IEEE Standard 493, Gold Book.

load varies according to space, scheduling, time of day, and day of the week. It was concluded in [9] that plug-load monitoring for two[31] months was needed to provide a sound estimate of receptacle energy consumption. The report author initially suggested that branch circuits be monitored during the coldest months to capture portable heater usage and seasonal task lighting, although portable fans and dehumidifiers may be used during warmer months. However, project sponsors[32] have commented that space heaters are often used in warmer weather, and fans are used during winter months, depending on an individual's personal comfort level. Therefore, for accurate branch-circuit receptacle load measurements, it seems that one year of monitoring is necessary.

8.4.2 Monitoring Equipment

Monitoring equipment cannot be selected until after Phase II further develops. These developments must include the selection of commercial building study type and system monitoring option and on the amount of funds raised for the project. The selection of monitoring equipment depends on existing metering equipment already on site; it may also be constrained by the building electrical system and cooperation of the building owners and site personnel.

This section is intended to provide a preliminary look at some equipment types. Monitoring options provided by other manufacturers may be more desirable regarding capabilities, better pricing especially in large quantity, or even possible sponsorship through equipment donation. A more comprehensive study of monitoring equipment should be conducted after further development of the Phase II project. Four different metering devices have been included in the following bullet point list. Additional information published by the manufacturer about this equipment is included in Appendix B.

- Main Feeder Monitoring: GE EPM 4600 Multi-feed Power and Energy Metering System
    - Monitoring 6 feeders at main switchboard, estimated cost $6,200 plus roughly $75 per split-core current transformer ($75x3x6), total estimated[33] = $7,550
    - EPM 4600 also available for monitoring 8 feeders
    - Monitors phase and feeder – W, VA, VAR, current, voltage, power, power factor, and neutral current and frequency

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[31] A plug-load study at Lawrence Berkeley National Labs [9] found that a 2-month study of plug-loads was long enough to estimate annual energy consumption with reasonable accuracy. The study monitored 455 plug loads for at least 6 months and many for over a year. The monitored plug-loads were selected from 4,454 inventoried plug-loads in an 89,500 square feet office building on site.

[32] In December 15, 2016 email, Robert Yanniello remarked that lighter summer clothing may cause some office employees to feel cold in air conditioning. In December 16, 2016 email, Bob Wajnryb stated, "Many times have come across space heaters in use in warm weather and fans in use in the cold weather depending on the individual."

[33] Cost provided by John Levine of Levine, Lectronics, and Lectric, Inc. in email on November 29, 2016.

  - Built-in RS-485 and USB communications; Ethernet and WiFi optional
  - Data logger for voltage, frequency, and energy usage at 15-minute intervals. May record for a minimum of 68 days to over a year, depending on options
- Panel Metering: Honeywell E-Mon Class 3400 Smart Meter[34] (and Data Logging)
  - Split core current sensors allow installation in existing systems
  - Stores kW and kVAR data for up to 72 days in 15-minute increments
  - Display also shows voltage, current, and power factor per phase
  - Built-in Ethernet and RS-485 Communications
  - Price: $950-$1,109 – for 200A and 400A 120/208V and 277/480V panels[35]
- Panel Metering: Onset Data Loggers for Real Power or Phase RMS Currents[36]
  - 250A Accu-CT split core current transformer, $45x3=$135
  - H22-001 Hobo Energy Logger $364, FlexSmart TRMS $95x2 = $190, USB Interface cable $59, estimated system cost = $748 for monitoring RMS three phase currents or $793 for RMS neutral current also
  - UX90-001 State logger $92, WattNote transducer for 208Y/120V panel $229, HOBOware Pro software $99, input voltage lead set $75, estimated system cost $630 for monitoring three-phase power
  - Length of data storage variable, likely over a year for three-phase power
- Panel and Branch Circuit Monitoring: GE ASPMETER-A Metering Panelboard
  - Monitors panel phase currents, voltages, powers, and pfs, also neutral current
  - Monitors panel kVA, total pf, average three-phase and phase voltages, frequency
  - Monitors branch circuit current, power, and power factor
  - MODBUS RTU Communication, sample frequency < 2 seconds
  - Panelboard with GE ASPMETER-A, B, or C options, approximate cost $6,250[37]

If loads are disaggregated at the main switchboard, as shown in Figure 40, the GE EPM 4600 metering system might be ideal. The EPM 4600 collects a wide range of measurements. It contains onboard memory for voltage and energy storage. More importantly, it should be fairly easy to establish communication with one central monitoring device so that the wide range of measurements can be accessed real time. For electrical safety reasons, the main switchboard would need to be shutdown to install the GE EPM 4600 in an existing switchboard.

For more limited panel metering, a trusted Honeywell E-Mon meter is a good option. In addition to kW and KVAR usage, the meter displays current, voltage, and power factor which could be transferred via a MODBUS (or other) communication protocol. If running communication lines is not feasible, at least real and reactive power consumption is stored in memory.

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[34] Another manufacturing representative (not identified to protect privacy) remarked to the report author in December 2016 that for pricing and reliability, E-Mon devices are hard to beat.
[35] Quote provided by Jake Wamble at Mayer Electric, Marietta, GA on November 4, 2016.
[36] Quotes provided by Rebecca Fish from Onset Computer Corporation on December 14, 2016.
[37] Cost estimate provided by Michael Seal, GE Energy Connections, in email dated December 12, 2016.

Onset Computer Corporation data loggers may be a good option when running communication lines is not an option or economy is essential. For a cost of $630, the UX90 data logger should be able to store three-phase power measurements recorded at 15-minute intervals for over a year. The Onset H22 Energy logger can record a wide variety of measurements. It can be configured to store the three phase currents for $748, or $793 if the neutral current is added.

A panelboard monitoring system like the GE ASPMETER-A is an excellent device for monitoring current and power consumption at a panel's branch circuits and mains. The ASPMETER is not a data logger; therefore, communication would need to be established with the panel. The GE ASPMETER is a complete panelboard which would replace an existing panelboard in a building. Panelboard replacement may be an attractive option in older buildings on university campuses where the panelboard is old and valuable knowledge can be gained through the installation of a new panelboard. The GE ASPMETER-A or similar product would provide data for consideration of the NEC's general requirement of 180 VA per receptacle in branch-circuit load calculations.

8.4.3 Method of Data Collection on Site and to Project Personnel

The project should provide an internet location where each monitoring site can upload the requested documentation and information. If the data is not accessible to project personnel via the Internet, but instead is collected by on-site employees (by downloading from device storage or LAN), data should be uploaded monthly (or more frequently). In buildings equipped with advanced monitoring, real-time data may be accessible to project personnel via the Internet.

8.5 Data Analysis[38]

8.5.1 Evaluation of Lighting Load

1. Review electrical drawings and lighting schedule; note the primary type of lighting used in different building spaces.
2. Calculate building lighting power densities from connected and demand load on panel schedules. Compare with NEC lighting power density. (If time and building layout permit, calculating lighting power density for office area specifically may be a useful comparison.)

[38] Bob Yanniello commented in December 15, 2016 email: "…I question if we could actually fund such an exhaustive data analysis?" However, Bob Arno commented in December 21, 2016 email: "I think it will be very beneficial and not too costly to add in the power Reliability and Quality. This data will be beneficial to many areas of NFPA and other organizations."

3. Review measured data. Observe any hourly, weekly, and seasonal patterns. Record peak power. Calculate mean power and other useful statistics.
4. Compare measured data with panel schedule connected and demand load.
5. As feasible from measured data, calculate peak and mean lighting power densities. Compare with power densities in Step 2.

8.5.2 Evaluation of Receptacle Load

1. Review electrical drawings. As feasible with a time constraint, record the number of receptacles assigned to each branch circuit. Compare receptacle count with connected and demand load listed on receptacle panel and the main distribution panel schedules.
2. Review measured branch circuit and panel data. Observe any hourly, weekly, and seasonal patterns. Record peak power. Calculate mean power and other useful statistics. Identify any correlations between space type and branch circuit loading.
3. Compare measured data with panel schedule connected and demand load.
4. With results of Step 3, comment on NEC receptacle VA requirements and panel and main service receptacle load after receptacle demand factors applied.
5. Review receptacle inventory. As feasible and time permits, analyze power requirements of the inventoried plug-in equipment and compare with measured load and calculated load. Comment on NEC receptacle VA requirements.

8.5.3 Evaluation of Other Loads

1. Review electrical and mechanical drawings and panel schedules. Note presence or absence of electrical heating, cooling, and hot water equipment. Note connected and demand load for “large” loads (over 10kVA) and any panels which exclusively serve one type of equipment (other than lighting and receptacle).
2. As feasible, compare panel schedule connected and demand load requirements with power requirements listed on the mechanical schedule. (Ideally, these will be manufacturer requirements, if not look up manufacturer requirements as time constraints and feasibility permit).
3. Review measured data. Observe any hourly, weekly, and seasonal patterns. Record peak power. Calculate mean power and other useful statistics.
4. Compare measured data with panel connected and demand load, and also with manufacturer requirements for any “large” loads monitored.

8.5.4 Evaluation of In-House Feeder Sizing and Transformer Loading

1. Review and comment on transformer power loss with reference to expected efficiency based on DOE requirements. As feasible and time permits, compare measured losses with estimations based on standard transformer tables and efficiency curves.
2. Review and comment on harmonic content. Calculate K-factor, if not directly measured. Compare measured K-factor with transformer K-factor rating, and K-factor rating recommended for load type.
3. Compare NEC feeder size requirements with feeder size and peak and mean measured loading. Note impact of spare capacity added to panels.
4. Compare panel schedule connected and demand load on panel served by transformer with transformer capacity, and peak and mean transformer loading.

8.5.5 Evaluation of Main Feeder Size and Service Transformer Loading

1. Review and comment on transformer power loss with reference to expected efficiency based on DOE requirements. As feasible and time permits, compare measured losses with estimations based on standard transformer tables and efficiency curves.
2. Review and comment on harmonic content, including in the context of IEEE 519.
3. Calculate K-factor, if not directly measured. Compare measured K-factor with transformer K-factor rating, and K-factor rating recommended for building type.
4. Review the measured load data. Observe hourly, weekly, and seasonal patterns. Note if main service loading similar to previous year. Calculate peak and mean power density for the building.
5. Compare connected and demand power requirements of main service panel, feeder size, and transformer rating, and feeder size and transformer rating needed to meet peak power measured.

8.5.6 General Evaluation of Power Quality

1. Note any power interruptions and duration.
2. Review voltage data. Comment on voltage stiffness and relationship to levels established in ANSI C84.1. Note the presence and frequency of any voltage fluctuations, sags, or surges.
3. Review and comment on harmonic levels.

8.6 Deliverables

The final deliverables will be:

- The report containing an extensive loading evaluation of each site and a comparison of sites, noting commonalities and differences.
- An executive summary with a database or one more spreadsheets. Key site information will be provided, including square foot, year of construction, number of employees, DOE geographic region, service voltage, and energy source for heating, cooling and hot water. Other summary information will include mean and peak power consumption (W/ft^2) of lighting, receptacle, HVAC, and other loads as applicable. Transformer capacity and mean and peak power requirements will also be included.
- Individual site archives: all requested documentation and information and data.

8.7 Budget

The budget depends largely on research project sponsorship and the commercial building study type selected. If universities sponsor the project, provide the monitoring equipment, and provide a working staff to install the equipment and supervise data collection on site, the only out-of-pocket expense would be for project management. Project management costs might be estimated to cover a two-year period from project inception to delivery of the final report. Otherwise, depending on the project scale and the buildings selected for study, project costs could reach $1 or even $2 million.

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[41] Peyton S. Hale, Robert G. Arno, and D. David Dylis, "Reliability and Availability Data Collection Program for Power Distribution, Power Generation, and HVAC Components of Commercial, Industrial, and Utility Installations," *IEEE Systems Technical Conference on Industrial and Commercial Power 2005*," Saratoga Springs, NY, 2005, pp. 199-203.

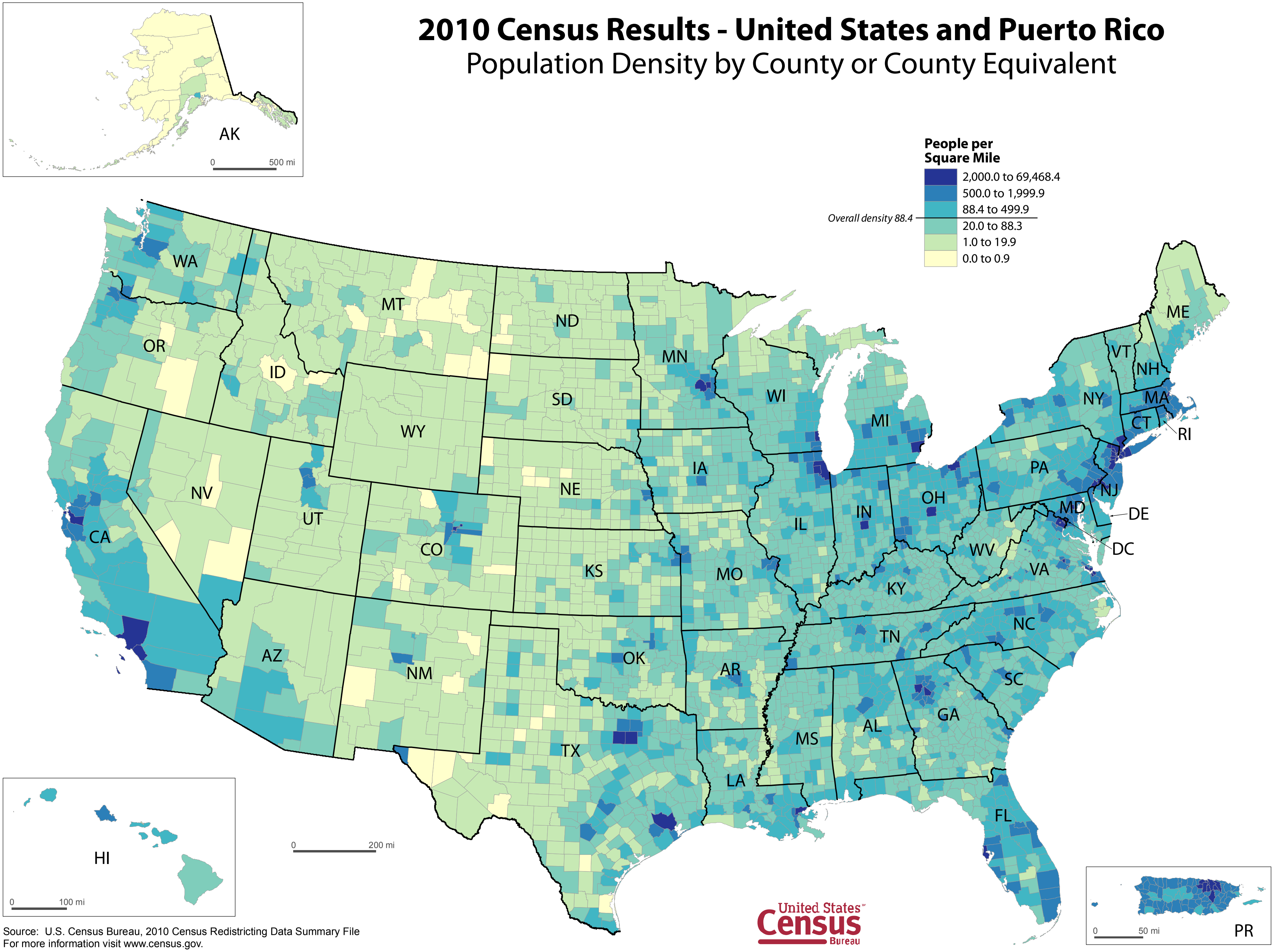
10 APPENDICES

Appendix A. U.S. Census Bureau Population Density Map

(Source: United States Census Bureau)

2010 Census Results - United States and Puerto Rico

Population Density by County or County Equivalent



Source: U.S. Census Bureau, 2010 Census Redistricting Data Summary File
For more information visit www.census.gov.

United States™ Census Bureau

Appendix B. Manufacturer Monitoring Equipment Information

Appendix B.1 GE EPM 4600 Multi-feed Power and Energy Metering System

(Reference source for Multilin™ EPM 4600 is GE Energy Connections. Reprint permission granted by General Electric.)

