

ASHÉ Monograph

Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas

Jason V. D'Antona, PE, LEED® AP

John Messervy, AIA



ASHE Monograph

Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas

Jason V. D'Antona, PE, LEED® AP

John Messervy, AIA



2014

The American Society for Healthcare Engineering (ASHE)
of the American Hospital Association
155 North Wacker Drive, Suite 400
Chicago, IL 60606
312-422-3800

ashe@aha.org
www.ashe.org

This monograph can be downloaded from under the Resources tab of the ASHE website. Paper copies can be purchased from www.ashestore.com.
ASHE catalog #: 055592

ASHE Disclaimer

This document was prepared on a volunteer basis as a contribution to ASHE and is provided by ASHE as a service to its members. The information provided may not apply to a reader's specific situation and is not a substitute for application of the reader's own independent judgment or the advice of a competent professional. Neither ASHE nor any author makes any guaranty or warranty as to the accuracy or completeness of any information contained in this document. ASHE and the authors disclaim liability for personal injury, property damage, or other damages of any kind, whether special, indirect, consequential, or compensatory, that may result directly or indirectly from use of or reliance on this document.

Contents

| | |
|---|----|
| Introduction | 1 |
| Plug Loads: Fixed vs. Cord-Connected | 2 |
| CBECS Benchmark | 2 |
| Challenges to Quantifying Cord-Connected Plug Loads | 3 |
| Plug Load Case Study | 4 |
| Areas Surveyed for Study | 4 |
| 120V Plug Load System Infrastructure | 5 |
| Case Study Methodology | 6 |
| Data Collected | 7 |
| Sub-Meters | 8 |
| Findings | 9 |
| Plug Load Demand | 9 |
| Plug Peak Load Demand vs. Design Capacity | 9 |
| Normal and Emergency Plug Load Demand | 10 |
| Normal vs. Emergency Use Trends | 10 |
| Plug Load Power Consumption | 11 |
| Plug Load Power Operational Costs | 12 |
| Conclusions | 12 |
| System Capacity | 13 |
| Downloading Plug Load Systems | 13 |
| Suggested Follow-Up Work | 13 |
| Appendix: Tables and Figures | 15 |
| References | 23 |

Abbreviations

| | |
|-------|--|
| A | amperes |
| Btu | British thermal unit |
| CBECS | Commercial Buildings Energy Consumption Survey |
| DOE | U.S. Department of Energy |
| EIA | Energy Information Agency |
| EKG | electrocardiogram |
| Hz | hertz |
| ICU | intensive care unit |
| kBtu | kilo British thermal unit |
| kVA | kilovolt-ampere |
| kW | kilowatt |
| kWH | kilowatt hour |
| NSF | net square feet |
| OR | operating room |
| PF | power factor |
| SF | square feet |
| V | volts |
| W | watts |

Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas

Introduction

According to the U.S. Department of Energy's Energy Information Agency (EIA), the health care sector is the second most energy-intensive industry in the United States, consuming 233 trillion Btu per year in site electricity (EIA 2014). This equates to over \$7 billion in electrical energy usage annually. The EIA also estimates that plug loads represent between 13 and 30 percent of the electrical consumption in hospitals (www.eia.doe.gov/emeu/consumptionbriefs/cbecs/pbaweb/site/health/health_howuseelec.htm). Despite their prevalence in the energy consumption portfolio of hospitals, plug loads in the health care setting remain enigmatic and are defined in only the most general terms. In fact, a hospital energy benchmarking study sponsored by the Lawrence Berkley National Laboratory commented, "Currently little is known about loads of medical equipment and other plug loads" (Singer et al. 2009).

The lack of empirical data on the nature of plug loads in the health care setting forces designers and energy modelers to estimate these loads when designing distribution systems or modeling plug load consumption. Often these estimates are based on the worst case scenario of simultaneous peak use of various portable medical equipment loads at the patient bed. This "worst case" methodology ensures that the actual load does not exceed the

estimate; however, it also leads to unnecessarily oversized electrical distribution and mechanical cooling systems and inaccurate energy models. Besides the burden of additional first costs, overstating plug loads can lead to lost opportunities for energy efficiency incentives and the higher life cycle costs associated with oversized building infrastructure.

This project was initiated to address the lack of empirical information describing plug loads in the healthcare environment. The results of this study were used to benchmark recorded energy consumption against both the anticipated design loading of the building and plug load energy intensity data compiled by the EIA. In addition, the authors hoped that the data gathered in this study could be used to start a framework that could be further developed into a guide to aid in the design and modeling of plug loads in future health care facilities.

Plug Loads: Fixed vs. Cord-Connected

Plug loads in the hospital setting are made up of fixed medical equipment and miscellaneous cord-connected convenience receptacle loads (Rivas 2009). This study focused specifically on the 120V cord-connected equipment typically found in the patient care suite. In general, this equipment falls into two categories, medical devices and office equipment. Most medical devices can be found in the immediate vicinity of the patient. This cord-connected equipment includes ventilators, intra-aortic balloon pumps (IABP), monitoring systems, portable x-ray machines, electric beds, EKG machines, infusion pumps, respiratory therapy equipment, dialysis machines, portable heaters, and compression pumps (IEEE 2007). Generally, the density of the medical equipment and medical equipment plug load increases with the acuity of the patient being treated. This is evidenced by the greater code requirements for 120V convenience receptacles at the headwall of a critical care bed vs. a standard care patient bed. The balance of receptacle load usually consists of office equipment such as printers, copy machines, fax machines, and computer work stations. Unlike medical devices, the density of these types of loads does not vary significantly with the acuity of the patient population being treated.

CBECS Benchmark

The EIA commissioned the 2003 Commercial Building Energy Consumption Survey (CBECS). This survey categorized electrical consumption in various types of buildings, including health care facilities. According to CBECS,

inpatient hospitals have an average annual energy intensity of 27.5kWh/ft². Of this, 0.3kWh/ft² is consumed by “office equipment,” 1.0kWh/ft² by “computers,” and 3.2kWh/ft² by “other” loads (see Table 1). The sum of these consumption intensities (4.5 kWh/ft²) describes the consumption intensity of cord-connected plug loads. This value was used as a benchmark for evaluating the cord-connected plug load energy intensity of patient care suites surveyed as part of this study.

Table 1 Electricity Consumption (kWh) Intensifies by End Use for Non-Mall Buildings, 2003

| Principal Building Activity | Electricity Energy Intensity (kWh/square foot) | | | | | | | | | | |
|-----------------------------|--|---------------|---------|-------------|---------------|----------|---------|---------------|------------------|------------|-------|
| | Total | Space Heating | Cooling | Ventilation | Water Heating | Lighting | Cooking | Refrigeration | Office Equipment | Composters | Other |
| Health Care | 22.9 | 0.5 | 3.1 | 3.9 | 0.2 | 9.7 | 0.1 | 0.8 | 0.3 | 0.9 | 3.3 |
| Inpatient | 22.7 | 0.5 | 3.8 | 5.9 | 0.3 | 11.7 | 0.1 | 0.6 | 0.3 | 1 | 3.2 |
| Outpatient | 16.1 | 0.7 | 2.1 | 1 | 0.1 | 6.6 | (*) | 1 | 0.4 | 0.8 | 3.5 |

See “Guide to the Tables” or “Glossary” for further explanations of the terms used in this table. Both can be accessed from the CBECS web site — www.ela.doe.gov/emeu/cbecs.

