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Electric Circuit Data Collection: An Analysis of Health Care Facilities

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Foreword

Over the last few decades, there has been significant technological innovation along the entire electrical power chain. Factors such as today's energy codes are driving down the electrical loads presented by end-use equipment. Thus, the service, feeder, and branch circuit load design requirements in *NFPA 70®*, *National Electrical Code®* (*NEC®*), such as the load growth assumptions that justify spare capacity, have been called into question.

The changing landscape of building operations and corresponding technological advances have also resulted in data-rich environments. While electrical data collection and the availability of relevant data have historically been lacking, insights from validated electrical data have become more prevalent today and are being utilized in the code development process to assess existing regulations or substantiate code changes.

Recognizing the need for data to inform the service, feeder, and branch circuit load design requirements in the NEC, the Fire Protection Research Foundation (FPRF) initiated a research program to gather electrical circuit data. A prior phase I project of the electrical data research program titled *Evaluation of Electrical Feeder in Branch Circuit Loading* focused on general commercial occupancies and entailed a literature review that helped to clarify key elements of a data collection plan to support the phase II effort. This phase II program, *Electrical Circuit Data Collection: An Analysis on Health Care Facilities*, implemented the data collection plan outlined in the phase I study, with a focus on health care facility electrical loads in patient care areas during the COVID-19 pandemic.

The Fire Protection Research Foundation is grateful for the report authors Troy Savage, Walt Vernon, and Eric Nimer who are with Mazzetti, Inc. located in San Francisco, CA, USA. The Research Foundation appreciates the guidance provided by the project technical panelists, the funding provided by the project sponsors, and all the others who contributed to this research effort.

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 65,000 individuals around the world.

Keywords: electrical circuits, electrical panels, demand factors, electrical load, calculated load, NEC, NFPA 70, healthcare, pandemic

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Electric Circuit Data Collection: An Analysis of Healthcare Facilities

MAZZETTI

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PREPARED FOR THE FIRE PROTECTION RESEARCH FOUNDATION

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EXECUTIVE SUMMARY

Since Samuel Insull applied the principles of diversity and demand factors to the creation of the first electrical grids, these ideas have been fundamental to the creation of reliable and cost-effective electrical systems. The determination of demand factors has long been a challenge—especially at the building level—due to the difficulty of obtaining quality data on which to base them. As a result, code minimums for demand factors have historically resulted in systems that are generally larger than the loads they serve. Some building designers tell stories of utility engineers perplexed at the service sizes designers request because the engineers know from their data that the building design minimums will prescribe systems that are much larger than the actual loads the building will produce.

There are several theories regarding what impacts receptacle electrical demand that make intuitive sense but have little to no actual evidence. As quality data on electrical demand has historically not been made available to regulatory bodies, the reliance on these intuitive theories has delayed changes to electrical demand requirements.

The Fire Protection Research Foundation, with funding support from the American Society of Health Care Engineering (ASHE) and the National Fire Protection Association (NFPA), initiated a project with Mazzetti to collect and analyze electric circuit data from multiple occupancies. In the infancy stage of the project, the COVID-19 pandemic resulted in the Foundation refocusing this effort solely on health care facilities. Through the generous donation of electrical metering equipment from Pacific Gas and Electric and the Smart Buildings Center, Mazzetti was able to deploy hundreds of meters to operating hospitals across the country. These meters enabled us to see the behavior of hospital electrical systems at the circuit level and compare those actual loads to the calculated loads in *NFPA 70®*, *National Electrical Code®* (*NEC®*)[1]. The resulting data highlights the oversizing of systems based on the current Code. The results of this study demonstrate that the hospital demand factors contained in the current (2020) edition of the *National Electrical Code* may result in electrical systems that are between 100 percent and 700 percent larger than the actual loads.

[1] *NFPA 70®*, *National Electrical Code®*, and *NEC®* refer to the same document. These are typically referred to as the NEC in this text, though *NFPA 70* may also appear.

1 INTRODUCTION

The conditions under which buildings operate are constantly changing given the rapid pace of technological innovation. As a result, it is appropriate for the electrical code to evolve. The expanded use of monitoring equipment has also resulted in data-rich environments. It is important to utilize the insights provided by this data to inform the codes and standards process.

Load requirements in the NEC have largely been in effect since 1968, with few modifications over the last 50 years. Factors such as today's energy codes are driving down the electrical load of end-use equipment. As a result, questions have arisen about whether the design requirements for feeder and branch circuit loads in the NEC have kept pace with the technological advancements and reduction in energy loads in facilities today. Specifically, load growth assumptions that justify spare capacity are being re-examined. Further, larger transformers that supply power to service, feeder, and branch circuits may expose electricians working on live equipment to unnecessary flash hazards. The 2020 edition of the NEC introduced significant changes to the lighting load requirements, which shows some progress toward calculated loads that reflect current usage and technology. For example, health care lighting loads went from 2 volt-amps per square foot (VA/ft^2) to 1.6 VA/ft^2.

1.1 TYPES OF HEALTH CARE PLUG LOADS

By *plug loads*, we mean those loads that are cord-connected to an electrical outlet. Most frequently, these loads are 120-volt single phase, though they may be 2- or 3- phase, and they can be as high as 208 volts.

Health care facilities include virtually every type of space — from residential spaces for housing patients to offices, retail spaces, religious spaces, educational spaces, workshops, laboratories, data centers, and procedure rooms.

From a licensing perspective, health care buildings fall into two categories; in-patient buildings, in which patients stay for 24 hours or more, and outpatient buildings, in which patients stay for fewer than 24 hours. In general, the range of procedures and the condition of patients in the former are more intense than those in the latter.

Within all of these spaces, there are two kinds of plug loads. For the purposes of this report, we will define them as *general receptacles*[2] and *dedicated receptacles*[3].

[2] These may also be referred to as general outlets.

[3] These outlets may also be referred to as dedicated receptacles, dedicated outlets, specific equipment receptacles, and specific equipment outlets throughout the report.

Within this report, *general receptacles* will refer to the ubiquitous single-pole, 15- or 20- amp receptacle. *Dedicated receptacles* will refer to those receptacles that are designed to serve a single piece of equipment on dedicated circuits.

1.2 NEED FOR DEMAND FACTORS

Many electrical loads are either on and operating at 100 percent of the rated load or off and operating at 0 percent of the rated load. Many loads vary over time with the controls being either automatic or manual. Logically, the probability that any one particular load is operating at 100 percent (fully on) is less than one, as the load will be off (or not operating at full load) at some point in time. However, the wiring serving one load needs to be capable of serving 100 percent of that load.

However, when a circuit serves more than one receptacle, that circuit is likely to experience a load range from 0 to 100 percent of all the connected loads and be on at full power, simultaneously. At higher levels of a system, such as at a panel, transformer, or other distribution equipment, the likelihood of all the devices being on at full power at the same time is much less than 1.

Demand factors allow components of the system to be sized at some fraction of the potential sum of all the connected loads. This gives system designers the ability to design systems that recognize the decreasing likelihood of all the dedicated and connected loads being on at the same time. Without the use of demand factors, all the elements of an electrical system would be designed to serve 100 percent of the connected load and systems would be oversized, more expensive, and generally unused.

This oversizing can result in wasted materials, space, and money, and an increased risk of arc-flash hazards.

1.3 HISTORY OF PLUG LOAD DEMAND FACTORS

Research through the NFPA library shows that the first instance of the use of the term *demand factor* in the NEC occurred in 1928. The *Report of the Electrical Committee* indicates that demand factors were included to avoid wasting copper, which would never be used because the system would never be called upon to carry all of the connected load at any one time.[4, 5]

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[4] *Report of the Electrical Committee*. pp. 142. Obtained from the NFPA library.

[5] The full quote is illustrative. It reads "There are a number of what we might class as major accomplishments in the next which we now recommend. For a great many years, installations of electric wiring in buildings was satisfactorily accomplished from the point of view of all concerned, when the copper from the service switch to the final outlet was put in on the basis of the current value given in what used to be Table 610 in the Code. But with the increase in the size of buildings and with the increase in the uses of electricity in premises, there has grown up to be what is known in electrical circles as a demand or a diversity factor, so that it has become uneconomic to install copper from the service switch throughout the installation on the theory that every bit of

Article 6 of the 1928 code indicates that hospitals (except in the operating suite and X-ray department) should be calculated at ¾ watt per square foot. It then states that for areas of 25,000 square feet or less per feeder, the demand is 100 (percent)[6]. For the excess area above 25,000 square feet per feeder, the demand is 60 (percent). The demand factors have changed since 1928; however, to the author's knowledge, there is no record of the rationale of these derivations of the demand factors. It is therefore presumed that previous changes to health care demand factors have not been based on comprehensive studies of health care plug loads.

Today, the requirements for calculating receptacle loads are as follows:

Dedicated outlets. NEC Section 220.14(A) requires circuits serving outlets dedicated to a specific appliance[7] to be calculated based on the ampere rating of the appliance or load served.[8]

General outlets. NEC Section 220.14(L) requires that other receptacle outlets be calculated at not less than 180 volt-amperes (VA) per receptacle.

NEC Section 220.44 applies a demand factor of 100 percent to the first 10 kVA of the calculated load and a demand factor of 50 percent to receptacle loads above 10 kVA for the 220.14(L) outlets.[9]

Using the 2020 NEC, the permissible ways to calculate the demand factor for plug loads in any building, including a health care building, are the following:

- Based on the service and calculated load based on 180 VA per receptacle for general receptacles and using the nameplate (ampere rating) for dedicated receptacles as described above.
- Based on the largest load, NEC 220.60 indicates that where two or more non-coincident loads will be used simultaneously, it is permissible to use only the largest load that will be used at one time to calculate the total load of a feeder or service.[10] In theory, this means that a calculation could consider a demand factor of 100% for the largest load and 0 for everything else.
- Based on a prudent demand factor (in health care). Section 517.31(D) of the Code allows sizing of the alternate power source to be based on (1) prudent demand factors and

that copper will be called upon to carry all the connected load at any one time. Perhaps, therefore, one of the most important economic changes which is recommended in this edition of the Code is the values for a so-called demand factor for calculating the sizes of copper for risers and feeders in buildings. It has been explained to me that this may result in a very substantial saving in investment in copper which remains in the building permanently and which, under previous conditions of the Code, if that Code were complied with, would represent a frozen investment with no economic return."

[6] The text itself indicates a demand factor of 100, not 100 percent. The percentage is implied.

[7] These outlets are referred to as specific equipment receptacles and specific equipment outlets throughout the report

[8] See NEC Section 220.14(A) in NEC Article 220, Branch-Circuit, Feeder, and Service Load Calculations.

[9] See NEC Section 220.44 in NEC Article 220, Branch-Circuit, Feeder, and Service Load Calculations.

[10] See NEC Section 220.60 in NEC Article 220, Branch-Circuit, Feeder, and Service Load Calculations

historical data, (2) the connected load, (3) the feeder calculation procedures from Article 220, or any combination of (1), (2), and (3).[11] This section of the Code recognizes that using historical data and prudent demand factors are acceptable ways to perform demand calculations.

It appears that peak health care plug loads are significantly different from those calculated in the NEC. The demand factors have not changed to reflect this difference.

It should be noted that many trends have changed the kinds, magnitudes, and behaviors of the loads that today's electrical systems need to serve. Among these factors are the following:

- An increasing number of electronic devices and the need to charge these devices
- Anecdotal evidence that generally suggests trends in device energy efficiency have led to a decreasing load per device

In addition, other factors specific to health care occupancies have driven changes to electrical systems in these buildings. Such factors include the following:

- Requirements from other codes, including NFPA 99, *Health Care Facilities Code*, and the Facilities Guidelines Institute's *Guidelines for Design and Construction*, for more outlets in various spaces
- Needs of health care facilities to plan for unexpected events, thus increasing the number of devices

Despite these factors, code-making bodies have had no or limited data on which to base revisions. Code-writers and generations of design engineers have been cautious about changing demand factors without substantial data.

1.4 SUMMARY OF PREVIOUS WORK

There is a history of studies on plug loads in general and plug loads in health care. This section will highlight key portions of that history.

1.4.1 IEEE Standard P241, "Gray Book," (1990).

The Institute of Electrical and Electronics Engineers (IEEE) published IEEE Std 241-1990, *IEEE Recommended Practice for Electric Power Systems in Commercial Buildings*, commonly known as the "Gray Book." IEEE 241-1990 notes that the 1 VA/ft^2 of net demand is adequate for appliance loads. It also notes that loads for large computers, plug-in type air conditioners, and cooking and laundry equipment should be considered separately. Table 5 in Chapter 2 of the Gray Book lists typical appliance/general purpose receptacle loads (excluding plug-in type air conditioning and heating equipment). Hospitals are listed as having a load of between 0.5 (low) and 1.5 VA/ft^2 (high).

[11] See NEC Section 517.31D in NEC Article 517, Health Care Facilities.

1.4.2 IEEE Standard P602, "White Book," (2007).

IEEE also published IEEE Std 602-2007, *IEEE Recommended Practice for Electric Systems in Health Care Facilities.* IEEE 602-2007 provides guidance for health care facility electrical design. It notes that "generally speaking, the actual loads that any given portion of an electrical system will experience will be less than the sum of the connected loads on that portion of the electrical system, and less than the connected loads adjusted by the code's specifically enumerated demand factors. … The explicit code-specified demand factors will result in actual demands, especially at the service or the generator, that are considerably higher than the maximum demand that point in the system will experience."[12]

Thus, the standard for electrical systems in health care facilities acknowledges the discrepancy between actual demand and the code-specified demand.

1.4.3 LBNL, "Evaluation of Miscellaneous and Electronic Device Energy Use in Hospitals," (2012).

Lawrence Berkeley National Laboratory (LBLN) published a study entitled *Evaluation of Miscellaneous and Electronic Device Energy Use in Hospitals.* The study, funded by the California Energy Commission Public Interest Energy Research Program looked at several hospitals in California.

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 that plugged into the receptacle outlets. Every 10 seconds, average power measurements were collected via a wireless metering system.

The study concluded that metering for a two-month period would have provided a reasonably accurate estimate of the annual energy consumption for most load categories. For categories such as miscellaneous lighting, in which usage might be impacted by seasons, longer metering periods would be needed for better estimates. The 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 estimated that plug loads account for 15 percent of the primary energy use in buildings in the United States.[13]

1.4.4 "Targeting 100!" (2012-14)

"Targeting 100!" was an initiative of the University of Washington and others to reduce energy use in hospitals with a detailed study of energy use at Legacy Salmon Creek Medical Center in Vancouver, Washington. The study, entitled *Energy Use and Model Calibration Study: Legacy*

[12] IEEE Std 602-2007, *IEEE Recommended Practice for Electric Systems in Health Care Facilities*, pp 18.

[13] Black, Douglas R., et al. *Evaluation of Miscellaneous and Electronic Device Energy Use in Hospitals*. (2012).

Salmon Creek Medical Center Vancouver, Washington, found an average 0.98 W/ft^2 plug load for miscellaneous equipment.[14]

1.4.5 *Plug and Process Loads in Medical Office Buildings, ASHRAE Transactions* (2015).

