Healthcare Energy End-Use Monitoring

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National Renewable Energy Laboratory

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Technical Report
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Prepared under Task No. ARCB1301

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- Partners HealthCare and Massachusetts General Hospital (MGH) in Boston, Massachusetts
- The State University of New York Upstate Medical University (SUNY UMU) in Syracuse, New York
- Mazzetti, Inc.

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Executive Summary

Hospital facility and energy managers find it challenging to identify the energy inefficiencies in their buildings, because the industry lacks measured energy use data for major hospital end uses, such as cooling, heating, lighting, and plug loads. Historically, when these managers have compared alternative energy efficiency investments for various end-use systems, their benchmarks have been limited to end-use estimates derived from modeling.

To address this challenge, DOE commissioned NREL to partner with two hospitals (MGH and SUNY UMU) to collect data on the energy used for multiple thermal and electrical end-use categories, including preheat, heating, and reheat; humidification; service water heating; cooling; fans; pumps; lighting; and select plug and process loads. Additional data from medical office buildings were provided for an analysis focused on plug loads. Facility managers, energy managers, and engineers in the healthcare sector will be able to use these results to more effectively prioritize and refine the scope of investments in new metering and energy audits.

Highlighted findings include:

- For the MGH Gray Building in Boston, Massachusetts, Table ES-1 lists the end-use categories with the highest site energy use intensities (EUIs). Whole-building meters were also available at this site, enabling estimation of end-use percentages relative to total building energy consumption.

Table ES-1 MGH Gray: End-Use Categories With the Highest EUIs

	Site EUI (kBtu/ft·yr)	% of Building Site Energy Use
Reheat and Heating	108.4	27%
Lighting and Other Electric Loads (e.g., Plug)	86.2	21%
Steam Piping Losses	58.5	14%
Fans (Supply, Return, and Exhaust)	51.0	13%
Chiller Plant Energy (Chillers, Cooling Tower Fans, Cooling System Pumps) Allocated to Building	42.3	10%

- For the SUNY UMU East Wing in Syracuse, New York, Table ES-2 lists the end-use categories with the highest site EUIs.

Table ES-2 SUNY UMU: End-Use Categories With the Highest EUIs

	Site EUI (kBtu/ft·yr)
Fans (Supply and Return/Exhaust)	63.0
Reheat and Heating	53.6
Lighting	28.9
Chiller Energy Allocated to Building	26.8
Pumps	14.4

- The variability in the medical imaging equipment load profiles and the nighttime power consumption of some medical office building plug loads suggest an opportunity for device manufacturers and healthcare stakeholders to examine device operational modes more closely to determine if improvements can be made to: (1) the energy efficiency of "idle" modes; and (2) built-in controls for transitions between operational modes. An example of the first case is that, when medical devices remain at full power in a medical office building during non-business hours, such devices should be assessed more carefully to determine which ones can be powered down. An example of the second case is that manufacturers should consider designing controls that can reduce idle power while ensuring fast response and emergency readiness.

Nomenclature

AHU	air handling unit
ATS	automatic transfer switch
BMS	building management system
Btu	British thermal units
CT	computed tomography
CTs	current transducers
DEM	digital energy meter
EUI	energy use intensity
HVAC	heating, ventilation, and air conditioning
kW	kilowatt
MGH	Massachusetts General Hospital
MRI	magnetic resonance imaging
SUNY UMU	State University of New York Upstate Medical University
UPS	uninterruptible power supply
VFD	variable frequency drive

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1.0 Background and Motivation

Hospital facility and energy managers find it challenging to identify the energy inefficiencies in their buildings, because the industry lacks measured energy use data for major hospital end uses, such as cooling, heating, lighting, and plug loads. Historically, when these managers have compared alternative energy efficiency investments for various end-use systems, their benchmarks have been limited to end-use estimates derived from modeling.

To address this challenge, the U.S. Department of Energy (DOE) commissioned the National Renewable Energy Laboratory (NREL) to partner with two hospitals to collect data on the energy used for multiple thermal and electrical end-use categories, including preheat, heating, and reheat; humidification; service water heating; cooling; fans; pumps; lighting; and select plug and process loads. The hospital partners in this study were Massachusetts General Hospital (MGH) and the State University of New York Upstate Medical University (SUNY UMU). Additional data from medical office buildings were provided for an analysis focused on plug loads. Facility managers, energy managers, and engineers in the healthcare sector will be able to use these results to more effectively prioritize and refine the scope of investments in new metering and energy audits. A list of complementary resources is also provided in Appendix D, including the “Targeting 100!” hospital end-use energy study conducted by the University of Washington (Hatten et al. 2011) and hospital benchmarking work conducted by Lawrence Berkeley National Laboratory (LBNL 2014).

2.0 Overview of Hospitals in This Study

This study included two hospitals in which major end uses were monitored. The hospital locations, ages, and square footage are summarized in Table 2-1. Both sites are located in Climate Zone 5A as defined by the 2006 International Energy Conservation Code and ASHRAE Standard 90.1.

Table 2-3 Location, Age, and Square Footage of the Hospitals

	MGH: Gray Building	SUNY UMU: East Wing
City	Boston, MA	Syracuse, NY
Year Built	1966	1995
Total Floor Space	332,664 ft^2	143,000 ft^2

2.1 Massachusetts General Hospital: The Gray Building

MGH is a 900-bed medical center located in the heart of Boston, Massachusetts, that offers diagnostic and therapeutic care in multiple specialties of medicine and surgery through four Boston area health centers. The hospital also holds concurrent Level 1 verification for adult and pediatric trauma and burn care.

The Gray Building is an inpatient facility located at 90 Blossom Street on the MGH campus. The building has 16 floors above ground, a basement, and a subbasement for a total floor area of 332,664 ft^2. It was built in 1966 and has been renovated substantially over the years.

Space types in the Gray Building include: exam rooms; treatment rooms; procedure rooms; operating rooms; research laboratory space; patient rooms; mechanical/electrical spaces; corridors, elevators, and stairs; offices; storage; and common areas.

2.2 The State University of New York Upstate Medical University: The East Wing

The East Wing, also known as the Concentrated Care Center, is a seven-story addition to SUNY UMU Hospital in Syracuse, New York. Opened in 1995, the building has a total gross floor area of approximately 143,000 ft^2.

The East Wing was built to provide expanded services that were formerly located in the University Hospital plus new service groups, including: the emergency medicine department; a diagnostic imaging center with three computed tomography (CT) units and two magnetic resonance imaging (MRI) units; the endoscopy department; 58 single-patient intensive care rooms, including 14 infectious isolation rooms and two protective environment rooms; and a pharmacy with pharmacy prep laboratories. All areas of the East Wing are used for hospital services and were covered in this monitoring study.

3.0 Analysis of Major End Uses

The figures and tables in this section summarize end-use energy consumption for the two monitored hospitals. Each hospital had a different metering approach based on site-specific conditions, including different systems and differences in the organization of existing electrical circuitry, so some of the end-use categories differ. The metering methodology for each building is documented in Appendix A, and a discussion of sources of uncertainty in end-use measurements and calculations is provided in Appendix B.

3.1 End-Use Energy for the Massachusetts General Hospital Gray Building

At the MGH Gray Building, the end-use categories that consumed the most annual site energy were: reheat and heating (27% combined); "other electric loads (including lighting)" (21%); steam piping distribution losses (14%); fans (13%); and chiller plant energy allocated to this building (10%). Its overall site energy use intensity (EUI) was 407 kBtu/ft^2·yr. Annual and monthly totals are summarized in Table 3-1 and Figure 3-1. The source energy calculation uses simplified typical site-to-source factors of 1.21 for steam and 3.34 for grid electricity (EPA 2011).

Table 3-4 MGH Gray Building: Annual End Use Summary

End-Use Category	Form of Energy Supply	Site MWh/yr	Site MMBtu/yr	Site EUI (kBtu/ft•yr)	% of Building Site Energy Use	Source MWh/yr	Source MMBtu/yr	Source EUI (kBtu/ft•yr)	% of Building Source Energy Use
Supply Fans	Electricity	2,917	9,952	29.9	7.3%	9,742	33,239	99.9	11.3%
Return Fans	Electricity	700	2,389	7.2	1.8%	2,339	7,980	24.0	2.7%
Exhaust Fans	Electricity	1,355	4,622	13.9	3.4%	4,524	15,436	46.4	5.2%
Pumps for Hot Water and Heat Recovery	Steam	162	553	1.7	0.4%	196	670	2.0	0.2%
Reheat and Heating	Steam	10,573	36,075	108.4	26.6%	12,793	43,651	131.2	14.8%
Preheat	Steam	2,730	9,314	28.0	6.9%	3,303	11,270	33.9	3.8%
Humidification	Steam	2,025	6,910	20.8	5.1%	2,451	8,361	25.1	2.8%
Domestic Hot Water	Steam	431	1,470	4.4	1.1%	521	1,779	5.3	0.6%
Chiller Plant Energy (Chillers, Cooling Tower Fans, Cooling System Pumps) Allocated to Building	Electricity	4,128	14,084	42.3	10.4%	13,787	47,040	141.4	15.9%
Elevators	Electricity	371	1,267	3.8	0.9%	1,240	4,232	12.7	1.4%
Medical Imaging	Electricity	193	657	2.0	0.5%	643	2,195	6.6	0.7%
Other Electric Loads*	Electricity	8,400	28,659	86.2	21.2%	28,055	95,722	287.7	32.4%
Steam Piping Losses	Steam	5,700	19,449	58.5	14.4%	6,897	23,533	70.7	8.0%
Building Total Energy Use	**Electricity and Steam**	**39,684**	**135,403**	**407**	**100.0%**	**86,492**	**295,109**	**887**	**100.0%**

*The “other electric loads” category includes lighting systems and plug and process load equipment that were not directly monitored during the study.

