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Douglas R. Black, Steven M. Lanzisera, Judy Lai,
Richard E. Brown, Brett C. Singer

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
Indoor Environment Group
Berkeley, CA 94720

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Douglas R. Black*, Steven M. Lanzisera, Judy Lai, Richard E. Brown, and Brett C. Singer
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, CA 94720
510-486-6658 (fax)
DRBlack@lbl.gov, SMLanzisera@lbl.gov, JLai@lbl.gov, REBrown@lbl.gov, and BCSinger@lbl.gov
*Corresponding Author

Abstract: Miscellaneous and electronic loads (MELs) consume about one-third of the primary energy used in U.S. buildings, and their energy use is increasing faster than other end-uses. In health care facilities, 30% of the annual electricity was used by MELs in 2008. This paper presents methods and challenges for estimating medical MELs energy consumption along with estimates of energy use in a hospital by combining device-level metered data with inventories and usage information. An important finding is that common, small devices consume large amounts of energy in aggregate and should not be ignored when trying to address hospital energy use.

Key words: commercial buildings, end-use, energy utilization intensity, health care, hospitals, medical, miscellaneous electrical load

Biographical Notes: Douglas R. Black is a Research Engineer in the Indoor Environment Department of the Environmental Energy Technologies Division of LBNL. He has a BS in Electrical Engineering from the University of Michigan and an MS and Ph.D. in Civil and Environmental Engineering from the University of California at Berkeley. He is a leader of LBNL's healthcare energy efficiency research including the development of hospital benchmarking metrics and procedures and measurements of medical equipment and miscellaneous electric loads in hospitals.

Steven M. Lanzisera is a Research Scientist in Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division. He received the B.S. degree in electrical engineering from the University of Michigan, Ann Arbor, in 2002 and the Ph.D. degree in electrical engineering and computer sciences from the University of California, Berkeley, in 2009. He studies energy use in buildings with a focus on distributed sensing and control as well as appliance energy efficiency. He has published research on embedded systems, wireless communication, networking, integrated circuits, building energy efficiency, and public policy.

Judy Lai is a Principal Research Associate in the Energy Analysis Department of Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division. Her current research interests include distributed generation, utility-customer

interactions, optimization of building energy systems, and appliance energy efficiency. She holds a B.A. degree in architecture from UC Berkeley.

Richard E. Brown received the B.S.E. degree in engineering and management systems from Princeton University, Princeton, NJ, in 1986 and the M.A. degree from the Energy and Resources Group, University of California at Berkeley, Berkeley, in 1993. He is a Research Scientist in the Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, CA. His current research interests include technical support to the Energy Star program, developing a home energy audit web site (the Home Energy Saver), developing solutions to address the growing energy use of electronics and miscellaneous equipment in buildings, and analyzing the energy use of drinking water and wastewater treatment systems.

Brett C. Singer, is a Staff Scientist who works in the Indoor Environment, Atmospheric Sciences, and Building Technologies Departments of the Environmental Energy Technologies Division of LBNL. He earned a B.S. in Mechanical Engineering from Temple University in 1991, then Masters (1994) and Ph.D. (1998) degrees in Civil and Environmental Engineering from the University of California at Berkeley. Dr. Singer has pursued a broad research agenda in the intersecting areas of air quality and energy efficiency and is a leader of LBNL's healthcare energy efficiency initiative. Specific efforts include the development of LBNL's prototype hospital benchmarking system and creation of a research and development road map for healthcare energy.

1 Introduction

Hospitals are known to be among the most energy intensive commercial buildings in California and throughout the United States, and there is concern that medical equipment comprises a substantial and sharply increasing fraction of energy use in hospitals. Both the California Commercial End-use Survey (CEUS, CEC 2006)) and the Commercial Building Energy Consumption Survey (CBECS, EIA 2006) provide estimates of hospital energy consumption resolved by end-use, but the estimates do a poor job of capturing medical equipment. The best estimate available today relies heavily on CBECS and a few estimates for large medical imaging equipment (e.g. MRIs) to estimate that 30% of health care facility annual electricity was used by MELs in 2008 (TIAX 2008). There is a dearth of information about the amount of energy used by medical equipment including both the high-power imaging systems such as MRIs and the smaller equipment that is ubiquitously distributed throughout hospitals. In addition, there are no meaningful bottom-up estimates that aggregated measured, or estimated, energy consumption of individual devices. The top-down estimates are typically derived from subtracting relatively uncertain estimates for other electrical loads (e.g. cooling, lighting, etc.) from uncertain total electrical use rates for hospital buildings. Owing in part to this uncertainty in attribution, efforts to reduce energy use in hospitals typically focus on discrete measures and technologies that may ignore the largest and most cost-effective opportunities for savings.