A study entitled *Plug and Process Loads in Medical Office Buildings*, published in *ASHRAE Transactions*, specifically considered loads in medical office buildings.[15] This study measured plug and process loads at five medical office building sites (taking up a total of 519,646 ft^2) in the San Francisco Bay Area. The report concluded that plug loads are overdesigned by 160 to 260 percent.

The peak plug and process load power density (by room type) recorded was 4.67 W/ft^2 in prep areas and pre-op spaces. These spaces had an average density of 2.93 W/ft^2. The peak W/ft^2 across the entire building was 1.04 W/ft^2. [16]

1.4.6 *Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas*, ASHE Monograph (2014).

The American Society for Health Care Engineering (ASHE) of the American Hospital Association (AHA) published a monograph entitled *Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas.* This monograph presented a six-month case study that tracked the emergency and normal power 120 V cord-connected plug loads at two inpatient care facilities located in Boston, Massachusetts, each of which was part of a tertiary care academic medical center.

The study noted that all of the distribution systems in all of the areas monitored as part of the study were oversized in comparison to the recorded demand load over the six-month period.

All of the suites monitored had 120 V plug load systems with design capacities between 9 and 10 W/ft^2. The highest plug load demand data from the most plug load-intensive suite peaked at only 1.95 W/ft^2 and averaged closer to 1.3 W/ft^2. 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 2 W/ft^2 in normal settings and 2 W/ft^2 in emergency settings (a total plug load system capacity of 4 W/ft^2) could have accommodated the plug loads of even the most clinically intense areas surveyed as part of this study.

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[14] More information on the Targeting 100!: Legacy Salmon Creek Overview is available here: http://t100.be.uw.edu/CAS_LSC.php

[15] The authors of this article were employees of Mazzetti at the time of its publication.

[16] Ruecker, Ross, Arash, Guity, and Jun, Timbang. *Plug and Process Loads in Medical Office Buildings*. *ASHRAE Transactions* 121, No. 2 (2015): 63–71.

This study also quantified some cost implications. Downsizing distribution transformation from 9 to 10 W/ft^2 to 4 to 6 W/ft^2 would result in a nest 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 considers the cost savings associated with smaller transformers and does not include savings from reductions in raceway, wiring, and other distribution equipment (such as switchboards and circuit breakers) or installation labor. These factors would only add to the calculated savings.[17]

1.4.7 NREL, *Healthcare Energy End-Use Monitoring*, (2014).

Another important contribution to the historical study of plug loads in hospitals came from the National Renewable Energy Laboratory (NREL). NREL partnered with two hospitals to collect data on multiple thermal and electrical end-use categories, including large medical equipment loads. The NREL study also used and analyzed data from Ruecker, et al. (2015).

The study of the two hospitals utilized multiple end-use categories. Plug loads were included as part of the "other electrical loads" category, which includes the lighting systems and plug and process load equipment that were not directly monitored during the study. The study also included specific information on medical imagining equipment. The study monitored three computed tomography (CT) scan units and two magnetic resonance imagining (MRI) units for one year and found these devices used, on average, between 3 kW and 13 kW. There were sporadic instances of higher power, with the maximum power recorded ranging from 33 kW to 111 kW.[18]

Noting the importance of end-use plug loads, the study also analyzed the data from Ruecker, et al. (2015). See Section 1.4.5 above for additional information.

1.4.8 Partners/TCI Plug Load Study

Mass General Brigham (formerly Partners HealthCare) and Thompson Consultants, Inc. (TCI) measured plug loads for six months at two acute care inpatient hospitals (totaling 214 general and 57 ICU beds) in Massachusetts. The highest average plug load was 1.47 VA/ft^2 in the neuro intensive care unit (28 beds). This area also saw the highest maximum plug load at 1.88 VA/ft^2. This data was presented to the health care engineering community at the 2018 International Summit & Technical Exhibition on Health Facility Planning, Design, and Construction, better known as the PDC Summit.

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[17] D'Antona, Jason and Messervy, John. *Quantifying Hospital Cord-Connected Plug Loads in Inpatient Areas.* ASHE Monograph. Chicago, IL (2014).

[18] Sheppy, Michael; Shanti Pless; and Feitau Kung. *Healthcare Energy End-Use Monitoring*. NREL/TP-5500-61064. Golden, CO (2014).

1.4.9 2018 Mazzetti Hospital Plug Load Study

In 2018, Mazzetti monitored receptacle loads in Kaiser Permanente Westside Medical Center in Portland, Oregon. Over the course of six months and eight individual phases, Panoramic Power amperage meters were installed on 37 panels and over 1,000 individual circuits. For each phase, one-minute interval data was collected for two weeks, then the equipment was removed and installed on new panels for the next phase. Circuits and panels were mapped to floor plans to determine the room type, department, and square footage they served.

This study reported a peak measured load of 1.98 VA/ft^2 in the imaging department.
The results of this work, including the raw data, have been shared with the NEC code-making panels, but no formal report has been published. A summary of the results is included in Appendix 2 of this report for comparison purposes.

1.4.10 Overall Summary

The above studies from different facilities in different jurisdictions generally point to an average plug load power usage of approximately 1 W/ft^2, with peak loads in the range of 2.0 W/ft^2. These studies and general engineering guidance from the IEEE and others support these expected levels of plug load demand in health care facilities.

1.5 DATA CONCERNS

Despite the growing evidence of the need to modify the current demand factors, code-making panels have been reluctant to modify demand factors for health care facilities based on the following intuitions:

a. ***The one year of data problem***. Some believe that loads would need to be measured over the span of one year to determine the accurate behavior of loads.
b. ***The red outlet problem***. Some have expressed a concern that, during an extended power outage, clinicians would unplug many devices from white receptacles (which do not have redundant power sources) and plug them into red receptacles (which do have redundant power sources)
c. ***The all-branch problem***. All the connected loads in hospitals are either connected to an essential or non-essential system. However, there have been some concerns that the research studies are not addressing all the branches of these systems.
d. ***The upstream problem***. The studies generally measure loads at the branch circuit level and the panel level. Without fully understanding how probabilities accumulate and how demand factors can take advantage of this, concerns have been raised that more aggressive demand factors will cause harm at other levels of an electrical system.
e. ***The representative hospital problem***. There are different kinds of hospitals; some focus on behavioral health, some are community hospitals, some are academic medical centers, etc. There have been concerns that demand loads may vary and, therefore, the

appropriate demand factors might be different in different types of hospitals. This concern sometimes manifests in terms of the size of a facility, its geographic location, or other variables.

f. ***The all department problem.*** There have been concerns that loads will vary widely between departments, so all department types would need to be measured in many instances to determine the appropriate demand factors.
g. ***The census problem***. There have been concerns that, if readings are taken while a hospital is empty, the load readings will be inaccurate.
h. ***The statistical significance problem***. Some have expressed that there is no way to do a study without measuring EVERY circuit in EVERY hospital in the country to show that any potential set of demand factors is correct.
i. ***The surge problem***. Some people believe that, during some kind of surge, such as a pandemic, the loads in a hospital would skyrocket such that load readings taken during normal times would not accurately reflect new electrical demands.
j. ***The spare capacity problem***. Some people think requiring systems to be significantly larger than needed for the existing load is a good thing because it leaves spare capacity for future expansion. That is, a hugely oversized electrical system makes it much easier to overcome future changes and additions of loads to the system.

2 STUDY METHODOLOGY

2.1 ORIGINAL PROJECT SCOPE

Recognizing the need for data to inform evolving electrical codes, the Fire Protection Research Foundation initiated a program to gather electrical circuit data. A prior Phase I project titled *Evaluation of Electrical Feeder in Branch Circuit Loading* focused on general commercial (office) occupancies and entailed a literature review that helped to clarify key elements of a data collection plan to support the Phase II *Electrical Circuit Data Collection* project.

The goal of this Phase II project was to implement a data collection plan to provide statistically significant load data for a variety of occupancies and loading types. This information could offer a technical basis for NEC code-making panels about feeder and branch circuit design requirements.[19,20,21]

The original scope of this Phase II project focused on three occupancy types: (A) business, (B) education, and (C) health care. Within those occupancies, four baseline comparable targeted spaces were identified for data collection: (1) breakrooms, (2) general office areas, (3) conference rooms, and (4) cubicles.

2.2 COVID-19 PANDEMIC

The sizing of electrical systems is an important issue in health care electrical design. As previously noted, data from an event that might cause atypically high electrical usage in a hospital, like a pandemic, is of particular interest to the electrical community.

In March 2020, the world faced an unprecedented global pandemic sparked by the SARS-CoV2 virus, which causes the disease COVID-19. Hospitals quickly prepared to treat patients suffering from COVID-19. The use of ventilators (a high electricity usage piece of medical equipment) was predicted to increase, as would the number of patients being treated at hospitals. A pandemic of this magnitude required hospitals to respond and therefore operate in unique ways that might, it was believed, stress the hospital electrical system in unique ways.

2.3 REVISED APPROACH

The COVID-19 pandemic created an opportunity to collect electrical load data from hospitals and hospital spaces that might experience abnormal (and potentially historic peak) demands. At the same time, it was not appropriate to collect data from education and business occupancies, as most of these facilities saw little to no demand during the pandemic. In many cases,

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[19] Ranganathan, Sreenivasan and Victoria Hutchison. "Balancing safety and efficiency," *Health Facilities Management*. Available online: https://www.hfmmagazine.com/articles/4072-balancing-safety-and-efficiency

[20] The original request focused on office spaces in health care, education, and business occupancies.

[21] Excerpt from the Request for Proposal by the Fire Protection Research Foundation.

education and business occupancies were closed or explicitly operating well below capacity. The data collected from such occupancies during this time would not be reflective of demand under normal operating conditions. Therefore, it was decided to adjust the focus of this project's scope to collecting hospital data during the COVID-19 pandemic.

The rare opportunity to collect hospital load data during a pandemic warranted shifting the focus entirely. As the focus of the study shifted, so did the duration of data collection. The electrical load data was now to be collected for an extended duration of one year as opposed to the originally planned duration of one month. Therefore, this study focuses on hospital patient care areas, specifically on key departments that saw surges because of COVID-19 (e.g., ICUs, patient care areas, departments that served as overflow, etc.)

Anticipating this, the project focused its resources to allow deployment of as many meters as possible to many different kinds, sizes, and geographical locations of hospitals for more than one year. The purpose of this study was to gather sufficient data to answer the intuitive concerns described above and to provide adequate data to code-making panels that could inform potential revisions to the NEC demand factors.

2.4 SURVEY OF HOSPITAL CONDITIONS

During the COVID-19 pandemic, hospitals went from being unoccupied (as hospitals canceled most procedures in anticipation of floods of patients) in the spring of 2020 to being filled with COVID-19 patients in varying degrees in the summer. Occupancy was somewhat back to normal in the fall but then elevated due to a second surge of COVID-19 in the winter of 2020.

There were a number of limitations with electric circuit data collection in hospitals during this time, including the availability of meters, hospital plans, panel schedules, and census data. As a result, the types of data collected for this analysis varied. However, in all cases, the study period was longer than one year, either the COVID hospitalization data or county-level COVID case rate was available, and meaningful comparisons could be made to corroborate the more detailed findings of the hospitals where circuit-level data was available.

2.5 HOSPITALS MEASURED

For this study, the research team approached several hospitals. The hospitals were selected based on the likelihood (at the time of meter installation) that they might experience a surge of COVID-19 patients, their willingness to have meters installed, and their comfort in sharing the data with the research team. The hospitals that participated in the study overcame this barrier by requesting anonymity. To protect the confidentiality of the participating hospitals, all the data in this report is presented generically by region. Table 1 summarizes the characteristics of the hospitals that participated in the study. Requests for metering were made during March and April of 2020, just as hospitals were preparing for an influx of patients due to the COVID-19 pandemic. During this incredibly difficult time, these hospitals graciously agreed to have meters installed to assess the impact of the pandemic on their systems. All the hospitals identified in Table 1 permitted metering of their electrical panels and/or circuits.

Table 1: Approximate beds, square footage, and description of studied hospitals

Name	Location	Beds	Description
West Coast hospital 1	Northern California	500-550	Urban high-rise trauma center
West Coast hospital 2	Oregon[22]	100-150	Urban/suburban general medical center
Southeast hospital 1	Georgia	100-150	Urban/suburban level II trauma center
Southeast hospital 2	Georgia	451	Urban academic medical center
Southeast hospital 3	Alabama	350-400	Urban level II trauma center
Southeast hospital 4	Alabama	350-400	Urban acute care facility
Southeast hospital 5	Georgia	900-1000	Urban high-rise level I trauma center
Northeast hospital	Massachusetts	900-1000	Urban high-rise academic medical center, level I trauma center

General information about the metering at each participating hospital is provided in Table 2.

Table 2: Data collection period, panels metered, and information availability at studied hospitals

Name	Data Collection Period	# Panels Metered	Metering and Scheduling Details
West Coast hospital 1	Mar 2020–May 2021	11[23]	Circuit-level and panel-level metering. Plans and panel schedules available.
West Coast hospital 2	~July 2017–January 2018[24]	37	Circuit-level and panel-level metering. Plans and panel schedules available.
Southeast hospital 1	April 2020–May 2021	5	Panel-level metering. Plans and panel schedules available.
Southeast hospital 2	April 2020–May 2021	8	Panel-level metering. No plans or panel schedules available.
Southeast hospital 3	April 2020–May 2021	4	Panel-level metering. No plans or panel schedules available.
Southeast hospital 4	April 2020–May 2021	4	Panel-level metering. No plans or panel schedules available.
Southeast hospital 5	April 2020–May 2021	30	Panel-level metering. Limited plans and panel schedules available.
Northeast hospital	April 2020–May 2021	(1 floor)	Panel/floor level metering. Plans available. General and specific receptacles cannot be distinguished.

[22] Data collection and analysis of the second West Coast hospital in Oregon was not performed during this study but was conducted previously by Mazzetti. Data from this previous study is provided in this report as an appendix. In general, this data is not used in this report, but it is consistent with the results of this study.
[23] A total of 11 panel sections (42 circuits per panel section). Some panels consisted of a panel section 1 and a panel section 2.
[24] The data for West Coast hospital 2 was collected independently in a separate study.

Each hospital developed a COVID-19 response plan. Some of the hospitals included in this study were part of a health system and were designated to be the system-wide COVID-19 facility. We worked with staff within each hospital to determine those locations most likely to experience surges in demand. Generally speaking, these locations included emergency departments, ICUs, converted patient wings, and surgical suites (these latter spaces, including prep and recovery, were well-suited to conversion to ICU functions). Given the limitations on metering, we deployed the meters where we anticipated the surge to manifest, so that we could literally catch the wave.

2.6 METERS

Electric circuit metering devices were installed in the data providers' hospitals when they appeared to be experiencing a surge in COVID-19 patients. In California, circuit-level metering was installed on select circuits that were anticipated to be impacted by pandemic-related surges. Panel-level meters were also installed in areas highly impacted by the pandemic at the California, Georgia, and Alabama hospitals. Meters in the Northeast hospital were integrated into the electrical system and thus permanently installed. The Northeast hospital simply provided data from these meters.