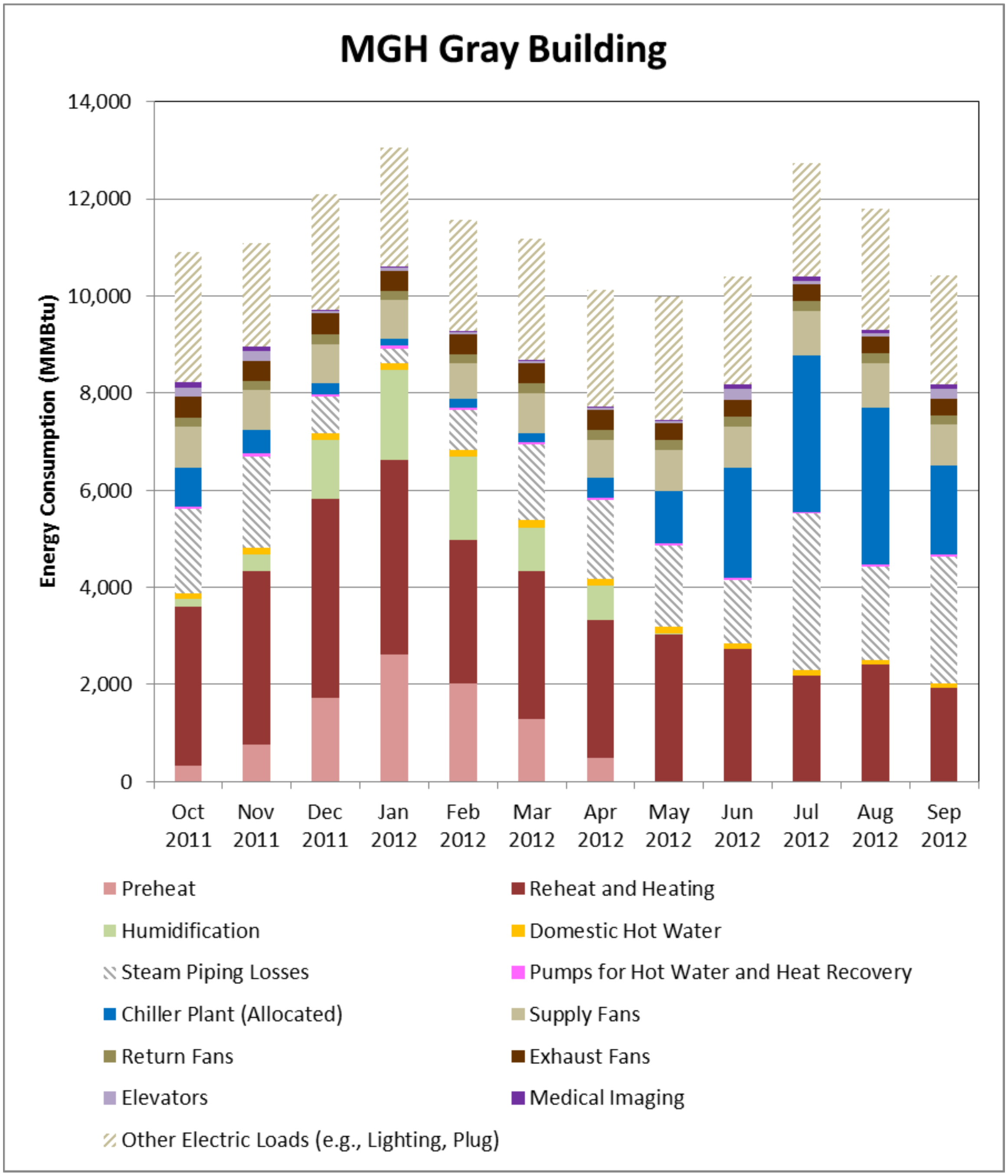

Figure 3-1 **MGH Gray Building: 1 year of monthly site energy end-use breakdowns**

Reheat and heating are coupled in the same measurement, but some information about these end uses can be inferred by reviewing the monthly data. From December 2011 through March 2012, cooling is minimal, so the “reheat and heating” energy is assumed to be predominantly heating energy. Similarly, during July and August 2012, this building is unlikely to have required significant heating, so the “reheat and heating” energy is assumed to be predominantly reheat energy. If the percent contributions of reheat and heating are interpolated for other months, an estimate of the annual site energy breakdown between reheat and heating would be 13,000

MMBtu/yr for reheat and 23,000 MMBtu/yr for heating. This would mean that reheat and heating consume 10% and 17% of annual whole-building site energy use, respectively.

The “other electric loads” category includes lighting systems and plug and process load equipment that were not directly monitored during the study. Energy consumption for this category was estimated by taking readings from a whole-building electric meter (excluding the chiller plant) and subtracting readings from electric end-use meters.

Similarly, energy consumption for the steam piping losses category was estimated by taking readings from a whole-building steam meter and subtracting readings from the steam end-use meters. Based on the steam end-use metering plan used in this building, one would expect the whole-building steam consumption value to be greater than the sum of the monitored steam end-use consumption values, because additional thermal losses occur from distributing steam throughout the building.

One apparent anomaly is that steam piping losses appear higher in summer months than in winter months. At the time of this report, this was being investigated. Sources of uncertainty are discussed further in Appendix B.

3.2 End-Use Energy for the State University of New York Upstate Medical University East Wing

At the SUNY UMU East Wing, the end-use categories with the highest annual site EUIs were: fans (63.0 $\text{kBtu/ft}^2\cdot\text{yr}$); reheat and heating (53.6 $\text{kBtu/ft}^2\cdot\text{yr}$ combined); lighting (28.9 $\text{kBtu/ft}^2\cdot\text{yr}$); chiller energy allocated to this building (26.8 $\text{kBtu/ft}^2\cdot\text{yr}$); and pumps (14.4 $\text{kBtu/ft}^2\cdot\text{yr}$). Monitoring at this site excluded cooling tower fans, six small fans with fractional horsepower motors, preheat, humidification, steam piping losses, plug loads, and a 10-ton process cooling unit that serves the rooms with MRI devices. In order to install meters for many of the excluded electrical loads, it would have been necessary to interrupt hospital operations, which was not practical. The site did not have whole-building meters for steam or electricity, but annual and monthly totals for monitored end uses are summarized in Table 3-2 and Figure 3-2. The source energy calculation uses simplified typical site-to-source factors of 1.21 for steam and 3.34 for grid electricity (EPA 2011).

Table 3-5 SUNY UMU East Wing: Annual End Use Summary

End-Use Category	Form of Energy Supply	Site MWh/yr	Site MMBtu/yr	Site EUI (kBtu/ft•yr)	Source MWh/yr	Source MMBtu/yr	Source EUI (kBtu/ft•yr)
Fans (Supply and Return/Exhaust)	Electricity	2,639	9,004	63.0	8,814	30,073	210.3
Pumps	Electricity	604	2,061	14.4	2,018	6,884	48.1
Chiller Energy Allocated to Building	Electricity	1,122	3,828	26.8	3,747	12,785	89.4
Lighting	Electricity	1,211	4,133	28.9	4,046	13,805	96.5
Medical Imaging	Electricity	345	1,178	8.2	1,154	3,936	27.5
Reheat Loop (Reheat and Heating)	Steam	2,181	7,440	52.0	2,639	9,003	63.0
Radiation Loop (Heating)	Steam	65	222	1.6	79	269	1.9
Domestic Hot Water	Steam	14	48	0.3	17	58	0.4

Additionally, during April 2013, plug load data were collected for multiple operating rooms and extrapolated to the total operating room area, as discussed in Appendix A. Total operating room plug load energy was estimated to have a monthly site EUI of 1.7 kBtu/ft^2·mo in April. Assuming these loads are fairly constant throughout the year, extrapolating this result to other months results in an estimated annual site EUI of 21.2 kBtu/ft^2·yr.

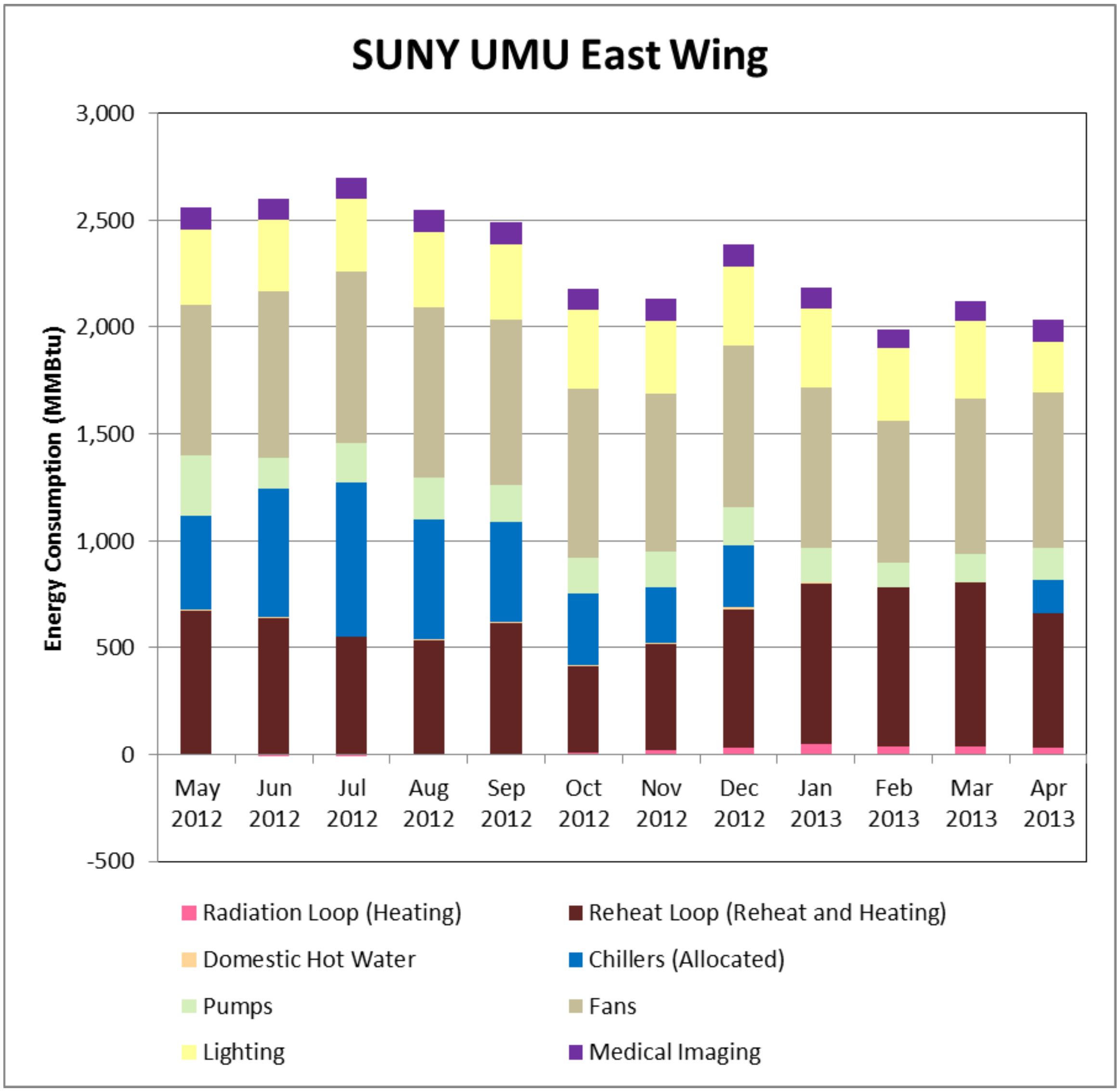

Figure 3-2 SUNY UMU East Wing: one year of monthly site energy end-use breakdowns