Although the visibility of medical equipment energy use has increased due to recent studies, the attention is typically focused on high-powered medical imaging devices such as MRIs or laboratory equipment (Jensen and Petersen 2011). The energy use of small medical devices is poorly characterized due to a lack of information, but these devices may be important based on their number (e.g. infusion pumps) and/or use patterns (e.g. monitoring systems). This paper reviews a proposed method for estimating medical MELs energy consumption, summarizes data collected in an example hospital, and presents the resulting energy estimates in the context of hospital energy consumption.

2 Case Study Hospital Background

This study was conducted at the Stanford University Medical Center's (SUMC's) Stanford Hospital and Clinics (SHC) and the Lucille Salter Packard Children's Hospital (LPCH). SHC and LPCH are acute care hospitals located in Palo Alto, California, USA that have approximate floor areas of 900,000 sq. ft. and 260,000 sq. ft., respectively. SHC and LPCH provided equipment inventories, assisted in making measurements of power consumption levels for medical devices in connection with calibration and maintenance activities, and provided estimates of device usage patterns. SHC and LPCH are located in the same physical building and share resources accordingly.

3 Methods

The focus of this study was to develop and demonstrate methodologies to quantify power and energy use both for medical devices and for devices with non-medical purposes that serve medical functions. As such, hospital MELs in this project have been separated into three broad categories: those with a uniquely medical function, devices which can have non-medical function but are used in hospitals for purposes of medical care, and electrical devices without a direct medical function. Examples of devices with a uniquely medical function include those that contribute to patient care, e.g., through diagnosis or treatment. These include patient monitors, patient beds, and infant warmers, among others. Devices that have non-medical application but are used for medical purposes include refrigerators, microwaves, and computers, among others. Finally, devices such as vending machines, televisions, and water fountain chillers exemplify devices without a direct medical function.

3.1 *Framework for Quantifying Medical Equipment Energy Use*

In developing a framework for quantifying energy consumption of medical equipment, we started with generic methodologies developed for miscellaneous electrical loads in other commercial buildings (Kawamoto et al., 2002). Figure 1 shows the basic framework for quantifying the energy consumed by MELs using a bottom-up approach. The approach is to calculate aggregate energy use from three component data sources: (1) power consumption in each operating mode for each device, (2) amount of time spent in each operating mode, and (3) population of devices in use. To begin, data are collected about the device's power consumption in each of its operational modes. Sources include existing data (e.g., from manufacturers) or data collected expressly for the research study (e.g., with logging power meters). The calculation of energy consumption by MELs also has a time element and requires data about the amount of time spent in each operational mode in a typical year. Ideally, this information would be derived from time-series data on device usage over a time period that is long enough to reflect "typical" use and capture variability over relevant time scales, e.g. diurnal and weekday vs. weekend variations. Although measured data on medical equipment energy use patterns is required to estimate how long of a metering period is needed to capture these patterns effectively, we expect weeks rather than days or hours of data would be required. The product of the power use in each mode and the time spent in each mode yields the unit energy consumption (UEC), which is the term for the annual energy use of a single device. Multiplying the UEC by the total number of devices in use allows calculation of aggregate energy consumption (AEC) for a given device category at the hospital. Figure 1 also shows the data sources used for calculating energy use in this study, and these sources will be discussed later in this paper.