The study used 366 Panoramic Power wireless sensors to collect information at the California hospital. The Panoramic Power system consists of wireless, self-powered sensors attached to individual circuits in an electrical panel. These sensors transmit current information to a wireless bridge, which then transfers that data to the cloud where it can be retrieved. These meters measured loads continuously for individual circuits. The Panoramic Power system was installed at West Coast hospital 1.

Additionally, the study used Fluke 1736 and 1738 three-phase power loggers (Fluke meters) at various sites. These meters measure all three phases and neutral through four current probes that are connected separately. These meters measured panel loads continuously, requiring periodic downloading of data.

The study also used Dent ElitePro XC power meters at various sites. These meters feature four analog input channels configurable for voltage or current. These meters measured panel loads continuously, requiring downloading of data once every six months.

The Northeast hospital used panel/floor meters that were permanently installed in the electrical system. This hospital works with an online meter data acquisition and reporting service to monitor data from these integrated meters. Floor-level data from the meters was provided as part of this study. These meters measured panel loads continuously.

2.7 DATA COLLECTION

The methodology for data collection differed depending on the facility and its condition. As mentioned above, floor plans and panel schedules were not available for all the hospital sites included in this study. In some cases, floor plans for some floors were obtained. For many of the Southeast hospital sites, limited floor plans and panel schedules were available. The study had four typologies:

A. West Coast hospital 1
   a. Circuit-level meters (only measured receptacle circuits[25])
   b. Panel-level meters (panel-level data necessarily did not align with circuit-level data because not all circuits were measured)
   c. Plans and panel schedules available
B. Southeast hospitals with drawings
   a. Panel-level meters
   b. Plans and panel schedules available
C. Southeast hospitals without drawings[26]
   a. Panel-level meters
   b. Plans and panel schedules NOT available
D. Northeast hospital
   a. Data from integrated meters available at panel level
   b. Plans available but not panel schedules
   c. Plans did not indicate loads for dedicated circuits, so value of 180 VA per receptacle was recorded

For all the hospitals, the following steps were taken:

- Identify hospitals that may experience a surge due to the pandemic.
- Contact hospital staff to obtain permission to install meters.
- Where permission was granted, meet with facility staff to identify areas that may have increased usage due to the surge (e.g., a facility anticipating converting recovery rooms into COVID-19 beds).

The remaining steps differed depending on the site:

For West Coast hospital 1[27]:

- Install circuit-level meters on circuits that serve general receptacles or dedicated equipment on panels that may have increased usage.
- Install panel-level meters on the panels associated with these meters.
- Check, identify, and correct any metering issues as they arise. (Several meter issues arose over the year, so not all circuits were 100 percent continuous).[28]

[25] Note: not all the circuits on the panels were measured.

[26] The distinction in the Southeast hospitals occurs at the panel level. In some cases, the facility was able to find some floor plans and panel schedules and an analysis indicating the specific receptacles could be performed. Otherwise, such a receptacle-specific analysis could not be performed.

[27] Panoramic Power circuit-level meters were used at West Coast hospital 1. This was the first hospital to permit meters to be installed. All the available circuit-level meters were installed at this site.

[28] Some of the circuits at the West Coast hospital lost connectivity in the early stages of data collection and, therefore, gaps exist in the data.

- Work with facility staff to identify extended power outages. (None were identified.)

For the Southeast hospitals:
- Install panel-level meters on panels that may have increased usage.
- Pull data routinely when needed.
- Check, identify, and correct any metering issues as they arise.
- Identify extended power outages. (None were identified.)

For the Northeast hospital:
- Meter data is integrated into the electrical system.
- Collect floor-/panel-level data from the hospital.
- Identify extended power outages. (None were identified.)

The study attempted to gather data on the building area served by a particular panel and census data for each unit served by a particular panel. However, census data for particular units or hospitals was unavailable. In most cases, COVID-19 hospitalization rates were available for the facility. Where specific hospitalization rates were not available, general county-level COVID rates were used. These are displayed as graphs in the data set. They are presented alongside the electrical load data so that the user can graphically see any significant correlation.

2.8 METHOD OF ANALYSIS

The calculations for plug loads on a particular circuit, panel, feeder, distribution panel, service, etc. are based on the number of general receptacles times 180 VA per receptacle plus the amperage rating for each piece of dedicated equipment. The NEC calculated load also includes a demand factor for general receptacles after the first 10,000 VA. These calculations are summarized as follows:

Connected load[29]:

$$\sum_{1}^{m} R_m * 180VA + \sum_{1}^{n} S_n * S_{R_n}$$

Where
m = number of general receptacles on each general receptacle circuit
R_m = The number of general receptacles on circuit m
V = volts
A = amperes
n = number of specified equipment receptacles
S = number of specified equipment pieces on receptacle n (typically 1)
S_{R_n} = the total amperage (nameplate) on circuit n in VA

[29] Sometimes referred to as the calculated load.

The NEC calculated load:

$$\sum_{1}^{m} R_m * 180\,VA + \sum_{1}^{n} S_n * S_{R_n};\ where \sum_{1}^{m} R_m * 180\,VA < 10{,}000\,VA$$

$$10{,}000\,VA + \left(\left(\sum_{1}^{m} R_m * 180\,VA\right) - 10{,}000\,VA\right) * 0.5 + \sum_{1}^{n} S_n * S_{R_n};\ where \sum_{1}^{m} R_m * 180\,VA => 10{,}000\,VA$$

The study compared the connected load and the NEC calculated load, as well as the actual load.

In this study, the calculated load consists of each general receptacle at 100 percent of 180 VA, and each dedicated receptacle at 100 percent of its nameplate rating, as required by the NEC.

The NEC demand load consists of the connected load with the demand factors described in NEC Section 220.44 applied.

For locations with neither floor plans nor panel schedules, calculating the connected load or demand load was not feasible. Thus, the data from these sites is useful only to corroborate the general magnitude of the loads seen in other locations and to test the variance of loads under differing conditions.

For panel-level readings, the actual load consists of the peak load experienced over the course of all the readings for one year for the particular panel. Note, in cases where circuit-level and panel-level readings were obtained, apples-to-apples comparisons were impossible, because, due to limitations on the number of circuit-level measurement devices available, the study focused ONLY on circuits serving either general or dedicated receptacles. In many instances, the panels also served other loads, primarily various lighting circuits.

For circuit-level readings, the actual load for each circuit consists of the peak load experienced over the course of all the readings while the devices were deployed.

For this analysis, the data was simplified in a way that is crucial to understand. The loads on any one circuit vary over time. Rarely did two circuits experience a peak at the same moment. Never did ALL of the circuits on one panel peak at the same time. However, because the measurements did not include any method for aggregating the loads at any one time, the study simplified the situation by using the sum of the peak loads of each circuit even though they never occurred at the same time. Thus, the numbers given in the actual load for circuits overstates the true peak load for these groups of circuits. That is, they already include a safety factor due to the method of analysis. The size of the safety factor is difficult to determine, so the study relies on this sum of peaks methodology.

The study groups together all of the dedicated receptacles for each panel where circuit-level data was available and compares the connected load, the NEC demand load, and the conservative actual load in the aggregate for each panel. The study notes the magnitude of the difference between the demand load and the actual load as a safety factor.

The study also groups together all of the general receptacle circuits for each panel where circuit-level data was available and compares the connected load, the NEC demand load, and the conservative actual load in the aggregate for each panel. The study notes the magnitude of the difference between the demand load and the actual load as a safety factor.

To mimic the effect of accumulating demand factors at various levels of a system, the overstated actual loads were summed and compared to the connected load and demand loads by applying the NEC demand factors as if these were the only loads on the aggregated load centers.

In addition, the study examines the peak readings of panels without circuit-level data over the course of the study period to identify the magnitude of variance and to identify, where possible, causes for variance. The study also examines the magnitude of panel-level loads for these facilities to provide substantiation for the loads experienced in the facilities with circuit-level data available.

More details on this methodology are described in Appendix 1.

3 RESULTS

3.1 METERED DATA

During this project, a large quantity of metered data was collected from hospital electrical circuits and panels. This data will be available for download from the Research Foundation website (www.nfpa.org/foundation), where this report will be published. Interested parties may also request this data from Research Foundation staff via email at foundation@nfpa.org.

3.2 WEST COAST HOSPITAL 1

3.2.1 West Coast Hospital 1 Panel-Level Analysis

Table 3 below summarizes the calculated and peak panel-level data measured at West Coast hospital 1. The lowest safety factor measured for an individual panel was 199 percent; the highest was 1,198 percent. This indicates that for the course of one year, the highest load ever measured on the panels was at least two times smaller than the minimum load required by the NEC.

When looking at the cumulative load for panels aggregated together, the safety factor ranges from 179 to 327 percent. Even considering the larger effect of the demand factor on additional panels, the system required by the NEC is sized between 179–327 percent over the peak measured value.

Table 3: Connected load and metered load at West Coast hospital 1.

Panel	Site/Panel Information (kVA)						Calculated Load Information (kVA)			CUMULATIVE LOADS					
	Department Served	Metered Peak Load (kVA)	# of General Receptacles	General Receptacle Load (kVA)	# Dedicated Receptacl-es	Sum of Nameplate of Dedicated Receptacles (kVA)	Total Connec-ted Load [30]	NEC Calcula-ted Load (w/ eqp at namepl-ate)	Safety Factor Above Measu-red	Measur-ed Peak Demand (kVA)	General Recepta-cle Load (kVA)	Dedicated Receptac-le Load (kVA)	Total Load (w/ eqp at namep-late) (kVA)	NEC Calculated Load (eqp at namepla-te) (kVA)	Cumulative Safety Factor
W4CL2 Pnl Sec 1 & 2	ICU	14.36	293	**52.74**	12	11.64	**64.38**	**43.01**	**199%**	**14.365**	**52.74**	**11.64**	**64.38**	**43.01**	**199%**
W4L1	ICU/Core/ Nurse Station	7.46	153	**27.54**	4	4.12	**31.66**	**22.89**	**207%**	**21.823**	**80.28**	**15.76**	**96.04**	**60.9**	**179%**
W4LC1 Sec 1 & 2	ICU Patient Rooms	12.77	346	**62.28**	5	6.18	**68.46**	**42.32**	**231%**	**34.594**	**142.56**	**21.94**	**164.5**	**98.22**	**184%**
W4LC3 Sec 1 & 2	ICU Patient Rooms	12.03	319	**57.42**	9	9.64	**67.06**	**43.35**	**260%**	**46.625**	**199.98**	**31.58**	**231.56**	**136.57**	**193%**
3LC7 pnl	PACU/Cath/ FSD/Brain Suite	11.28	239	**43.02**	21	25.38	**68.4**	**51.89**	**360%**	**57.906**	**243**	**56.96**	**299.96**	**183.46**	**217%**
3LC6 pnl Sec 1 & 2	IT Room/OR Supply/ Cryo/PACU/ Equip	9.23	192	**34.56**	27	26.11	**60.67**	**48.39**	**425%**	**67.131**	**277.56**	**83.07**	**360.63**	**226.85**	**238%**
W4LC4 Sec 1	ICU Patient Beds	6.85	336	**60.48**	1	0.96	**61.44**	**36.2**	**428%**	**73.986**	**338.04**	**84.03**	**422.07**	**258.05**	**249%**
3L3 pnl Sec 1 & 2	PACU/ Office/ Printer/Cath	7.00	394	**70.92**	3	2.72	**73.64**	**43.18**	**517%**	**80.986**	**408.96**	**86.75**	**495.71**	**296.23**	**266%**
3LC3 pnl Sec 1 & 2	PACU/Cath	11.52	398	**71.64**	20	45.88	**117.52**	**86.7**	**653%**	**92.506**	**480.6**	**132.63**	**613.23**	**377.93**	**309%**
W4L2	ICU/Core/ Nurse Station	2.71	145	**26.1**	5	6.72	**32.82**	**24.77**	**815%**	**95.215**	**506.7**	**139.35**	**646.05**	**397.7**	**318%**
3L7 pnl	Consult/ Corridor/ Cath	1.55	110	**19.8**	3	5.25	**25.05**	**20.15**	**1198%**	**96.767**	**526.5**	**144.6**	**671.1**	**412.85**	**327%**

[30] 0.18kVA per receptacle + equipment at nameplate.

The cumulative analysis is best depicted in chart form. Figure 1, below, depicts the cumulative kVA as additional panels are added to the analysis. The actual load, the NEC calculated load, and several other calculations are depicted. Increasing the number of panels increases the gap between the peak load and the calculated load.

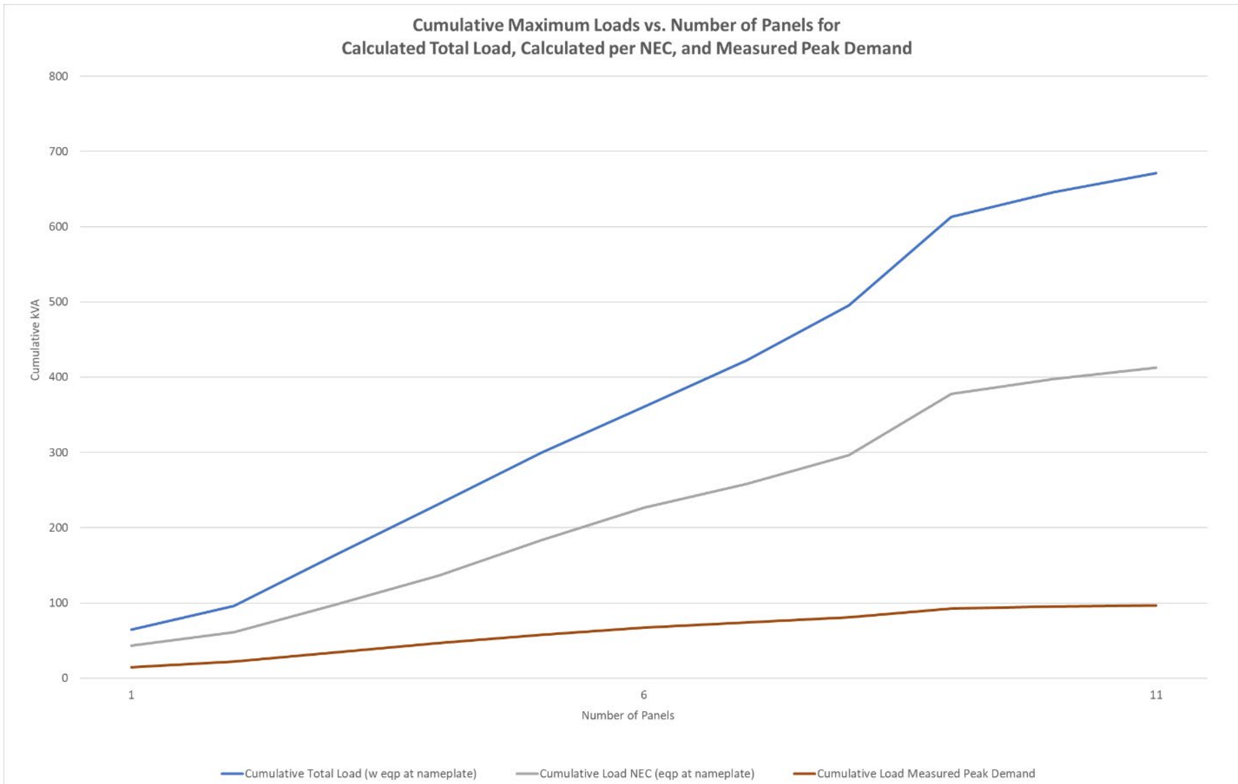

Figure 1: Comparison of panel-level calculated and actual load values at West Coast hospital 1.