In Figure 3-2, the “reheat loop” provides both reheat and heating; thus, the reheat loop values are positive in months with little or no cooling. As with the MGH Gray Building, some information about reheat and heating in the SUNY UMU East Wing can be inferred from review of the monthly data. From January through March 2013, cooling is minimal, so the “reheat and heating” energy is assumed to be predominantly heating energy. Similarly, during July and August 2012, this building is unlikely to have required significant heating, so the “reheat and heating” energy is assumed to be predominantly reheat energy. If the percent contributions of reheat and heating are interpolated for other months, an estimate of the annual site energy breakdown between reheat and heating would be 4,300 MMBtu/yr for reheat and 3,100 MMBtu/yr for heating. This would mean that reheat and heating have annual site EUIs of 30.2 $kBtu/ft^2 \cdot yr$ and 29.2 $kBtu/ft^2 \cdot yr$, respectively.

One anomaly was that radiation loop energy use was negative (–1 MMBtu) in June and July 2012. The SUNY UMU team investigated and reported that the radiation pumps were not switched off when heating was not needed, so they continuously circulated water throughout the system during the summer. On very warm days, the radiation loop would pick up heat from spaces such as stair towers, which were normally unoccupied and uncooled, causing the radiation energy use to appear negative.

4.0 Medical Equipment in Hospitals and Medical Office Buildings

Medical equipment energy is unique to the healthcare sector, so facility and energy managers may be particularly interested in data for this end-use category. This section includes additional detail on medical equipment devices that were directly monitored at the SUNY UMU East Wing. It also includes a summary of data provided by Mazzetti, Inc., from a plug load study that it conducted in five medical office buildings in California.

4.1 Hospital Medical Imaging Equipment

At the SUNY UMU East Wing, three CT units and two MRI units were monitored for 1 year with power measured at 15-minute intervals. Figure 4-1 and Figure 4-2 depict how often the measured power was at various magnitudes.

Most CT measurements fell within a range of about 1 to 15 kW, and most MRI measurements fell within a range of about 8 to 20 kW, but there were sporadic instances of higher power. In Figure 4-1 and Figure 4-2, the “over” bin indicates how often the measured power exceeded 30 kW. The maximum power recorded for each device ranged from 33 to 111 kW, depending on the device.

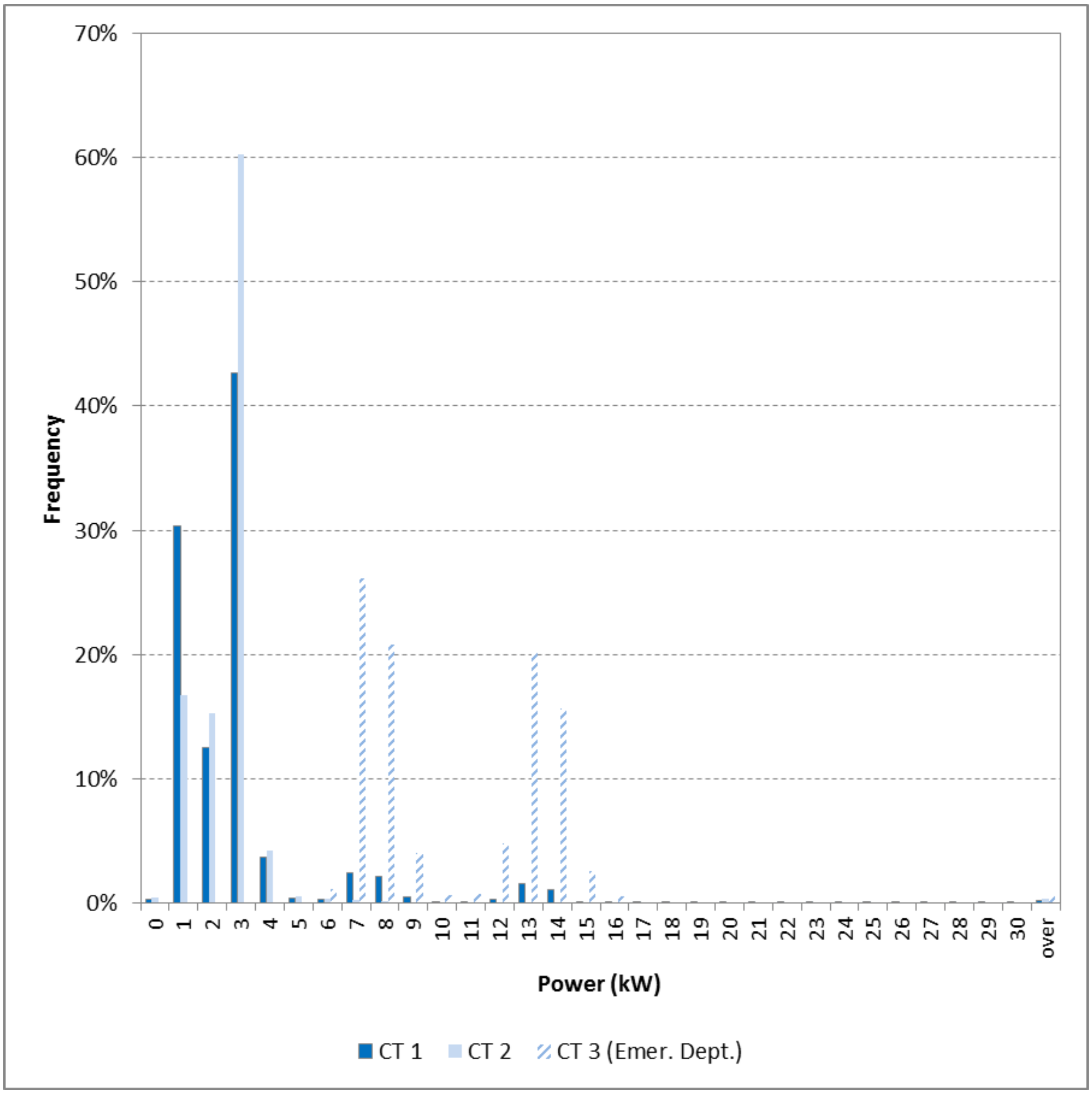

Figure 4-3 Frequency of CT power measurements rounded to the nearest 1 kW

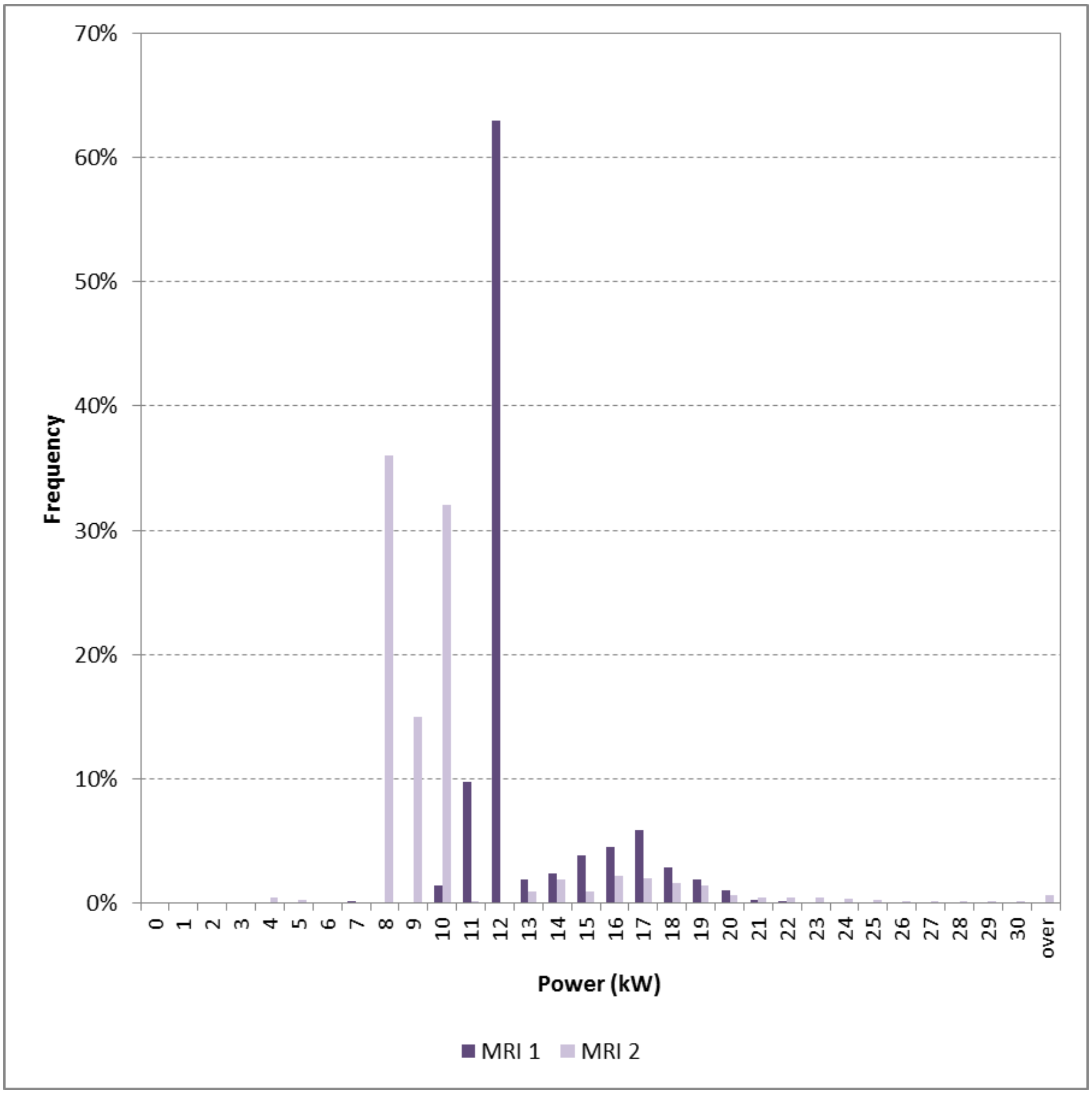

Figure 4-4 Frequency of MRI power measurements rounded to the nearest 1 kW

The average, minimum, and maximum power measurements for the CT and MRI units are summarized in Table 4-1, which shows that the peak power is much higher than the average power for each unit. CT 1 and CT 2 have lower average power requirements than the other three devices, and the emergency department CT has the highest peak power of the five devices (111 kW).