*Figures in this table do not include enclosed malls and strip malls. In the 1999 CNECS, malls represented 9.7 percent of total electricity consumption.

Source: Energy Information Administration, Office of Energy Markets and End Use, Form EIA-871A, C, and E of the 2003 Commercial Buildings Energy Consumption Survey.

Challenges to Quantifying Cord-Connected Plug Loads

In the hospital patient care suite, the majority of cord-connected equipment is located in the patient room. This makes metering electrical consumption of individual pieces of equipment nearly impossible. Typically, cord-connected medical equipment is mobile and may not be dedicated to a single patient care suite. Even if the load of individual pieces of equipment is determined, it is difficult to accurately predict the number of devices in use in a suite at any given time. Often (e.g., with the design of the two buildings monitored),

the plug load distribution systems are sized based on worst case equipment population with concurrent peak loading.

The authors of this study decided to monitor aggregate loading at key 120V distribution points. As will be discussed, these points afforded an opportunity to capture actual cord-connected loading of entire patient care suites, including patient medical devices, computers, and office equipment.

Plug Load Case Study

This six-month case study trended the emergency and normal power 120V cord-connected plug loads at two inpatient care facilities located in Boston, Massachusetts, each part of a tertiary care academic medical center. Both facilities are newer than ten years old and feature state-of-the-art diagnostic and treatment equipment as well as single patient rooms. One facility houses a 29-bed cardiac intensive care unit and three additional inpatient care suites for treating patients of varying acuity. The second facility contains a 29-bed neurosciences intensive care unit and four general medical inpatient suites. These areas were selected for two reasons. First, the acuity of recovering neurology and cardiac ICU patients afforded an opportunity to selectively profile the worst case medical equipment plug loads, which could be used as an upper limit plug load benchmark. Second, the buildings selected were both relatively new and designed with both segregated receptacle power distribution and integral networked sub-metering systems. As will be described, this load-segregated system architecture allowed accurate trending of both normal and emergency 120V cord-connected equipment loads on each patient floor. The resultant plug load power and energy data presented in Table 2 depict six months' worth of 15-minute interval trend profiles from the nine inpatient suites.

Areas Surveyed for Study

The areas surveyed represented varying acuities of patient populations from neurosciences intensive care (most) to general medical inpatient (least). Each suite comprised a single patient care floor with between 29 and 32 inpatient beds. Table 2 outlines the vital statistics of the areas monitored as part of this study.

Patient population will directly affect the amount of medical equipment in use in a given area and as such will have a direct impact on medical equipment

Table 2 Inpatient Care Suite Vital Statistics

| Hospital | Clinical Space | Beds | nSF | Normal Plug Load Capacity | Emergency Plug Load Capacity | Total Plug Load Capacity |
|----------|--|------|--------|---------------------------|------------------------------|--------------------------|
| A | Surgical Intensive Care Unit | 29 | 21,691 | 112.5 kVA | 150 kVA | 262.5 kVA |
| A | Cardiac Inpatient Unit | 29 | 21,543 | 112.5 kVA | 150 kVA | 262.5 kVA |
| A | Cardiac Interventional and Vascular Surgery Unit | 29 | 21,966 | 112.5 kVA | 150 kVA | 262.5 kVA |
| A | Cardiac and Routine Medical Unit | 28 | 21,855 | 112.5 kVA | 150 kVA | 262.5 kVA |
| B | Neurosciences Intensive Care Unit | 28 | 22,608 | 150 kVA | 150 kVA | 300 kVA |
| B | Non-Acute Inpatient Unit #1 | 32 | 23,857 | 150 kVA | 150 kVA | 300 kVA |
| B | Non-Acute Inpatient Unit #2 | 32 | 23,423 | 150 kVA | 150 kVA | 300 kVA |
| B | Non-Acute Inpatient Unit #3 | 32 | 23,475 | 150 kVA | 150 kVA | 300 kVA |
| B | Non-Acute Inpatient Unit #4 | 32 | 23,268 | 150 kVA | 150 kVA | 300 kVA |

plug loads. Throughout the study period, the occupancy on all floors surveyed averaged above 90 percent. This ensured parity among the various clinical spaces monitored and provided a sufficient sample set for worst case medical equipment plug loads in each area.

120V Plug Load System Infrastructure

Both buildings surveyed contained 277V lighting fed from dedicated 480Y/277V lighting branch circuit panels. As such, all 208Y/120V distribution was designed to serve plug loads. Although the 120V branch circuit panels monitored did in some cases serve other miscellaneous 120V loads, they were predominantly dedicated to feed receptacle loads in the patient care suites. Figure 1 shows a typical panel schedule from one of the panels monitored for the study. Note that this panel exclusively serves receptacles in patient care areas. This level of segregation of plug loads was typical of all areas surveyed and allowed metering of plug loads without bias from other types of 120V loads.

Hospital A used one 112.5kVA step-down transformer serving six normal 208Y/120V double tub panels per floor and one 150kVA step-down transformer serving six emergency 208Y/120V double tub panels. In total, the