Additionally, Table 4 below shows the peak load per receptacle and the average peak load per receptacle on each panel at West Coast hospital 1. Peak load per receptacle represents the peak load measured on the panel divided by the number of receptacles. Dedicated equipment receptacles are counted as one receptacle. The average max load per receptacle is determined by averaging the measured peak load during each interval.

Table 4: Peak load per receptacle and average peak load per receptacle for panels at West Coast hospital 1

Panel	Department Served	Peak Load per Receptacle (VA/Receptacle)	Average Max Load per Receptacle (VA/receptacle)
W4CL2 Pnl Sec 1 &2	ICU	47.10	23.12
W4L1	ICU/Core/Nurse Station	47.51	23.97
W4LC1 Sec 1 & 2	ICU Patient Rooms	36.38	20.64
W4LC3 Sec 1 & 2	ICU Patient Rooms	36.68	15.53
3LC7 pnl	PACU/Cath/FSD/Brain Suite	43.39	30.46
3LC6 pnl Sec 1 & 2	IT Room/OR Supply/Cryo/PACU/Equip	42.12	27.37
W4LC4 Sec 1	ICU Patient Beds	20.34	3.44
3L3 pnl Sec 1 & 2	PACU/Office/ Printer/Cath	17.63	4.80
3LC3 pnl Sec 1 & 2	PACU/Cath	27.56	18.62
W4L2	ICU/Core/Nurse Station	18.06	9.11
3L7 pnl	Consult/Corridor/Cath	13.74	8.24

3.2.2 West Coast Hospital 1 Circuit-Level Analysis — General Receptacles

Circuit-level data is available for the West Coast hospital. This data is useful because it allows for the separation of data for general receptacles and dedicated receptacles.

Figure 2 below compares the calculated load and the actual load for the general receptacle circuits (only). The data represents the demand at each circuit at the moment the panel experiences its peak load. That is, the hour the peak load on the panel occurred can be identified. Then, the load on each measured circuit on that panel can be identified. The chart shows this load. Since, at the circuit level, peak loads will never occur simultaneously, this method better depicts the loading on these panels.

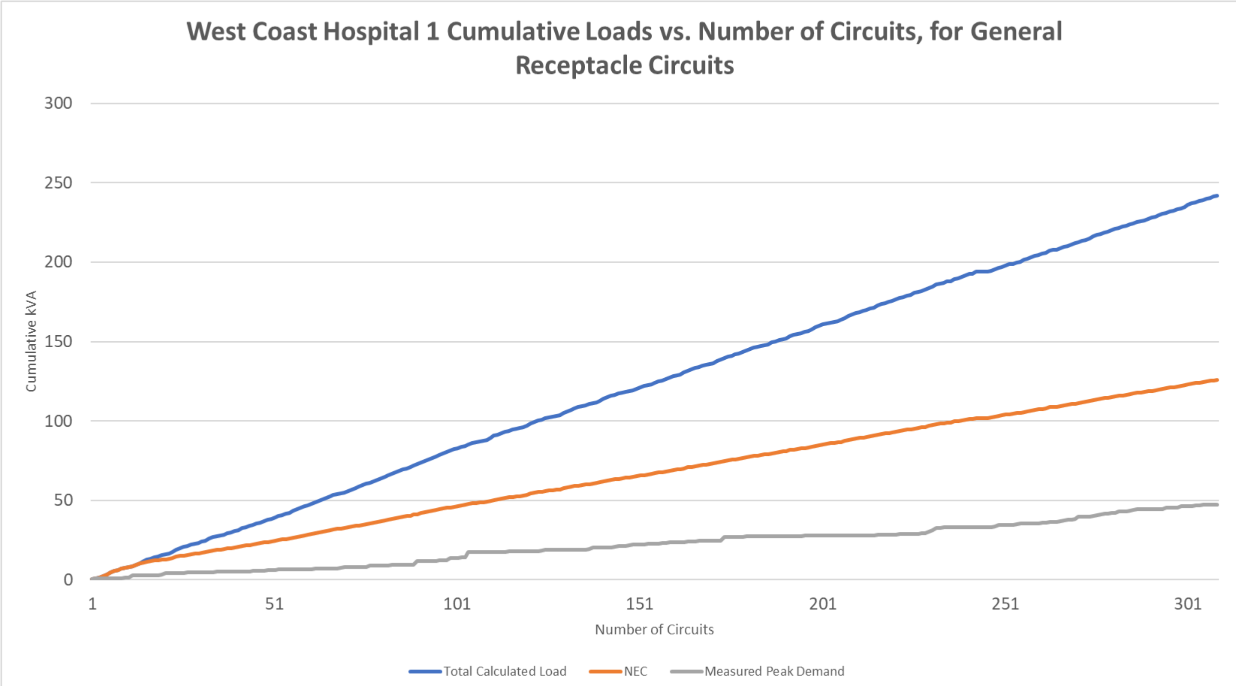

Figure 2: Cumulative calculated vs. metered load at the circuit level for general receptacles. The load on each circuit is captured at the point of peak demand on that circuit's panel.

3.2.3 West Coast Hospital 1 Circuit-Level Analysis — Dedicated Receptacles

Similarly, Figure 3 below depicts the comparison of the calculated load and the actual load for the dedicated equipment receptacle circuits (only) at the moment of peak demand. Together, these figures can offer a sense of what is happening between the general and dedicated receptacles at peak power moments. It should be noted that not all of the circuits on each panel were monitored, so the data shown here is only for the monitored circuits at the point the panel reached a peak. As per the graphs in Figures 2 and 3, for the circuits monitored at the point of peak demand, the safety factor between the measured peak and the calculated total load is greater for the dedicated equipment receptacles than it is for the general receptacles.

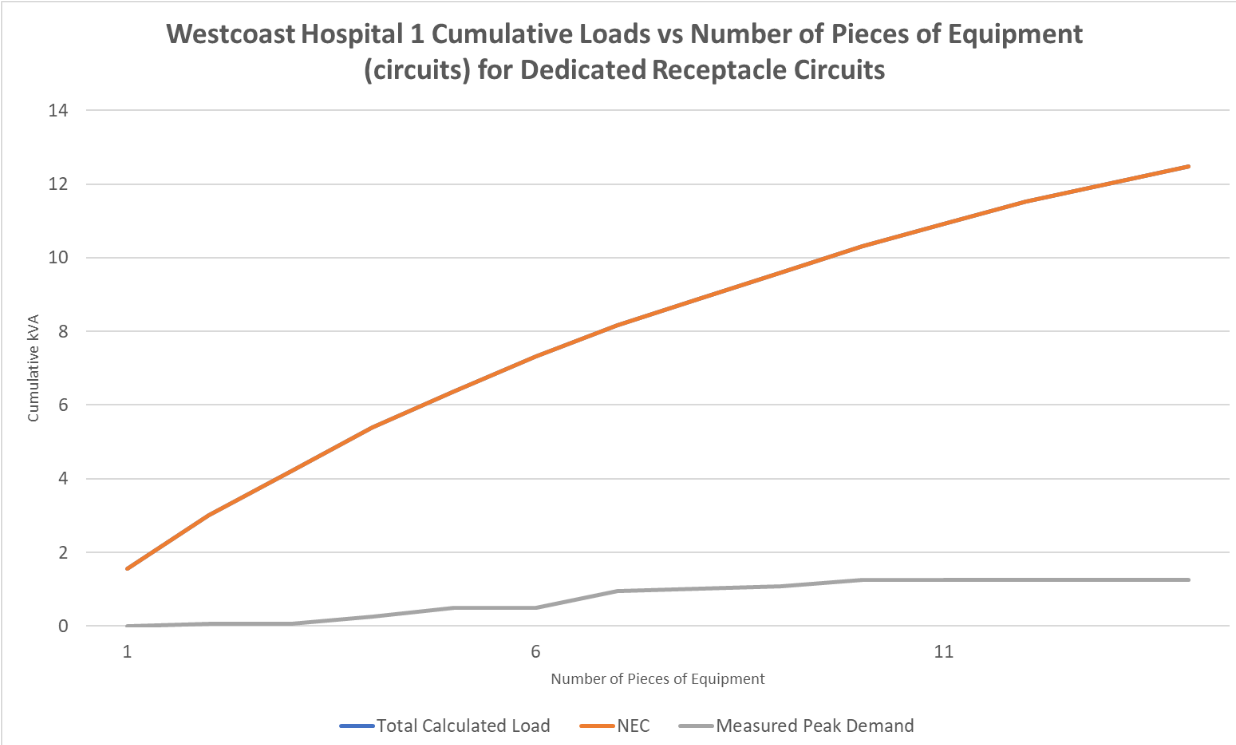

Figure 3: Cumulative calculated vs. metered load at the circuit level for specific equipment receptacle circuits captured at the point of peak demand on each panel.

3.3 SOUTHEAST HOSPITALS WITH DRAWINGS AVAILABLE

The analysis of the Southeast hospitals with drawings available was conducted in a similar manner to the West Coast hospital 1 panel-level analysis.

Table 5 below provides a summary of the calculated and measured load at Southeast hospital 1 for panels where the number of general receptacles and dedicated equipment receptacles could be determined from floor plans. The safety factor on each panel is between 176 and 325 percent. The cumulative safety factor is 181 percent.

Figure 4 below represents the calculated loads and the maximum metered load for Southeast hospital 1. Table 7 below highlights the peak load per receptacle and the average max load per receptacle for Southeast hospital 1.

Table 5: Connected load and metered load at Southeast hospital 1

	Site/Panel Information (kVA)						Calculated Load Information (kVA)			CUMULATIVE LOADS		
Panel	**Department Served**	**Max Power KVA (metered) Peak Load**	**# of Receptacles (non-dedicated)**	**Receptacle Load (non-dedicated) (KVA)**	**# Cord Connected (dedicated) Equipment Circuits**	**Nameplate Dedicated Equipment (KVA)**	**Total Load (0.18 kVA per recep + equipment at nameplate)**	**NEC Demand Load (w/ eqp at nameplate)**	**Safety Factor Above Measured**	**Total Load (w/ eqp at name plate)**	**NEC (eqp at nameplate)**	**Cumulative Safety Factor**
2CLB	ICU	21.45	202	36.36	64	36.11	72.47	**59.29**	**176%**	**72.47**	**59.29**	**176%**
2CLA	Patient Rooms	14.08	160	28.8	22	10.33	39.13	**29.73**	**111%**	**111.6**	**89.02**	**151%**
2NLB	Patient Rooms	7.62	256	46.08	6	4.32	50.4	**32.36**	**325%**	**162**	**121.38**	**181%**

Table 6: Connected load and metered load at Southeast hospital 5

	Site/Panel Information (kVA)						Calculated Load Information (kVA)			CUMULATIVE LOADS		
Panel	**Department Served**	**Max Power KVA (metered) Peak Load**	**# of Receptacles (non-dedicated)**	**Receptacle Load (non-dedicated) (KVA)**	**# Cord Connected (dedicated) Equipment Circuits**	**Nameplate Dedicated Equipment (KVA)**	**Total Load (0.18 kVA per recep + equipment at nameplate)**	**NEC Demand Load (w/ eqp at nameplate)**	**Safety Factor Above Measured**	**Total Load (w/ eqp at nameplate)**	**NEC (eqp at nameplate)**	**Cumulative Safety Factor**
11BCBA	Patient Rooms	**16.65**	231	41.58	16	13.27	**54.85**	**39.06**	**135%**	**54.85**	**39.06**	**135%**
7BNBB	ICU	**11.58**	144	25.92	18	9.99	**35.91**	**27.95**	**141%**	**90.76**	**67.01**	**137%**
7BCBA	ICU	**13.39**	274	49.32	12	9.82	**59.14**	**39.48**	**195%**	**149.9**	**106.49**	**156%**
7BCBB	ICU	**14.85**	235	42.3	20	18.9	**61.2**	**45.05**	**203%**	**211.1**	**151.54**	**168%**

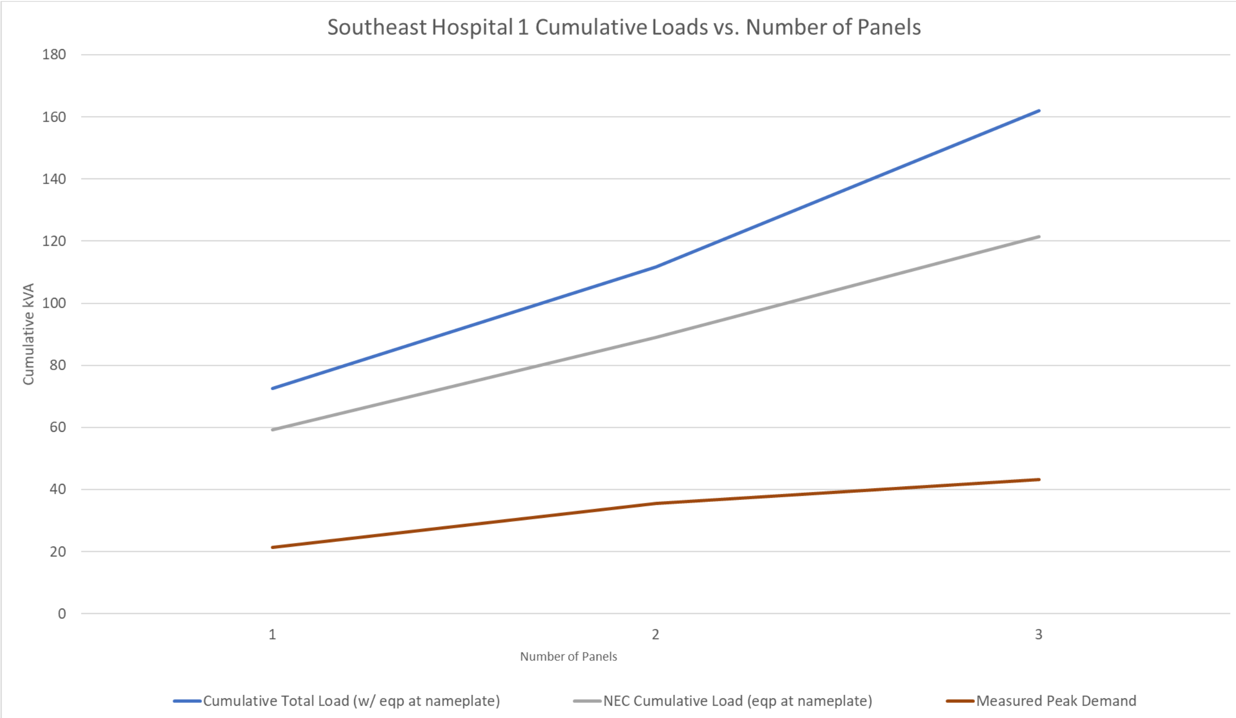

Figure 4: Comparison of cumulative connected, NEC calculated, and peak measured demand for panels at Southeast hospital 1.