Table 4-6 CT and MRI Power Summary

Device	Avg kW	Min kW	Max kW
CT 1	3	0	67
CT 2	3	0	65
CT 3 (Emergency Department)	11	0	111
MRI 1	13	0	33
MRI 2	11	4	54

Average power for these units may be of interest to engineers who need to estimate internal gains when sizing heating, ventilation, and air-conditioning (HVAC) systems. On the other hand, engineers who are concerned with electrical power system impacts may be interested in peak power and more comprehensive load profiles. The load profiles tend to vary with time of day and day of the week. Load profiles for an example weekend day and an example weekday are depicted in Figure 4-3 through Figure 4-6.

The 15-minute data from this study are informative for engineers who are interested in understanding potential impacts of these devices on electricity demand charges, because such charges are often based on data collected at 15-minute intervals. To characterize different modes of operation, however, a finer data collection interval would be necessary, because operational modes and power input for medical imaging equipment can vary significantly within a 15-minute span.

Engineers should be cautioned that medical imaging equipment power input can vary with functionality, and different CT and MRI devices can have different average power, peak power, and load profiles. Load profiles also depend on usage patterns, which are expected to vary from hospital to hospital, or even from department to department.

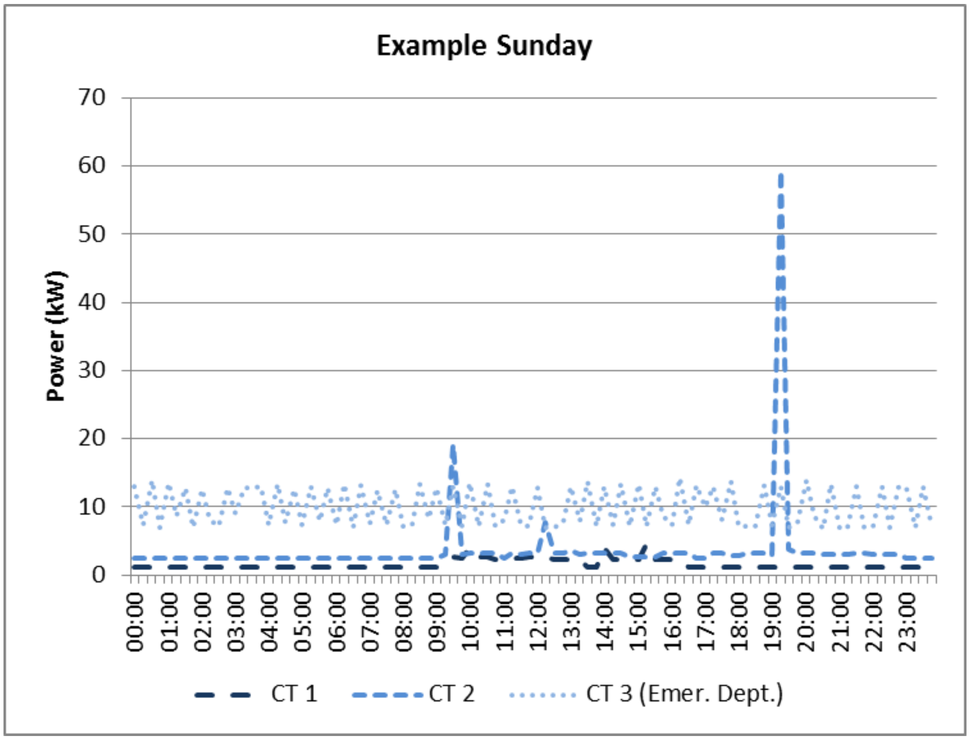

Figure 4-5 CT 15-minute load profiles for an example weekend day (Sunday)

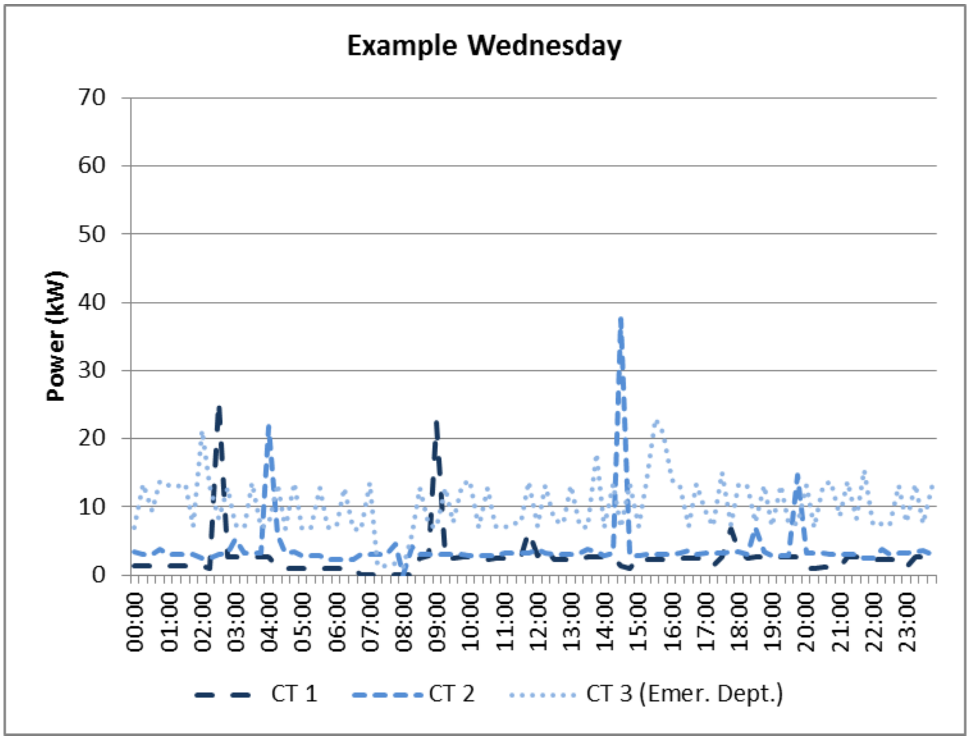

Figure 4-6 CT 15-minute load profiles for an example weekday (Wednesday)

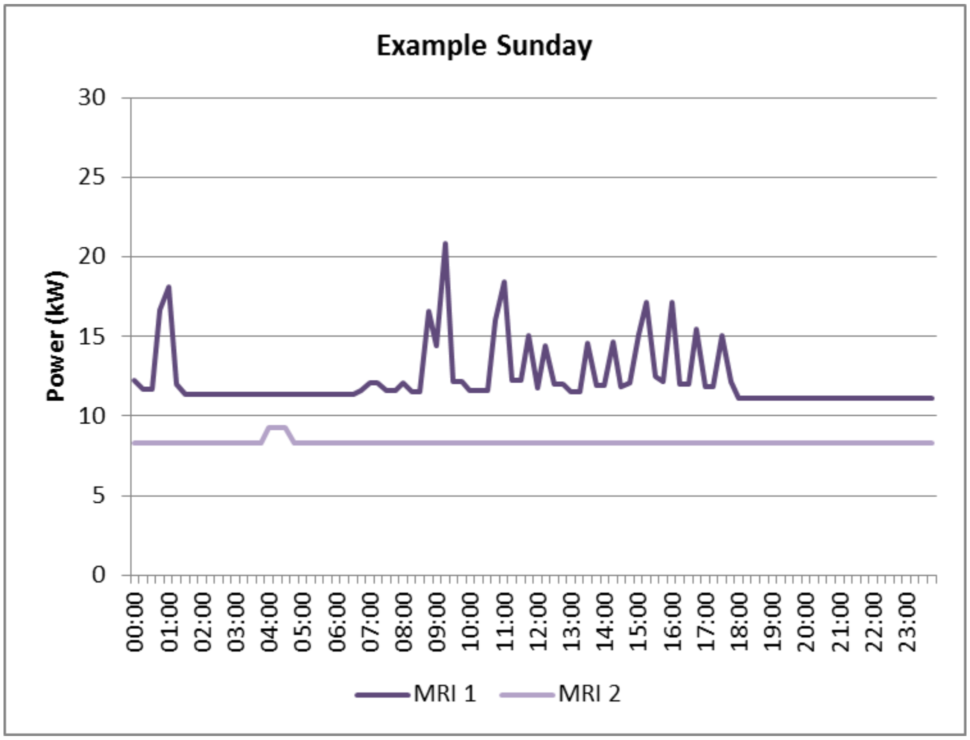

Figure 4-7 MRI 15-minute load profiles for an example weekend day (Sunday)