Multilin™ EPM 4600 Metering System

Chapter 2: EPM 4600 Metering System Overview and Specifications

The EPM 4600 unit is a multi-port, high-density power and energy metering system, designed to be used in high-density metering environments such as data centers, commercial high-rise complexes, high-density power distribution panels, and branch circuits.

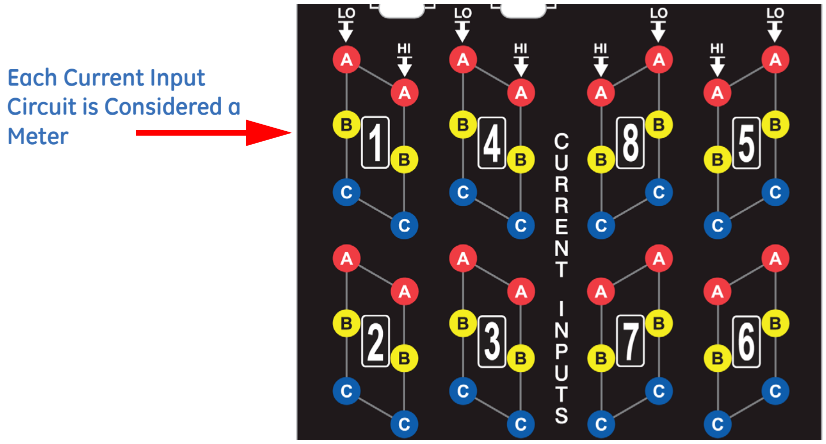
FIGURE 2.1: EPM 4600 Metering System

The EPM 4600 metering system provides 8 three phase or 24 single phase meters served by one central processing unit, which delivers the measured data in multiple formats via RS485 serial communication, USB port communication, RJ45 Ethernet, or 802.11 WiFi Ethernet options. The EPM 4600 metering system also has data logging and load profiling capability to provide historical data analysis.

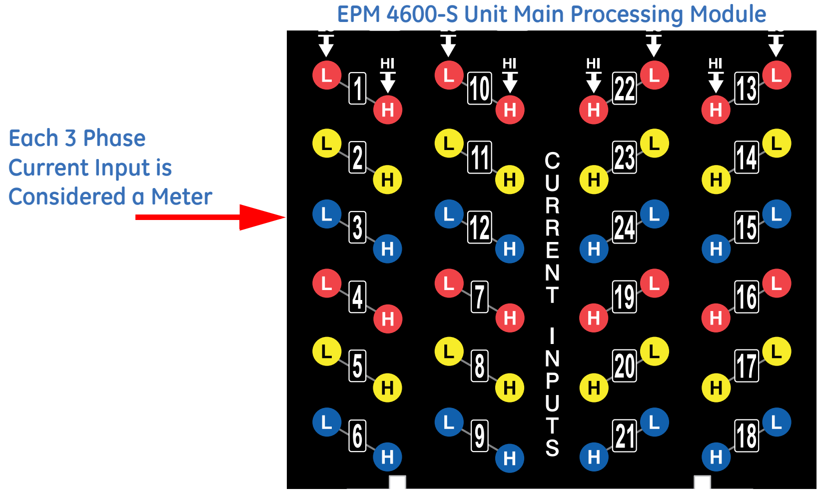
The EPM 4600 unit can be ordered as either an EPM 4600-T for three phase systems or as an EPM 4600-S for single phase systems. The EPM 4600 unit is designed to be a cost-effective instrument for high density metering. It is important to note that for this design to function properly, all loads must be powered from a common voltage (or three phase voltage) set.

The EPM 4600 metering system was designed using the following concept:

EPM 4600-T Unit Main Processing Module



EPM 4600-S Unit Main Processing Module



The EPM 4600 metering system offers up to 32 MegaBytes of non-volatile memory for per-circuit Energy usage trending. The EPM 4600 unit provides you with up to 5 logs: two historical logs, a log of limit alarms, a log of I/O changes, and a sequence of events log.

The EPM 4600 metering system is designed with advanced measurement capabilities, allowing it to achieve high performance accuracy. It is rated as a 0.5% Class accuracy metering device, meeting ANSI C12.20 and IEC 62053-22 0.5% classes.

Optional Display

The EPM 4600 unit offers an optional touch-screen color LED display. The display is available in two sizes: 3.5" (DIS3500) and 5.7" (DIS5700). The display lets you view readings from all of the meters on the EPM 4600 unit. See "Using the Optional Display" on page 10-1 for DIS3500/DIS5700 display details.

Voltage and Current Inputs

Universal Voltage Inputs

Voltage inputs allow measurement up to Nominal 480VAC (Phase to Reference) and 600VAC (Phase to Phase). This insures proper safety when wiring directly to high voltage systems. The EPM 4600 unit will perform to specification on 69 Volt, 120 Volt, 230 Volt, 277 Volt, and 347 Volt power systems.

Higher voltages require the use of potential transformers (PTs). The EPM 4600 unit is programmable to any PT ratio needed.

Current Inputs

The EPM 4600 unit can be ordered with either a 10 Amp or a 2 Amp secondary for current measurements. Depending on the EPM 4600 metering system model, there are either 8 three phase current inputs, or 24 single phase current inputs. The current inputs are only to be connected to external current transformers that are approved or certified.

The 10 Amp or 2 Amp secondary is an ordering option and as such it cannot be changed in the field. The 10 Amp secondary model (10A) allows the unit to over-range to 10 Amps per current circuit. The 2 Amp secondary model (02A) allows the unit to overrange to 2 Amps per current circuit.

Ordering Information

Table 2–2: EPM 4600 Meter Order Codes

	PL4600	–	*	–	*	–	*	–	*	–	*	Description
Base Unit	PL4600		|		|		|		|		|	
Feed Configuration			T		|		|		|		|	Three Phase
			S		|		|		|		|	Single Phase
Frequency					5		|		|		|	50 Hz AC frequency system
					6		|		|		|	60 Hz AC frequency system
Current Inputs							10A		|		|	Up to 10A Current
							02A		|		|	Up to 2A Current
Software									A		|	Transducer
									B		|	Basic Logging-2MB Memory
									C		|	Advanced Logging-32MB Memory
Communications											S	Serial (RS485) Modbus
											W	WiFi, RJ45 100BaseT Ethernet

Example:

PL4600-T-6-10A-B-S

EPM 4600 metering system with three phase circuit configuration, 60 Hz Frequency, 10 Amp Secondary, B Software option, and Serial (RS485) Modbus communication.

NOTE on Frequency: It is important to specify the frequency to insure the highest possible calibration accuracy from the factory.

Table 2–3: EPM 4600 Display Order Codes

	PL4600	–	*	Description
Displays	**PL4600**	-	**DIS3500**	3.5" Touch Screen Display with Installation Kit
			DIS5700	5.7" Touch Screen Display with Installation Kit

Software option

The EPM 4600 metering system is equipped with a Software option, which is a virtual firmware-based switch that lets you enable features through software communication. The Software option allows feature upgrades after installation without removal from service.

Available Software option upgrades are as follows:

- Software option A: Transducer
- Software option B: Basic logging with 2 MegaBytes* memory
- Software option C: Advanced logging with 32 MegaBytes* memory

* The table below shows the number of days of logging available with B and C, for the EPM 4600-T and EPM 4600-S circuit configurations, based on a 15 minute logging interval. Note that both EPM 4600-T and EPM 4600-S units have Log 1; Log 2 is used for EPM 4600-T units, only, and Log 3 is used for EPM 4600-S units, only.

Model	Wiring	Log 1 B	Log 2/3 B	Log 1 C	Log 2/3 C
EPM 4600-T	Three Phase/ 8 circuits	68 days	105 days	3617 days	2872 days
EPM 4600-S	Single Phase/24 circuits	136 days	47 days	7235 days	1247 days

Obtaining a Software option:

Contact GE Digital Energy’s inside sales staff at sales@gedigitalenergy.com and provide the following information:

1. Serial number(s) of the EPM 4600 unit(s) you are upgrading. Use the number(s), with leading zeros, shown in the GE Communicator Device Status screen (from the GE Communicator Main screen, click **Tools>Device Status**).
2. Desired Software option.
3. Credit card or Purchase Order number. GE Digital Energy will issue a Software option encrypted key.

Enabling the Software option:

1. Open GE Communicator software.
2. Power up your EPM 4600 unit.
3. Connect to the EPM 4600 unit through GE Communicator software (see “Communicating with the Meter” on page 5-1).
4. Click **Tools>Change Software option** from the Title Bar. A screen opens, requesting the encrypted key.
5. Enter the Software option key provided by GE Digital Energy.
6. Click the **OK** button. The Software option is enabled and the EPM 4600 unit resets.

Measured Values

The EPM 4600 metering system provides the following measured values, all in real time instantaneous. As the following tables show, some values are also available in average, maximum and minimum.

Table 2.1: Single Phase Circuit Configuration

Measured Values	Instantaneous	Avg	Max	Min
Voltage L-N	X		X	X
Current	X	X	X	X
WATT	X	X	X	X
VAR	X	X	X	X
VA	X	X	X	X
PF	X	X	X	X
+Watt-Hour	X			
-Watt-Hour	X			
Watt-Hour Net	X			
+VAR-Hour	X			
-VAR-Hour	X			
VAR-Hour Net	X			
VA-Hour	X			
Frequency	X		X	X
Current Angle	X			

Table 2.2: Three Phase Circuit Configuration

Measured Values	Instantaneous	Avg	Max	Min
Voltage L-N	X		X	X
Voltage L-L	X		X	X
Current per Phase	X	X	X	X
Current Neutral (see NOTE, below)	X	X	X	X
WATT (A,B,C,Tot.)	X	X	X	X
VAR (A,B,C,Tot.)	X	X	X	X
VA (A,B,C,Tot.)	X	X	X	X
PF (A,B,C,Tot.)	X	X	X	X
+Watt-Hour (A,B,C,Tot.)	X			
-Watt-Hour (A,B,C,Tot.)	X			
Watt-Hour Net	X			
+VAR-Hour (A,B,C,Tot.)	X			
-VAR-Hour (A,B,C,Tot.)	X			
VAR-Hour Net (A,B,C,Tot.)	X			
VA-Hour (A,B,C,Tot.)	X			
Frequency	X		X	X
Voltage Angles	X			
Current Angles	X			

NOTE

Neutral current is calculated only when the voltages are connected; if voltages are not connected, the neutral current will not be calculated.

Utility Peak Demand

The EPM 4600 metering system provides user-configured Block (Fixed) window or Rolling window Demand modes. This feature lets you set up a customized Demand profile. Block window Demand mode records the average demand for time intervals you define (usually 5, 15 or 30 minutes). Rolling window Demand mode functions like multiple, overlapping Block windows. You define the subintervals at which an average of Demand is calculated. An example of Rolling window Demand mode would be a 15-minute Demand block using 5-minute subintervals, thus providing a new Demand reading every 5 minutes, based on the last 15 minutes.

Utility Demand features can be used to calculate Watt, VAR, VA and PF readings. Voltage provides an instantaneous Max and Min reading which displays the highest surge and lowest sag seen by the meters. All other parameters offer Max and Min capability over the user-selectable averaging period.

Specifications

Power Supply

Range:	Universal, 90-300VAC @50/60Hz or 150VDC
Power Consumption:	18VA, 12W, Maximum

Voltage Inputs (Measurement Category III)

(For Accuracy specifications, see “Accuracy” on page 2-12.)

Range:	Universal, Auto-ranging up to 576VAC L-N, 721VAC L-L
Supported hookups:	EPM 4600-T: 3 Element Wye
	EPM 4600-S: Single Phase, 2 wire, 3 wire
Input Impedance:	4.2M Ohm/Phase
Burden:	0.09VA/Phase Max at 600 Volts; 0.014VA at 120 Volts
Pickup Voltage:	20VAC
Connection:	7 Pin 0.400” Pluggable Terminal Block
	AWG#12 -26/ (0.08 -2.5) mm2
Fault Withstand:	Meets IEEE C37.90.1
Reading:	Programmable Full Scale to any PT ratio

Current Inputs

(For Accuracy specifications, see “Accuracy” on page 2-12.)

Class 10:	5A Nominal, 10A Maximum
Class 2:	1A Nominal, 2A Maximum
Burden:	0.005VA Per Input Max at 11 Amps
Pickup Current:	0.1% of Nominal Class 10: 5mA Class 2: 1mA
Current Input Terminals:	8-32 Threaded Studs
Reading:	Programmable Full Scale to any CT ratio
Continuous Current Withstand:	20 Amps
Maximum Voltage across Current Inputs:	1VAC

Maximum Voltage from Current Inputs to Ground: 50VAC

NOTE

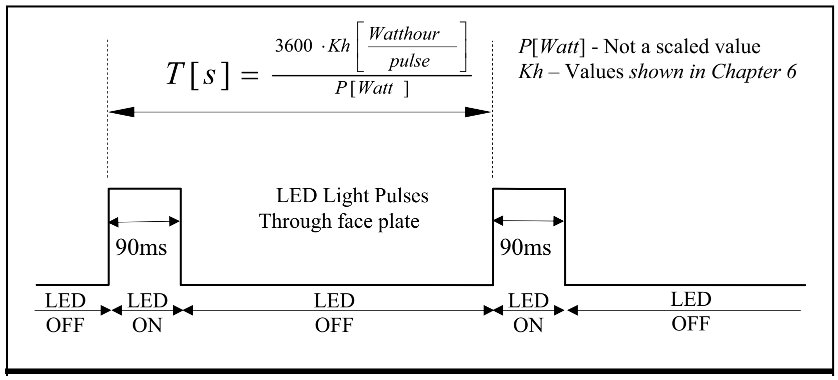
For detailed electrical specifications for the optional display see “DIS3500/DIS5700 Specifications” on page 10-3

Wh Pulses

Red LED light pulses through top cover (see “Performing Watt-Hour Accuracy Testing” on page 6-2 for Kh values):

Peak Spectral wavelength: 574nm

Output timing:



See **“Performing Watt-Hour Accuracy Testing” on page 6-2** for Kh values.

Isolation

All Inputs and Outputs are galvanically isolated to 2500 VAC

Environmental Rating with and without Optional Display DIS3500/DIS5700

Storage:	(-20 to +70)^{o} C/(-4 to +158)^{o} F
Storage with Display:	(-20 to +60)^{o} C/(-4 to +140)^{o} F
Operating:	(-20 to +60)^{o} C/(-4 to +140)^{o} F
Operating with Display:	(0 to +50)^{o} C/(+32 to +122)^{o} F
Humidity:	to 95% RH Non-condensing
Humidity with Display:	to 85% RH Non-condensing; Wet bulb temperature 39°C/ 102.2° F or less

Measurement Methods

Voltage, current:	True RMS
Power:	Sampling at over 400 samples per cycle on each channel simultaneously

Update Rate

All parameters:	Every 60 cycles (e.g., 1 s @ 60 Hz)

Communication

Standard:

1. RS485 port (Com 1)
2. USB port (Com 2)
3. RS485/Display port (Com 3)

4. Energy pulse output LED for meter testing: there are 8 pulses, one for each of the three phase loads of the EPM 4600-T; for the EPM 4600-S, the test pulses are shared, with one pulse for every three loads (see "Using the Metering System's Watt-Hour Test Pulses" on page 6-1 for more details and instructions for using the Test pulses).