Table 7: Peak load per receptacle and average max load per receptacle for Southeast hospital 1

Panel	Department Served	Peak Load per Receptacle (VA/receptacle)	Average Max Load per Receptacle (VA/receptacle)
2CLB	ICU	80.63	48.80
2CLA	Patient Rooms	77.34	36.88
2NLB	Patient Rooms	29.09	0.75

Similarly, Table 6 above and Table 8 and Figure 5 below represent the same information for Southeast hospital 5. The safety factor for individual panels is between 135 and 195 percent. The cumulative safety factor across panels with information is 195 percent. In all cases, the calculated load is greater than the metered load. This creates a gap between the calculated load and the metered load, and the magnitude of that gap, as well as its variance over time, is remarkably similar to the loads from the West Coast hospital's panel-level monitoring.

Table 8: Peak load per receptacle and average max load per receptacle for Southeast hospital 5

Panel	Department Served	Peak Load per Receptacle (VA/receptacle)	Average Max Load per Receptacle (VA/receptacle)
11BCBA	Patient Room	67.40	30.60
7BNBB	ICU	71.45	21.61
7BCBA	ICU	46.81	16.99
7BCBB	ICU	58.25	26.69

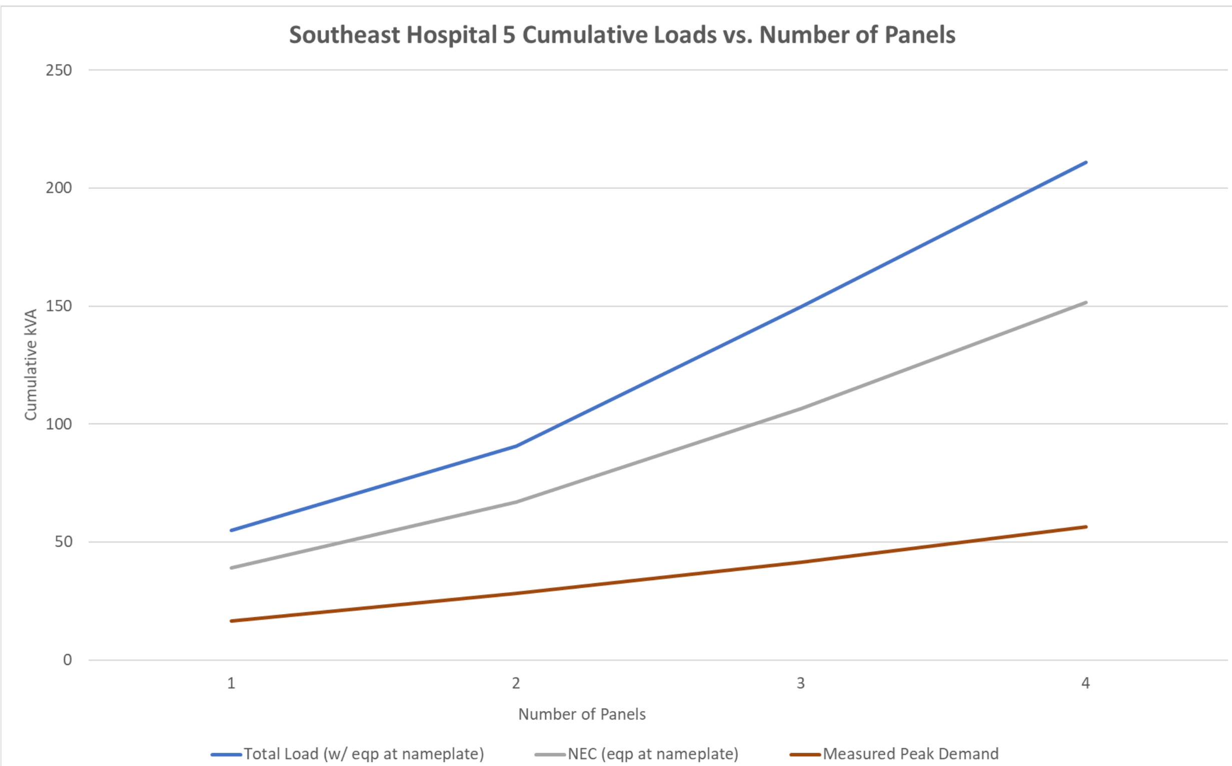

Figure 5: Southeast hospital 5 cumulative loads vs. number of panels.

3.4 SOUTHEAST HOSPITALS WITHOUT DRAWINGS

As indicated above, neither electrical floor plans nor panel schedules were available for most of the panels monitored in the Southeast hospitals. A rich data set was provided to these hospitals, and it is believed this data will be beneficial for researchers in the future. However, because the electrical floor plans associated with these panels are unavailable, performing the same analysis and comparison (as was completed for the data with floor plans) is impossible. Therefore, for these panels, time series graphs, as presented below (max kVA vs. date), were created. The graphs show the peak kVA for each day.[31]

Time series graphs are useful for understanding the maximum load on an electrical panel over time. These graphs depict the maximum kVA per day, regardless of how long that maximum kVA occurs, including if it occurs for only fractions of a second. These data points were not cleaned from the raw data sets. Instead, the data for any particular day can be reviewed to determine whether the maximum was a momentary spike or represented a longer time period of relatively high usage.

Some representative graphs are provided in Figures 6 and 7. The remainder of these graphs can be viewed and examined in the full data set, which is available from the Foundation upon request.

The data for these panel-level readings showed no significant load variation over the course of the year, and it was similar to the loads experienced by West Coast hospital 1 and the Southeast hospitals with floor plans, thus providing further corroboration for these readings.

Figure 6 below depicts an example of such a time series graph. It depicts fairly consistent peak loads on each day except when a spike in the peak load occurred on January 5, 2021. Because the daily graphs were created from the available interval data, the respective underlying data for this spike is available. Figure 6 and Figure 7 depict the electrical load ratings on panel 11ANBC at Southeast hospital 5 on January 5, 2021. Reviewing this graph, we see that the spike was momentary and occurred sometime between 7:35 and 7:40 a.m. on that day. The data from around this time period (including the average load data over this interval and the max load data at the adjacent intervals) suggests that the peak depicted here was momentary.[32]

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[31] The raw data provides the peak kVA over a much smaller time interval (5 minutes to 1 hour); however, that level of resolution makes it difficult to understand the graphs. Therefore, a graph depicting the daily maximum is presented here.

[32] These data sets have not been cleaned. That is, no data points in the data set have been removed. Instead, those interested are invited to review and interpret the raw data and use it to understand trends and any deviations from those trends.

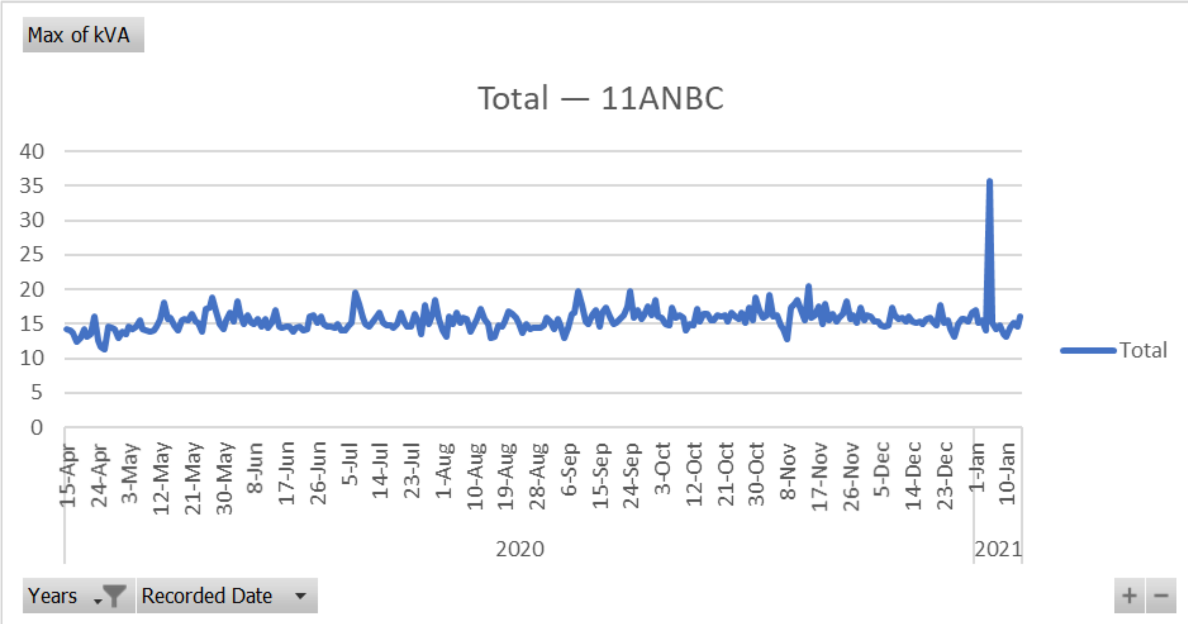

Figure 6: Time series graph showing peak load for each day in the series.

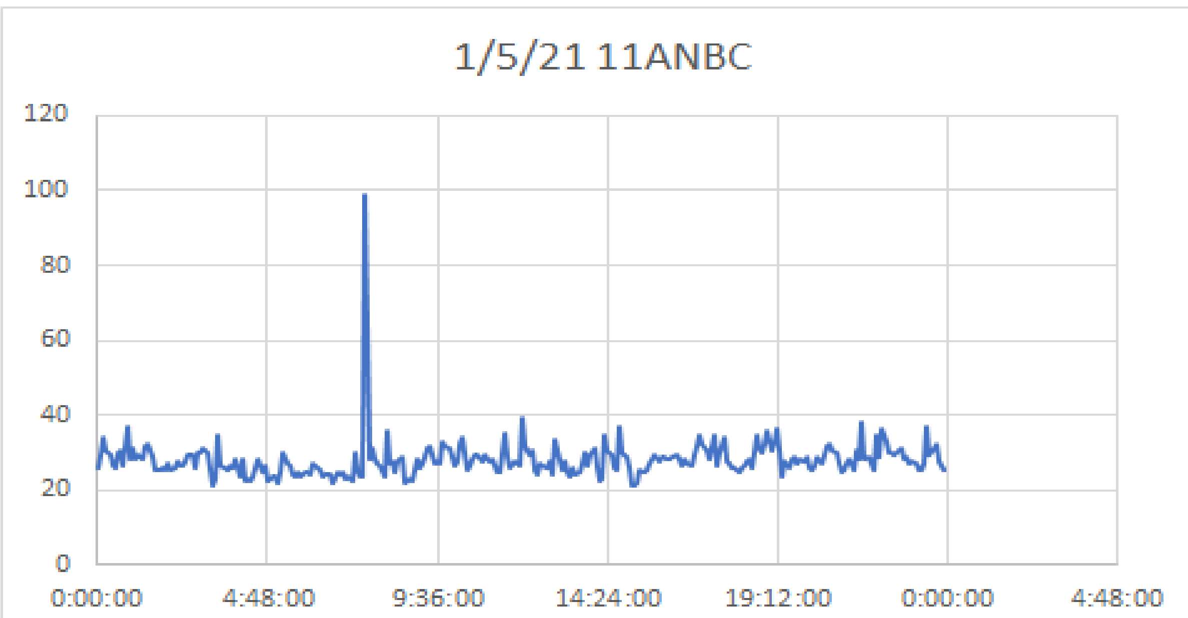

Figure 7: Data from panel 11ANBC on January 5, 2021.

3.5 NORTHEAST HOSPITAL

The Northeast hospital provided data from meters permanently integrated into their system and floor plans for the associated floors. However, the available floor plans did not distinguish between general and dedicated receptacles, and panel schedules were not available. Therefore, the provided calculations assume all the receptacles are general use receptacles and each receptacle is calculated at 180 VA. In addition, it should be noted that the meters installed at this location provided the average electrical load during a time interval as opposed to a peak load during a time interval.[33]

Table 9 below provides the number of receptacles, connected load, calculated loads, and maximum metered load for the Northeast hospital.

Table 9: Connected, calculated, and maximum metered loads for the Northeast hospital

Panel	# of Receptacles	Connected Load (kVA)	NEC Calculated Load (kVA)	Maximum Metered Load (kVA)
CB7 1-2 (E)	132	23.76	16.88	3
CB7-2-2 (B)	144	25.92	17.96	7
Total:	**276**	**49.68**	**34.84**	**10**

Figure 8 below provides the same information in graphical form. Because the analysis at the Northeast hospital was performed at the floor/area level as opposed to the panel level (given the format of the information provided), the graph showing the cumulative effect of adding additional panels is not provided. Instead, a simple bar graph is provided as a graphical depiction of the information in Table 9.

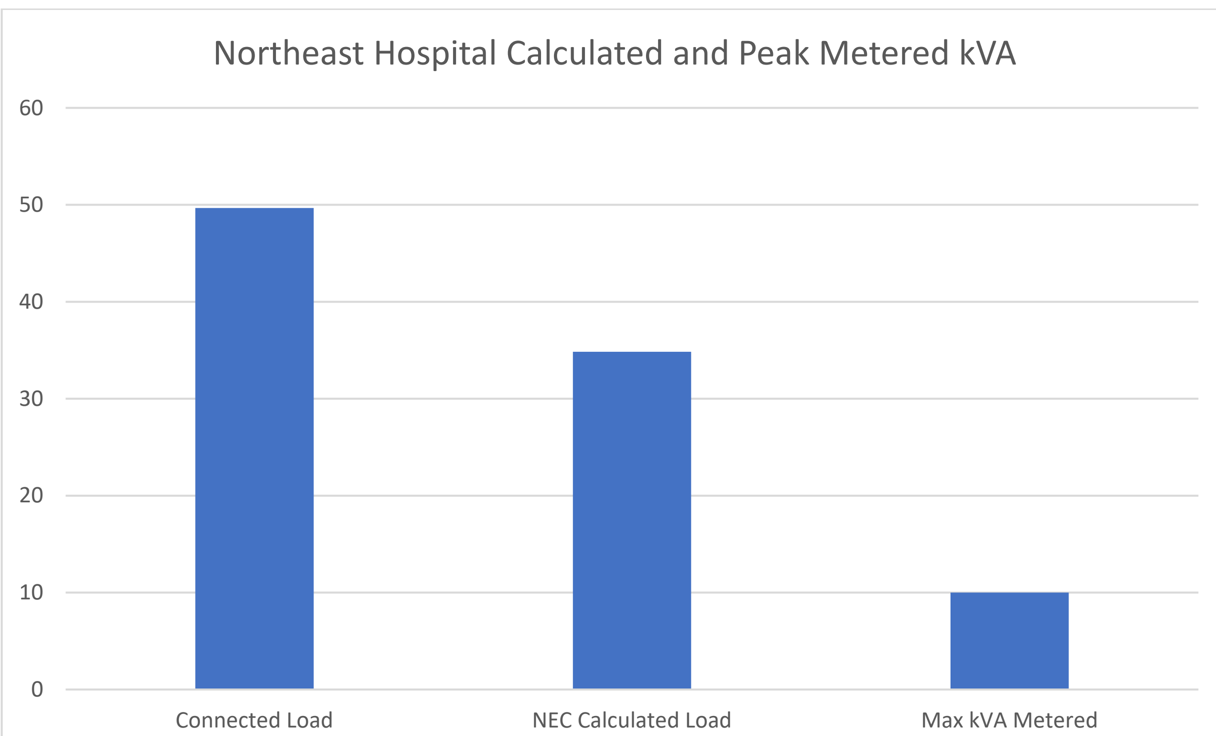

Figure 8: Graphical depiction of the connected, calculated, and maximum metered loads for the Northeast hospital

[33] The meters at the Northeast hospital are integrated into their electrical panels. Meters were not specifically installed by Mazzetti for this study. These meters measure the average electrical load instead of peak loads.