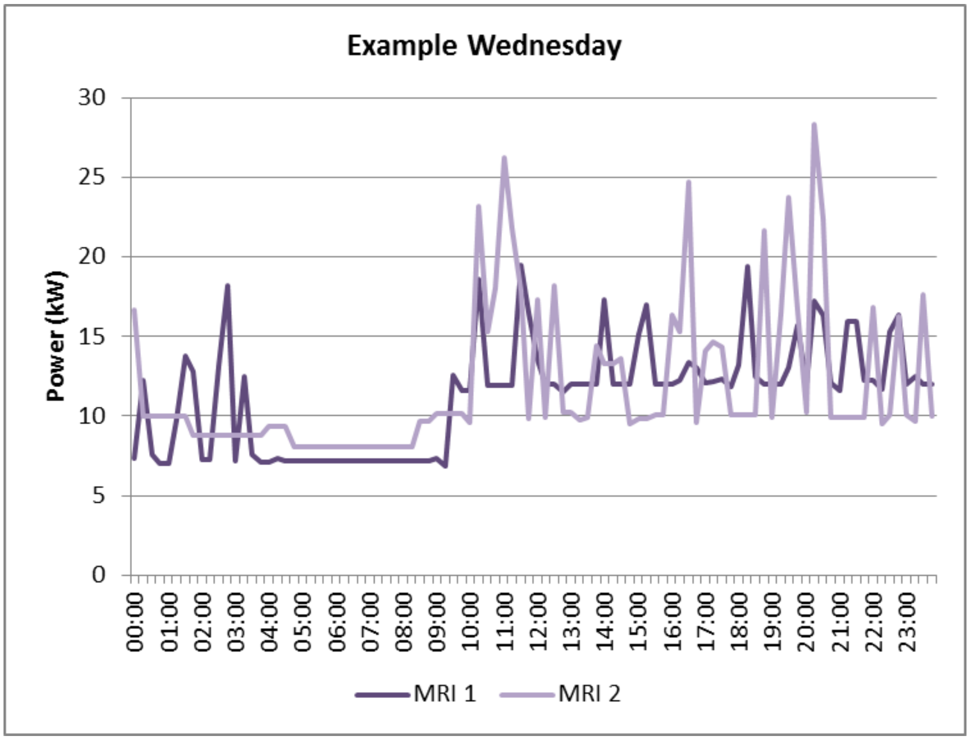

Figure 4-8 MRI 15-minute load profiles for an example weekday (Wednesday)

4.2 Medical Office Building Plug Loads

Mazzetti, Inc., conducted an in-depth metering study of plug loads in five medical office buildings in California. Building characteristics are summarized in Table 4-2. Mazzetti's estimates of plug load densities (Watts per square foot) for a variety of departments and space types in these buildings are summarized in Appendix C.

Table 4-7 Medical Office Building Characteristics

Location	Facility Age (Years)	Square Footage	Functions
Building 1	28	50,950	Adult Medicine, Family Medicine, Flu Clinic, Optometry, Pediatrics, Pharmacy, Radiology/Diagnostic Imaging, Women's Health
Building 2	5	160,883	Adult Medicine, Ambulatory Surgery, Cancer Center (Chemotherapy/Infusion, Hematology, Oncology, Radiation Oncology), Dermatology, Health Education, Internal Medicine, Laboratory, Neurology, Occupational and Employee Health, Pediatric Rehabilitation, Pharmacy, Therapy
Building 3	90	43,050	Dermatology, EEG Sleep Laboratory, Head & Neck Surgery, Neurology, Orthopedic Surgery, Podiatry, Urology
Building 4	15	243,329	Cardiology, Dermatology, EKG, Infusion Center, Injury Center and Sports Medicine, Internal Medicine, Laboratory, Obstetrics & Gynecology, Oncology, Orthopedics, Radiology/Diagnostic Imaging, Urgent Care - After Hours
Building 5	11	21,434	Ambulatory Surgery

At two of the medical office buildings, Mazzetti measured power input to a range of specific medical plug load devices at 15-minute intervals. Depending on the device, the monitoring period ranged from about 13 to 48 hours. Average, minimum, and maximum power measurements are summarized in Table 4-3, Figure 4-7, and Figure 4-8; location abbreviations are listed in Table 4-4.

Some plug loads had a fairly consistent power input; others had widely ranging power input. Plug loads with a high minimum power, such as one of the exam chairs, may represent opportunities for energy savings. Such loads could be investigated on a case-specific basis to determine whether devices can be switched off or to a lower power mode during nonbusiness hours.

Table 4-8 Summary of Medical Office Medical Plug Load Data

Device and Location Abbreviation	First Timestamp	Last Timestamp	Avg W	Min W	Max W
Blood Pressure Cuff, S1, Hea	Sun 00:00	Mon 01:00	3.99	0.64	6.08
Blood Pressure Cuff, S1, InfInf	Sun 00:00	Mon 16:00	3.92	3.77	4.88
Blood Pressure Device, S2, Inf	Thu 05:00	Thu 19:45	3.93	3.77	4.88
Electrosurgical Unit, S1, DerExa	Sun 00:00	Mon 23:45	5.85	5.76	5.94
Electrosurgical Unit, S1, DerPro	Sun 00:00	Mon 23:45	0.53	0.00	5.26
Electrosurgical Unit, S1, HeaPro	Sun 00:00	Mon 01:00	0.41	0.00	14.73
Exam Bed, S1, DerExa	Sun 00:00	Mon 23:45	2.53	2.44	2.64
Exam Bed, S1, DerPro	Sun 00:00	Mon 23:45	26.26	25.63	28.42
Exam Bed, S1, InfExa	Sun 00:00	Mon 16:00	1.36	1.33	1.51
Exam Bed, S1, InfInf	Sun 00:00	Mon 16:00	1.28	1.22	2.58
Exam Bed, S1, InfMin	Sun 00:00	Mon 16:00	2.27	2.16	3.92
Exam Bed, S2, Exa	Thu 05:00	Thu 19:45	1.35	1.33	1.37
Exam Bed, S2, Min	Thu 07:00	Thu 19:45	1.35	1.33	1.37
Exam Chair, S1, HeaExa	Sun 00:00	Mon 01:00	27.50	27.12	27.83
Exam Chair, S1, HeaPro	Sun 00:00	Mon 01:00	5.28	0.00	179.73
Exam Chair, S2, Inf	Thu 05:00	Thu 19:45	1.32	1.22	2.58
Exam Light, S1, DerExa	Sun 00:00	Mon 23:45	0.06	0.00	5.66
Exam Light, S1, InfExa	Sun 00:00	Mon 16:00	0.01	0.00	2.18
Infusion Pump, S1, InfInf	Sun 00:00	Mon 16:00	11.51	11.49	11.56
Infusion Pump, S2, Inf	Thu 05:00	Thu 19:45	11.51	11.49	11.53
Phototherapy Equipment, S1, DerPho	Sun 00:00	Mon 23:45	5.05	3.82	37.67
Smoke Evaporator, S1, DerPro	Sun 00:00	Mon 23:45	0.27	0.00	21.97
Surgical Clipper, S1, DerPro	Sun 00:00	Mon 23:45	2.88	2.78	3.01
Surgical Light 1, S1, HeaPro	Sun 00:00	Mon 01:00	10.75	7.37	125.66
Surgical Light 2, S1, HeaPro	Sun 00:00	Mon 01:00	3.36	0.00	185.62
Vital Signs Monitor, S1, InfInf	Sun 00:00	Mon 16:00	5.47	5.44	5.60
Vital Signs Monitor, S2, Inf	Thu 05:00	Thu 19:45	5.46	5.44	5.60

Table 4-9 Plug Load Location Abbreviations

Abbr.	Description	Abbr.	Description
S1	Site 1 (25–48 hours)	HeaExa	Head and Neck Surgery Exam Room
S2	Site 2 (about 13 hours)	HeaPro	Head and Neck Surgery Procedure Room
DerExa	Dermatology Exam Room	Inf	Infusion Center
DerPro	Dermatology Procedure Room	InfExa	Infusion Center Exam Room
DerPho	Dermatology Phototherapy	InfMin	Infusion Center Minor Procedure
Exa	Exam Room	InfInf	Infusion Center Infusion Station
Hea	Head and Neck Surgery	Min	Minor Procedure

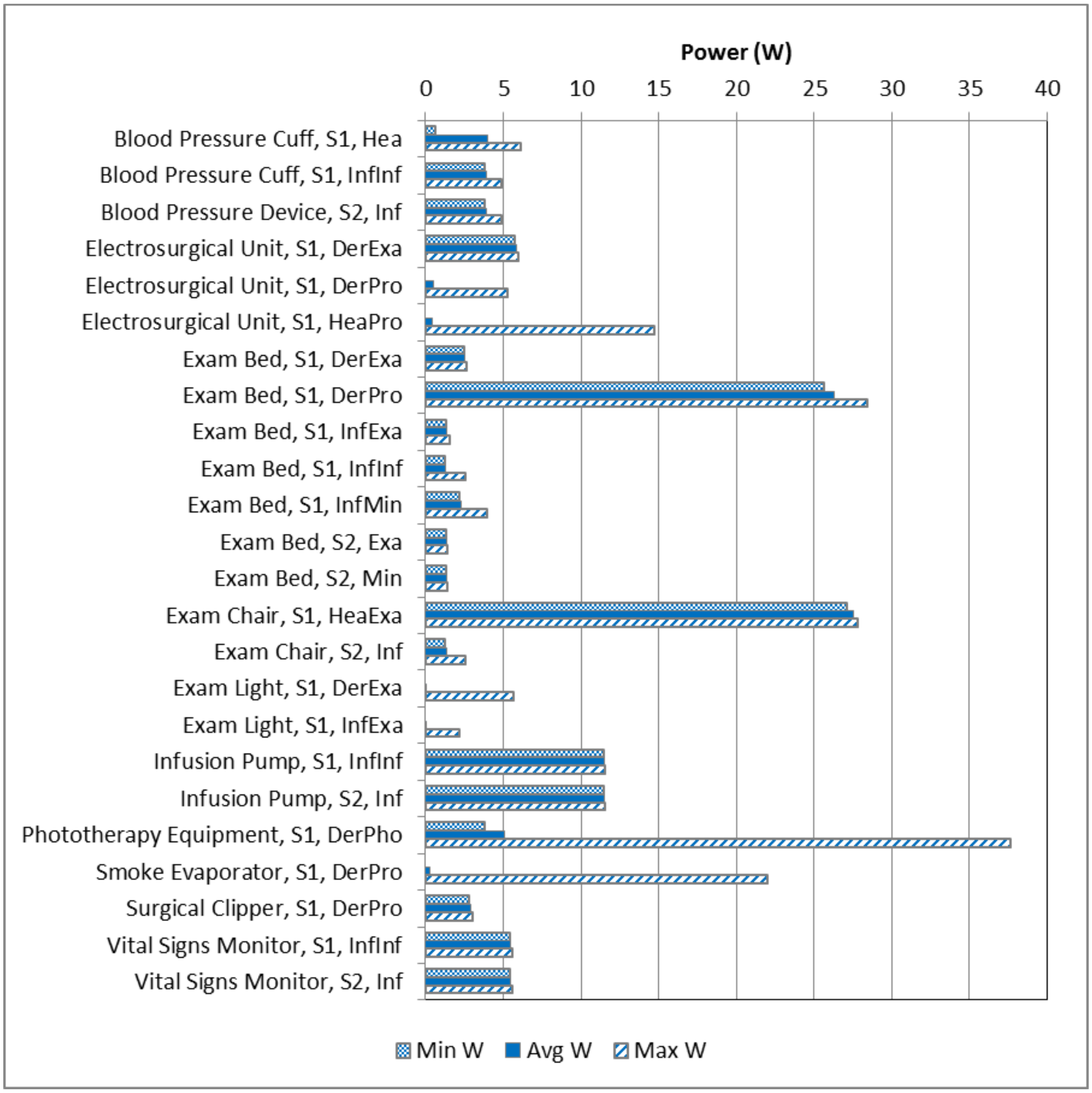

Figure 4-9 Medical office plug loads (with peak power lower than 40 W)