Figure 1 Typical 208Y/120V Panelboard Schedule

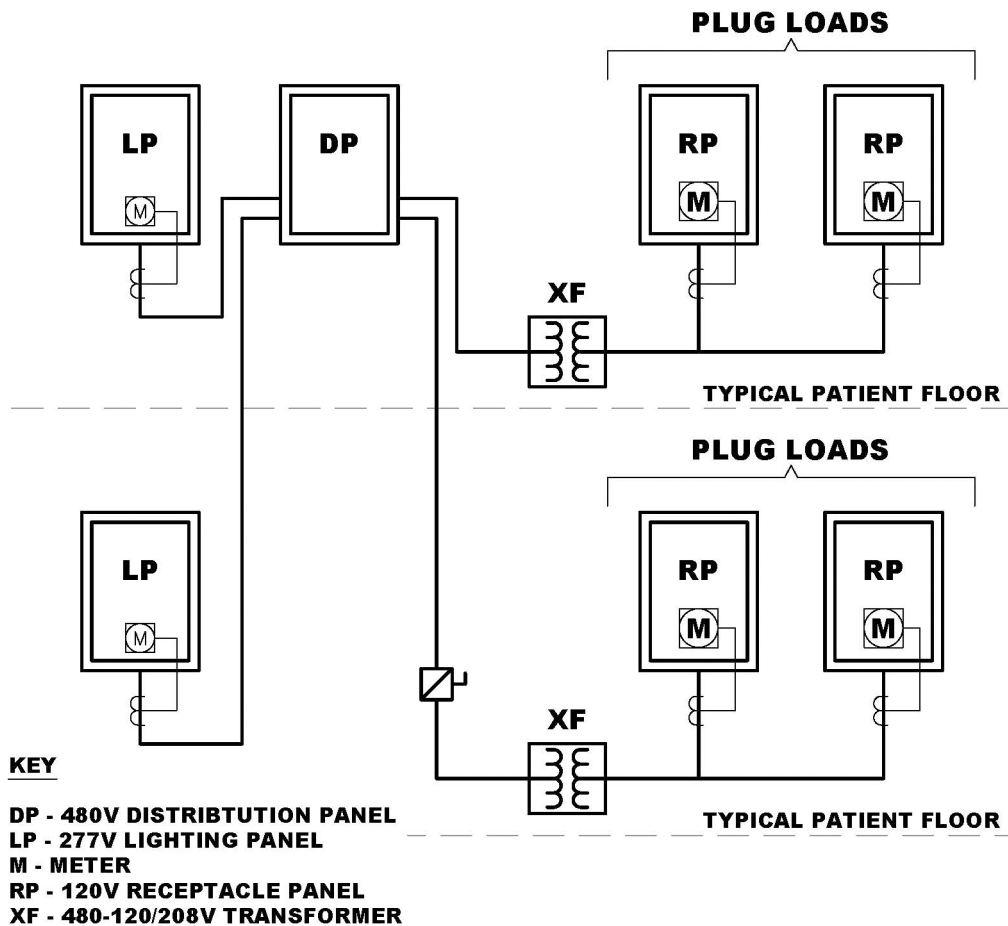
| Panel: NP6-2-2 Volt/Amp: 208Y/120V - 150A | | | |
|--|--------------------------|-----|------------------------|
| Ckt | Load | Ckt | Load |
| 1 | Rec-ICU Patient Rm 638 | 2 | Rec-ICU Patient Rm 624 |
| 3 | Rec-ICU Patient Rm 638 | 4 | Rec-ICU Patient Rm 624 |
| 5 | Rec-ICU Patient Rm 638 | 6 | Rec-ICU Patient Rm 624 |
| 7 | Rec-ICU Patient Rm 638 | 8 | Rec-ICU Patient Rm 624 |
| 9 | Rec-ICU Patient Rm 636 | 10 | Rec-ICU Patient Rm 622 |
| 11 | Rec-ICU Patient Rm 636 | 12 | Rec-ICU Patient Rm 622 |
| 13 | Rec-ICU Patient Rm 636 | 14 | Rec-ICU Patient Rm 622 |
| 15 | Rec-ICU Patient Rm 636 | 16 | Rec-ICU Patient Rm 622 |
| 17 | Rec-ICU Patient Rm 634 | 18 | Rec-ICU Patient Rm 620 |
| 19 | Rec-ICU Patient Rm 634 | 20 | Rec-ICU Patient Rm 620 |
| 21 | Rec-ICU Patient Rm 634 | 22 | Rec-ICU Patient Rm 620 |
| 23 | Rec-ICU Patient Rm 634 | 24 | Rec-ICU Patient Rm 620 |
| 25 | Rec-ICU Patient Rm 632 | 26 | Rec-ICU Patient Rm 618 |
| 27 | Rec-ICU Patient Rm 632 | 28 | Rec-ICU Patient Rm 618 |
| 29 | Rec-ICU Patient Rm 632 | 30 | Rec-ICU Patient Rm 618 |
| 31 | Rec-ICU Patient Rm 632 | 32 | Rec-ICU Patient Rm 618 |
| 33 | Rec-Multi Patient Rm 638 | 34 | Rec-ICU Patient Rm 624 |
| 35 | Rec-ICU Patient Rm 636 | 36 | Rec-ICU Patient Rm 624 |
| 37 | Rec-ICU Patient Rm 636 | 38 | Rec-ICU Patient Rm 624 |
| 39 | Rec-ICU Patient Rm 636 | 40 | Rec-ICU Patient Rm 624 |
| 41 | Rec-ICU Patient Rm 636 | 42 | Rec-ICU Patient Rm 640 |

distribution system could support up to 262.5kVA of 208Y/120V cord-connected plug loads on each floor. At 0.8 power factor in a 22,000ft² patient care suite, this equates to a design loading of approximately 9.5 watts per square foot (W/SF). Hospital B used two 75kVA step-down transformers to serve normal 208Y/120V to two double tub and two single tub panels per floor and two 75kVA step-down transformers to serve emergency 208Y/120V to two double tub and two single tub panels. In total, the distribution system could support up to 300kVA of 208Y/120V cord-connected plug loads on each floor. At 0.8 power factor in a 23,500ft² patient care suite, this equates to a design loading approximately 10.2 W/SF.

Case Study Methodology

Patient care area cord-connected plug loads were quantified by patient care unit type (e.g., intensive care unit and general care inpatient) as well as by plug load system (normal or emergency) and trended. Segregation of plug loads by inpatient unit was made possible by two concurrent circumstances. First, both buildings' electrical distribution systems were designed to separate floor loads for maintenance and operability reasons (see Figure 2 for a typical electrical distribution system). This system architecture was intended to allow electrical isolation of a floor without affecting adjacent floors. This feature has proved especially useful in facilitating renovation work and localizing outages in the event of an electrical fault. Second, the care delivery model used in both confined each unit to a single floor. This arrangement conveniently segregated patient care units by floor, with each floor containing only

Figure 2 Sub-Meter Location in Electrical Distribution System





one unit. These factors combined allowed electrical consumption by floor (and thus by patient care unit) to be isolated and metered separately.

Data Collected

Metering samples were collected over a six-month period. The actual sampling periods varied in each of the hospitals surveyed. In the facility containing the surgical ICU, cardiac inpatient, cardiac/vascular inpatient and cardiac/routine medical units, plug loading was measured in 15-minute intervals over 181 days starting on July 1, 2009 and concluding on December 31, 2009. In the facility containing the neurosciences ICU and four non-acute inpatient units, plug loading was measured in 30-minute intervals over 183 days starting on October 1, 2011 and concluding on April 1, 2012. Since the plug loads were metered at each panel and each unit contained multiple normal and emergency plug load panels, 84 separate sub-meters were used to gather data. In all, over 840,000 points of interval data were captured and analyzed for this study. The data collected was aggregated and categorized by inpatient area and power source (normal or emergency power) and

Table 3 Electrical Sub-Meters Functionality

| | |
|--|--|
|  |  |
| <p>Schneider Electric PM800 meter</p> | <p>Eaton IQ Universal Power Sentinel meter</p> |
| <p>Metering / Monitoring Parameters:</p> <ul style="list-style-type: none"> Phase currents (A) Phase voltages (V) Peak demand (kW) Present demand (kW) Forward energy (kWh) Reverse energy (kWh) Total energy (kWh) Power factor Power: real, apparent, reactive Frequency (Hz) | <p>Metering / Monitoring Parameters:</p> <ul style="list-style-type: none"> Phase currents (A) Phase voltages (V) Peak demand (kW) Present demand (kW) Forward energy (kWh) Reverse energy (kWh) Total energy (kWh) Power factor Power: real, apparent, reactive |

used to calculate annual energy consumption (annual kWh/SF and annual kBTU/SF) and average plug load consumption intensity (W/SF). Watts per square foot were calculated based on the net square footages of the inpatient area surveyed. Average and peak kW interval values were also calculated and recorded.