Optional:

Ethernet/WiFi port (Com 1): 802.11b Wireless or RJ45 Connection 10/100BaseT Ethernet

Com Specifications

RS485 Ports (Com 1 and Com3):

RS485 Transceiver; meets or exceeds EIA/TIA-485 Standard

Type:	Two-wire, half duplex
Min. input impedance:	96kΩ
Max. output current:	±60mA
Protocol:	Modbus RTU, Modbus ASCII
Com port baud rates:	9600 to 57600 bps
Device address:	001-247
Data format:	8 Bit

WiFi/Ethernet Port (optional Com 1):

Wireless security:	64 or 128 bit WEP; WPA; or WPA2
Protocol:	Modbus TCP
Device address:	001-247

USB Port (Com 2):

Protocol:	Modbus ASCII
Com port baud rate:	57600 bps
Device address:	1

Com Specifications for Optional Displays DIS3500/DIS5700

Serial Interface COM1:

Asynchronous Transmission: RS232C / RS422 / RS485

Data Length:	7 or 8 bits
Stop Bit:	1 or 2 bits
Parity:	None, odd or even
Data Transmission Speed:	2,400 to 115.200 kbps, 187,500 bps
Connector:	D-Sub 9-pin (plug)

Ethernet Interface:

Ethernet (LAN):	IEEE802.3i/ IEEE802.3u, 10BASE-T/100BASE-TX
Connector:	D-Sub 9-pin (plug)

LED:

Green, lit:	Data transmission is available
Green, blinking:	Data transmission is occurring

Relay Output/Digital Input Board Specifications at 25° C

Relay outputs:

Number of outputs: 2

Contact type:	Changeover (SPDT)
Relay type:	Mechanically latching
Switching voltage:	AC 150V / DC 30V
Switching power:	750VA / 150W
Switching current:	5A
Switching rate max.:	10/s
Mechanical life:	5×10^7 switching operations
Electrical life:	10^5 switching operations at rated current
Breakdown voltage:	AC 1000V between open contacts
Isolation:	AC 3000V / 5000V surge system to contacts
Reset/power down state:	No change - last state is retained

Inputs:

Number of inputs:	4
Sensing type:	Wet or dry contact status detection
Wetting voltage:	DC (1-24)V, internally generated
Input current:	2.5mA – constant current regulated
Minimum input voltage:	0V (input shorted to common)
Maximum input voltage:	DC 150V (diode protected against polarity reversal)
Filtering:	De-bouncing with 50ms delay time
Detection scan rate:	100ms
Isolation:	AC 2500V system to inputs
External Connection:	AWG 12-26/(0.129 - 3.31)mm^2 11 pin, 0.200" pluggable terminal block

Mechanical Parameters

Dimensions:	7.6(L) x 11.28(W) x 4.36(H) in / 19.3(L) x 28.65(W) x 11.07(H) cm
Weight:	7 pounds (3.18kg)

Compliance

- UL Listing: UL61010-1, CAN/CSA C22.2 No. 61010-1, UL file number E250818
- IEC 62053-22 (0.5% Class)
- ANSI C12.20 (0.5% Accuracy)
- ANSI (IEEE) C37.90.1 Surge Withstand
- ANSI C62.41 (Burst)
- EN61000-6-2 Immunity for Industrial Environments
- EN61000-6-4 Emission Standards for Industrial Environments
- EN61326 EMC Requirements

Accuracy

(For full Range specifications see "Specifications" on page 2-8.)

EPM 4600 metering system Clock accuracy:

±3.5ppm max. (±0.3024 second/day) over the rated temperature range

For 23 °C, three phase or single phase 3 wire connected balanced load:

Parameter	Accuracy	Accuracy Input Range
Voltage L-N [V]	0.3% of reading*	(69 to 480)V
Voltage L-L [V]	0.5% of reading	(120 to 600)V
Current Phase [A]	0.3% of reading	(0.15 to 5)A
Current Neutral (calculated) [A]	2.0% of Full Scale	(0.15 to 5)A @ (45 to 65)Hz
Active Power Total [W]	0.5% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0.5 to 1) lag/ lead PF
Active Energy Total [Wh]	0.5% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0.5 to 1) lag/ lead PF
Reactive Power Total [VAR]	1.0% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0 to 0.8) lag/ lead PF
Reactive Energy Total [VARh]	1.0% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0 to 0.8) lag/ lead PF
Apparent Power Total [VA]	1.0% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0.5 to 1) lag/ lead PF
Apparent Energy Total [VAh]	1.0% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0.5 to 1) lag/ lead PF
Power Factor	1.0% of reading*	(0.15 to 5)A @ (69 to 480)V @ +/- (0.5 to 1) lag/ lead PF
Frequency	+/- 0.01Hz	(45 to 65)Hz

* For unbalanced voltage inputs where at least one crosses the 150V auto-scale threshold (for example, 120V/120V/208V system), degrade accuracy by additional 0.4%.

The EPM 4600 metering system's accuracy meets the IEC62053-22 and ANSI C12.20 Accuracy Standards for 0.5% Class Energy meters.

Appendix B.2 Honeywell E-Mon Class 3400 Smart Meter

(Unfortunately, permission has been delayed for reprinting the specification sheet for the Class 3400 Smart Meter, a product of E-Mon D-Mon: Energy Monitoring Products & Systems, Honeywell Corporation. Since the publication of this report cannot be delayed, the report will be published without it.)

The specification sheet for the Class 3400 Smart Meter, as well as other documents for the Class 3400 Smart Meter and other E-Mon meters, can be downloaded from:

http://www.emon.com/en/downloads

A summary of the specification sheet for the Class 3400 Smart Meter can be found on the following two pages.

Class 3400 Smart Meter

Advanced kWh/Demand Meters with Communication

4-line by 20-character backlit LCD display for

- kWh
- Real-time kW load and kW demand with peak data and time
- Power factor, current, and voltage per phase

Onboard optional set-up for

- IP address
- Meter date and time
- Load control settings (optional expanded feature package)
- ID codes for EZ7, Modbus, and BACnet

Onboard installation diagnostics and verification

Split-core current sensors (0-2V output)

Built-in RS-485 communications

- Supports up to 52 Class 3200, 3400, or 5000 meters per channel
- Cables in daisy chain or star configuration, 3-conductor, 18-22 AWG, up to 4,000 feet total per channel

Built-in communication

- RS-485
- Ethernet
- Pulse output
- Optional telephone modem

Protocols

- EZ7
- Modbus RTU or TCP/IP
- BACnet MS/TP or IP
- LonWorks FT-10

Records KWh and kVARh delivered, and kWh and kVARh received in the first four channels

- Data stored in 15-minute intervals for 72 days (or 5-minute intervals for 24 days)
- Data stored in first-in, first-out format

Compatible with E-Mon Energy software using EZ7 protocol for automatic meter reading, billing, and profiling of energy data

Meter appropriate for use on three-phase, 3-wire (delta) or three-phase, 4-wire (wye) circuits

Enclosure

- Standard - Outdoor NEMA 4X polycarbonate enclosure with padlocking hasp and mounting flanges for indoor/outdoor installation (stand alone)
- Optional – Industrial grade JIC steel enclosure with padlocking hasp and mounting flanges for indoor installation (stand alone)

UL/CUL listed. Certified to ANSI C12.20 national accuracy standards

Meters available for three-phase 120/208-240V, 277/480V, and 347/600V systems

Meter ampacity sizes: 100A, 200A, 400A, 800A, 1600A, 3200A

Appendix B.3 Onset Data Loggers for Real Power or Phase RMS Currents

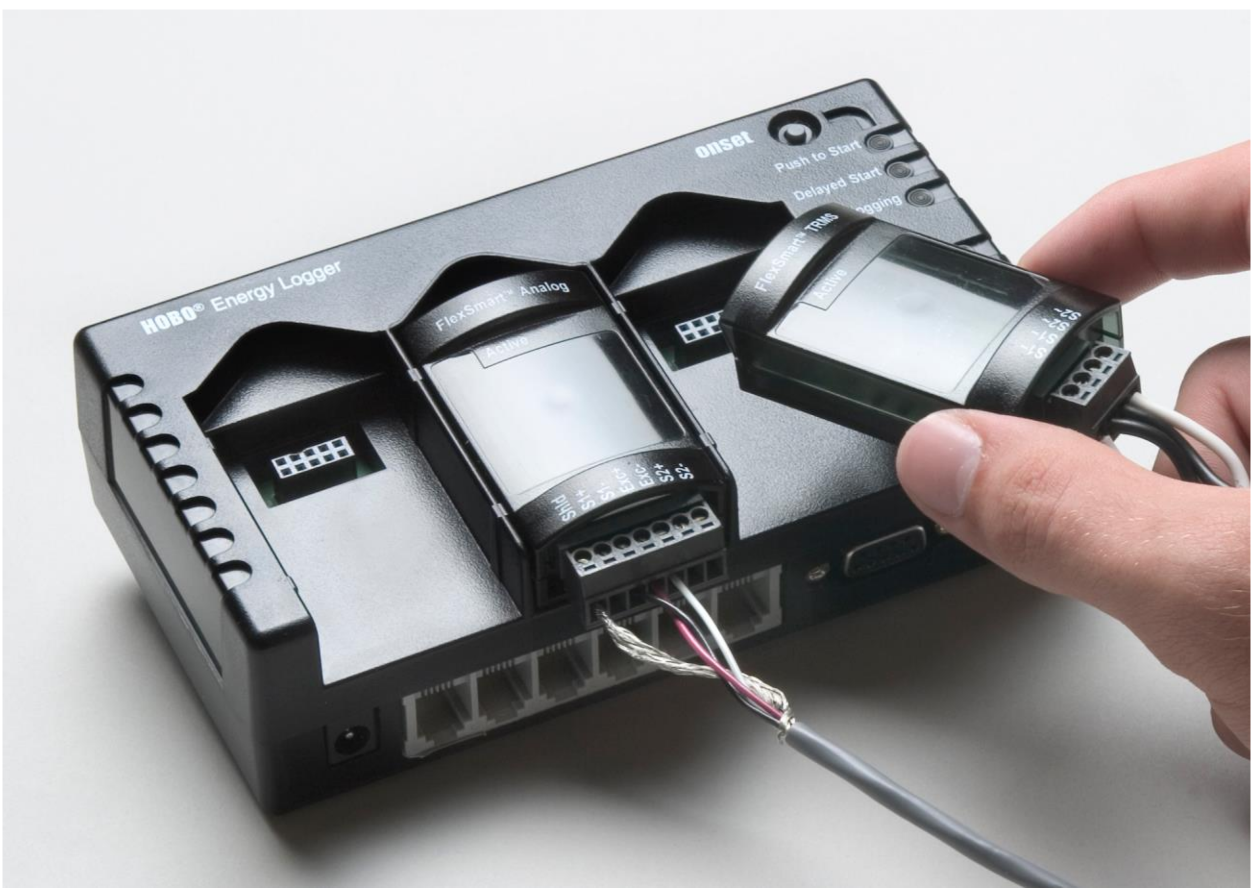
Reference source for the following devices is Onset Corporation / www.onsetcomp.com:

- HOBO Energy Logger
- FlexSmart TRMS Module
- HOBO® State Data Logger (UX90-001x)

Reprint permission granted by Onset Computer Corporation.

Reference source for the WattNode Pulse is WattNode BACnet energy meter manufactured by Continental Control Systems, LLC. Reprint permission granted by Continental Control Systems, LLC.


onset
FlexSmart™ Analog
FlexSmart™ TRMS
FlexSmart™ TRMS
Active
Push to Start
Delayed Start
Logging
Memory Low
Battery Low
Sensor Fail

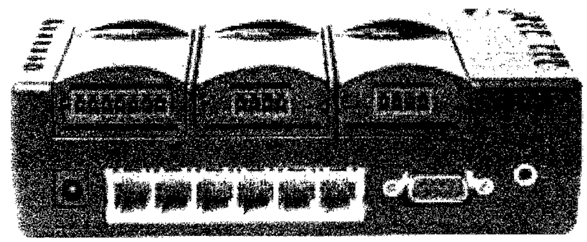

onset
Push to Start
Delayed Start
HOBO® Energy Logger
FlexSmart™ Analog
Active
FlexSmart™ TRMS
Active
Shld
S1+
S1-
Exc+
S2+
S2-

onset

HOBO® Energy Logger

Multi-channel energy data logging system

The HOBO Energy Logger multi-channel data logger is a modular, reconfigurable data logging system for energy and industrial monitoring applications.



The 15-channel system enables energy and facility management professionals to quickly and easily solve a broad range of monitoring applications without having to purchase a toolbox full of data loggers.

Supported Measurements: Temperature, Relative Humidity, Dew Point, 4-20mA, AC Current, AC Voltage, Air Velocity, Amp Hour, Carbon Dioxide, Compressed Air Flow, DC Current, DC Voltage, Differential Pressure, Gauge Pressure, Kilowatt Hours, Kilowatts, Power Factor, Pulse Input, Volatile Organic Compound, Volt-Amp Reactive, Volt-Amp Reactive Hour, Volt-Amps, Water Flow, Watt Hours, Watts, Wind

Key Advantages:

- Records up to 15 channels
- Provides 12v excitation for third-party sensors
- Pre-configured Smart Sensors for fast setup
- Signal conditioning modules retain configurations until you change them, providing plug-and-play convenience for commonly used sensors
- Flexible power options include battery operation or AC power adapter
- Works with Onset's E50B2 Power & Energy Meter to measure Power Factor, Reactive Power, Watt Hours, and more

Minimum System Requirements:

Software

Interface Cable*

Sensor

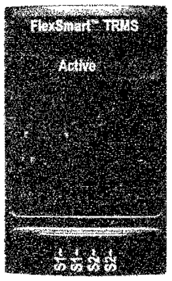
*USB to Serial interface cable, part #CABLE-PC-3.5

Part number	H22-001
Memory	512K nonvolatile flash data storage
Operating Range	-20° to 50°C (-4° to 122°F) with alkaline batteries -40° to 60°C (-40° to 140°F) with lithium batteries
Sensor Inputs	6 RJ-12 Smart Sensor jacks plus 3 FlexSmart module slots
Communication	RS-232 via 3.5 mm serial port*
Logging Interval	1 second to 18 hours, user-specified interval
Sensor Excitation	12 V DC at 200 mA total, with user-programmable warm up time on a per-channel basis
Battery Life	1 year typical
Battery Type	8 standard AA alkaline batteries (included)
External Power	Supports optional 13.6 V DC regulated AC Wall Adapter Connector
Time Accuracy	0 to 2 seconds for the first data point and ± 5 seconds per week at 25°C (77°F)
Dimensions	15.6 cm x 8.4 cm x 4.6 cm (6.13 in x 3.31 in x 1.81 in)
CE Compliant	Yes

*USB to Serial interface cable, part #CABLE-PC-3.5


FlexSmart™ TRMS
Active
S1~
S1~
S2~
S2~

FlexSmart™ TRMS Module
(Part No: S-FS-TRMSA & S-FS-TRMSA-D)



Quick Start Guide

Inside this package:

- FlexSmart TRMS Module
- Detachable screw terminal connector
- Imprintable label
- This guide

Note: Refer to the documentation provided with the Onset HOBO® H22 or U30 series data logger and HOBOware® Pro software for additional information on using and configuring the FlexSmart TRMS Module.

Introduction

Thank you for purchasing an Onset FlexSmart TRMS Module. With proper care, it will give you years of accurate and reliable measurements.

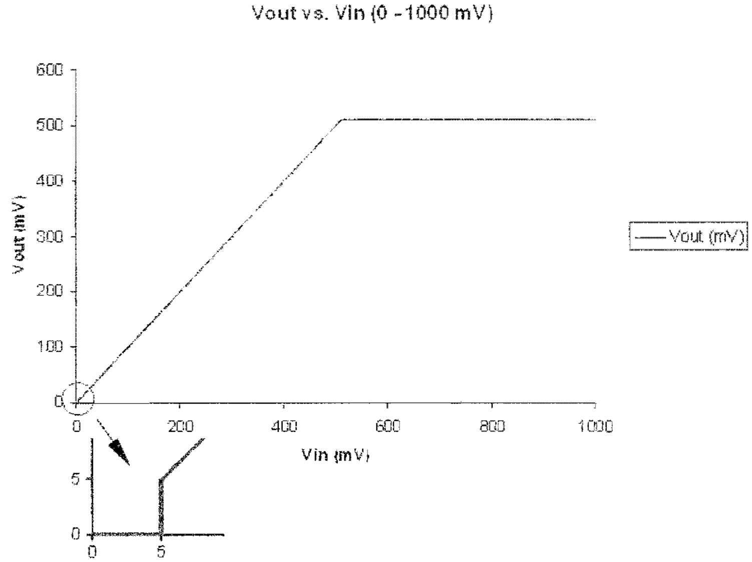
The S-FS-TRMSA and S-FS-TRMSA-D are easy-to-configure, True-RMS input measurement modules. The S-FS-TRMSA is compatible with Onset's HOBO H22 series data loggers. The S-FS-TRMSA-D is compatible with both the HOBO U30 and H22 series loggers. The "-D" variant has a modular connector for connecting to an available smart-sensor port. Both 2-channel modules have an input range of 512 millivolts RMS full-scale. Thus, they are fully compatible with industry-standard voltage and current transformers (PT and CT) which output 333 millivolts RMS full-scale.

The modules feature extremely low-power operation, resulting in long battery life for unattended data logging applications.