3.6 COMPARISON OF COVID-19 CASE LOAD TO MEASURED ELECTRICAL LOADS

To provide further insight into the impact of a pandemic on hospital electrical loads, graphs comparing the maximum daily electrical load on a panel with the COVID-19 rates are provided. For example, Figure 9 below provides the 7-day average of new COVID-19 cases for the county in which Southeast hospital 5 with panel 11ANBC is located. A quick review of the graph shows that, for panel 11ANBC, COVID-19 rates in that county were not driving electrical use rates. More data and additional comparative graphs are available for the full data set.

In no case did the data suggest a correlation between the measured electrical loads and the specific COVID hospitalization rates (or the county case rates where specific hospitalization rates were not available).

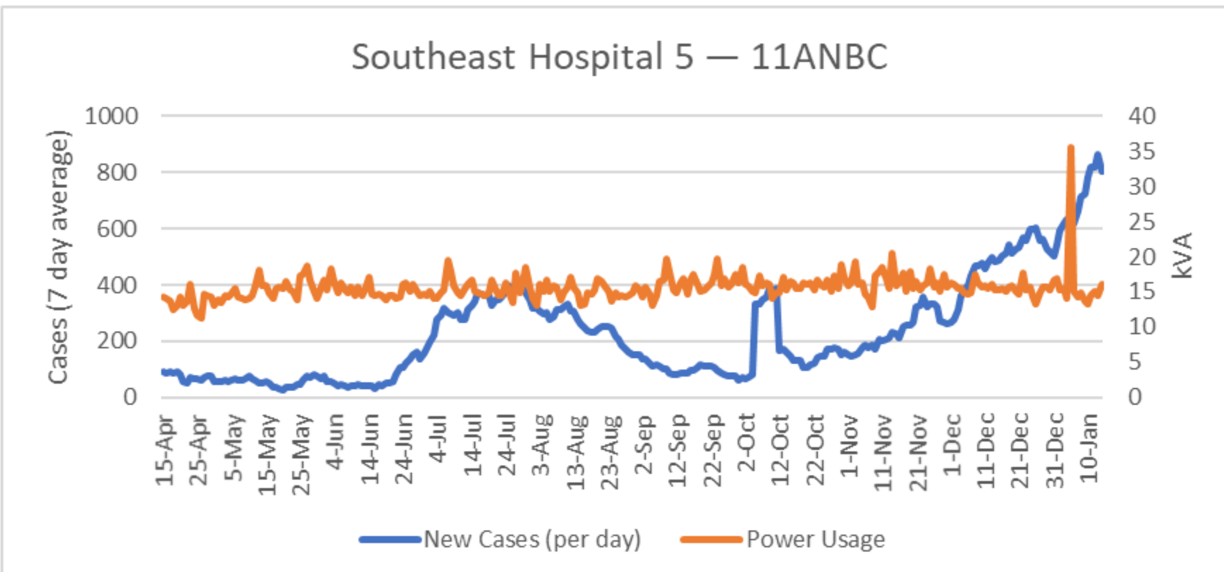

Figure 9: Time series graph depicting the maximum load per day on panel 11ANBC and the 7-day average of new COVID cases in Southeast hospital 5.

4 DISCUSSION

4.1 MAJOR FINDINGS

The data analysis resulted in the following summary observations:

1. Current NEC® demand factors for patient care areas in hospitals result in systems that are at least twice as large as needed for all the receptacle loads. The oversizing increases at higher levels in the distribution system.
2. Oversizing is a bigger issue for dedicated receptacles than it is for general receptacles.
3. These results are consistent across geographies and hospital size, age, and type.
4. The receptacle loads for a hospital patient care area do not vary over a year.
5. The receptacle loads for a hospital do not appear to substantially increase during a pandemic.

4.2 POSSIBLE PROBLEMS WITH METHODOLOGY AND DATA

The limitations of the data collection process and the methodology utilized for data analysis are summarized herein.

Because of the wide variance in the numbers and kinds of meters (circuit level vs. panel level), and the wide variance in available design documents (drawings and panel schedules), the granularity of analysis across the different sites necessarily varies. The lack of detailed census data for most facilities makes it difficult to draw precise conclusions about the relationship between the census and electrical loads.

The study only examined the patient care areas of the various hospitals. Therefore, at this time, sufficient data to make recommendations with respect to other, non-patient care areas within hospitals does not exist. Note that patient care areas often contain offices, nourishment stations, and other support spaces, and receptacles in these areas are included in the various studies, including the historical ones. Therefore, there is at least some data available for these spaces, especially those within a clinical department.

Because a method for measuring the aggregate peak loads for a group of receptacles is lacking, the sum of peaks methodology was used for this analysis. A true measurement of aggregate peak loads would likely provide an even larger opportunity for demand factor adjustments than those suggested by this study.

It is important to note that no hospital included in this study experienced an extensive power outage during the time it was monitored.

In some cases, access to meters varied, so data was downloaded at different intervals. Different meters were used in different locations as enumerated above. Because of these differences, the output data is different depending on the site and methodology used. This has a negligible effect on the actual data; however, it does yield different columns, time frames, and characteristics depending on the meter used and its setup.

Lastly, different staff installed the meters and downloaded information from them. This was necessary due to the speed at which meters were installed and the distance between hospitals. The effect of different people being involved in the installation and data downloads is negligible.

4.3 COMPARISON OF RESULTS TO PREVIOUS STUDIES

All of the previous studies suggested that the NEC demand factors, especially if applied to levels of an electrical system beyond the branch circuit panel, result in electrical systems sized much larger than the loads the systems will actually experience. This study further validates these findings.

Past research also suggested that using nameplate data without modification for dedicated receptacles in a hospital, especially if applied to levels of an electrical system beyond the branch circuit panel, results in electrical systems sized larger than the loads the systems will actually experience. These previous studies suggested the gap between actual peak loads and the NEC calculated load will be larger for these dedicated receptacles than it is for general receptacles. This study further validates these findings.

All the previous studies measured loads over a limited duration, with a maximum duration of two weeks. This study corroborated these findings and provided a clear indication that receptacle loads for patient care spaces in hospitals remain constant throughout the year. This study validates that a shorter monitoring period is adequate to understand the behavior of electrical loads.

4.4 IMPLICATIONS OF FINDINGS

NFPA codes and standards prescribe the minimum requirements to ensure safety. The availability of good quality data of a sufficient quantity can help code-making bodies make more informed decisions.

Based on the analysis above, the following should be noted:

- In all cases where receptacle information was available, there is significant spare capacity above the peak load experienced by a system over the metered period of one year.
- These findings are generally consistent with other studies and/or analysis of healthcare plug loads.
- The data suggests that the current demand factors for general receptacles in patient care areas may be reduced, especially at higher levels of a system.
- The data in this study suggests that the current demand factors for dedicated receptacles in patient care areas may be reduced, especially at higher levels of a system.

This data confirms what hospital electrical engineers have generally assumed — that the current demand factors systematically cause the oversizing of equipment in hospitals. The data strongly suggests this remains true even in pandemic situations.

Ultimately, the data from this study can be used to consider revisions to the NEC demand factors. Recommendations and the determination of the appropriate demand factors based on this information are left to the consensus process of NFPA codes and standards.

The study also provided decisive responses to many of the intuitive concerns noted in earlier sections of this paper.

a. **The one-year problem**. This project extended beyond one year in all the hospitals measured. The project demonstrated that a one-year minimum requirement for receptacle load measurements may not be necessary.
b. **The red outlet problem.** This study did not include a hospital that endured an extended utility outage.
c. **The all-branch problem.** All the receptacles in the hospital patient care areas are on the critical branch or the non-essential system. This study included all the critical branch panels and all the non-essential panels serving a particular area. Therefore, no further work is needed in this regard.
d. **The upstream problem.** This study did not measure loads upstream from the branch circuit panels. However, the summary figures above show the cumulative effect of adding additional panels. These figures show that the demand factors for distribution equipment upstream (away from the loads and toward the sources) from the branch circuit panels require even lower capacities than the demand factors for the branch circuit panels.
e. **The representative hospital problem**. This study included community hospitals, urban hospitals, and academic medical centers and found no difference between them. The aforementioned *Plug and Process Loads in Medical Office Buildings* study (see Section 1.4.5) shows similar results in outpatient facilities, indicating the applicability of these demand factors to all healthcare systems.
f. **The all department problem.** This study, together with the previous studies cited, included the vast majority of the clinical spaces within any hospital. The results are similar across all departments, indicating the applicability of the results to receptacles in all the patient care areas of all the hospitals.
g. **The census problem.** The hospitals in this study went through various phases of occupancy. When patient care areas were empty, the loads on the receptacles were low. As occupancy rose, loads went up. However, most of the load readings taken, including those in earlier studies, occurred during high occupancy times. This study focused on peak loads over a year and used the sum of peaks methodology to ensure the results are reliable.
h. **The statistical significance problem**. All the references cited suggest results similar to the ones found in this study. All the hospitals measured in this study over the course of

more than one year, showed similar results. The results of all of this cumulative work are definitive.

i. **The surge problem.** During a hospitalization surge caused by a pandemic, the electrical loads did not skyrocket as feared. This is largely due to the way that hospitals are managed — they canceled elective procedures, diverted patients to other sites, set up surge facilities, and even turned away patients. It is also due to the limitations of other systems in the hospital, such as staff and equipment. Because health care systems are rate-limited, the data suggests that the potential benefit of installing oversized electrical systems is limited if these other systems are incapable of serving the surge.

j. **The spare capacity problem**. The purpose of a code is to describe the minimum requirements for safety. It is explicitly not for future expansion of electrical use. In the introduction of the NEC®, Article 90.1(B) says, "This Code contains provisions that are considered necessary for safety. Compliance therewith and proper maintenance result in an installation that is essentially free from hazard but not necessarily efficient, convenient, or adequate for good service or future expansion of electrical use."[34]

This study corroborates other previous studies showing that the current NEC demand factors for sizing electrical systems in health care facilities, especially when applied to distribution elements upstream from the branch circuit panels, result in systems that are much larger than the loads they will likely experience.

4.5 SUGGESTED FURTHER RESEARCH

Suggested further receptacle load research is categorized below as (a) health care occupancies and (b) business and education occupancies.

4.5.1 Health Care Occupancies

This study provides significant insight into receptacle loads at hospitals. Additional study on this important topic can be helpful, specifically in relation to the following:

Higher levels

Explicit study of higher levels of a distribution system may be helpful in developing a complete understanding of electrical loads. While the circuit- and panel-level data reviewed in this study provides a sufficient basis for understanding higher levels of a system, there may be some interest in having direct measurements of these levels.

Dedicated circuits

Additional study of dedicated receptacles is warranted. Research suggests that many pieces of equipment will never operate at their rated amperage and will only rarely operate at their actual peak load. A greater understanding of dedicated circuit loads may be beneficial.

[34] NEC Article 90.1(B) Introduction, NEC 70: National Electrical Code, 2020 Edition. NFPA (© 2019)

Non-patient spaces
The focus of this study was on patient spaces. Studying non-patient spaces in hospitals could be beneficial, especially if the metering results in those spaces are compared to those in similar spaces in non-health care settings. Study of non-patient areas and different space categories may be helpful in confirming how the findings in this and previous studies should be interpreted for non-patient care spaces.

Extended power outage
No significant power outages occurred during the study period. When an opportunity arises, it may be helpful to study what occurs to electrical loads during an extended power outage.

In general, this study is a significant step toward obtaining a deeper understanding of hospital plug loads. However, the implications of changes to medical equipment and other trends must also be studied. It may be prudent to perform additional work.

4.5.2 Business and Education Occupancies

The Fire Protection Research Foundation originally commissioned a study on health care, business, and education occupancies before the COVID-19 pandemic caused a change in direction (See Section 2.2). The original study was meant to focus on office spaces across the three occupancy types.

If electrical engineers design a building and each space (e.g., office space, patient care area, etc.) has a different demand factor, the calculations and design can become complicated, more expensive, and more difficult for a reviewer to inspect.

One research approach would be to focus data collection and analysis on one type of occupancy at a time. This may provide more specific information. For example, one might study restaurant plug loads, university plug loads, then laboratory plug loads. Once multiple studies are performed, comparisons between different spaces in different occupancies are possible. This approach may make it more likely for codes to be updated based on building type and not specific spaces within a building, reducing the complexity for designers and code officials. In addition, the depth of information available would be richer than with the opposite approach (studying spaces to enable comparison of space types across occupancy types).

Similarly, future studies should attempt to obtain data over a longer duration. While plug load data is not thought to be weather-dependent, code-making committees and policymakers typically give more credence to data that covers a longer duration. The original study required data collection for at least one month at each location. However, the minimum could be increased to two months with data collection taking place for as long as possible within the resource constraints.

5 REFERENCES

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6 APPENDIX 1: ADDITIONAL METHODOLOGICAL DETAILS

As mentioned above, data was available for several different sites. For each type of site, a different analysis was performed.

6.1 FOR WEST COAST HOSPITAL 1

At West Coast hospital 1, circuit and panel-level metering were performed, and specific floor plans and schedules were available. Therefore, the most comprehensive analysis could be performed at this site.

6.1.1 Panel-Level Analysis

The focus of this analysis is to compare the calculated, NEC calculated, and actual measured circuit loads. Several steps are necessary to prepare such an analysis. It is helpful to understand how these comparisons are produced. The steps are as follows:

Identify floor plans and panel schedules for the circuits and panels metered.

Figure 10 below depicts a portion of a typical electrical floor plan. The clouded sections indicate the panel and circuit numbers for the receptacles feeding this particular area. Each circuit and each receptacle is associated with a specific location and use in the hospital.