Sub-Meters

The electrical meters used for this study were manufactured by Eaton Electric and Schneider. The Eaton sub-meters were the IQ Universal Power Sentinel type. The Schneider meters used in the study were PM800 meters. The meters were capable of monitoring and trending the electrical system parameter listed in Table 3. In general, the sub-meters' accuracy was in the +/-2% range for the application in which they were used. The plug load data collected represents 120V plug loads throughout the entire floor of the area surveyed. This includes all patient-related medical equipment located at the patient bed and support equipment in staff areas.

Findings

After careful analysis, the data gathered provided an interesting insight into the loading and usage patterns of medical equipment plug loads in various inpatient care areas. The following sections discuss in detail the findings as they relate to plug load demand, power consumption, energy intensity, and usage trends.

Plug Load Demand

Of the units surveyed, the highest peak plug load demand was recorded in the intensive care units. The 28-bed neuroscience intensive care unit had a peak plug load demand of 44 kW with an average demand of just under 30 kW, and the 29-bed surgical intensive care unit had a peak plug load demand of just over 31 kW with an average demand of 21.5 kW. This translates into a demand density of 1.95 kW/nSF (maximum) and 1.32 kW/nSF (average) for the neuroscience intensive care unit and 1.44 kW/nSF (maximum) and 0.99 kW/nSF (average) for the surgical intensive care unit. The lowest peak demand of 23 kW was recorded in the 32-bed non-acute inpatient care unit #1. The plug load demand averaged around 13.6 kW in this unit. Table

A.1 in the appendix tabulates the plug load demand and power density of all of the units surveyed.

Peak Plug Load Demand vs. Design Capacity

As described previously, the patient care suites surveyed had 120V plug load system capacities of between 262.5kVA and 300kVA. When these system capacities were compared against the peak kVA recorded in each area, it became apparent that the 120V distribution systems are quite oversized for the demand load that they serve. For example, the plug load system serving the 29-bed surgical intensive care unit could accommodate up to 210kW (assuming an average power factor of 80 percent) of 120V plug loads; however, the peak demand load recorded during the six-month monitoring period on this floor was only 31kW. This represents a peak demand utilization factor of only 14 percent. Even considering spare capacity for future load growth, this system appears to be oversized for its intended loads. Table A.2 in the appendix compares the record peak plug load demands of the areas monitored against the capacity of their 120V plug load distribution, and Figure A.1 graphically illustrates the recorded peak power density vs. the design capacity.

Normal and Emergency Plug Load Demand

The division of plug loading between the normal and emergency sources varied among spaces. The highest peak normal power plug load demand of 19.0kW was recorded in the 28-bed neurosciences intensive care unit. This translates into a demand density of approximately 0.84W/nSF. The highest peak emergency power plug load demand of 25.0kW was recorded in the same unit. This plug load translates into a demand density of approximately 1.11W/nSF. The lowest peak normal power plug load demand of 9.4kW was recorded in the 29-bed cardiac inpatient unit. This translates into a demand density of approximately 0.44W/nSF. And the lowest peak emergency power plug load demand of 8.0kW was recorded in one of the 28-bed non-acute inpatient units. This translates into a demand density of approximately 0.34W/nSF. Table A.3 in the appendix tabulates the plug load demand and power density of all the units surveyed in comparison to their design capacity, and Figure A.2 illustrates the total plug load demand on a per net square foot basis (broken down by normal and emergency) for each of the spaces monitored.

Normal vs. Emergency Use Trends

The daily load demand profiles of normal and emergency plug power loads differed greatly with respect to each other. The emergency power plug load consumption varied little throughout the day, whereas the normal varied based on the time. Figure A.3 in the appendix is a sample load profile that illustrates the difference in normal and emergency usage patterns. In this example, the normal power load profile clearly tracks the work week, whereas the emergency plug load remains relatively constant. In general, the load factors for the emergency plug loads were higher than those of the normal plug loads. The average load factor for normal plug loads in all the areas surveyed was 66.3 percent, whereas the average load factor for emergency plug loads was 78.9 percent. We surmise that emergency plug loads are mostly made up of medical devices that are in constant use, whereas the normal plug loads are made up of less critical office equipment (such as computers) used by the staff. Table A.4 in the appendix lists the normal, emergency, and total plug load factor for all the areas surveyed.

Load Factor

The load factor describes the frequency relationship between the highest demand interval and the overall average loading of the system. It is defined as the ratio of the average load in kilowatts supplied during a designated period to the peak or maximum load in kilowatts occurring in that period (see equation below). Load factor can be represented as a percent by multiplying the kilowatt-hours (kWh) in the period by 100 and dividing by the product of the maximum demand in kilowatts and the number of hours in the period. If a system has constant and unvarying electrical load, peak demand is equal to all other demand intervals over a given period of intervals. Such a system will have a load factor of 100 percent. Load factor is important to understanding how often demand loading occurs in a given period of time.

$$f_{\text{Load}} = \frac{\text{Average load}}{\text{Maximum load in a given time period}}$$

Plug Load Power Consumption

Not surprisingly, the highest peak plug load power consumption occurred in the intensive care units. The 29-bed neuroscience intensive care unit consumed 118,388 kWh over the 183-day sampling period. This translates into an annual plug load power consumption of 236,130 kWh and an annual

power consumption intensity of 10.44 kWh/nSF. The 32-bed surgical intensive care unit had the second highest plug load power consumption, at 94,727 kWh, measured over the 183-day sampling period. This translates into an annual plug load power consumption of 189,455 kWh and an annual power consumption intensity of 8.73 kWh/nSF. The lowest plug load power consumption was recorded in the 32-bed non-acute inpatient care unit 1, where plug load consumption was only 61,427 kWh over the 183-day sampling period. This translates into an annual plug load power consumption of 122,520 kWh and an annual consumption intensity of slightly over 5.0 kWh/nSF. Table A.5 in the Appendix tabulates the plug load demand and power density of all the units surveyed.

Plug Load Power Operational Costs

Assuming an average electricity cost of \$0.12 per kWh, the plug loads in the most energy intensive space surveyed (the neuroscience ICU) cost approximately \$28,300 per year to operate. This equates to a per bed operational cost of approximately \$1,011, or approximately \$1.25 per net square foot (when averaged across the whole suite). In contrast, the plug loads in the least energy intensive space surveyed (non-acute inpatient care unit 1) cost just over half as much, \$14,700 per year, to operate. This equates to a per bed operational cost of approximately \$460, or approximately \$0.61 per net square foot (when averaged across the whole suite). Table A.6 in the appendix tabulates calculated operational costs associated with the plug loads measured as part of this study.