Specifications

Input Channels	Two, AC-coupled
Field Wiring	Two-wire via screw terminals on detachable connector, 16-24 AWG Replacement detachable connectors: Part of spares kit, Onset part no: A-FS-TRMSA-4P-1
Input Range	5 to 512 mVRMS
Minimum Input Voltage	5mVRMS; Input voltages < 5mV will be clipped to zero (see graph below)
Maximum Input Voltage	+/- 1V referred to AC- terminals (pins 2 and 4)
Input Frequency	50/60 Hz
Accuracy	+/- 0.3% of reading +/- 0.5% of FSR
ADC Resolution	15 bits
AC Waveform	< 4 Crest Factor
Power Requirements	+3.3V @ 3mA active, 6µA sleep
Transfer Function	$VRMS = \sqrt{\frac{1}{T}\bullet\int_0^T [V(t)^2]dt}$
Measurement Averaging Option	Yes
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).

Minimum Input Voltage Graph



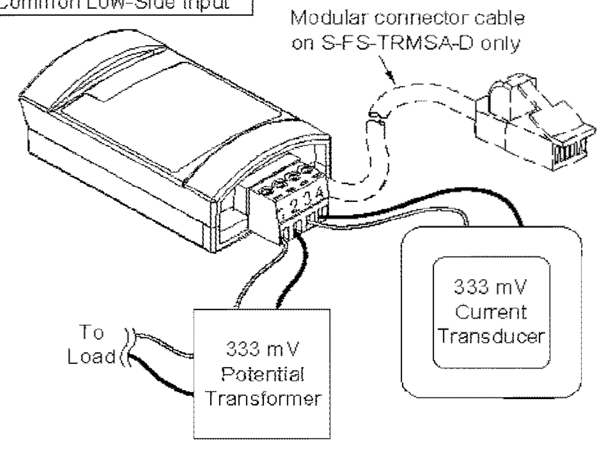
Module Connections

Potential Transformers (PT) and Current Transducers (CT) are connected to the module via a four-pin Phoenix-style detachable screw terminal connector. Once the PTs and/or CTs are connected, the module can then be configured using HOBOware Pro software (with the module installed on the HOBO H22 or U30 series data logger).

The diagram at below illustrates *typical* connections for a PT and CT. For module connection instructions specific to PTs and CTs purchased from Onset, refer to the documentation provided with each PT and CT.

Note: For three-phase monitoring, each of the three modules should be wired so that similar parameters are connected to corresponding pin numbers. For example, voltage inputs pins 1 and 2 on each module; current inputs pins 3 and 4 on each module.

Pin #	Function
1	Channel 1 High-Side Input
2	Common Low-Side Input
3	Channel 2 High-Side Input
4	Common Low-Side Input



Measurement Averaging

This sensor supports measurement averaging. When measurement averaging is enabled, data is sampled more frequently than it is logged. The multiple samples are then averaged together and the average value is stored as the data for the interval. For example, if the logging interval is set at 10 minutes and the sampling interval is set at 1 minute, each recorded data point will be the average of 10 measurements. Measurement averaging is useful for reducing noise in the data.

HOBO® State Data Logger (UX90-001x) Manual

HOBO State Data Logger

Models: UX90-001
UX90-001M

Included Items:

- 2.5 mm input cable
- Command™ strip
- Double-sided tape
- Hook & loop strap
- Magnet with 2 screws

Required Items:

- HOBOware 3.3 or later
- USB cable (included with software)

Accessories:

- Wattnode kWh transducers
- Power & Energy Meter (T-VER-E50B2)
- Water Flow Meter Sensor (T-MINOL-130-NL)
- U-Shuttle (U-DT-1)

The HOBO State/Pulse/Event/Runtime data logger records state changes, electronic pulses and mechanical or electrical contact closures from external sensing devices. Using HOBOware®, you can easily configure the internal magnetic reed switch or the external sensor to monitor and record data in a wide variety of applications, such as energy consumption, mechanical equipment operation, and water and gas flow. This compact data logger also has a built-in LCD screen to monitor logging status, battery use, and memory consumption. There are two models of the HOBO state logger: the UX90-001 has 128 KB of memory while the UX90-001M has 512 KB.

Specifications

Internal Sensor

Maximum State, Event, Runtime Frequency	1 Hz
Preferred Switch State	No magnet present (normally open)

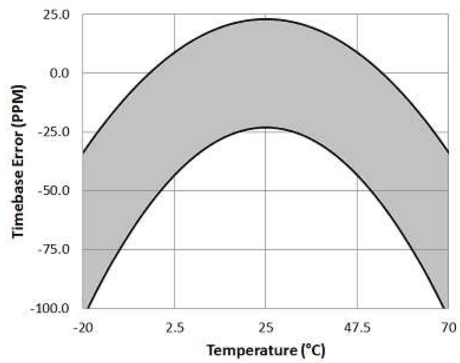
External Input

External Contact Input	Electronic solid state switch closure or logic driven voltage output
Range	0 to 3 V DC (USB powered), 0 to 2.5 V DC (battery powered)
Maximum Pulse Frequency	50 Hz
Maximum State, Event, Runtime Frequency	1 Hz
Pulse, Event Lockout Time	0 to 1 second in 100 ms steps
Solid State Switch Closure	Input Low: < 10 KΩ; Input High: > 500 KΩ
Internal Weak Pull-Up	100 KΩ
Input Impedance	Solid state switch closure: 100 KΩ pull up

Logger

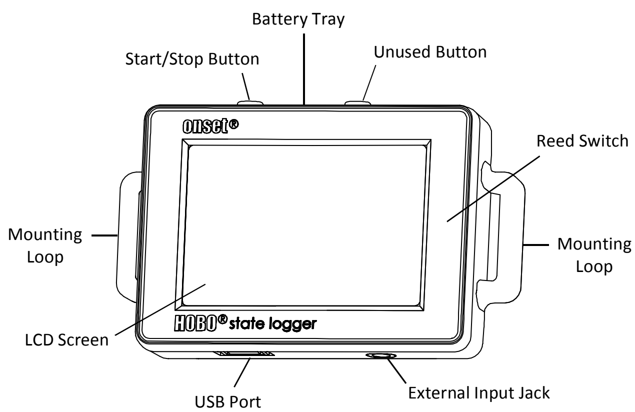
Resolution	Pulse: 1 pulse, Runtime: 1 second, State and Event: 1 State or Event
Logging Rate	1 second to 18 hours, 12 minutes, 15 seconds
Memory Modes	Wrap when full or stop when full
Start Modes	Immediate, push button, date & time, or next interval
Stop Modes	When memory full, push button, or date & time
Time Accuracy	±1 minute per month at 25°C (77°F) (see Plot A)
Power Source	One 3V CR2032 lithium battery and USB cable
Battery Life	1 year, typical with logging intervals greater than 1 minute and normally open contacts
Memory	UX90-001: 128 KB (84,650 measurements, maximum) UX90-001M: 512 KB (346,795 measurements, maximum)
Download Type	USB 2.0 interface
Full Memory Download Time	10 seconds for 128 KB; 30 seconds for 512 KB
Logger Operating Range	Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing) Launch/Readout: 0° to 50°C (32° to 122°F) per USB specification
LCD	LCD is visible from: 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Size	3.66 x 5.94 x 1.52 cm (1.44 x 2.34 x 0.6 in.)
Weight	23 g (0.81 oz)
Environmental Rating	IP50
CE	The CE Marking identifies this product as complying with all relevant directives in the European Union (EU).

Specifications (continued)



Plot A: Time Accuracy

Logger Components and Operation



Start/Stop Button: Press this button for 3 seconds to start or stop logging data. This requires configuring the logger in HOBOware with a push button start or stop (see *Setting up the Logger*). You can also press this button for 1 second to record an internal event (see *Recording Internal Logger Events*) or to turn the LCD screen on if the option to turn off the LCD has been enabled (see *Setting up the Logger*). Note that the other button on the top of the logger is not functional for this model.

Battery Tray: Remove the battery tray (not visible in the diagram) on the top of the logger to access the logger battery (see *Battery Information*).

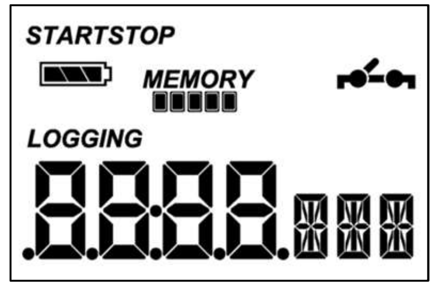
Reed Switch: The internal reed switch (not visible in the diagram) inside the logger housing allows for monitoring when windows and doors are open or closed (see *Using the Magnet*).

Mounting Loops: Use the two mounting loops to mount the logger with the hook-and-loop strap (see *Mounting the Logger*).

External Input Jack: Use this jack to attach the 2.5 mm input cable to an external sensing device (see *Using the Input Cable*).

USB Port: Use this port to connect the logger to the computer or the HOBO U-Shuttle via USB cable (see *Setting up the Logger* and *Reading Out the Logger*).

LCD Screen: This logger is equipped with an LCD screen that displays details about the current status. This example shows all symbols illuminated on the LCD screen followed by definitions of each symbol in the following table.



LCD Symbol	Description
START	The logger is waiting to be launched. Press and hold the Start/Stop button for 3 seconds to launch the logger.
STOP	The logger has been launched with a push button stop enabled; press and hold the Start/Stop button for 3 seconds to stop the logger. **Note**: If you also launched the logger with a push button start, this symbol will not appear on the display for 5 minutes.
	The battery indicator shows the approximate battery power remaining.
	If the logger has been configured to stop logging when memory fills, the memory bar indicates the approximate space remaining in the logger to record data. In this example, the logger memory is almost full.
	If the logger has been configured to never stop logging (wrapping enabled), then a single block will blink starting at the left and moving right over time. Each block represents a segment of memory where the data is being recorded. In this example, the middle block is blinking.
	The switch is open or off.
	The switch is closed or on.
	The logger is configured to record pulse or event data.
LOGGING	The logger is currently logging.
0538 M-S	**Time display when logger is logging:** This shows the total amount of time the switch has been closed or on since logging began, ranging from seconds to days. This example indicates the switch has been closed or on for a total of 5 minutes and 38 seconds. The logger must be launched with the LCD set to show "Time" for this symbol to display. **Time display when logger is stopped:** This indicates the logger has been configured to start logging on a particular date/time. The display will count down to the start date/time until logging begins. In this example, 5 minutes and 38 seconds remain until logging will begin.
24 %	This shows the percentage of time the switch has been closed or on since logging began. This example indicates the switch has been closed or on for a total of 24% of the time since logging began. The logger must be launched with the LCD set to show "%" for this symbol to display.
StoP	The logger has been stopped.

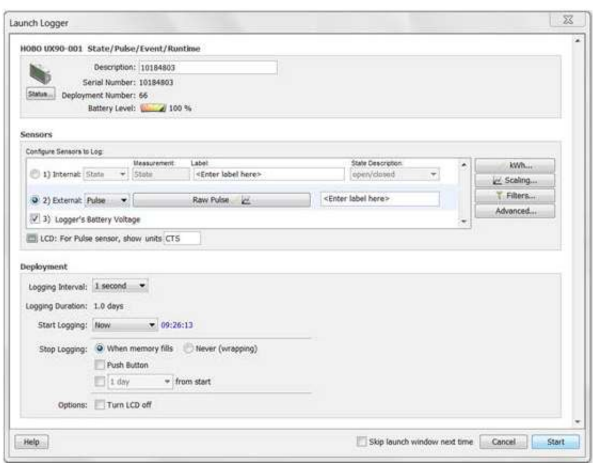
Notes:

- You can disable the LCD screen when logging. Select “Turn LCD Off” when setting up the logger as described in the next section. When this option is enabled, you can still temporarily view the LCD screen by pushing the Start/Stop button for 1 second. The LCD will then remain on for 10 minutes.
- When the logger has stopped logging, the LCD will remain on until the logger is offloaded to a computer or HOBO U-Shuttle (unless launched with the “Turn LCD Off” option). Once the logger has been offloaded and disconnected from the computer, the LCD will turn off automatically after 2 hours. The LCD will turn back on the next time the logger is connected to the computer.
- If the pulse count exceeds 9,999 or -999, a second decimal point will be illuminated on the LCD to indicate the count has surpassed the 4-digit display.

Setting up the Logger

Use HOBOware to set up the logger, including selecting the start and stop logging options, configuring the sensors, and entering scaling factors as necessary. It may be helpful to set up the logger to start at a specific date/time or with a push button stop and then bring it to the location where you will mount it to connect any external devices and test the connections before logging begins.

1. **Connect the logger and open the Launch Logger window**. To connect the logger to a computer, plug the small end of the USB cable into the side of the logger and the large end into a USB port on the computer. Click the Launch icon on the HOBOware toolbar or select Launch from the Device menu.



Important: USB 2.0 specifications do not guarantee operation outside the range of 0°C (32°F) to 50°C (122°F).

2. **Configure the sensor.** Choose either the internal or external sensor. Enter the name and select the state description as necessary or select the sensor type. Type a label for the sensor if desired.

   The internal sensor can be configured to log:

   - **State.** This records how long an event lasts by storing the date and time when the state or switch changes (logic state high to low or low to high). The logger checks every second for a state change, but will only record a time-stamped value when the state change occurs. One state change to the next represents the event duration.
   - **Runtime.** The logger checks the state of the switch once every second. At the end of each logging interval, the logger records how many seconds the line was in the logic low state.

   The external channel can be configured to log state or runtime as described above or the following:

   - **Pulse.** This records the number of pulse signals per logging interval (the logger records a pulse signal when the input transitions to the logic low). There are built-in scaling factors you can select for supported devices and sensors, or you can set your own scaling when you select raw pulse counts. Click the Advanced button to adjust the maximum pulse frequency and lockout time as needed (see *Setting the Maximum Pulse Frequency and Lockout Time* for more details). **Note:** Setting maximum pulse frequency to 50 Hz will reduce battery life.
   - **Event.** This records the date and time when a connected relay switch or logic low transition occurs (the logger records an event when the input transitions to the logic low). This is useful if you need to know when a switch closes, but the duration of the closure is not important. Click the Advanced button to adjust the lockout time to debounce switches as needed.

3. **Configure optional filters as necessary.** Click the Filters button to create additional filtered data series based on the sensor configuration. Any filtered series will be automatically available upon reading out the logger.

4. **Set the units to display on the LCD screen.** For State and Runtime sensors, select either Time or %. For external sensors, you can either use the default units or enter your own units up to three characters.

5. **If the logger is configured to record pulse or runtime, choose a logging interval from 1 second to a maximum of 18 hours, 12 minutes, and 15 seconds.**

6. **Choose when to start logging:**

   - **Now.** Logging begins immediately.
   - **At Interval.** Logging will begin at the next even interval (available when logging pulse or runtime).
   - **On Date/Time.** Logging will begin at a date and time you specify.
   - **Push Button.** Logging will begin once you press the Start/Stop logging button for 3 seconds.

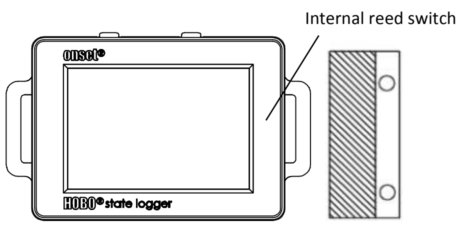
7. **Choose when to stop logging:**

   - **When Memory Fills.** Logging will end once the logger memory is full.
   - **Never (Wrapping).** The logger will continue recording data indefinitely, with newest data overwriting the oldest.
   - **Push Button.** Logging will end once you press the Start/Stop logging button for 3 seconds. Note that if you also choose Push Button to start logging, then you will not be able to stop logging until 5 minutes after logging begins.
   - **Specific Stop Time.** Logging will end at a date and time you specify.

8. **Choose whether to keep the LCD on or off.** By default, the LCD will always remain on while logging. If you select the “Turn LCD off” checkbox, the LCD will not show the current readings, status, or other information while the logger is logging. You will, however, be able to temporarily turn the LCD screen on by pressing the Start/Stop button for 1 second if you select this option.
9. **Click the Start button to launch the logger.** Disconnect the logger from the computer and deploy it using the mounting materials (see *Mounting the Logger*). After logging begins, you can read out the logger at any time (see *Reading Out the Logger* for details).

Using the Magnet (Internal Sensor)

The logger contains an internal reed switch that can be used with the included magnet as the input to the logger. This configuration can be used to determine when a door or window is open or closed. The magnet must be oriented as shown below, positioned to the right side of the logger when the LCD screen is facing up.