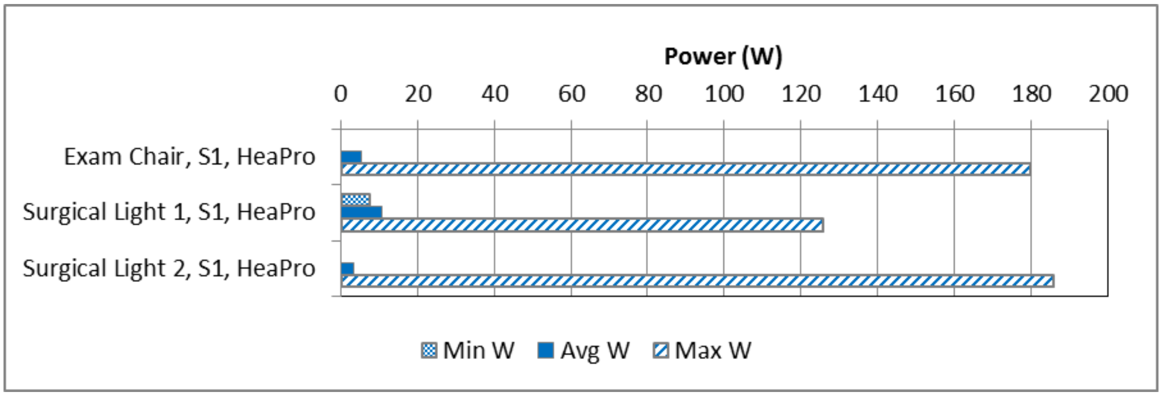

Figure 4-10 Medical office plug loads (with peak power higher than 40 W)

5.0 Conclusions

End-use data from this study provided several valuable insights, including the following key ideas.

5.1 End-Use Data for Informing Decisions

The relative magnitude of the energy consumption of different end uses can be a starting point for prioritizing energy investments and action, whether the scope under consideration involves new metering, targeted energy audits, or end-use equipment upgrades. To inform such decisions, options for acquiring data for comparing end use energy consumption include:

1. Facility and energy managers can begin by assessing their current metering capabilities. For a link to guidance about how to build up metering capabilities, starting with no- and low-cost actions, see Appendix D.
2. For healthcare facilities without end-use level metering capabilities, facility and energy managers can review the data in this report to decide whether their facilities have characteristics (e.g., size, vintage, function, climate) that are similar to those of the hospitals in this study.

   If the buildings are similar, facility and energy managers may wish to use the findings to help them prioritize early actions in an energy investment decision process, such as deciding where to invest first when expanding metering capabilities or defining the scope of a targeted energy audit.

The monitored facilities do not represent a statistically significant sample of hospitals; however, the data can help others to prioritize where to invest next in metering strategies or audits that can gather information specific to their hospitals.

5.2 Considerations for Medical Equipment

Medical equipment is unique to the healthcare sector, so facility and energy managers may be particularly interested in how medical equipment energy consumption compares to that of other hospital end uses. A comprehensive assessment of medical devices was outside the scope of this study, but several large, hard-wired, medical imaging devices were monitored. At both hospitals, these devices accounted for less than 5% of annual site energy use. In the near term, this percentage suggests that facility managers at other hospitals should start with other, larger end uses if they do not yet have end-use metering and want to increase metering capabilities.

On the other hand, the variability in the medical imaging equipment load profiles and the nighttime power consumption of some medical office building plug loads suggest an opportunity for device manufacturers and healthcare stakeholders to examine device operational modes more closely to determine if improvements can be made to: (1) the energy efficiency of "idle" modes; and (2) built-in controls for transitions between operational modes. An example of the first case is that, when medical devices remain at full power in a medical office building during non-business hours, such devices should be assessed more carefully to determine which ones can be powered down. An example of the second case is that manufacturers should consider designing controls that can reduce idle power while ensuring fast response and emergency readiness.

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Appendix A: Hospital End-Use Energy Metering Methodology

At MGH and SUNY UMU, time-series energy end-use data were collected over a period of 1 year and disaggregated by major end use. All meters were monitored at intervals no greater than 15 minutes throughout the year.

A.1 Data Collection for the Massachusetts General Hospital Gray Building

The following sections summarize the major end uses monitored in the Gray Building.

Preheat, Heating, and Reheat

Heating-related end uses were monitored at AHUs and at terminal boxes. At this site, preheat was defined to include thermal energy input at the AHUs, which was used when needed to raise the supply air temperature to 55°F.

The thermal energy input at the terminal boxes included a combination of heating and reheat energy. Energy input at this location was defined as reheat if it was preceded by cooling; otherwise, it was defined as heating.

The source of heat for these systems is district steam, and the building has no boilers. Steam is used at the preheat coils in the AHUs; at the heat exchangers serving the reheat hot water loop; directly at the humidifiers; and for the domestic water heaters. Steam for the building was measured with a steam meter. The steam consumption through each meter was monitored at an interval no greater than 15 minutes. The steam consumption for the preheat coils was calculated by measuring the temperature rise through the preheat coil and volumetric airflow rate across the coil.

Reheat is accomplished with individual hot water reheat coils at variable air volume terminals throughout the HVAC system. Hot water is provided through steam-to-hot water converters. The building reheat energy consumption was determined by using Btu meters consisting of supply and return hot water temperature sensors and flow meters on these loops.

Humidification

The humidifiers use district steam directly and are located at the central AHUs. The quantity of steam used for humidification was determined by subtracting preheat energy and fan energy from the measured heat gain at the AHUs.

Service Water Heating

Steam is used to heat domestic water using steam converters. Steam energy consumption for this application was determined by using flow meters at the domestic hot water systems and calculating the difference between temperature measurements for the water entering and leaving the converters.

Cooling and Dehumidification

Chilled water is provided from a central plant that is located in this building and serves multiple buildings. The cooling capacity consumed by the Gray Building and the total capacity generated at the plant were measured using Btu meters, each of which consists of a flow meter, supply temperature sensor, and return temperature sensor.

The cooling tower energy, condenser water pump energy, chilled water pump energy, and chiller energy of the entire plant were measured as described in the following subsections. The energy consumed by each system was allocated in proportion to the chiller capacity consumed by this building in relation to the amount generated by the plant. The data were captured at an interval of no less than 15 minutes throughout the year. These measured data were used to calculate the following variables with respect to the chiller plant:

Chiller plant capacity (tons of cooling)
Building cooling usage (tons of cooling)
Building consumption compared to plant capacity (%)
Cooling tower fan energy (building percentage)
Condenser water pump energy (building percentage)
Chilled water pump energy (building percentage)
Chiller energy (building percentage)
Entire plant efficiency (kW/ton).

Cooling Tower Fan Energy

Six open-cell cooling towers serve this plant. Each cooling tower fan is controlled through a variable frequency drive (VFD). Current transducers (CTs) measured amperage to enable monitoring of power input to the cooling tower fans. A constant voltage (480 V) and a constant power factor (0.85) were assumed based on data from previous metering efforts. (The same voltage and power factor assumption was used for all fans and pumps in this building.)

Chiller Energy

Five chillers are used to produce chilled water in the spring, summer, and fall, and one flat plate heat exchanger is used for “free cooling” in the winter.

Three of the chillers are 800-ton units, and two of the chillers are 1,500-ton units. CTs measured amperage to enable monitoring of power input to the chillers. Four of five chillers use VFDs to modulate the compressor speed and are controlled directly by the chiller manufacturer control system, which is integrated with the building management system (BMS). The BMS directly controls the 1,500-ton chiller that does not have a VFD.

The building also uses a flat plate heat exchanger with an 800-ton capacity. The unit does not consume electricity directly.

Fans

Supply Fans (in Air Handling Units)

Before this study, most AHU supply fans already had CTs installed on their feeders. The power consumption of AHU supply fans was calculated by using the measured amperage and a predetermined voltage and power factor. Before the data collection phase, amperage was measured and recorded at fan speed intervals of 10%, starting at 10% and continuing to full speed. These measurements were performed for each AHU. Power input to each fan was calculated and uploaded into a database at 15-minute intervals throughout the project. The airflow and discharge static pressures were also measured and collected at the same interval.

Return Fans

Energy consumption of return fans was measured via the same approach used for the AHU supply fans.

Exhaust Fans

The exhaust fans are constant volume. The amperage and voltage for each fan motor were measured at the start, midway point, and end of the project. The status of each fan was continuously monitored and uploaded to a database at 15-minute intervals.

Ventilation Fans (Mechanical and Electrical Spaces)

The ventilation fans are constant volume. The amperage and voltage for each fan motor were measured at the start, midway point, and end of the project. The status of each fan was continuously monitored and uploaded to a database at 15-minute intervals.

Pumps

The pumps serving this building include:

Hot water pumps

Heat recovery pumps

Domestic water booster pumps

Chilled water pumps

Condenser water pumps.

The energy consumption for each pump was monitored. The amperage and voltage for each pump motor were measured at the start, midway point, and end of the project. The status of each pump was continuously monitored and uploaded to a database at 15-minute intervals.

Chilled water and condenser water pumping energy are described in greater detail in the following subsections. Pumping energy was allocated to the building based on the portion of cooling capacity the building consumed as a percentage of chiller plant production. This calculation was required because the chiller plant serves multiple buildings.

Condenser Water Pumping Energy

All these condenser water pumps are controlled by VFDs. CTs measured the amperage of the electrical input, which was used to determine power.

Chilled Water Pumping Energy

All the primary chilled water pumps are constant volume and do not have VFDs. Their power consumption was determined with CTs.

All the secondary chilled water pumps were controlled by VFDs. CTs measured the amperage of the electrical input, which was used to determine power.