Figure A.4 in the Appendix compares the recorded plug load consumption intensities to the CBECS consumption intensities. These measured plug load consumption intensities were significantly higher than the 4.5 kWh/SF values the 2008 CBECS survey found. The discrepancy may be attributed to the fact that the CBECS data is aggregated over the total square footage of the hospitals sampled, whereas the data gathered for this study is only aggregated among the inpatient care suites, where the medical equipment plug load density is higher than in other areas of the hospital.

Conclusions

The load-segregated electrical distribution systems, along with the integrated power metering systems in the two inpatient care buildings selected as part of this study, afforded an opportunity to closely study the usage patterns of

120V cord-connected plug loads in various types of patient care spaces. As expected, the demand for plug load increased appreciably with the acuity of the patient care population being treated. In general, the plug load energy consumption density was much higher than the 4.5 kWh/SF/year value described in the CBECS study. This discrepancy may be attributed to the fact that the CBECS data is aggregated throughout a whole facility, whereas the plug load energy consumption described in this study was focused on inpatient care suites only. Invariably the medical equipment plug load density of these inpatient care spaces will be higher than in other parts of the facility. Despite this, it is not clear whether this alone can account for the discrepancy between the observed plug load energy consumption and the CBECS survey data.

It is, however, clear that all of the distribution systems in all of the areas monitored as part of this study were quite oversized in comparison to the recorded demand loading over the six-month trending period.

System Capacity

All of the suites monitored had 120V plug load systems with design capacities between 9 and 10W/SF. The highest plug load demand data from the most plug load-intensive suite peaked at only 1.95W/nSF and averaged closer to 1.3W/nSF. This means that the plug load systems examined were at a minimum six times the capacity of the peak demand load recorded in the six-month study.

The results indicate that a system capacity of 2W/SF of normal and 2W/SF of emergency (total plug load system capacity of 4W/SF) could have easily accommodated the plug loads of even the most clinically intense areas surveyed as part of this study.

Downsizing Plug Load Systems

Downsizing the distribution transformation from 9 to 10 W/SF to 4 to 6W/SF would result in a net transformation reduction of 1200 kVA across all of the areas surveyed. This reduction would have resulted in over \$315,000 in equipment savings. This figure only takes into account the cost savings associated with smaller transformers and does not include savings from reductions in raceway, wiring, other distribution equipment (such as switchboards and circuit breakers), or installation labor. These factors would only add to

the calculated savings. Refer to Table A.7 in the appendix for a detailed tabulation of this analysis. Taking all of this into consideration, design professionals should contemplate emphasizing equipment population and usage patterns prior to calculating estimated demand of cord-connected medical devices in inpatient spaces.

Suggested Follow-Up Work

The data gathered in this study provides a useful insight into the medical equipment plug load power consumption patterns and demand density in modern inpatient care units. Although the findings outlined herein help describe the contribution of cord-connected loads at various types of inpatient care suites, the contribution of plug loads in other clinically intense areas of the hospital remain for the most part undocumented. Follow-up studies taking a similar approach to document plug loads in the following areas would be useful:

- operating rooms/suites
- clinical laboratories
- emergency departments
- intervention radiology suites
- radiation oncology suites
- imaging suites

The results could be used to develop a space-by-space guide for plug load energy intensity, which could be used by engineers and energy modelers.

Appendix: Tables and Figures

Table A.1 Annual Plug Power Consumption and Density

| Clinical Space | Beds | nSF | Power Demand | | Power Density | |
|--|------|--------|--------------|------------|---------------|----------------|
| | | | Max kW | Average kW | Max kW/nSF | Average kW/nSF |
| Neurosciences Intensive Care Unit | 28 | 22,608 | 44.0 | 29.9 | 1.95 | 1.32 |
| Surgical Intensive Care Unit | 29 | 21,691 | 31.2 | 21.5 | 1.44 | 0.99 |
| Cardiac & Routine Medical Unit | 28 | 21,855 | 29.8 | 20.4 | 1.36 | 0.93 |
| Non-Acute Inpatient Unit #4 | 32 | 23,268 | 25.0 | 15.7 | 1.07 | 0.67 |
| Cardiac Interventional & Vascular Surgery Unit | 29 | 21,966 | 24.6 | 18.3 | 1.12 | 0.83 |
| Non-Acute Inpatient Unit #2 | 32 | 23,423 | 24.0 | 15.9 | 1.02 | 0.68 |
| Non-Acute Inpatient Unit #3 | 32 | 23,475 | 24.0 | 14.6 | 1.02 | 0.62 |
| Cardiac Inpatient Unit | 29 | 21,543 | 23.4 | 17.1 | 1.08 | 0.79 |
| Non-Acute Inpatient Unit #1 | 32 | 23,857 | 23.0 | 13.6 | 0.96 | 0.57 |

Table A.2 Plug Power System Demand Utilization

| Clinical Space | Plug Load Demand Max kW | Plug Load Design Capacity kW | Plug Load System Utilization |
|--|-------------------------|------------------------------|------------------------------|
| Neurosciences Intensive Care Unit | 44.0 | 240 | 18.3% |
| Surgical Intensive Care Unit | 31.2 | 210 | 14.8% |
| Cardiac & Routine Medical Unit | 29.8 | 210 | 14.2% |
| Non-Acute Inpatient Unit #4 | 25.0 | 240 | 10.4% |
| Cardiac Interventional & Vascular Surgery Unit | 24.6 | 210 | 11.7% |
| Non-Acute Inpatient Unit #2 | 24.0 | 240 | 10.0% |
| Non-Acute Inpatient Unit #3 | 24.0 | 240 | 10.0% |
| Cardiac Inpatient Unit | 23.4 | 210 | 11.1% |
| Non-Acute Inpatient Unit #1 | 23.0 | 240 | 9.6% |

Table A.3 Recorded Plug Load: Normal and Emergency

Normal Power Plug Loads

| Clinical Space | Beds | nSF | Power Demand | | Power Demand Density | | Design |
|---|------|--------|---------------|------------------|----------------------|---------------------|--------|
| | | | Normal Max kW | Emergency Max kW | Normal Max W/nSF | Emergency Max W/nSF | |
| Surgical ICU | 29 | 21,691 | 11.6 | 19.5 | 0.5 | 0.9 | 5.2 |
| Cardiac Inpatient | 29 | 21,543 | 9.4 | 14.0 | 0.4 | 0.6 | 5.2 |
| Cardiac Interventional & Vascular Surgery | 29 | 21,966 | 9.7 | 14.9 | 0.4 | 0.7 | 5.1 |
| Cardiac; Routine Medical | 28 | 21,855 | 11.7 | 18.1 | 0.5 | 0.8 | 5.1 |
| Neurosciences ICU | 28 | 22,608 | 19.0 | 25.0 | 0.8 | 1.1 | 6.6 |
| Non-acute inpatient unit | 32 | 23,857 | 15.0 | 8.0 | 0.6 | 0.3 | 6.3 |
| Non-acute inpatient unit | 32 | 23,423 | 14.0 | 10.0 | 0.6 | 0.4 | 6.4 |
| Non-acute inpatient unit | 32 | 23,475 | 16.0 | 8.0 | 0.7 | 0.3 | 6.4 |
| Non-acute inpatient unit | 32 | 23,268 | 16.0 | 9.0 | 0.7 | 0.4 | 6.4 |