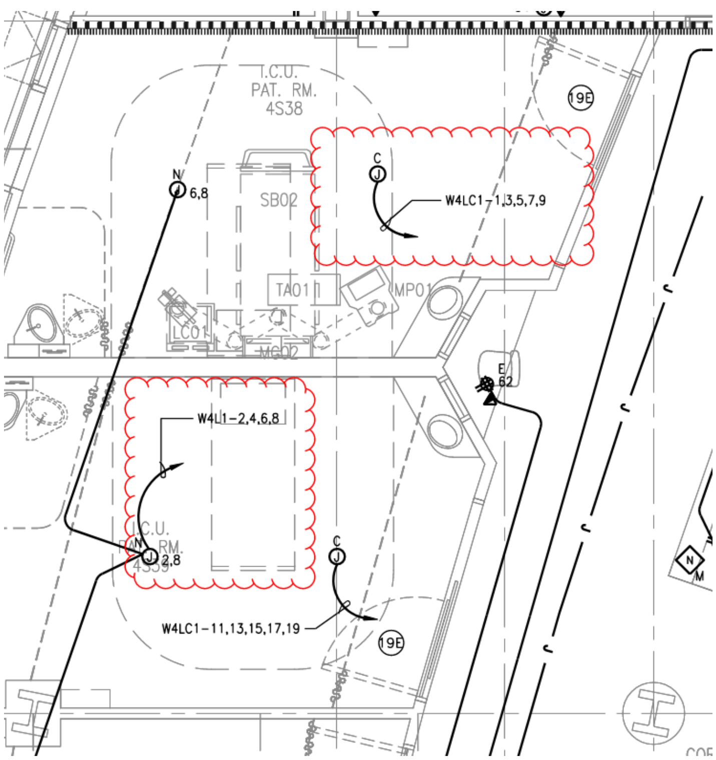

Figure 10: Floor Plan Example

The drawing in Figure 10 includes panels W4LC1 and W4L1 and indicates the circuits on those panels that are connected in this room. For example, circuits 1, 3, 5, 7, and 9 on panel W4CL1 are connected to the junction box for this room. The important thing to note here is that specific circuits that serve floors of the hospital are then connected back to the panel. These receptacle circuits may be general receptacles or dedicated equipment receptacles if the plans specifically note that one piece of equipment should be plugged in. For example, if the designer indicates that a refrigerator is in a certain location, they may specify that the refrigerator (and only the refrigerator) be plugged into a certain circuit. This load would then be from a dedicated piece of equipment.

Where available, the electrical floor plan is analyzed to determine the connected load, the NEC connected load (which applies a demand factor to general receptacle circuits), and, in some instances, a calculation based on the proposals in CMP-2 and CMP-15.

The following is a brief explanation of how this was done. The plans must be reviewed, and each circuit should be identified and traced back to its panel.

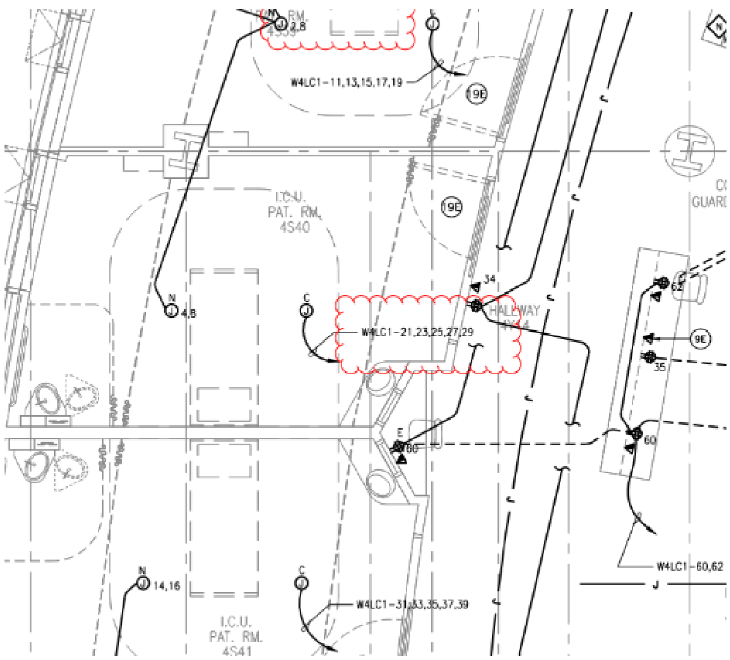

Figure 11: Another Floor Plan Example

Count the number of general receptacles and specific equipment receptacles on each panel.

Next, the panel schedules are reviewed. Each item on the panel schedule indicates either a general receptacle (type 2), equipment receptacle (type 7, i.e., a dedicated receptacle), or some other receptacle type.

Figures 12 and 13 below depict typical panel schedules that can be used to identify a type of load and its associated calculated load.

Panel:	W4LC1	Bus Rating (Amps):	225
Main:	L.O.	Volts (L-L):	120/208
Enclosure:	Surface	Phase:	3
AIC Rating:	10,000	Wires:	4

Ckt	Description	Load Type	Load (KVA)	OC Device Amps	OC Device Poles	Phase	OC Device Amps	OC Device Poles	Load (KVA)	Load Type	Description	Ckt
1	4SO- ICU rm -Boom	2	0.54	20	1	A	20	1	0.54	2	4SO- ICU rm -Boom	2
3	4SO- ICU rm -Boom	2	0.54	20	1	B	20	1	0.54	2	4SO- ICU rm -Boom	4
5	4SO- ICU rm -Bed	2	1.20	20	1	C	20	1	1.20	2	4SO- ICU rm -Bed	6
7	4SO- ICU rm -Recept-5GP	2	0.90	20	1	A	20	1	0.90	2	4SO- ICU rm -Recept-5GP	8
9	4SO- ICU rm -Recept-4GP	2	0.72	20	1	B	20	1	0.72	2	4SO- ICU rm -Recept-4GP	10
11	4SO- ICU rm -Boom	2	0.54	20	1	C	20	1	0.54	2	4SO- ICU rm -Boom	12
13	4SO- ICU rm -Boom	2	0.54	20	1	A	20	1	0.54	2	4SO- ICU rm -Boom	14
15	4SO- ICU rm -Bed	2	1.20	20	1	B	20	1	1.20	2	4SO- ICU rm -Bed	16
17	4SO- ICU rm -Recept-5GP	2	0.90	20	1	C	20	1	0.90	2	4SO- ICU rm -Recept-5GP	18
19	4SO- ICU rm -Recept-4GP	2	0.72	20	1	A	20	1	0.72	2	4SO- ICU rm -Recept-4GP	20
21	4SO- ICU rm -Boom	2	0.54	20	1	B	20	1	0.54	2	4SO- ICU rm -Boom	22
23	4SO- ICU rm -Boom	2	0.54	20	1	C	20	1	0.54	2	4SO- ICU rm -Boom	24
25	4SO- ICU rm -Bed	2	1.20	20	1	A	20	1	1.20	2	4SO- ICU rm -Bed	26
27	4SO- ICU rm -Recept-5GP	2	0.90	20	1	B	20	1	0.90	2	4SO- ICU rm -Recept-5GP	28
29	4SO- ICU rm -Recept-4GP	2	0.72	20	1	C	20	1	0.72	2	4SO- ICU rm -Recept-4GP	30
31	4SO- ICU rm -Boom	2	0.54	20	1	A	20	1	0.54	2	4SO- ICU rm -Boom	32
33	4SO- ICU rm -Boom	2	0.54	20	1	B	20	1	0.54	2	4SO- ICU rm -Boom	34
35	4SO- ICU rm -Bed	2	1.20	20	1	C	20	1	1.20	2	4SO- ICU rm -Bed	36
37	4SO- ICU rm -Recept-5GP	2	0.90	20	1	A	20	1	0.90	2	4SO- ICU rm -Recept-5GP	38
39	4SO- ICU rm -Recept-4GP	2	0.72	20	1	B	20	1	0.72	2	4SO- ICU rm -Recept-4GP	40
41	4SO- ICU rm -Boom	2	0.54	20	1	C	20	1	0.54	2	4SO- ICU rm -Boom	42

LOAD TYPE (NUMBER)	0	1	2	3	4	5	6	7	
LOAD TYPE (DESCRIPTION)	P.Rm.Lt	Lighting	Receps	Motors	L. Mot.	Kitch	Elevator	Equip	Total
CONNECTED LOAD SECTION 1 (KVA)	0.00	0.00	32.28	0.00	0.00	0.00	0.00	0.00	32.28
CONNECTED LOAD SECTION 2 (KVA)	0.00	0.00	29.86	0.00	0.00	0.00	0.00	6.18	36.04
TOTAL CONNECTED LOAD	0.00	0.00	62.14	0.00	0.00	0.00	0.00	6.18	68.32
DEMAND MULTIPLIER:	1.00	1.25	formula	1.00	1.25	1.00	1.00	1.00	
TOTAL DESIGN LOAD	0.00	0.00	36.07	0.00	0.00	0.00	0.00	6.18	42.25

FEEDER:

*Type 2 (receptacles) formula is as follows: If the Total Connected Load is greater than 10KVA, Then the demand load is ((Connected Load – 10) * .5) +10, Else Demand Load equals Connected Load.

NOTES
1 –
2 –

Figure 12: Example panel schedule (1)

Panel:	W4L1	(NORMAL, FCB = 225A)	Bus Rating (Amps):	225
Main:	L.O.		Volts (L-L):	120/208
Enclosure:	Surface		Phase:	3
AIC Rating:	10,000		Wires:	4

Ckt	Description	Load Type	Load (KVA)	OC Device Amps	OC Device Poles	Phase	OC Device Amps	OC Device Poles	Load (KVA)	Load Type	Description	Ckt
1	4SO- ICU rm -Recept- 5GP	2	0.90	20	1	A	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	2
3	4SO- ICU rm -Recept- 5GP	2	0.90	20	1	B	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	4
5	4SO- ICU rm -Recept- 5GP	2	0.90	20	1	C	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	6
7	4SO- ICU rm-Recpt-3GP	2	0.54	20	1	A	20	1	0.54	2	4SO- ICU rm-Recpt-3GP	8
9	SPARE			20	1	B	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	10
11	SPARE			20	1	C	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	12
13	SPARE			20	1	A	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	14
15	SPARE			20	1	B	20	1	0.54	2	4SO- ICU rm-Recpt-3GP	16
17	4SO- Nourish - Coffee	7	1.44	20	1	C	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	18
19	4SO- Nourish - Microwave	7	0.96	20	1	A	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	20
21	4SO- CORE - Microwave	2	0.96	20	1	B	20	1	0.90	2	4SO- ICU rm -Recept- 5GP	22
23	4SO- CORE	7	0.72	20	1	C	20	1	0.54	2	4SO- ICU rm-Recpt-3GP	24
25	4SO- CORE - Recept- 4GP	2	0.72	20	1	A	20	1	0.90	2	4SO- CORE - Recept- 5GP	26
27	4SO- CORE - Recept- 3GP	2	0.54	20	1	B	20	1	0.90	2	4SO- CORE - Recept- 5GP	28
29	4SO- NS, CT - Recept- 5GP	2	0.90	20	1	C	20	1	1.08	2	4SO- CORE - Recept- 6GP	30
31	4SO- NS, CT - Recept- 5GP	2	0.90	20	1	A	20	1	1.08	2	4SO- Corridor - Recept- 6GP	32
33	4SO- CORE - Recept- 5GP	2	0.90	20	1	B	20	1	1.08	2	4SO- Corridor - Recept- 6GP	34
35	4SO- CORE - Recept- 5GP	2	0.90	20	1	C	20	1	1.08	2	4SO- Corridor - Recept- 6GP	36
37	4SO- CORE - Recept- 5GP	2	0.90	20	1	A	20	1	1.00	7	4LV1	38
39	4SO- X-RAY - Recept- 4GP	2	0.72	20	1	B	20	1			SPARE	40
41	4SO- CORE - Recept- 5GP	2	0.90	20	1	C	20	1			SPARE	42

LOAD TYPE (NUMBER)	0	1	2	3	4	5	6	7	
LOAD TYPE (DESCRIPTION)	P.Rm.Lt	Lighting	Receps	Motors	L. Mot.	Kitch	Elevator	Equip	Total
CONNECTED LOAD SECTION 1 (KVA)	0.00	0.00	27.42	0.00	0.00	0.00	0.00	4.12	31.54
CONNECTED LOAD SECTION 2 (KVA)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL CONNECTED LOAD	0.00	0.00	27.42	0.00	0.00	0.00	0.00	4.12	31.54
DEMAND MULTIPLIER:	1.00	1.25	formula	1.00	1.25	1.00	1.00	1.00	
TOTAL DESIGN LOAD	0.00	0.00	18.71	0.00	0.00	0.00	0.00	4.12	22.83

FEEDER:

*Type 2 (receptacles) formula is as follows: If the Total Connected Load is greater than 10KVA, Then the demand load is ((Connected Load - 10) * .5) +10, Else Demand Load equals Connected Loa

NOTES
1 -
2 -

Figure 13: Example panel schedule (2)

Calculate the connected load and NEC connected load for each panel.

A calculation is then performed to determine the required demand. General receptacles (type 2) are calculated at 180 VA (0.18 kVA) per receptacle. Dedicated equipment receptacles (type 7) are calculated at the nameplate amperage rating per the NEC. For the general receptacles, any receptacle loads above 10 kVA of the total are reduced by 50 percent per the existing demand factors in the NEC.

Review the meter data and determine the peak load on each panel.

The calculated load is then compared to the peak load measured on each panel. The peak load is the maximum load seen on a panel over the entire time period. At West Coast hospital 1, the panoramic meters provide the maximum load seen over an interval period. The interval period is hourly; therefore, the meters record the highest load seen each hour.

The calculated load is then compared to the actual metered load.

Table 10 and Table 11 provide an example of how this information is then used to compare the calculated load to the measured load. For example, in the CT-2 row in Table 10, the circuit has five general receptacles and, therefore, a raw calculated load of 0.9 kVA (5 receptacles x 0.18

kVA/receptacle = 0.9 kVA). The maximum demand metered on this circuit is 0.4703. Therefore, the calculated load (i.e., what it was designed for) is 91 percent more than the maximum actual load on this circuit [(0.9 – 0.4703)/0.4703 = 91 percent]. This value is defined as the safety factor in the tables below.

Table 10: Example comparison of metered vs. calculated load on a circuit

ICU Patient Rooms (normal power) (kW)	Max kVA	# of Gen Receptacles	Calculated Design Load at 180VA/Rec	Safety Factor
CT-2	0.4703	5	0.9	91%
CT-4	0.445	5	0.9	102%
CT-6	0.4317	3	0.54	25%
CT-8	0.4052	5	0.9	122%

Table 11: Another example comparison of metered vs. calculated load on a circuit

ICU Patient Rooms (emergency power) (k'	Max kVA	# of Gen Receptacles	Calculated Design Load at 180VA/Rec	Safety Factor
CT-7	0.1534	5	0.9	487%
CT-9	0.4815	4	0.72	50%
CT-27	0.0164	5	0.9	5388%
CT-29	0.0365	4	0.72	1873%

Create the summary chart.
For an example of a summary chart, please refer to Table 3.