Lighting

The energy consumption of lighting systems was not directly monitored in the Gray Building. An estimate of the combination of lighting loads and miscellaneous plug loads was derived by subtracting other monitored loads from whole-building electricity consumption.

Large Hard-Wired Medical Imaging Equipment

All medical imaging equipment in the Gray Building is fed from a dedicated imaging branch that is fed from both normal and emergency power via an automatic transfer switch (ATS). Individual imaging equipment feeders are fed from a dedicated distribution panel that is served by the ATS. The combined energy consumption of six fluoroscopy X-ray devices was measured at the normal power feeder circuit breaker to the imaging ATS by the circuit breaker trip unit and uploaded to the database at 15-minute intervals throughout the entire length of the project. The discrete meter in the ATS serving the imaging distribution panel was used for validation of consumption data.

Elevators

All elevators in the Gray Building are fed from a dedicated elevator branch. An ATS allows the elevators to be fed by either normal or emergency power. Individual elevator feeders are fed from a dedicated distribution panel that is served by the ATS. Total elevator energy consumption was measured at the normal power switchgear using a discrete metering device and uploaded into a database at 15-minute intervals throughout the project. The discrete meter in the ATS serving the distribution panel was used to validate consumption data.

Other specific plug and process loads were not directly monitored as part of this study.

A.2 Data Collection for the State University of New York Upstate Medical University East Wing

The following sections summarize the major end uses monitored in the East Wing.

Preheat, Heating, and Reheat

Heating for the SUNY UMU hospital buildings is provided by a university-owned and -operated boiler plant consisting of three boilers, each with a net capacity of 43.5 million pounds of steam at 125 pounds per square inch gauge. The boilers are primarily supplied by gas with #2 fuel oil for backup. Boiler gas use is continuously monitored by a digital meter. Boiler output is measured by a steam meter in the primary distribution line and recorded by a chart recorder that does not have an electronic interface to the BMS.

The East Wing has a system of hot water duct coils supplied by a central steam-to-hot water heat exchanger, which delivers constant temperature hot water to a building reheat loop. Energy use monitoring for the hot water coils was calculated using a flow meter on the heating supply and the temperature difference between the water entering and leaving the reheat converters. This metering point captured a combination of reheat and heating energy.

The East Wing also has a hot water radiation system. Steam-to-hot water heat exchangers deliver constant temperature hot water to unit heaters and a fin tube radiation system, which is used on the perimeter of the building to offset thermal transmission losses, as well as for spaces that do not receive heated air via the ventilation system. Energy use monitoring for the radiation loop system was calculated using a flow meter on the heating supply and the temperature difference between the water entering and leaving the radiation convertor.

Preheat coils on ventilation systems consist of low-pressure steam coils, but preheat energy was not directly measured.

Humidification

Humidification was not separately monitored during this study. The steam used for humidification is part of the energy used by the steam preheat coils.

Service Water Heating

The East Wing has semi-instantaneous steam water heaters that provide 120°- to 125-°F water for all areas of the building. Hot water in this building is mainly used for hand washing. This building has no major hot water process uses. (Primary sterilization is done in another facility.)

Energy use for the water heating system was determined by using a flow meter in the primary loop combined with temperature sensors on the entering and leaving water streams.

Cooling and Dehumidification

The East Wing has two electric centrifugal chillers providing chilled water to cooling coils within the building. Energy use monitoring for the electric chillers was conducted by using data from manual log readings taken up to six times daily. Recorded voltages, amperages, and runtime hours were multiplied to determine daily total energy use.

The chillers served both the East Wing and part of a tower addition that was outside the scope of this study. The square footage of the East Wing is about 40% of the total square footage served by the chillers, so meter readings for the chillers were multiplied by 40% to estimate the portion of chiller energy that is attributable to the East Wing.

The East Wing and East Tower chillers use a common cooling tower, and its power is provided through the electric service to the East Tower (not the East Wing), which was not monitored in this study.

Fans

All HVAC fans and some exhaust fans are monitored by the BMS. Single-phase fan motors less than ½ horsepower were not monitored.

Energy monitoring was accomplished with a digital energy meter (DEM) that was added to monitor motor current draw through the BMS. A DEM is a product that collects data from devices such as CTs and can communicate data to a BMS or log data locally.

Pumps

All pumps except condensate and sanitary pumps are monitored by the BMS. The pumps monitored in this study included primary and secondary chilled water pumps, condenser water pumps, reheat loop hot water pumps, and radiation loop hot water pumps.

The condenser water pumps served both the East Wing building and part of a tower addition that was outside the scope of this study. The square footage of the East Wing is about 40% of the total square footage served by the condenser water pumps, so meter readings for the condenser water pumps were multiplied by 40% to estimate the portion of chiller energy that is attributable to the East Wing.

The monitored chilled water and hot water pumps were dedicated solely to serving the East Wing building, so 100% of their energy was included in the East Wing end-use calculations.

One pump (labeled “Pump P-3”) was a spare that could be manually lined up as either a condenser water pump or a chilled water pump, but its designation was not recorded by SUNY UMU. For the calculations in this report, this pump was assumed to be used equally for both purposes, and its meter readings were multiplied by 70% (the average of the aforementioned 40% and 100% utilization factors).

Energy monitoring was accomplished with a DEM added to monitor motor current draw through the BMS.

Interior Ambient Lighting

The energy consumption of interior ambient lighting (which excludes task lighting) was monitored in the East Wing. The lighting systems include 277-V fluorescent troffers with a variety of 120-V T4 accent downlights and a few standard 120-V fixtures with compact fluorescent bulbs. Power for the 277-V lighting distribution is segregated from the receptacle power.

Energy monitoring was accomplished with a DEM to record feeder current on the distribution riser.

Large Hard-Wired Medical Imaging Equipment

Several pieces of large medical imaging equipment are located in the East Wing. This study included monitoring of two MRI and three CT units.

Energy use monitoring was provided by a DEM in the branch circuit to each system. In some cases, these systems are supplied power via an uninterruptable power supply (UPS); for the UPS-supplied systems, the DEM was located on the discharge side of the UPS.

Operating Room Plug Loads

Toward the end of the project, DEMs were installed on part of the primary distribution panel serving the operating rooms, providing data for April 2013 for eight of the 14 operating rooms and one half of the recovery room. The SUNY UMU team extrapolated the measured data to the building’s total operating room area based on the plug load Watts per square foot found in the monitored fraction of the operating rooms.

Appendix B: Sources of Uncertainty in End-Use Measurements and Calculations

Uncertainty in commercial building energy end-use calculations has a variety of sources. Major sources of uncertainty include (but are not limited to) the following:

- Metering design for existing buildings is particularly challenging, given that many buildings do not have dedicated panels for energy end uses of interest; as a result, a single panel may feed circuits that serve multiple types of loads (e.g., lighting and plug loads). Furthermore, existing building electrical panels sometimes have poorly labeled circuits—a problem that is exacerbated over time as space uses and equipment change, which can cause panel uses to change. These changes are not always well documented.

  These factors complicate the design of metering systems, as well as verification and troubleshooting of metered data. These factors can cause a variety of errors, including failing to capture certain loads, mischaracterizing circuits under incorrect end-use categories, and double-counting loads with multiple meters.
- In healthcare buildings such as hospitals, it may be infeasible to shut down circuits to install metering devices. This can limit the number of meters that can be installed for a particular end use. For example, when the SUNY UMU team attempted to monitor operating room plug load energy, the team was only able to access circuits for eight of the 14 operating rooms and one half of the recovery room. The SUNY UMU team extrapolated the measured data to the building's total operating room area based on the plug load Watts per square foot found in the monitored fraction of the operating rooms. This is a less accurate approach than directly monitoring all rooms, but it reflects practical obstacles that are typical in a healthcare setting.
- Chiller plant energy allocations were estimated in both hospitals. In the MGH Gray Building, the allocation was based on using flow meters and temperature measurements to disaggregate the fraction of cooling capacity supplied to the monitored building. In the SUNY UMU East Wing, a comparable disaggregation was not feasible, and a simple square footage multiplier was applied, which introduces a potentially much greater source of error.
- In some cases, monitored equipment may serve multiple functions, which can complicate assignment of their energy use to the right category. Reheat coils in terminal boxes, for example, can serve both reheat and heating functions, depending on environmental conditions and how the HVAC system is controlled and operated.
- Assumed constant values can introduce additional error. A few examples from this study include:
  - The meters for fans and pumps in the MGH Gray Building were monitored by measuring current, but not voltage or power factor; the latter two values were assumed to be constant and were based on data from previous metering efforts.
  - Measured motor speeds were used as a proxy for energy consumption. This is sometimes done by initially measuring motor current at a discrete set of motor speeds before a monitoring period begins; later, during the monitoring period, motor speed is measured as a proxy for current.

- The building steam meter recorded only mass flow. To translate this into an energy estimate, the building's rate of steam energy consumption per unit mass of steam was assumed to be a constant 1,066 Btu/lbm—this value was estimated from conditions for the steam entering the building and the condensate leaving the building, which involved additional assumptions:
    - The steam was assumed to enter the building at about 68 pounds per square inch gauge, based on the pressure set point of the district steam system. The metered quantity of steam was also assumed to be entirely saturated vapor, which at this pressure would be about 314°F. Differences in actual entering steam conditions are a potential source of error.
    - The calculations also assumed that condensate left the building at a constant 150°F, because condensate temperature was not monitored. Building staff reported that condensate temperatures fluctuate between 140° and 160°F, so the constant temperature assumption is a potential source of error.

These sources of uncertainty are typical in commercial building metering. When viewing the results of this and other end-use metering studies, engineers and facility managers should recognize that end-use breakdowns based on field data are approximations that reflect the practical constraints of implementing metering in existing, occupied, operational buildings.