Emergency Power Plug Loads

| Clinical Space | Beds | nSF | Power Demand | |
|---|------|--------|--------------|-----------------|
| | | | Normal Power | Emergency Power |
| Surgical ICU | 29 | 21,691 | 37% | 63% |
| Cardiac Inpatient | 29 | 21,543 | 40% | 60% |
| Cardiac Interventional & Vascular Surgery | 29 | 21,966 | 40% | 60% |
| Cardiac; Routine Medical | 28 | 21,855 | 39% | 61% |
| Neurosciences ICU | 28 | 22,608 | 43% | 57% |
| Non-acute inpatient unit | 32 | 23,857 | 65% | 35% |
| Non-acute inpatient unit | 32 | 23,423 | 58% | 42% |
| Non-acute inpatient unit | 32 | 23,475 | 67% | 33% |
| Non-acute inpatient unit | 32 | 23,268 | 64% | 36% |

Table A.4 Plug Load: Normal and Emergency Load Factor

| Hospital | Clinical Space | Beds | nSF | Normal Plug Load Demand Factor | Emergency Plug Load Demand Factor | Total Plug Load Demand Factor |
|----------|--|------|--------|--------------------------------|-----------------------------------|-------------------------------|
| A | Surgical Intensive Care Unit | 29 | 21,691 | 54.5% | 77.3% | 78.3% |
| A | Cardiac Inpatient Unit | 29 | 21,543 | 59.6% | 78.2% | 78.4% |
| A | Cardiac Interventional & Vascular Surgery Unit | 29 | 21,966 | 60.2% | 83.5% | 81.0% |
| A | Cardiac & Routine Medical Unit | 28 | 21,855 | 54.5% | 77.5% | 78.8% |
| B | Neurosciences Intensive Care Unit | 28 | 22,608 | 71.0% | 74.3% | 72.9% |
| B | Non-Acute Inpatient Unit #1 | 32 | 23,857 | 71.3% | 77.1% | 73.4% |
| B | Non-Acute Inpatient Unit #2 | 32 | 23,423 | 78.8% | 91.4% | 84.1% |
| B | Non-Acute Inpatient Unit #3 | 32 | 23,475 | 72.5% | 74.1% | 73.1% |
| B | Non-Acute Inpatient Unit #4 | 32 | 23,268 | 74.6% | 76.4% | 75.4% |
| Average | | | | 66.3% | 78.9% | 77.3% |

Table A.5 Annual Plug Power Consumption and Consumption Intensity

| Clinical Space | Beds | nSF | Annual kWh Consu | Annual kBTU mption | Annual kWh/nSF Consumption Intensity | Annual kBTU/nSF |
|--|------|--------|------------------|--------------------|--------------------------------------|-----------------|
| Surgical Intensive Care Unit | 29 | 21,691 | 189,455 | 646,477 | 8.73 | 29.8 |
| Cardiac Inpatient Unit | 29 | 21,543 | 150,720 | 514,300 | 7.00 | 23.9 |
| Cardiac Interventional & Vascular Surgery Unit | 29 | 21,966 | 161,599 | 551,424 | 7.36 | 25.1 |
| Cardiac & Routine Medical Unit | 28 | 21,855 | 180,018 | 614,274 | 8.24 | 28.1 |
| Neurosciences Intensive Care Unit | 28 | 22,608 | 236,130 | 805,746 | 10.44 | 35.6 |
| Non-Acute Inpatient Unit #1 | 32 | 23,857 | 121,520 | 414,663 | 5.09 | 17.4 |
| Non-Acute Inpatient Unit #2 | 32 | 23,423 | 139,266 | 475,219 | 5.95 | 20.3 |
| Non-Acute Inpatient Unit #3 | 32 | 23,475 | 127,339 | 434,519 | 5.42 | 18.5 |
| Non-Acute Inpatient Unit #4 | 32 | 23,268 | 137,986 | 470,849 | 5.93 | 20.2 |

Table A.6 Annual Plug Load Power Operational Costs

| Clinical Space | Beds | nSF | Annual kWh Consu | Annual kBTU mption | Annual kWh/nSF Consumption Intensity | Annual kBTU/nSF |
|--|------|--------|------------------|--------------------|--------------------------------------|-----------------|
| Surgical Intensive Care Unit | 29 | 21,691 | 189,455 | 646,477 | 8.73 | 29.8 |
| Cardiac Inpatient Unit | 29 | 21,543 | 150,720 | 514,300 | 7.00 | 23.9 |
| Cardiac Interventional & Vascular Surgery Unit | 29 | 21,966 | 161,599 | 551,424 | 7.36 | 25.1 |
| Cardiac & Routine Medical Unit | 28 | 21,855 | 180,018 | 614,274 | 8.24 | 28.1 |
| Neurosciences Intensive Care Unit | 28 | 22,608 | 236,130 | 805,746 | 10.44 | 35.6 |
| Non-Acute Inpatient Unit #1 | 32 | 23,857 | 121,520 | 414,663 | 5.09 | 17.4 |
| Non-Acute Inpatient Unit #2 | 32 | 23,423 | 139,266 | 475,219 | 5.95 | 20.3 |
| Non-Acute Inpatient Unit #3 | 32 | 23,475 | 127,339 | 434,519 | 5.42 | 18.5 |
| Non-Acute Inpatient Unit #4 | 32 | 23,268 | 137,986 | 470,849 | 5.93 | 20.2 |