Using the Input Cable (External Sensor)

The 2.5 mm input cable included with the logger can be used to measure contact closures and allows the logger to be mounted remotely from the contacts. Connect the contacts to the black and white wires, and plug the other end of the cable into the external input jack on the bottom of the logger. Do not connect the contacts to any other devices or cables.

If the external sensor was configured to record raw pulse counts or events in HOBOware, there is also an option to specify lockout time. This can prevent false readings from mechanical contact closure bouncing. For more details on setting lockout time, see the HOBOware Help.

Determining Logging Duration Data

The logger’s storage capacity and logging duration depends on the interval between state changes and events. The longer the interval between state changes, the more memory is needed to store each data point.

The following table shows how memory capacity is affected by the amount of time between events:

Time Between Events	Approximate Total Data Points	Approximate Logging Duration (1 Year Battery Life)	Logger Part Number
1 to 15 seconds	84,650	23.51 hours to 14.7 days	UX90-001
	346,795	4.01 to 60.21 days	UX90-001M
16 seconds to 4.25 minutes	63,488	11.76 to 187.38 days	UX90-001
	260,096	48.17 days to 2.1 years	UX90-001M
4.26 to 68.25 minutes	50,790	150.49 days to 6.6 years	UX90-001
	208,077	1.69 years to 2.7 decades	UX90-001M
68.26 minutes to 18.2 hours	42,325	5.5 years to 8.8 decades	UX90-001
	173,397	2.25 to 36.03 decades	UX90-001M

Notes:

- Typical battery life is 1 year when state or event changes are at 1 minute or greater intervals.
- The logger can record battery voltage data in an additional channel. This is disabled by default. Recording battery voltage reduces storage capacity and is generally not used except for troubleshooting.

Setting Maximum Pulse Frequency and Lockout Time

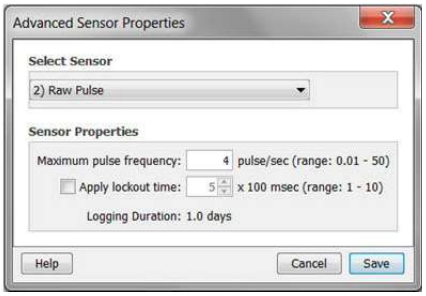
When recording raw pulse counts, the logger dynamically adjusts its memory use from 4 to 32 bits instead of a typical fixed width. This results in the ability to store more data using less space, which in turn extends logging duration. The default pulse rate is 4 Hz; the maximum pulse frequency is 50 Hz. Decreasing the rate will increase logging duration. The following table shows examples of how pulse rate and logging interval affect logging duration.

Logging Interval	Pulse Rate (Hz)	Number Bits Required	Approx. Total Data Points	Approx. Logging Duration	Logger Part Number
1 min	4	8	126,976	88 days	UX90-001
			520,192	361 days	UX90-001M
1 min	50	12	84,650	58 days	UX90-001
			346,795	240 days	UX90-001M

You can change the maximum pulse frequency in HOBOware. In addition, you can also set a lockout time for raw pulse and event channels to prevent false readings from mechanical sensors as their relay state changes. To change the maximum pulse frequency or lockout time:

1. Click the Advanced button from the Launch Logger window in HOBOware.
2. Select the sensor that corresponds with the pulse channel you wish to configure.
3. Set the maximum pulse frequency (on raw pulse channels only) keeping in mind that the larger the pulse frequency, the shorter the logging duration will be.
4. Click the “Apply lockout time” checkbox if you wish to specify a time period when pulses will be ignored (only available for raw pulse channels and event channels). Select the lockout time value from 1 to 10. On sensors with both

pulse frequency and lockout time settings, lockout time will affect the maximum pulse frequency: the higher the lockout time, the lower the maximum pulse frequency will be. **Note:** When lockout time is enabled, you can specify a value from 1 to 10 (with a default of 5), which is then multiplied by 100 milliseconds for a range of 0.1 to 1 second. The available range for the maximum pulse frequency is automatically recalculated based on the lockout time. For example, if the lockout time is set to 2, the maximum pulse frequency range changes to 0.01 to 5 Hz.



5. Click Save. Note that the selections will not take effect in the logger until you launch it.

Reading Out the Logger

There are two options for reading out the logger: connect it to the computer with a USB cable and read out it with HOBOware, or connect it to a HOBO U-Shuttle (U-DT-1, firmware version 1.15m030 or higher) and then offload the data files from the U-Shuttle to HOBOware. Refer to the HOBOware Help for more details.

Recording Internal Logger Events

The logger records the following internal events (different from state/event changes) to help track logger operation and status:

Internal Event Name	Definition
Host Connected	The logger was connected to the computer.
Started	The Start/Stop button was pressed to begin logging.
Stopped	The logger received a command to stop recording data (from HOBOware or by pushing the Start/Stop button).
Button Up/Button Down	The Start/Stop button was pressed for 1 second.
Safe Shutdown	The battery level dropped below 2.5 V; the logger performs a safe shutdown.

Mounting the Logger

There are several ways to mount the logger using the materials included:

- Attach the Command strip to the back of the logger to mount it a wall or other flat surface.
- Use the double-sided tape to affix the logger to a surface.
- Insert the hook-and-loop strap through the mounting loops on both sides of the logger to mount it to a curved surface, such as a pipe or tubing.

Protecting the Logger

The logger is designed for indoor use and can be permanently damaged by corrosion if it gets wet. Protect it from condensation. If the message FAIL CLK appears on the LCD screen, there was a failure with the internal logger clock possibly due to condensation. Remove the battery immediately and dry the circuit board.

Note: Static electricity may cause the logger to stop logging. The logger has been tested to 8 KV, but avoid electrostatic discharge by grounding yourself to protect the logger. For more information, search for "static discharge" in the FAQ section on onsetcomp.com.

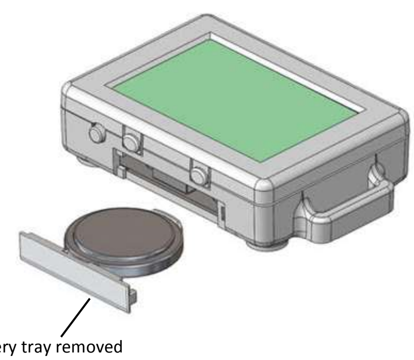
Battery Information

The logger is installed with a 3V CR2032 battery (HRB-TEMP). Expected battery life varies based on the ambient temperature where the logger is deployed, the logging interval, the rate of state changes and/or events, the frequency of offloading to the computer, and battery performance. A new battery typically lasts 1 year with logging intervals greater than 1 minute and when the input signals are normally open or in the high logic state. Deployments in extremely cold or hot temperatures, logging intervals faster than 1 minute, or continuously closed contacts may reduce battery life. Estimates are not guaranteed due to uncertainties in initial battery conditions and operating environment.

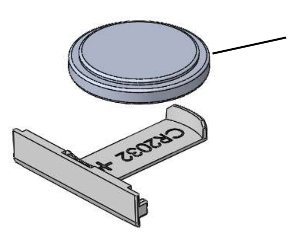
The logger can also be powered by the USB cable when the remaining battery voltage is too low for it to continue logging. Connect the logger to the computer, click the Readout button on the toolbar, and save the data as prompted. Replace the battery before launching the logger again.

To replace the battery:

1. Holding the logger with the LCD screen facing up, pull the battery tray out of the logger housing.



2. Remove the old battery from the tray.
3. Place the new battery in the tray with the positive side facing down.



4. With the LCD screen still facing up, slide the tray back into the logger. The LCD should display "HOBO" briefly after correctly installing the battery.

⚠ **WARNING:** Do not cut open, incinerate, heat above 85°C (185°F), or recharge the lithium battery. The battery may explode if the logger is exposed to extreme heat or conditions that could damage or destroy the battery case. Do not dispose of the logger or battery in fire. Do not expose the contents of the battery to water. Dispose of the battery according to local regulations for lithium batteries.

HOBOware provides the option of recording the current battery voltage at each logging interval, which is disabled by default. Recording battery life at each logging interval takes up memory and therefore reduces logging duration. It is recommended you only record battery voltage for diagnostic purposes.


Continental Control Systems LLC
WATTNODE® BACNET
A–
B+
C
X
MS/TP
Com
WNC-3Y-208-BN
120V~ 50-60Hz 3W
SN 117096
Ver 1.13
2013-05-15
N
ØA CT 0.333V~
Status
ØA
Ø-N 120V~
Ø-Ø 240V~
240V CAT III
ØB CT 0.333V~
Status
ØB
ØC CT 0.333V~
Status
ØC
1
0
Watthour Meter
US LISTED 3KNN
Boulder, CO USA

Overview

Congratulations on your purchase of the WattNode® BACnet® watt/watt-hour transducer (meter). The WattNode meter offers precision energy and power measurements in a compact package. It enables you to make power and energy measurements within existing electric service panels avoiding the costly installation of subpanels and associated wiring. It is designed for use in demand side management (DSM), sub-metering, and energy monitoring applications. The WattNode meter communicates on an EIA RS-485 two-wire bus using the BACnet protocol. Models are available for single-phase, three-phase wye, and three-phase delta configurations for voltages from 120 Vac to 600 Vac at 50 and 60 Hz.

Measurements

The WattNode BACnet meter measures the following:

- True RMS Power - Watts (Phase A, Phase B, Phase C, Sum)
- Reactive Power - VARs (Phase A, Phase B, Phase C, Sum)
- Power Factor (Phase A, Phase B, Phase C, Average)
- True RMS Energy - Watthours (Phase A, Phase B, Phase C, Sum)
- Reactive Energy - VAR-hours (Sum)
- AC Frequency
- RMS Voltage (Phase A, Phase B, Phase C)
- RMS Current (Phase A, Phase B, Phase C)
- Demand and Peak Demand

One WattNode BACnet meter can measure up to three different "single-phase two-wire with neutral" branch circuits from the same service by separately monitoring the phase A, B, and C values. If necessary, you can use different CTs on the different circuits.

Communication

The WattNode meter uses a half-duplex EIA RS-485 interface for communication. The standard baud rates are 9,600, 19,200, 38,400, and 76,800 baud. The meter uses the industry standard BACnet MS/TP communication protocol, allowing up to 64 devices per RS-485 subnet.

Diagnostic LEDs

The meter includes three power diagnostic LEDs—one per phase. During normal operation, these LEDs flash on and off, with the speed of flashing roughly proportional to the power on each phase. The LEDs flash green for positive power and red for negative power. Other conditions are signaled with different LED patterns. See **Installation LED Diagnostics (p. 22)** for details.

The BACnet WattNode meter includes a communication LED that lights green, yellow, or red to diagnose the RS-485 network. See **BACnet Communication Diagnostics (p. 27)** for details.

Options

The WattNode BACnet meter can be ordered with options. For more details and documentation, see article WattNode BACnet - Options on our website.

General Options

- ***Option CT=xxx*** - Pre-assign xxx as the ***CtAmpsA, B, and C*** values.
- ***Option CT=xxx/yyy/zzz*** - Pre-assign xxx to ***CtAmpsA***, yyy to ***CtAmpsB***, and zzz to ***CtAmpsC***.

Current Transformers

The WattNode meter may use split-core (opening), solid-core (toroidal), and flexible Rogowski current transformers (CTs), with a full-scale voltage output of 333.33 mVac and opening widths ranging from 0.3 in (7.6 mm) up to 12 in (305 mm) or Rogowski lengths up to 48 in (1220 mm). Split-core and Rogowski CTs are easier to install without disconnecting the circuit being measured. Solid-core CTs installation requires that you disconnect the circuit to install the CTs.

Additional Literature

These additional documents are available on the Continental Control Systems, LLC website or BACnet.org website.

- WattNode BACnet Object List (Excel format): WNC-BACnet-Object-List
- Continental Control Systems, LLC website
  - http://www.ccontrolsys.com/w/WattNode_BACnet - main page.
  - http://www.ccontrolsys.com/w/Category:WattNode_BACnet - support articles.
- http://www.bacnet.org
  - BACnet Standard: ASHRAE/ANSI Standard 135-2010

Front Label

This section describes the connections, information, and symbols on the front label.

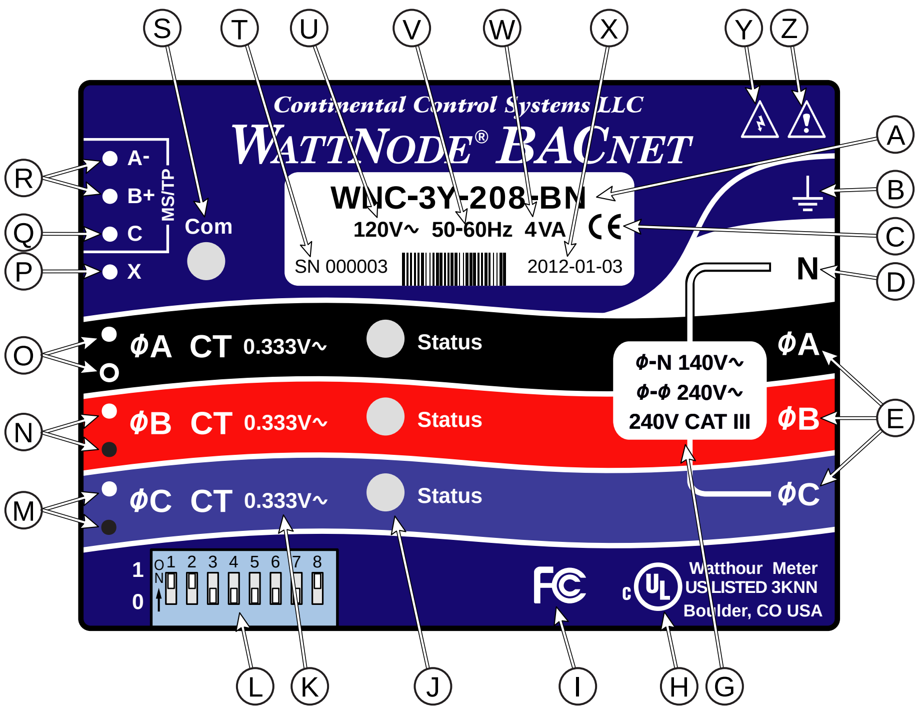


Figure 1: Front Label Diagram

A: WattNode model number. The "**WNC**" indicates a third generation WattNode meter. The "**3**" indicates a three-phase model. The "**Y**" or "**D**" indicates wye or delta models, although delta models can measure wye circuits (the difference is in the power supply). The "**208**" (or other value) indicates the nominal line-to-line voltage. Finally, the "**BN**" indicates BACnet output.

B: Functional ground. This terminal should be connected to earth ground if possible. It is not required for safety grounding, but ensures maximum meter accuracy.

C: CE Mark. This logo indicates that the meter complies with the regulations of the European Union for Product Safety and Electro-Magnetic Compatibility.

D: Neutral. This terminal "**N**" should be connected to neutral for circuits where neutral is present.

E: Line voltage inputs. These terminals connect to the **ϕA** (phase A), **ϕB** (phase B), and **ϕC** (phase C) electric mains. On wye models the meter is powered from the **ϕA** and **N** terminals. On delta models, the meter is powered from the **ϕA** and **ϕB** terminals.

G: Line voltage measurement ratings. This block lists the nominal line-to-neutral "**ϕ-N 120V∿**" voltage, line-to-line "**ϕ-ϕ 240V∿**" voltage, and the rated measurement voltage and category "**240V CAT III**" for this WattNode model. See the **Specifications (p. 50)** for more information about the measurement voltage and category.

H: UL Listing mark. This shows the UL and cUL (Canadian) listing mark and number "**3KNN**".

I: FCC Mark. This logo indicates that the meter complies with part 15 of the FCC rules.

J: Status LEDs. These are status LEDs used to verify and diagnose meter operation. See **Installation LED Diagnostics (p. 22)** for details.

K: Current transformer (CT) voltage rating. These markings "**0.333V∿**" indicate that the meter must be used with CTs that generate a full-scale output of 0.333 Vac (333 millivolts).

L: DIP switch. This DIP switch block is used to set the BACnet MAC (network) address and baud rate. See **Setting the BACnet Address (p. 19)**.

M, N, O: Current transformer (CT) inputs. These indicate CT screw terminals. Note the white and black circles at the left edge of the label: these indicate the color of the CT wire that should be inserted into the corresponding screw terminal. The terminals marked with black circles are connected together internally.

P: Auxiliary output terminal. This screw terminal is used for the X terminal options.

Q: BACnet common terminal. This is the common or ground terminal for BACnet EIA RS-485 communication wiring. It is also the common for the X terminal options if they are installed.