An additional consideration is the measurement uncertainty associated with random instrument error and any uncorrelated error source. Such errors are calculated as follows. Suppose a value of interest, Y, takes the following form (NIST 2014):

$$Y = a_1X_1 + a_2X_2 + \ldots a_NX_N \qquad \text{(Equation 1)}$$

where the values of X_1 through X_N are uncorrelated and can be estimated with measurements at points 1 through N. In such cases, the combined measurement error (excluding systematic bias) can be estimated with the following equation (NIST 2014):

$$u_c(y) = \sqrt{a_1^2u_1^2(x_1) + a_2^2u_2^2(x_2) + \ldots + a_N^2u_N^2(x_N)} \qquad \text{(Equation 2)}$$

where:

y = estimate of Y

$x_{1 \ldots N}$ = measured estimates of X_1 through X_N

u_c = combined error

$u_{1 \ldots N}$ = error for measurements at points 1 through N

$a_{1 \ldots N}$ = coefficients from Equation 1

End-use power input or energy consumption can take the form of Equation 1, where Y is end-use power or energy, x_1 through x_N are power values from specific metering points, and each coefficient from a_1 through a_N equals 1. In such cases, Equation 2 reduces to:

$$u_c = \sqrt{\sum_{i=1}^{N}(u_i^2)} \qquad \text{(Equation 3)}$$

For any given end-use category with a reported energy consumption value, the combined measurement uncertainty for that value is therefore a function of the accuracy of the meters associated with the end-use category.

For some end uses in this study, there were insufficient data on meter specifications to quantify the combined measurement error, particularly if existing meters were involved. In other cases, sufficient data were available to estimate combined measurement error. For example, the end-use category of medical imaging equipment in the SUNY UMU East Wing was evaluated using five electrical meters, each associated with a different medical imaging device. Each meter had a reported accuracy of ± 1%. Applying Equation 3 to this case, the estimated combined measurement error associated with total medical equipment energy is:

$$\sqrt{\sum_{i=1}^{N}(u_i^2)} = \sqrt{5(\pm 1\%)^2} = \pm 2.2\% \qquad \text{(Equation 4)}$$

Appendix C: Additional Medical Office Building Plug Load Data

Table C-1 through Table C-6 summarize additional data provided by Mazzetti from its study of plug loads in medical office buildings. (For a summary of the buildings' characteristics, see Section 4.2, Table 4-2.) For buildings 1, 2, 3, and 5, Mazzetti collected or estimated sufficient square footage data to generate department- and space-specific estimates of plug load Watts per square foot.

Table C-10 Medical Office Building 1: Plug and Process Load Data by Panel and Department

Panel	Department	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
L1A	Primary Care	8,850	0.66	0.07	1.61	0.18	111	0.65
L1B	Pediatrics	6,840	1.91	0.28	2.80	0.41	322	2.45
L1C	Shipping/Receiving, Tele. Equip. Room, Injection Room	6,400	3.26	0.51	7.80	1.22	547	4.45
L1D	Laboratory	6,430	1.58	0.25	2.84	0.44	266	2.15
L2A	Internal Medicine	5,930	1.48	0.25	3.67	0.62	248	2.18
L2B	Surgery-O.B./GYN	5,720	2.65	0.46	4.47	0.78	445	4.04
EL1A	L1A+L1D	15,280	0.66	0.04	1.29	0.08	111	0.38
EL1B	L1B+L1C	13,240	1.55	0.12	3.43	0.26	260	1.02
EL2A	Internal Medicine	5,930	0.96	0.16	2.86	0.48	161	1.41
EL2B	Surgery-O.B./GYN	5,720	0.33	0.06	0.80	0.14	55	0.50

Table C-11 Medical Office Building 1: Plug and Process Load Data by Space Type

Space Type	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
Waiting Area/Corridors	4,952	1.38	0.28	3.12	0.63	232	2.44
Reception	2,230	0.50	0.22	1.04	0.46	83	1.94
Exam Rooms	10,040	3.36	0.33	5.57	0.55	567	2.93
Offices	5,031	1.02	0.20	1.77	0.35	171	1.77
Nurse/Work Station	701	1.12	1.59	2.74	3.91	190	14.09
Breakroom/Lounge	320	0.03	0.09	0.79	2.47	6	0.90
Procedure/Operating Rooms	4,292	1.02	0.24	1.78	0.42	172	2.08
Imaging	1,935	0.88	0.46	1.83	0.95	151	4.06
Lab/Storage	1,394	0.27	0.19	0.69	0.50	45	1.69
Mechanical/Electrical Rooms	960	0.30	0.31	0.40	0.41	51	2.79
Other	8,765	1.68	0.19	5.72	0.65	285	1.69
Pharmacy	280	0.06	0.20	0.21	0.74	9	1.73

Table C-12 **Medical Office Building 2: Plug and Process Load Data by Department**

Department	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
Oncology	12,800	7.37	0.58	11.24	0.88	1,238	5.03
Material Services/Biomed	2,500	0.83	0.33	1.62	0.65	140	2.91
Conference Rooms/ Classrooms	8,700	2.72	0.31	4.50	0.52	458	2.74
Neurology	12,000	1.30	0.11	6.17	0.51	218	0.95
Pharmacy and Medical Legal	12,000	0.23	0.02	0.81	0.07	39	0.17
Physical/Occupational Therapy Pediatric Rehab	24,000	5.35	0.22	10.22	0.43	899	1.95
Hemo/Oncology & Infusion Center	11,800	4.47	0.38	7.70	0.65	751	3.31
Eye Procedures, Hospice, Medical Transcription	12,200	2.64	0.22	7.44	0.61	444	1.89
Dermatology	10,500	2.49	0.24	11.05	1.05	419	2.08
Internal Medicine	13,500	3.13	0.23	5.88	0.44	526	2.03
Employee Health/ Occupational Health, Medical Staff Development	13,000	3.72	0.29	5.90	0.45	626	2.50
Medical Secretaries, Health Education Admin	11,000	4.85	0.44	9.03	0.82	816	3.86

Table C-13 **Medical Office Building 2: Plug and Process Load Data by Department**

Space Type	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
Waiting Area/Corridors	4,520	0.30	0.07	1.01	0.22	51	0.58
Reception	840	1.33	1.58	3.78	4.50	223	13.79
Exam Rooms	8,810	3.09	0.35	6.14	0.70	520	3.07
Offices	5,100	2.02	0.40	5.00	0.98	339	3.45
Nurse/Work Station	5,740	3.03	0.53	7.00	1.22	509	4.61
Breakroom/Lounge	1,890	1.63	0.86	6.36	3.37	274	7.54
Prep Area, Pre-Op	800	3.93	4.91	5.34	6.67	660	42.88
Procedure/Operating Rooms	3,690	0.79	0.21	2.12	0.57	133	1.87
Imaging/Linear Accelerator	3,590	3.02	0.84	9.14	2.55	507	7.34
Lab/Storage	1,350	0.57	0.42	1.19	0.88	96	3.69
Mechanical/Electrical Rooms	1,835	2.89	1.57	3.81	2.08	485	13.75
Other	5,400	0.77	0.14	2.89	0.54	130	1.25
Conference/Meeting Areas	5,075	0.37	0.07	1.51	0.30	62	0.63
Pharmacy	300	0.90	3.01	0.94	3.14	152	26.27

Table C-14 Medical Office Building 3: Plug and Process Load Data by Department/Space Type

Department/Space Type	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
Head & Neck Surgery	12,000	2.57	0.21	6.71	0.56	432	1.87
Dermatology	12,000	1.92	0.16	6.92	0.58	322	1.40
Urology, Neurology, EEG/ Sleep Lab	12,000	1.96	0.16	4.45	0.37	329	1.43
Orthopedics & Podiatry	6,000	0.51	0.08	1.87	0.31	86	0.74
Cast Room	2,000	0.23	0.11	0.47	0.24	38	1.00
Waiting Area & Reception	1,500	0.62	0.42	1.37	0.91	105	3.63
Procedure Room	2,500	0.93	0.37	3.04	1.21	157	3.26

Table C-15 Medical Office Building 5: Plug and Process Load Data by Space Type

Space Type	Square Footage	Avg kW	Avg W/ft^2	Peak kW	Peak W/ft^2	kWh/wk	kWh/ft^2·yr
Public/Waiting Area	2,246	0.33	0.15	0.54	0.24	55	1.27
Corridors/Auto Doors	3,568	0.18	0.05	0.47	0.13	30	0.44
Exam Rooms	404	0.73	1.82	2.12	5.26	124	16.00
Offices	400	0.04	0.11	0.26	0.65	9	1.14
Nurse/Work Stations	565	1.11	1.97	2.01	3.56	189	17.38
Breakroom/Lounge	572	1.06	1.85	2.53	4.43	195	17.72
Prep Area/Pre-Op	3,136	2.98	0.95	8.35	2.66	540	8.95
Procedure/Operating Rooms	2,840	1.22	0.43	4.99	1.76	241	4.41
Labs/Medical Storage	2,343	0.99	0.42	1.58	0.68	168	3.73
Mechanical/Electrical Rooms	2,690	0.00	0.00	0.08	0.03	1	0.02
Post-Op	2,662	1.83	0.69	2.52	0.95	309	6.04

Appendix D: Additional Resources

Research has shown that that metering leads to better energy management and improved energy performance (Torcellini et al. 2006). For hospital facility managers and energy managers who are interested in increasing metering capabilities at their sites, the following resources may be helpful:

- For a comprehensive guide on metering in commercial buildings, please refer to the Federal Energy Management Program's (FEMP) *Metering Best Practices* guide at http://www1.eere.energy.gov/femp/pdfs/mbpg.pdf (FEMP 2011). This guide includes case study and success story information from the National Institutes of Health headquarters in Bethesda, Maryland, and a metering program at the U.S. Department of Veterans Affairs.

- For benchmarking resources that address hospitals and medical office buildings, see the ENERGY STAR® website at http://www.energystar.gov/buildings/sector-specific-resources/healthcare-resources (EPA 2014). For follow-on benchmarking and measurement steps for major end uses, see the *High-Performance Buildings for High-Tech Industries* website at http://hightech.lbl.gov/benchmarking-hcf.html (LBNL 2014).

- For a study of end uses from a hospital in Vancouver, Washington, see the "Targeting 100!" reports at http://idlseattle.com/t100/TOL_DWN.php (Hatten et al. 2011).

- For a high-level summary of recommended steps for building a metering program for healthcare facilities, as well as examples of success from peer hospitals, see the *Healthcare Energy Metering Guidance* brochure at http://www.nrel.gov/docs/fy11osti/50942.pdf (NREL 2011).

- For a simple guide on data processing and analysis for commercial buildings, refer to *Metering Best Practices Applied in the National Renewable Energy Laboratory's Research Support Facility: A Primer to the 2011 Measured and Modeled Energy Consumption Datasets* at http://www.nrel.gov/docs/fy13osti/57785.pdf. (Sheppy et al. 2013).