Table A.7 Transformer Savings Cost Comparison

| Hospital | Clinical Space | Normal Plug Load Design Capacity | Emergency Plug Load Design Capacity | Total 120V System Capacity W/SF ^④ | Total 120V Transformer Cost [⊖] | Normal Plug Load Resized Capacity | Emergency Plug Load Resized Capacity | Total Resized 120V System Capacity W/SF ^④ | Total 120V Transformer Cost [⊖] | Transformer First Cost Savings | nSF |
|----------|--|----------------------------------|-------------------------------------|--|--|-----------------------------------|--------------------------------------|--|--|--------------------------------|--------|
| A | Surgical Intensive Care Unit | 112.5 kVA | 150 kVA | 9 | \$73,094 | 75 kVA | 75 kVA | 5 | \$47,602 | \$25,492 | 22,608 |
| A | Cardiac Inpatient Unit | 112.5 kVA | 150 kVA | 10 | \$73,094 | 75 kVA | 75 kVA | 6 | \$47,602 | \$25,492 | 21,691 |
| A | Cardiac Interventional & Vascular Surgery Unit | 112.5 kVA | 150 kVA | 10 | \$73,094 | 75kVA | 75 kVA | 5 | \$47,602 | \$25,492 | 21,855 |
| A | Cardiac & Routine Medical Unit | 112.5 kVA | 150 kVA | 9 | \$73,094 | 75kVA | 75 kVA | 5 | \$47,602 | \$25,492 | 23,268 |
| B | Neurosciences Intensive Care Unit | 150 kVA [⊖] | 150 kVA | 10 | \$95,204 | 60 kVA [⊕] | 60 kVA [⊕] | 4 | \$52,504 | \$42,700 | 21,966 |
| B | Non-Acute Inpatient Unit #1 | 150 kVA [⊖] | 150 kVA [⊖] | 10 | \$95,204 | 60 kVA [⊕] | 60 kVA [⊕] | 4 | \$52,504 | \$42,700 | 23,423 |
| B | Non-Acute Inpatient Unit #2 | 150 kVA [⊖] | 150 kVA [⊖] | 10 | \$95,204 | 60 kVA [⊕] | 60 kVA [⊕] | 4 | \$52,504 | \$42,700 | 23,475 |
| B | Non-Acute Inpatient Unit #3 | 150 kVA [⊖] | 150 kVA [⊖] | 11 | \$95,204 | 60 kVA [⊕] | 60 kVA [⊕] | 4 | \$52,504 | \$42,700 | 21,543 |
| B | Non-Acute Inpatient Unit #4 | 150 kVA [⊖] | 150 kVA [⊖] | 10 | \$95,204 | 60 kVA [⊕] | 60 kVA [⊕] | 4 | \$52,504 | \$42,700 | 23,857 |
| | | | | | | | | | Total Savings | \$315,468 | |

NOTES

⊖ 2 x 75kVA Transformers

⊖ Transformer costs based on Schneider 75kVA EE75T3HFUCU: \$23,801; 112.5kVA EE112T3HFUCU: \$31,706 & 150kVA EE150T3HFUCU: \$41,388