R: BACnet signal terminals. These are the RS-485 A– and B+ signals (half-duplex, two-wire). There are several names for these terminals:

- **Inverting pin**: A–, A, –, TxD–, RxD–, D0, and on rare devices "B"
- **Non-inverting pin**: B+, B, +, TxD+, RxD+, D1, and on rare devices "A"

S: Communication status. This LED indicates communication status. See **BACnet Communication Diagnostics (p. 27)** for details.

T: Serial number. This is the meter serial number. The barcode contains the serial number in Code 128C format.

U: Mains supply rated voltage. This is the rated supply voltage for this model. The **V∿** indicates AC voltage. For wye models, this voltage should appear between the **N** and **ϕA** terminals. For delta models, this voltage should appear between the **ϕA** and **ϕB** terminals.

V: Mains frequencies. This indicates the rated mains frequencies for the meter.

W: Maximum rated volt-amps. This is the maximum apparent power consumption (volt-amps) for this model.

X: Manufacture date. This is the date of manufacture for this WattNode meter.

Y: Caution, risk of electrical shock. This symbol indicates that there is a risk of electric shock when installing and operating the meter if the installation instructions are not followed correctly.

Z: Attention - consult Manual. This symbol indicates that there can be danger when installing and operating the meter if the installation instructions are not followed correctly.

Symbols

	Attention - Consult Installation and Operation Manual	Read, understand, and follow all instructions in this Installation and Operation Manual including all warnings, cautions, and precautions before installing and using the product.
	Caution – Risk of Electrical Shock	Potential Shock Hazard from Dangerous High Voltage.
	CE Marking	Complies with the regulations of the European Union for Product Safety and Electro-Magnetic Compatibility. ● Low Voltage Directive – EN 61010-1: 2001 ● EMC Directive – EN 61327: 1997 + A1/1998 + A2/2001

Installation

Precautions

DANGER — HAZARDOUS VOLTAGES
WARNING - These installation/servicing instructions are for use by qualified personnel only. To avoid electrical shock, do not perform any servicing other than that contained in the operating instructions unless you are qualified to do so.

Always adhere to the following checklist:

1) Only qualified personnel or **licensed electricians** should install the WattNode meter. The mains voltages of 120 Vac to 600 Vac can be lethal!
2) Follow all applicable local and national electrical and safety codes.
3) Install the meter in an electrical enclosure (panel or junction box) or in a limited access electrical room.
4) Verify that circuit voltages and currents are within the proper range for the meter model.
5) Use only UL listed or UL recognized current transformers (CTs) with built-in burden resistors, that generate 0.333 Vac (333 millivolts AC) at rated current. **Do not use current output (ratio) CTs such as 1 amp or 5 amp output CTs: they will destroy the meter and may create a shock hazard.** See **Current Transformers (p. 55)** for CT maximum ratings.
6) Ensure that the line voltage input leads to the meter are protected by fuses or circuit breakers (not needed for the neutral wire). See **Circuit Protection (p. 18)** for details.
7) Equipment must be disconnected from the HAZARDOUS LIVE voltages before access.
8) The terminal block screws are **not** insulated. Do not contact metal tools to the screw terminals if the circuit is energized!
9) Do not place more than one line voltage wire in a screw terminal; use wire nuts instead. You may use more than one CT wire or communication interface wire per screw terminal.
10) Before applying power, check that all the wires are securely installed by tugging on each wire.
11) Do not install the meter where it may be exposed to temperatures below –30°C or above 55°C, excessive moisture, dust, salt spray, or other contamination. The meter requires an environment no worse than pollution degree 2 (normally only non-conductive pollution; occasionally, a temporary conductivity caused by condensation must be expected).
12) Do not drill mounting holes using the meter as a guide; the drill chuck can damage the screw terminals and metal shavings can fall into the connectors, causing an arc risk.
13) If the meter is installed incorrectly, the safety protections may be impaired.

Appendix B.4 GE ASPMETER Metering Panelboard

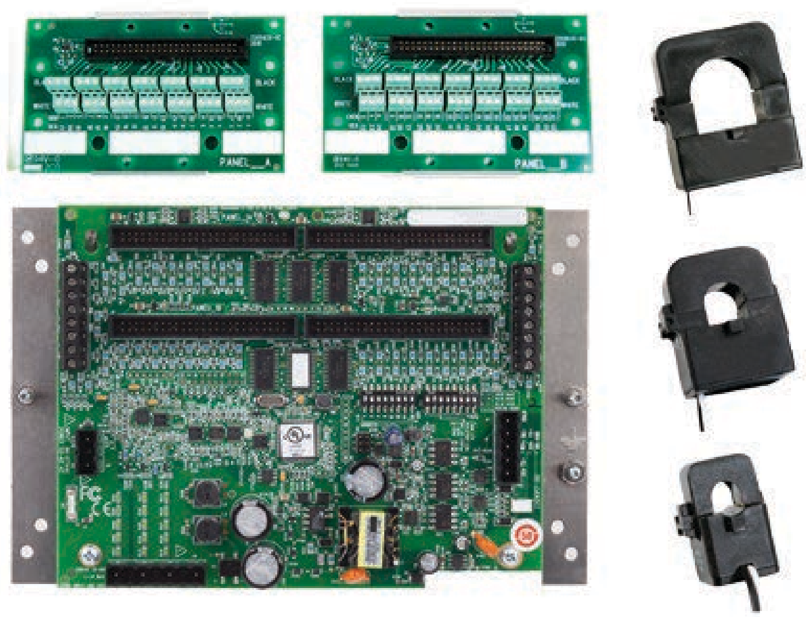
(Reference source for DEH-40700 ASPMETER Panelboard Monitoring System is GE Energy Connections. Reprint permission granted by General Electric.)

GE
Industrial Solutions

DEH-40700 Installation Instructions

ASPMETER Panelboard Monitoring System

Split Core



Safety

FCC PART 15 INFORMATION NOTE: This equipment has been tested by the manufacturer and found to comply with the limits for a class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a residential environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. This device complies with part 15 of the FCC Rules.

Operation is subject to the following two conditions:
(1) This device may not cause harmful interference, and
(2) This device must accept any interference received, including interference that may cause undesired operation.

Modifications to this product without the express authorization of the manufacturer nullify this statement.

A qualified person is one who has skills and knowledge related to the construction and operation of this electrical equipment and the installation, and has received safety training to recognize and avoid the hazards involved.

NEC2011 Article 100: No responsibility is assumed by manufacturer for any consequences arising out of the use of this material.

Control system design must consider the potential failure modes of control paths and, for certain critical control functions, provide a means to achieve a safe state during and after a path failure. Examples of critical control functions are emergency stop and over-travel stop.

	This symbol indicates an electrical shock hazard exists.
	Documentation must be consulted where this symbol is used on the product.

DANGER: Hazard of Electric Shock, Explosion or Arc Flash
Failure to follow these instructions will result in death or serious injury.

- Follow safe electrical work practices. See NFPA 70E in the USA, or applicable local codes.
- This equipment must only be installed and serviced by qualified electrical personnel.
- Read, understand and follow the instructions before installing this product.
- Turn off all power supplying equipment before working on or inside the equipment.
- Use a properly rated voltage sensing device to confirm power is off. DO NOT DEPEND ON THIS PRODUCT FOR VOLTAGE INDICATION
- Only install this product on insulated conductors.

NOTICE:

- This product is not intended for life or safety applications.
- Do not install this product in hazardous or classified locations.
- The installer is responsible for conformance to all applicable codes
- Mount this product inside a suitable fire and electrical enclosure.

WARNING: Loss of Control
Failure to follow these instructions may cause injury, death or equipment damage.

- Assure that the system will reach a safe state during and after a control path failure.
- Separate or redundant control paths must be provided for critical control functions.
- Test the effect of transmission delays or failures of communication links.
- Each implementation of equipment using communication links must be individually and thoroughly tested for proper operation before placing it in service.

For troubleshooting or service related questions, contact GE at 1-800-GE-1-STOP (1-800-431-7867).

Save These Instructions

Specifications

Inputs	
Input Power	90-277 VAC, 50/60 Hz
Accuracy	
Power/Energy	IEC 62053-21 Class 1, ANSI C12.1-2008
Voltage	±0.5% of reading 90-277 V line-to-neutral
Operation	
Sampling Frequency	2560 Hz
Update Rate	1.8 seconds (both panels)
Overload Capability	22 kAIC
Outputs	
Type	Modbus RTU™
Connection	DIP switch-selectable 2-wire or 4-wire, RS-485
Address	DIP switch-selectable address 1 to 247 (in pairs of 2)[1]
Baud Rate	DIP switch-selectable 9600, 19200, 38400
Parity	DIP switch-selectable NONE, ODD, EVEN
Communication Format	8-data-bits, 1-start-bit, 1-stop-bit
Termination	5-position depluggable connector (TX+ TX- SHIELD TX+/RX+ TX-/RX-)
Terminal Block Torque	4.4 to 5.3 in-lb (0.5 to 0.6 N-m)
Mechanical	
Ribbon Cable Support	4 ft. (0.9m) flat ribbon cable ships standard; up to 20 ft. (6m) available
Operating Conditions	
Operating Temp Range	0° to 60°C (32° to 140°F); <95% RH, non-condensing
Storage Temp Range	-40° to 70°C (-40° to 158°F)
Altitude of Operation	3000m
Compliance	
Agency Approvals	UL508 open type device, EN61010-1
Installation Category	Cat III, pollution degree 2

[1] See Configuration Section for details.

Notes:
- If ASPMETER products are used in installations with circuits higher than the product ratings, the circuits must be kept segregated per UL508A Sec. 17.5.
- 277/480VAC Wye connected (center grounded) power systems operate within the 300VAC line to neutral safety rating of the ASPMETER series, and the operational voltage limit (single-phase connection) as the line to neutral voltage is 277VAC in such power systems. Corner-grounded delta 480VAC systems would not qualify, as the actual line to earth voltage is 480VAC on each leg, exceeding the ASPMETER ratings.
- ASPMETER internal circuitry (cables and CTs) are not circuits as defined by UL508A, as they do not extend beyond the ASPMETER itself without further safety/fire isolation.

Product Overview

The ASPMETER Panelboard Monitoring System is designed to measure the current, voltage, and energy consumption of up to 92 circuits (84 branch circuits, 2 3-phase mains, 2 neutrals) on a single board. One ASPMETER can monitor up to two panels.

The ASPMETER consists of a data acquisition board and up to 84 split-core current sensors (50A, 100A, or 200A), with eight auxiliary inputs. Each conductor passes through a current sensor and terminates at the breaker. Each sensor transmits the current data to the data acquisition board. Data is transmitted using an RS-485 Modbus protocol. Each data acquisition board requires two addresses, one for each set of 42 current sensors and four auxiliary inputs. Data is updated roughly every two seconds. As a circuit approaches the user-defined threshold, the ASPMETER activates the alarm indicators.

The ASPMETER-A measures both current and power for the mains and branch circuits. The ASPMETER-B measures both current and power for the mains, and current only in each circuit. The ASPMETER-C measures current only for the mains and branch circuits.

Product Identification

ASPMETER ☐ ☐

Description

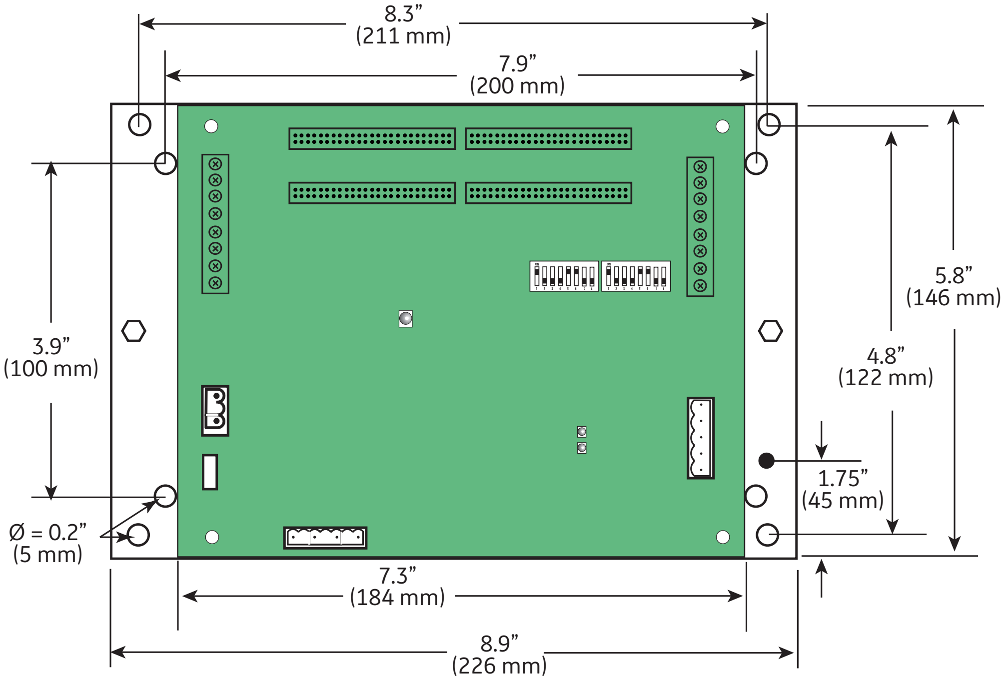
A = Advanced board
B = Intermediate board
C = Basic board

# of CTs

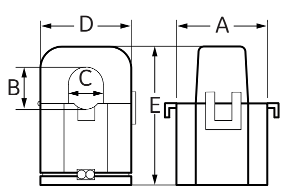
002 = 2 adapter boards, no CTs, no cables
004 = 4 adapter boards, no CTs, no cables
42 = 2 adapter boards, (42) 50A CTs, (2) 4 ft. round ribbon cables
84 = 4 adapter boards, (84) 50A CTs, (4) 4 ft. round ribbon cables

Dimensions

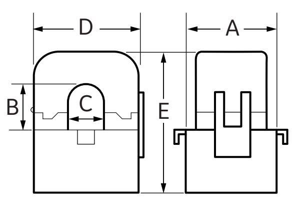
Circuit Board and Mounting Bracket



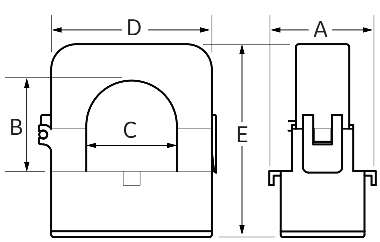
Current Sensors



ASPCT0 50 Amp
A = 1.0" (26 mm)
B = 0.5" (11 mm)
C = 0.4" (10 mm)
D = 0.9" (23 mm)
E = 1.6" (40 mm)

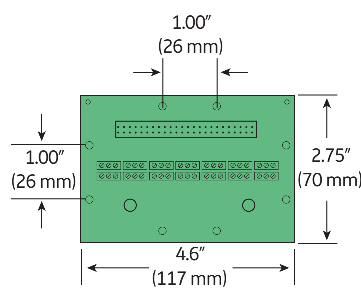


ASPCT1 100 Amp
A = 1.5" (37.5 mm)
B = 0.6" (16 mm)
C = 0.6" (16 mm)
D = 1.85" (47 mm)
E = 2.1" (53 mm)

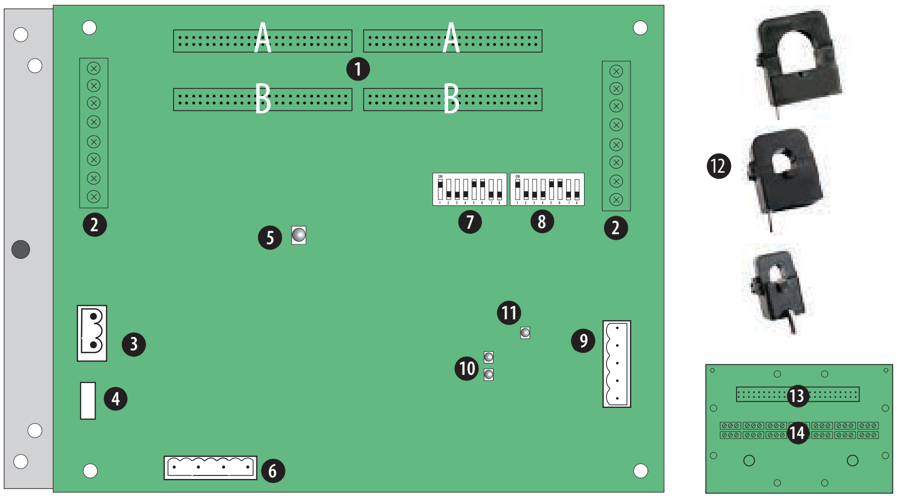


ASPCT3 200 Amp
A = 1.5" (39 mm)
B = 1.25" (32 mm)
C = 1.25" (32 mm)
D = 2.5" (64 mm)
E = 2.8" (71 mm)

Adapter Board



Product Diagrams



1. **50-Pin Ribbon Cable Connectors:** Ribbon cables attach here for easy connection of adapter boards to the data acquisition board. The two connectors on the left are for panelboard 1; the two on the right are for panelboard 2.