Create the graph.
A graph is then prepared to compare the connected load, NEC connected load, and the maximum peak metered load. (See, for example, Figure 1.) The graph is cumulative, reflecting the impact as additional panels are summed. This cumulative value considers the effects of demand factors. In this way, it mimics the effect of calculating further upstream where the demand factor impacts more of the connected load.

For example, if the calculated load of 50,000 VA is reached over five panels (assume 10,000 VA for each panel), the NEC load at that point would be calculated as 10,000 VA + 40,000 VA * 0.5 = 30,000 VA. Note, this is less than if we summed the NEC load of the 5 individual panels (this would result in 50,000 VA NEC load).

The graph provides a quick and easy visual depiction of the difference in calculated versus measured demand as more capacity is aggregated.

6.1.2 Circuit Level — West Coast Hospital 1

Circuit-level metering was installed at West Coast hospital 1 using Panoramic Power meters. By monitoring at the circuit level, the power draw was mapped to specific circuits.

Panoramic Power meters easily snap onto the wires of individual circuits providing an unobtrusive installation. The CT amperage meters communicate with a wireless bridge, which collects data and provides access to that data via the cloud.

The panel-level data provides a clear picture of the plug load at the site. The circuit-level data allows disaggregation between general receptacle circuits and specified equipment circuits to obtain a clearer sense of what happens at general receptacles and equipment receptacles. Because every circuit on each panel was not metered, this data provides a sample of how receptacles and dedicated loads function.

The steps for performing circuit-level analysis at the West Coast site are similar to the panel-level analysis. The steps are as follows.

Step 1: Identify floor plans and panel schedules for the circuits and panels metered.

Step 2: Count the number of general receptacles and specific equipment receptacles on each circuit.

This is the same process as for the panel-level analysis above, only calculated at the individual circuit level.

Step 3: Calculate the connected load and NEC calculated load for each circuit.

Step 4: Review the meter data and determine the load on each circuit when the peak load on the panel is reached.

Each panel has a maximum output. The analysis of what the circuits are doing at the time of maximum output is helpful because it demonstrates the split between general receptacles and equipment receptacles at peak power intervals.

Step 5: Create the graph.

The graph is similar to that created for the panel-level analysis except, in this case, two graphs are created — one for general receptacles and one for dedicated receptacles.

6.2 SOUTHEAST HOSPITALS WITH DRAWINGS AVAILABLE

For the Southeast hospitals, the availability of plans and panel schedules was limited. However, where floor plans and panel schedules were available, the analysis procedure was exactly the same as for the panel-level analysis for West Coast hospital 1.

6.3 SOUTHEAST HOSPITALS WITHOUT DRAWINGS AVAILABLE[35]

Most of the Southeast hospitals did not have plans and panel schedules available. However, these sites were still able to provide valuable information, including how COVID-19 affected overall demand. By examining the peak electrical load (and the general trend) and comparing it to available hospitalization data (and/or COVID caseload data), the impact of COVID hospitalization on the electrical load can be assessed.

Therefore, where detailed plans were not available, the general trend was examined and inferences were made on if and how the load on these panels changed during and after the COVID-19 surge.

[35] The distinction in the Southeast hospitals occurs at the panel level. In some cases, the facility was able to find some floor plans and panel schedules and an analysis indicating the specific receptacles could be performed. Otherwise, such a receptacle-specific analysis could not be performed.

6.4 NORTHEAST HOSPITAL

For the Northeast hospital, floor plans were available, but panel schedules were not. It was possible to determine the number of receptacles in the hospital, but it was not possible to determine which receptacles had dedicated equipment. Therefore, all the receptacles were calculated at 180 VA per receptacle.

Additionally, an integral meter at the Northeast hospital site provided the data. This meter provides the average and not the maximum load over the metered time period.

Therefore, the analysis of the Northeast hospital follows the procedure from the West Coast hospital 1 panel-level analysis, except that all the receptacles are considered general receptacles.

7 APPENDIX 2 – WEST COAST HOSPITAL 2 DATA

Data from a circuit-level monitoring study conducted at Kaiser Permanente Westside Medical Center is provided here as an appendix. This hospital is identified as West Coast hospital 2 above. Permission was granted to identify this hospital.

The data provided here was previously submitted to the NEC code-making panels. The data comes from the monitoring of receptacle loads in Kaiser Permanente Westside Medical Center. Over the course of 6 months and 8 individual phases, Panoramic Power amperage meters were installed on 37 panels and over 1,000 individual circuits. For each phase, 1-minute interval data was collected for 2 weeks, then the equipment was removed and installed on new panels for the next phase. Circuits and panels were mapped to floor plans to determine the room type, department, and square footage that they served. Panel-level peak demand data is presented in Table 12 below.[36] Figure 14 provides a comparison of the connected, NEC calculated, and maximum load accumulated across panels during this study.

[36] This data is also included in the dataset.

Table 12: Connected load and metered load at West Coast hospital 2

Panel	Department	Connected Load (VA)					Measured Peak VA	NEC DEMAND LOAD	Safety Factor Above Measured Demand	Cumulative Loads				
		# Receps	Recep Load	# CORD CONN EQP	Cord Con Load (nameplate)	Total Conn. Load (equip at nameplate)		CORD CONN (at nameplate)	NEC (w/ eqp at nameplate)	Measured Peak Demand	Recep Load	Cord Conn Load (nameplate)	Total Load (w/ eqp at nameplate)	NEC (w/ eqp at nameplate)
1ACL1	ICU – Critical	164	29,520	4	3,400	32,920	6,240	23,160	271%	6,240	29,520	3,400	32,920	23,160
1ANL2	ICU – Normal	164	29,520	0	0	29,520	2,780	19,760	611%	9,020	59,040	3,400	62,440	37,920
1ECL2	ED – Critical	119	21,420	10	6,883	28,303	2,170	22,593	941%	11,190	80,460	10,283	90,743	55,513
1ENL2	ED – Normal	156	28,080	0	0	28,080	2,170	19,040	777%	13,360	108,540	10,283	118,823	69,553
1DCL1	Imaging – Critical	111	19,980	17	12,914	32,894	7,230	27,904	286%	20,590	128,520	23,197	151,717	92,457
1DCL2	Imaging – Critical	156	28,080	9	5,101	33,181	1,900	24,141	1171%	22,490	156,600	28,298	184,898	111,598
1DNL1	Imaging – Normal	147	26,460	10	7,007	33,467	5,950	25,237	324%	28,440	183,060	35,305	218,365	131,835
1DNL2	Imaging – Normal	118	21,240	11	11,326	32,566	7,680	26,946	251%	36,120	204,300	46,631	250,931	153,781
1DNL3	Imaging – Normal	107	19,260	14	8,976	28,236	6,620	23,606	257%	42,740	223,560	55,607	279,167	172,387
1DNL4	Imaging – Normal	28	5,040	21	8,716	13,756	3,010	13,756	357%	45,750	228,600	64,323	292,923	183,623
2ANL1	Patient – Normal	148	26,640	8	6,205	32,845	4,160	24,525	490%	49,910	255,240	70,528	325,768	203,148
2ANL2	Patient – Normal	147	26,460	0	0	26,460	3,170	18,230	475%	53,080	281,700	70,528	352,228	216,378
2ANL3	Patient – Normal	95	17,100	1	500	17,600	2,000	14,050	603%	55,080	298,800	71,028	369,828	225,428
2ACL1	Patient – Critical	128	23,040	0	0	23,040	3,150	16,520	424%	58,230	321,840	71,028	392,868	236,948
2ACL2	Patient – Critical	110	19,800	6	2,310	22,110	3,880	17,210	344%	62,110	341,640	73,338	414,978	249,158

Panel	Department	Connected Load (VA)					Measured Peak VA	NEC DEMAND LOAD	Safety Factor Above Measured Demand	Cumulative Loads				
		# Receps	Recep Load	# CORD CONN EQP	Cord Con Load (nameplate)	Total Conn. Load (equip at nameplate)		CORD CONN (at nameplate)	NEC (w/ eqp at nameplate)	Measured Peak Demand	Recep Load	Cord Conn Load (nameplate)	Total Load (w/ eqp at nameplate)	NEC (w/ eqp at nameplate)
2ACL3	Patient – Critical	3	540	23	16,712	17,252	5,780	17,252	198%	67,890	342,180	90,050	432,230	266,140
2ENL1	Surgery – Normal	138	24,840	4	3,333	28,173	3,650	20,753	469%	71,540	367,020	93,383	460,403	281,893
2ENL2	Surgery – Normal	117	21,060	8	9,165	30,225	3,740	24,695	560%	75,280	388,080	102,548	490,628	301,588
2ENL3	Surgery – Normal	114	20,520	5	6,704	27,224	3,410	21,964	544%	78,690	408,600	109,252	517,852	318,552
2DCL1	Surgery – Critical	102	18,360	1	360	18,720	3,850	14,540	278%	82,540	426,960	109,612	536,572	328,092
2DCL2	Surgery – Critical	92	16,560	9	7,602	24,162	6,140	20,882	240%	88,680	443,520	117,214	560,734	343,974
2DCL4	Surgery – Critical	22	3,960	8	4,681	8,641	3,290	8,641	163%	91,970	447,480	121,895	569,375	350,635
2DNL2	Surgery – Normal	136	24,480	0	0	24,480	2,890	17,240	497%	94,860	471,960	121,895	593,855	362,875
2DNL3	Surgery – Normal	119	21,420	5	3,620	25,040	3,710	19,330	421%	98,570	493,380	125,515	618,895	377,205
OR-1	OR – Critical	50	9,000	13	11,302	20,302	6,420	20,302	216%	104,990	502,380	136,817	639,197	393,007
OR-4	OR – Critical	47	8,460	7	8,302	16,762	5,760	16,762	191%	110,750	510,840	145,119	655,959	405,539
3DCL3	OB – Critical	57	10,260	18	12,767	23,027	4,350	22,897	426%	115,100	521,100	157,886	678,986	423,436
3DNL1	OB – Normal	112	20,160	8	5,728	25,888	2,930	20,808	610%	118,030	541,260	163,614	704,874	439,244
3DNL3	OB – Normal	106	19,080	2	2,522	21,602	2,350	17,062	626%	120,380	560,340	166,136	726,476	451,306
3ECL2	OB – Critical	76	13,680	7	5,584	19,264	4,000	17,424	336%	124,380	574,020	171,720	745,740	463,730
3ECL3	OB - Critical	66	11,880	13	15,805	27,685	5,920	26,745	352%	130,300	585,900	187,525	773,425	485,475
3ENL2	OB – Normal	113	20,340	7	7,837	28,177	4,750	23,007	384%	135,050	606,240	195,362	801,602	503,482
3ENL3	OB – Normal	87	15,660	0	0	15,660	1,030	12,830	1146%	136,080	621,900	195,362	817,262	511,312

		Connected Load (VA)					Measured Peak VA	NEC DEMAND LOAD	Safety Factor Above Measured Demand	Cumulative Loads				
Panel	Department	# Receps	Recep Load	# CORD CONN EQP	Cord Con Load (nameplate)	Total Conn. Load (equip at nameplate)		CORD CONN (at nameplate)	NEC (w/ eqp at nameplate)	Measured Peak Demand	Recep Load	Cord Conn Load (nameplate)	Total Load (w/ eqp at nameplate)	NEC (w/ eqp at nameplate)
C-Section 1	OB – Critical	28	5,040	7	5,843	10,883	3,790	10,883	187%	139,870	626,940	201,205	828,145	519,675
C-Section 2	OB – Critical	28	5,040	7	5,663	10,703	3,670	10,703	192%	143,540	631,980	206,868	838,848	527,858
BDNL1	Pharm. – Normal	97	17,460	11	10,372	27,832	2,870	24,102	740%	146,410	649,440	217,240	866,680	546,960
BDNL2	Ops/Admin – Normal	113	20,340	5	5,080	25,420	7,550	20,250	168%	153,960	669,780	222,320	892,100	562,210

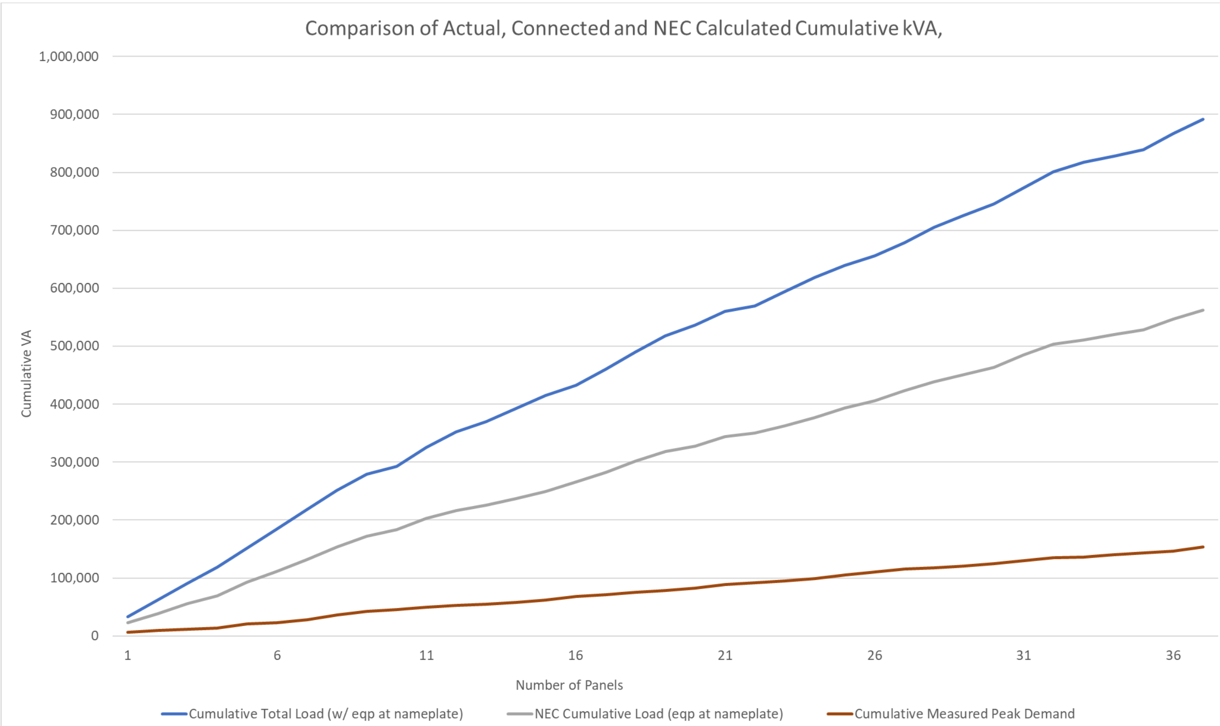

Figure 14: Comparison of calculated and actual load values at the panel level at West Coast hospital 2