⊕ 2 x 30kVA Transformers

Figure A.1 Plug Load Power Density Design vs. Actual

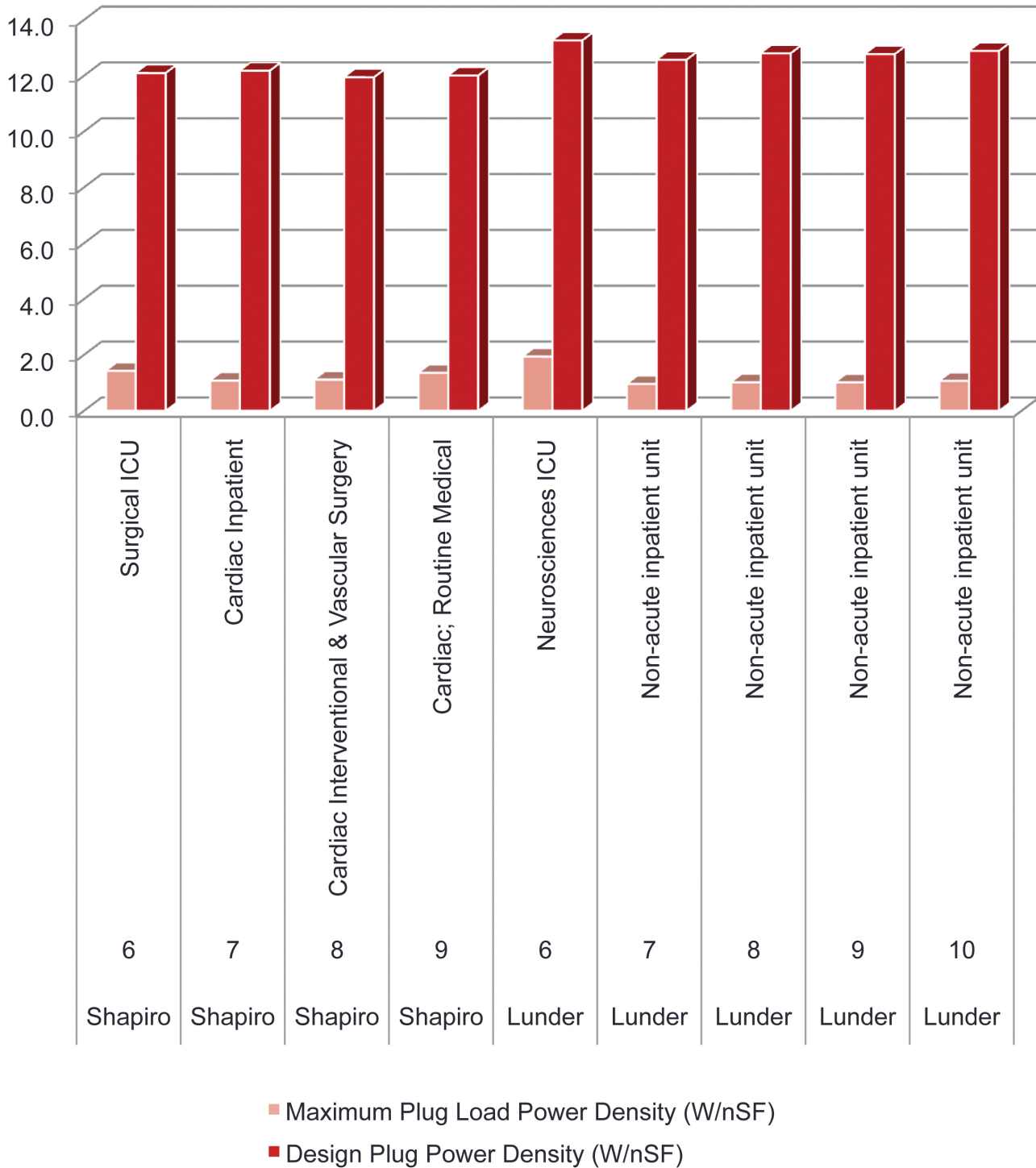


Figure A.2 Plug Load Peak Demand Density

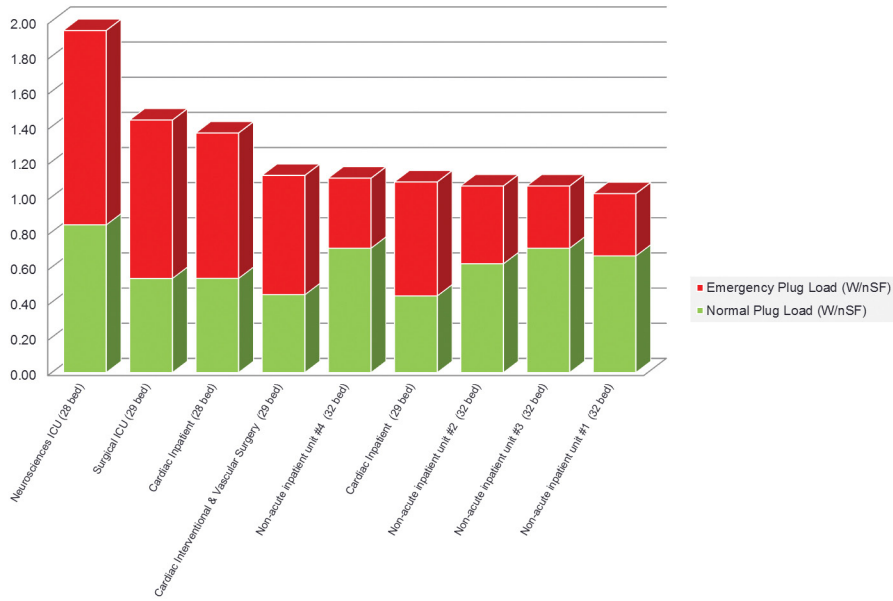


Figure A.3 Neuroscience ICU Plug Load February 2012

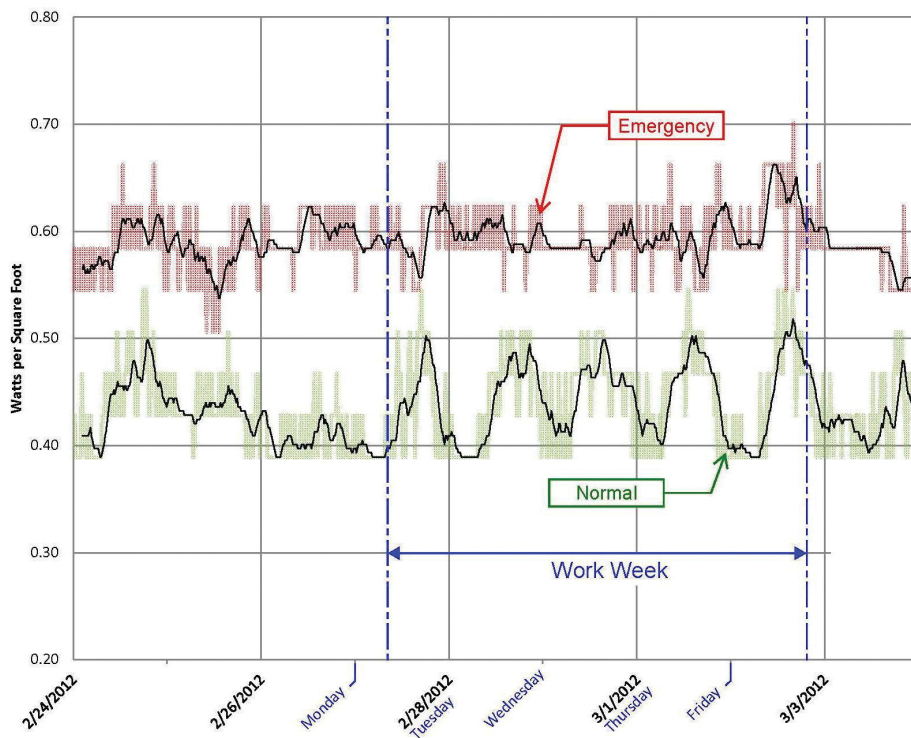
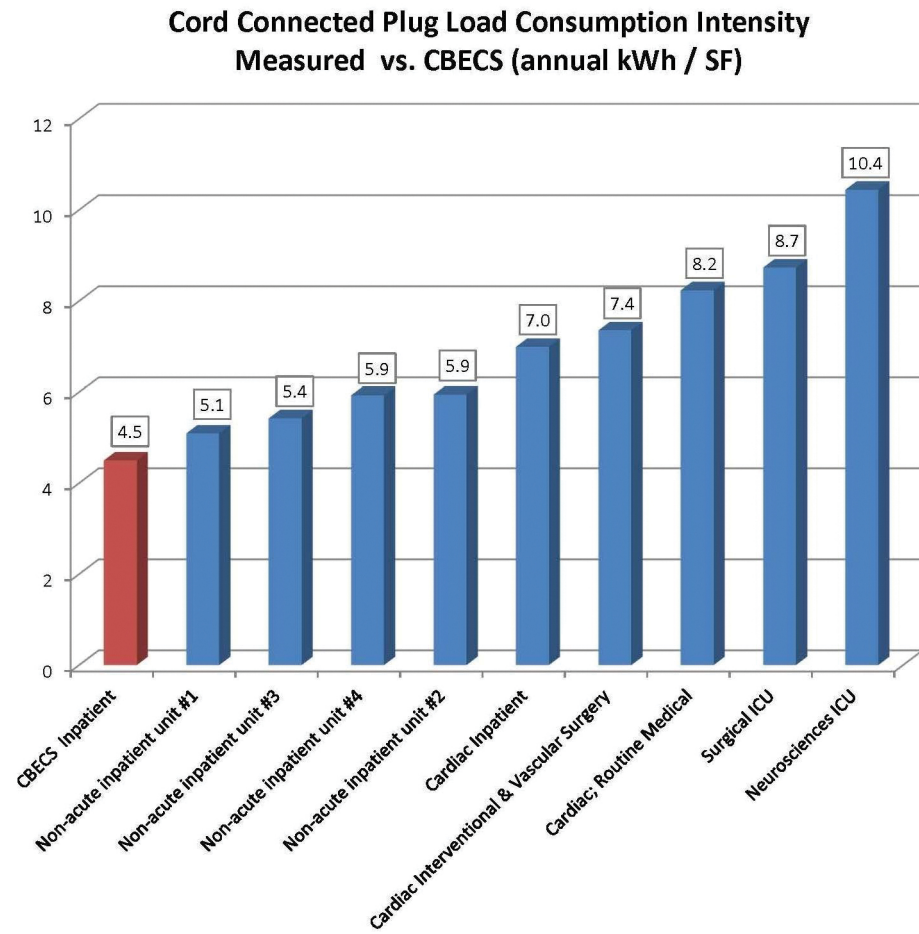


Figure A.4 Recorded Plug Load Consumption Intensity vs. CBECS

References

- Institute of Electrical and Electronics Engineers (IEEE). 2007. Standard 602: “IEEE Recommended Practice for Electric Systems in Health Care Facilities.” New York: IEEE.
- Rivas, J. 2009. “Managing Plug Loads: Laptops and Chargers and Fans, Oh My!” *Environmental Protection Agency*. Published February 11. www.epa.gov/climateleaders/documents/events/11feb_plugloads.pdf.
- Singer, B. C.; P. Matthew; S. Greenberg; W. Tschudi; D. Sartor; S. Strom; and W. Vernon. 2009. “Hospital Energy Benchmarking Guidance: Version 1.0.” *Berkeley Lab*. www.eia.doe.gov/emeu/consumptionbriefs/cbecs/pbawebbsite/health/health_howuseelec.htm.
- U.S. Energy Information Administration (EIA). 2014. “Commercial Buildings Energy Consumption Survey.” U.S. Energy Information Administration. www.eia.gov/consumption/commercial/index.cfm.



www.ashe.org