   NOTE: Connect Adapter Boards A and B to the correct ribbon cable connectors for each panel. The top connector is for Adapter Board A, and the bottom connector is for Adapter Board B.

   NOTE: Ribbon Cable is not included with all ASPMETER models. For ribbon cable options, see Recommended Accessories on page 14.

2. **Auxiliary Inputs:** These 0.333 VAC inputs are used for monitoring the main breaker or other high amperage source. Inputs on the left are for panelboard 1; inputs on the right are for panelboard 2.

3. **Control (Mains) Power Connection:** Easy 2-wire 90-277 VAC 50/60 Hz connection.

4. **Control Power Fuse:** 600 VAC, 500 mA time lag, factory-replaceable.

5. **Alive LED:** Red/green/amber LEDs. Blink codes are on page 5.

6. **Voltage Taps:** 1, 2, or 3 phase plus neutral connections. For voltage sensing and power calculations (no voltage taps on the ASPMETER-C). Voltage taps are shared by both panels.

7. **Communications Address DIP Switches:** Each Modbus device must have a unique address. Switches are binary weighted. Left-most switch has a value of 1; right-most switch has a value of 128.

   NOTE: Switches set the address for panel 1; panel 2 is automatically set to (Panel 1 address + 1).
   See Configuration section for details.

8. **Communications Settings DIP Switch:** Configures baud rate, parity, 2/4 wire communications.

9. **RS-485 Connection:** Used for Modbus serial communications. The Universal plug accommodates 2 or 4 wire connections.

10. **RS-485 LEDs:** The RX LED (closest to DIP switches) indicates the RS-485 is receiving information; the TX LED (farthest from DIP switches) indicates transmission of information.

11. **Power LED:** Indicates power to main board .

12. **Branch Current Sensors:** Each split-core current sensor is capable of monitoring conductors rated up to a maximum of 50, 100, or 200 amps. Up to 84 sensors can be purchased with the ASPMETER (see Recommended Accessories on page 14). One of each style is pictured here.

13. **Ribbon Cable Connectors**

14. **CT Terminal Connectors**

Data Output

Monitoring at Mains	ASPMETER-A	ASPMETER-B	ASPMETER-C
Current per phase	✓	✓	✓
Max. current per phase	✓	✓	✓
Current demand per phase	✓	✓	✓
Max. current demand per phase	✓	✓	✓
Energy (kWh) per phase	✓	✓	
Real Power (kW) per phase	✓	✓	
Apparent Power (kVA)	✓	✓	
Power factor total *	✓	✓	
Power factor per phase	✓	✓	
Voltage - L-L and average of 3 phases	✓	✓	
Voltage - L-N and average of 3 phases	✓	✓	
Voltage - L-N and per phase	✓	✓	
Frequency (phase A)	✓	✓	
Monitoring at Branch Circuit			
Current	✓	✓	✓
Max. current	✓	✓	✓
Current demand	✓	✓	✓
Max. current demand	✓	✓	✓
Real power (kW)	✓		
Real power (kW) demand	✓		
Real power (kW) demand max.	✓		
Energy (kWh) per circuit	✓		
Power factor	✓		
Apparent Power (kVA)	✓		
Modbus Alarms			
Voltage over/under	✓	✓	
Current over/under	✓	✓	✓

* Based on a 3-phase breaker rotation.

Blink Code for Status LED

Color and Pattern	Status Description
Green, once per second	Normal operation
Amber, once per second	Volts or Amps clipping
Amber, twice per second	Invalid firmware image
Red, solid or blink	Diagnostic event detected

Split-Core CT Accuracy

Description	Split-Core CT		
	50A	100A	200A
Voltage rating	300 VAC	300 VAC (CE), 600 VAC (UL)	300 VAC (CE), 600 VAC (UL)
Accuracy	±1%	±0.5%	±1%
Temperature	0° to 60°C		
Agency	UL508 recognized, EN61010-1		

Commissioning

1. Install according to instructions in Mechanical Installation.
2. Provide control power to panel.
3. Configure installation mode using Modbus Register 6.
4. Configure CT scaling.
5. Configure alarms.
6. Configure demand.

Download the free Configuration Tool “NetConfig” from www.veris.com/modbus_downloads.aspx to commission the E3x for operation.

Wiring

⚠	Power must be disconnected and locked out before making any wiring connections.

Connect 2-wire or 4-wire Modbus RS-485 daisy chain network (Figures 1 and 2).

Figure 1.

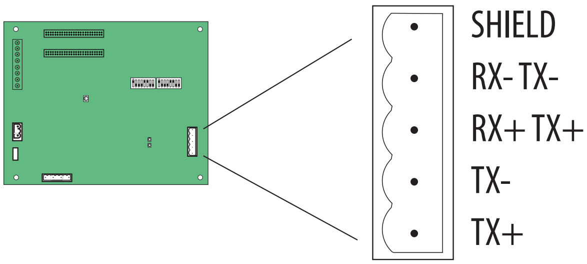
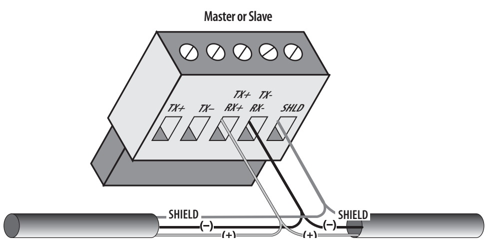
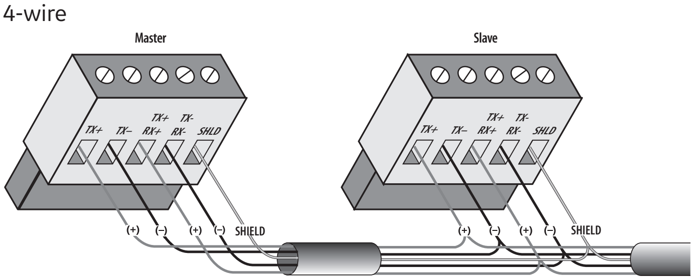


Figure 2.

2-wire



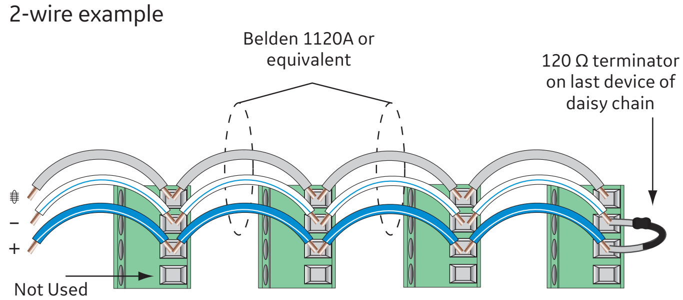
4-wire



1. Mechanically secure the RS-485 cable where it enters the electrical panel.
2. Connect all RS-485 devices in a daisy-chain fashion, and properly terminate the chain (Figure 3).

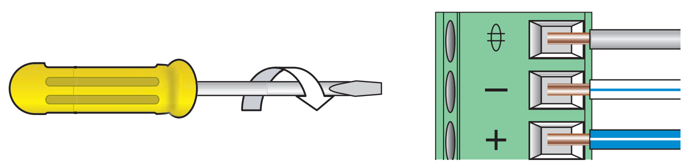
Figure 3.

2-wire example



3. Shield the RS-485 cable using twisted-pair wire, such as Belden 1120A. The cable must be voltage-rated for the installation.
4. When tightening terminals, ensure that the correct torque is applied: 0.5 to 0.6 N·m (0.37 to 0.44 ft·lb) for connectors on main board, 0.22 to 0.26 N·m (0.16 to 0.19 ft·lb) for connectors on adapter boards (Figure 4).

Figure 4.

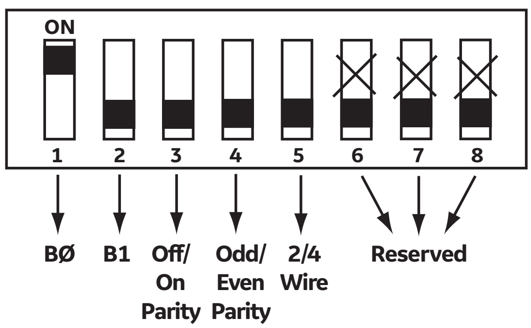


⚠	**WARNING**: After wiring the RS-485 cable, remove all scraps of wire or foil shield from the electrical panel. Wire scraps coming into contact with high voltage conductors could be DANGEROUS!

Configuration

1. **Communications Configuration:** Communications parameters for the ASPMETER series are field selectable for your convenience. Please see the Product Diagrams section (page 5) for selector location. The following parameters are configurable:
   - Baud Rate: 9600, 19200, 38400
   - Parity On or Off
   - Parity: odd or even
   - Wiring: two or four

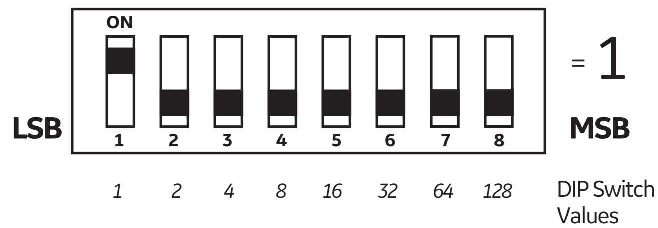
Example: 2-wire 19200 Baud, no parity (default only)



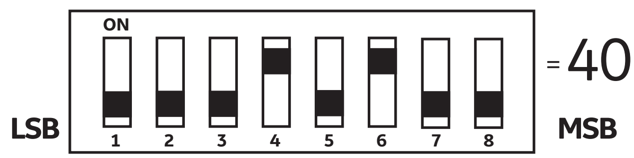
1	2	3	4	5	6	7	8	
Off	Off				X	X	X	**9600**
On	Off				X	X	X	**19200**
Off	On				X	X	X	**38400**
On	On				X	X	X	**Reserved**
		Off	Off		X	X	X	**No Parity**
		On	Off		X	X	X	**Odd Parity**
		Off	On		X	X	X	**No Parity**
		On	On		X	X	X	**Even Parity**
				On	X	X	X	**4-wire RS-485**
				Off	X	X	X	**2-wire RS-485**

2. **Address Configuration:** Each Modbus device on a single network must have a unique address. Set the switch block to assign a unique address before the device is connected to the Modbus RS-485 network. If an address is selected which conflicts with another device, neither device will be able to communicate.

3. The ASPMETER uses two logical addresses. Panel 1 uses the base address as set on the DIP switches, and Panel 2 uses this base address + 1. Address the ASPMETER as any whole number between and including 1-246. Each unit is equipped with a set of 8 DIP switches for addressing. See below.



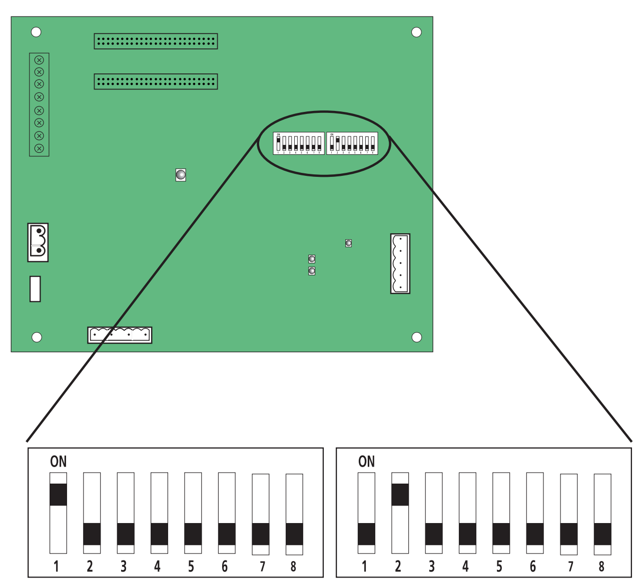
4. T o determine an address, simply add the values of any switch that is on. For example:



Switch number 4 has an ON Value of 8 and switch number 6 has an ON Value of 32. (8 + 32 = 40). Therefore, the address for Panel 1 is 40 and the address for Panel 2 is 41. See the Address Setup section (page 9) for a pictorial listing of the first 63 switch positions.

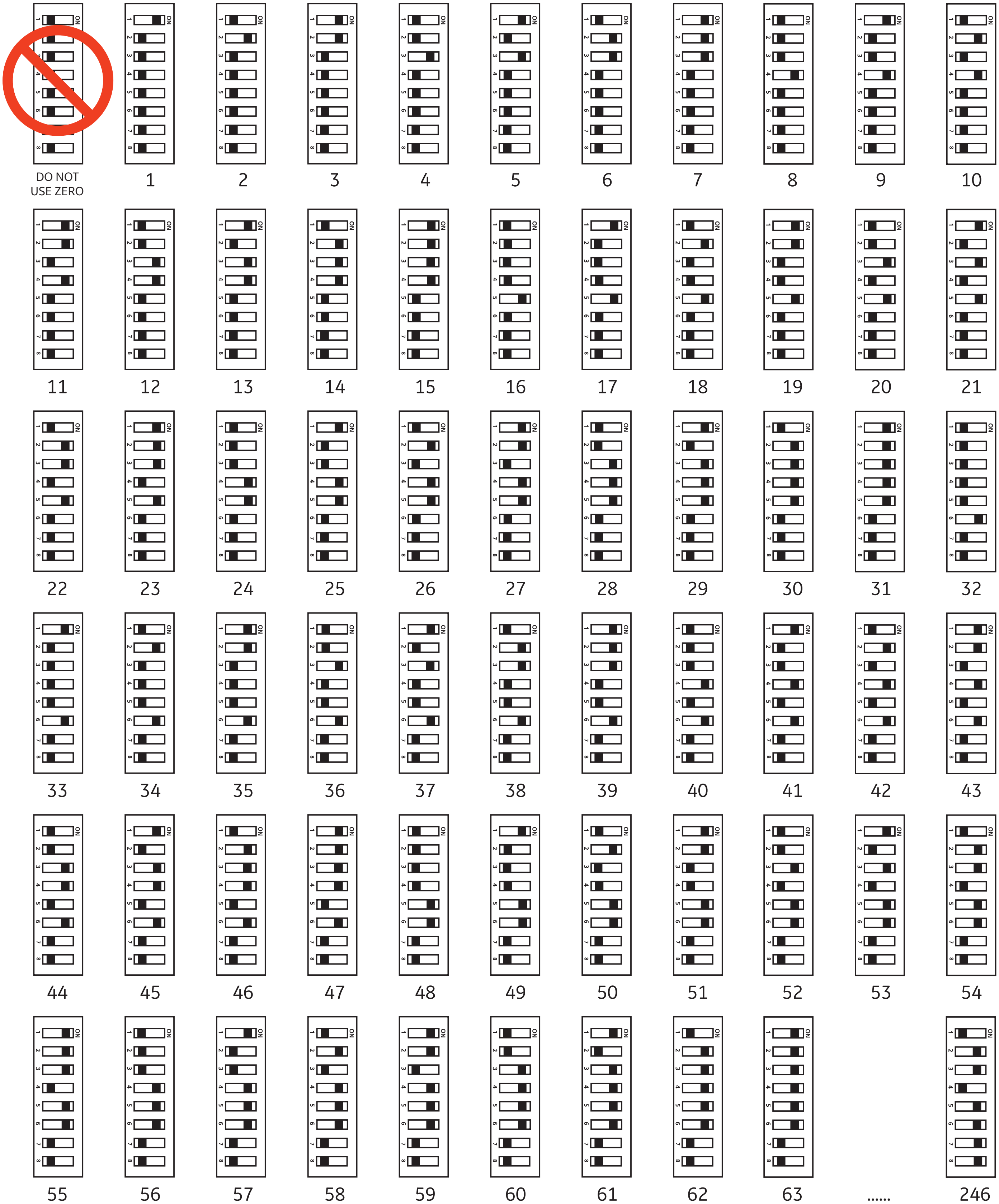
Default DIP Switch Settings

The ASPMETER includes two DIP switches, as shown below. Switches are shown in their default positions.



Comms Address Comms Settings

Address Setup



Mechanical Installation

ATTENTION	Observe precautions for handling static sensitive devices to avoid damage to the circuitry that is not covered under the factory warranty.

⚠	Disconnect power to the electrical panel and lock it out.

1. Install the acquisition board mounting bracket in the panel using screws and bolts provided. Panels can be oriented side-by-side (Figure 5A) or vertically (Figure 5B). A grounding connection is located on the mounting bracket, near the lower right corner. Use this stud to ground the bracket when mounting on a non-conductive surface.

Figure 5A.
Side-by-side

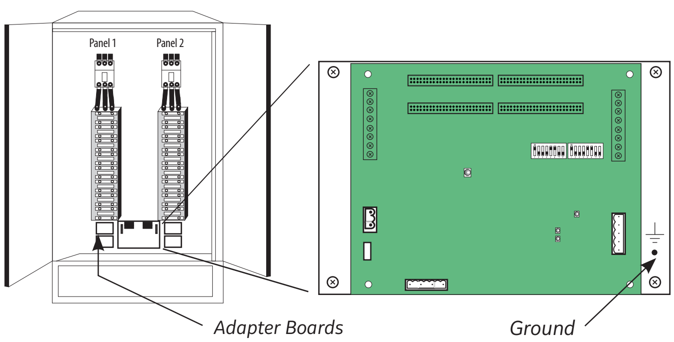
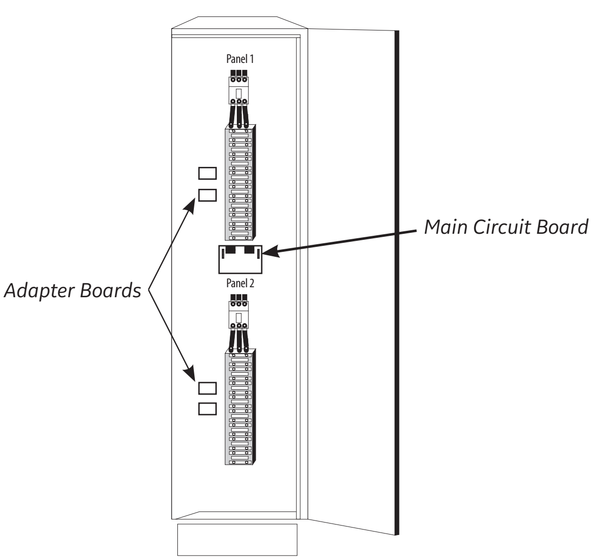
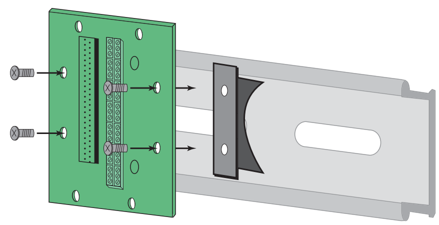


Figure 5B.
Vertically



2. Mount the adapter boards to either DIN rail or SNAPTRACK.
   — **DIN Rail:** Use the supplied screws to secure the plastic DIN clip to the adapter board. Affix the clip to the DIN rail (Figure 6).
   — **SNAPTRACK:** Secure the SNAPTRACK to the mounting surface. Click the adapter board into place (Figure 7).

Figure 6.
DIN Option – Vertical Mount



DIN Option – Horizontal Mount

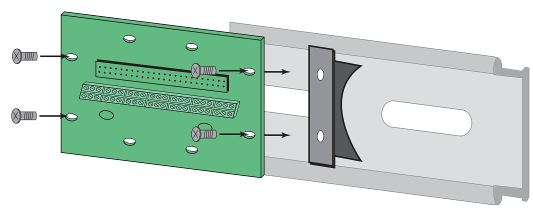
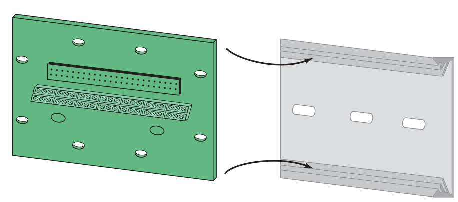


Figure 7.
SNAPTRACK



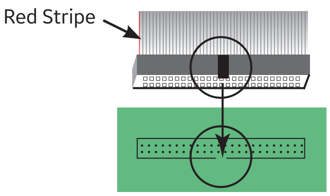
3. Connect adapter boards to the main board using ribbon cable (Figure 8). Ribbon cables are keyed to ensure proper installation.

   Orient cables so that the red stripe is on the left.

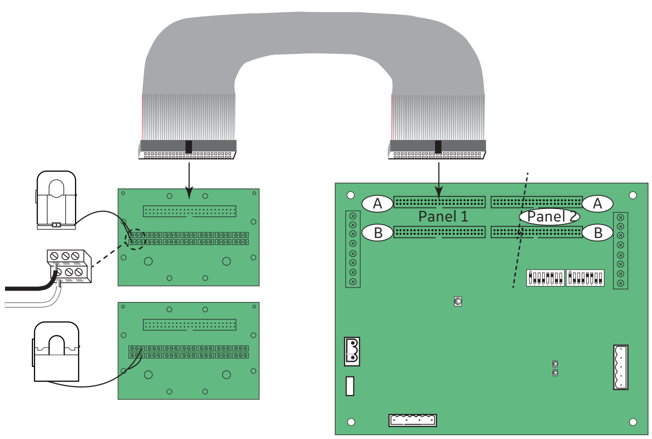
   NOTE: Flat and round ribbon cable are available. See Recommended Accessories.

4. Connect current sensors to the terminals on the adapter boards (Figure 8).

Figure 8.



Align ribbon cable key with connector keyhole. Orient ribbon cable so that the red stripe is on the left side of the connector.

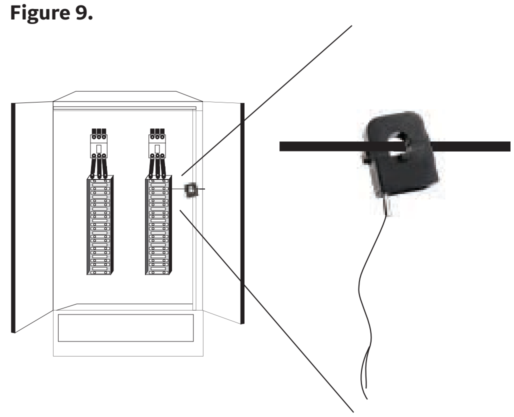


If the signed power factor feature is NOT enabled, then the current sensor orientation does not affect meter behavior. If this feature IS enabled, orient the current sensors so that the arrow points toward the load for proper operation.

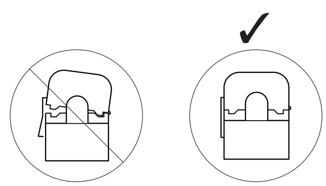
5. Install the current sensors onto the conductors to be monitored (Figure 9). Sensors can be mounted facing either direction; orientation does not affect meter accuracy.

   NOTE: Clean split-core contacts before closing. The hinge can detach, allowing the base and the top to separate for easier cleaning and installation

Figure 9.



The 50 A CT accepts a maximum #2 AWG (0.384" O.D.) wire with THHN insulation. The 100A CT accepts a maximum 3/0 AWG (0.584" O.D.) wire with THHN insulation. The 200A CT accepts a maximum of 350 MCM wire with THHN insulation. Use this gauge wire or smaller for each circuit.



Close CTs until the clasp clicks into place to ensure that contact surfaces are firmly seated.

6. Plastic cable ties are included with the product for strain relief. Insert the strain relief device into one of the available holes on the adapter board (Figure 10A). Gather all current sensor wires connected to that adapter board and secure the cable tie around them (Figure 10B).

Figure 10A.

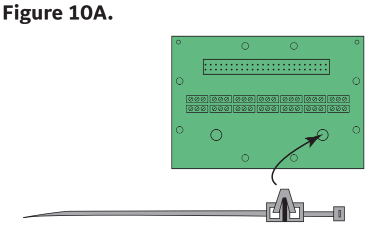
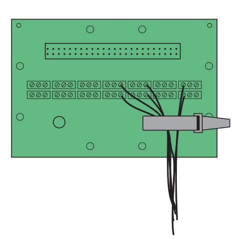
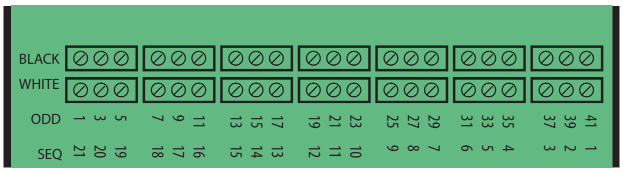


Figure 10B.



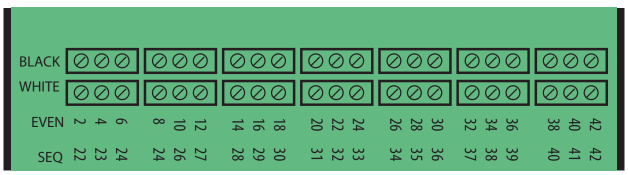
7. The adapter boards are silk screened with two rows of numbers. For applications that require odd/even branch circuit numbering, use the row designated ODD or EVEN. For applications that require sequential numbering, use the number row marked SEQ (Figures 11 and 12).

Figure 11.



Numbering – Adapter Board A:

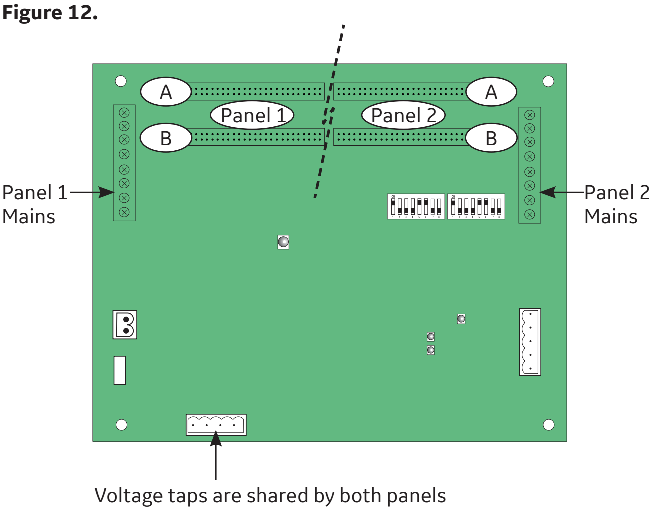
ODD	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41
SEQ	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1



Numbering – Adapter Board B:

EVEN	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
SEQ	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42

Figure 12.



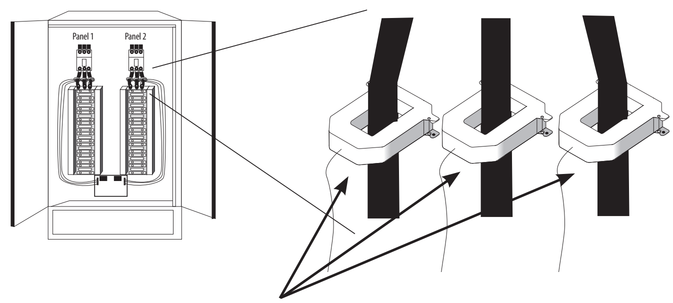
Panel 1 uses base Modbus address as set by DIP switches.
Panel 2 uses base + 1 Modbus address as set by DIP switches.

8. Configure communication and addressing parameters using DIP switches. The ASPMETER requires two addresses, one for each set of 42 current sensors and four auxiliary inputs. See the Configuration section for more information.

9. Wire RS-485 communications (see diagrams in Wiring section).

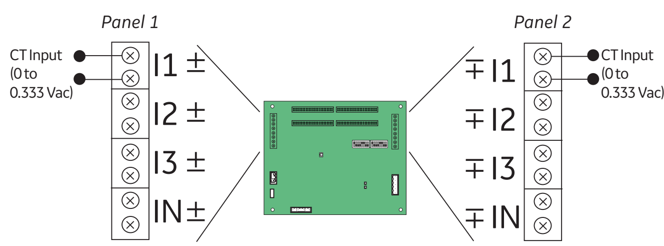
10. Connect 0.333VAC current transducers (CTs) to the main conductors by snapping CTs around lines, observing local codes regarding bending radius (optional; Figures 13 and 14).

Figure 13.



Recommended CT: AMP1 Series available in 100A max. to 2000A max. Contact your local GE sales rep for recommended CTs amperages or if higher amperages are required.

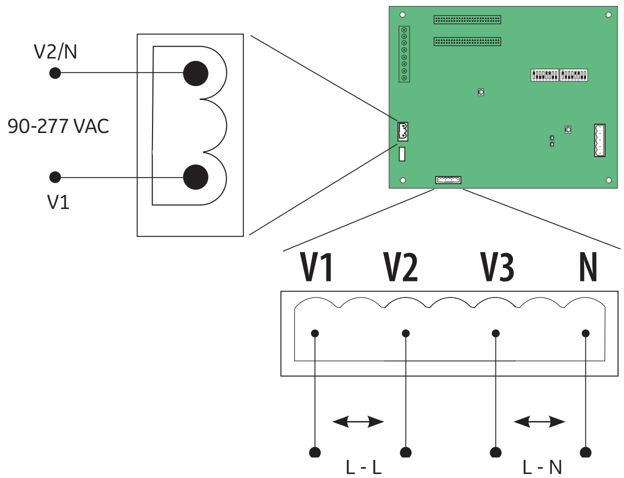
Figure 14.



Set up Modbus registers 115-118 for CT scaling.
Use base + 1 address for Panel 2 setup.
NOTE: (+) represents black, (-) represents white

11. Connect 2-wire 90-277VAC power to main power terminals. Observe polarity. For the ASPMETER-A and ASPMETER-B, connect voltage lines to the voltage taps (Figure 15). Equip voltage lines with fuses.

Figure 15.



Line to Line (L-L) Voltage: 150 to 480 VAC
Line to Neutral (L-N) voltage: 90 to 277 VAC

Recommended Accessories

Catalog Number	Description
ASPCT0	Six-pack 50 A CT, 6 ft. (1.8 m) lead
ASPCT1	Six-pack 100 A CT, 6 ft. (1.8 m) lead
ASPCT2	Single 200A CT, 6ft (1.8m) lead

Troubleshooting

Problem	Solution
Product is not communicating over Modbus daisy chain	• Check the unit Modbus address to ensure that each device on the daisy chain has a unique address. • Check Parity. • Check the communications wiring. • Check that the daisy chain is properly terminated.
RX LED is solid	• Check for reversed polarity on Modbus comms. • Check for sufficient biasing on the Modbus bus. Modbus physical specification calls for 450-650 Ω biasing. This is usually provided by the master.
The main board has a fast flashing amber light	• Verify ribbon cable connectors are inserted in the correct orientation. • If cables are correct, reset main board to re-initialize product.
The main board has a slow flashing amber light	• One or more channels is clipping. This can be caused by a signal greater than 100 A or 277 V L-N, or by a signal with high THD near the gain stage switching points (1.5 A and 10 A).
The main board has a flashing green light	• Everything is wired properly and the main board has power.
The main board is a flashing or solid red light	• Light may be red briefly while device powers up. • If light is red for more the 60 sec. device has encountered a diagnostic event. Contact technical support.
Split-core product is reading zero for some values	• Device was unable to read split-core adapter boards on power up. Verify adapter boards are connected. • Verify ribbon cable connectors are inserted in the correct orientation. • Reset main board to re-initialize product.
Power factor reading is not as expected	• Verify voltage taps are connected in appropriate phase rotation. • Verify phase rotation of breakers (firmware rev. 1.012 or higher allows for custom rotation if needed).
Current reading is not as expected, or reading is on different CT number than expected	• Verify ribbon cable is fully seated and in the correct orientation.
Current is reading zero, even when small currents are still flowing through circuit	• The product cuts off at 50 mA, and will set the reporting register to 0 mA for currents near or below this range.
Configuration Tool "NetConfig" returns Modbus error on read/write	• Verify using the latest release of Configuration Tool "NetConfig" as older versions may not support all features in current product firmware. Latest version is available on the website http://www.veris.com/modbus_downloads.aspx

For troubleshooting or service related questions, contact GE at 1-800-GE-1-STOP (1-800-431-7867).

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