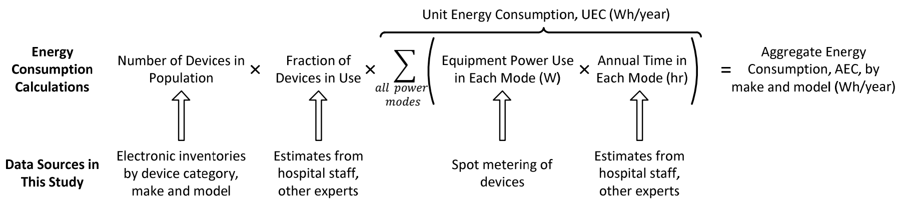

Figure 1. Framework for estimating medical equipment energy consumption in hospitals

In principle, the data necessary to quantify medical equipment energy consumption can be collected with one of two basic approaches: (1) separately obtain information on power use in each operational mode and time spent in each mode for a sample population of devices, or (2) collect accurate time-series measurements of power use for a sample population of devices. The former has the advantage of being obtainable even with less accurate time-series metering. The latter is more direct. In either case, the variability among different makes and models (e.g., different generations) of devices that perform a given function (e.g., patient bed, infant warmer, IV pump, etc.) can be measured. Moreover, the variability in use patterns can also be measured. The variability in use patterns may be correlated with medical service (e.g., the different activity pattern of a ventilator in an ICU as compared to a ventilator in radiology), and measurements in different use areas should be collected to mitigate this issue.

3.2 *Special Challenges and Opportunities in Hospitals*

Working with staff at SHC and LPCH, we learned that the standard MEL methodologies described above could not be applied directly or even adapted to hospitals; fundamentally different methods were needed. The special characteristics of hospitals make some elements of this approach prohibitively difficult and/or limiting.

The first limiting element is access for cataloging equipment. In most buildings, device prevalence can be cataloged in a smaller area that is considered as representative of some larger area; this typically occurs during off-hours, but can be accomplished during occupied periods when necessary. In hospitals, most functional areas (e.g. service areas) are comprised of specialized sub-areas with no single sub-area being representative of the larger area. In addition, many areas are not accessible to researchers without a dedicated escort and some areas are essentially inaccessible due to privacy or safety concerns. To further complicate matters, equipment is constantly in flux and typically moved into the place of use only when needed by a patient. The most restricted access is in any area in which patient care is ongoing. Thus, access is restricted precisely at the times and locations most relevant to equipment cataloging.

The second and perhaps even more problematic restriction at the hospital in this study, and likely at other hospitals, is that energy meters cannot be connected in-line to any device that is being used for patient care or patient services due to potential safety issues. This restriction on connecting to in-use equipment limits the potential for either direct metering of energy use or even metering to determine activity data. In consideration of these critically limiting conditions, we identified a need for a non-intrusive method of metering a single device's activity pattern. More information on this new meter is described in a subsequent section.

The many medical devices that can be powered both from a wall outlet and internal rechargeable batteries poses another challenge. These devices have levels of power consumption that vary depending on if they are charging while operating or not, and the state of the battery charge. Even with thorough in-use power metering, it may be difficult to determine the power consumption levels of the various modes.

3.3 *Medical equipment inventory processing and sorting*

SHC and LPCH staff provided several equipment inventories. For each hospital, we obtained inventories for medical devices, hospital beds, IT equipment, and facilities equipment. Hospital staff provided much needed guidance in interpreting the inventories, which was especially helpful in the case of the medical device inventories.

The medical equipment inventories for SHC and LPCH contained 18,540 and 10,500 devices, respectively. Several clean up steps had to be taken prior to sorting the medical device inventories into approximately 50 categories based on device function. Devices that do not consume electricity (e.g. attachments or extensions that would never be powered directly) were removed from the inventories. Devices that are exclusively powered by non-rechargeable batteries were removed from the inventories. Items that use rechargeable batteries were left in the inventory. This sorting step required significant effort due to the fact that the power supply requirements of any given device type often varied by manufacturer and also differ from model to model. A fetal heart detector, depending on manufacturer and model number, for example, can run on plug or battery power, and/or can run on rechargeable or non-rechargeable batteries.

The revised SHC and LPCH medical device inventories number 14,648 and 7,372 items each. Table 1 shows the total number of medical devices in each category in both SHC and LPCH.

Table 1. Total number of medical devices in each category.

Medical Device Category	SHC	LPCH	Total
Airway Clearance	9	11	20
Analyzer-Patient	49	81	130
Anesthesia Unit	56	29	85

Medical Device Category	SHC	LPCH	Total
Aspirator	276	78	354
Autotransfusion	50	5	55
Camera-Video	262	85	347
Charger	75	61	136
Circulatory Assist	552	5	557
Compressor	25	0	25
Computer-Infosys	194	529	723
Contrast Media Injector	24	0	24
Data interface unit	320	0	320
Defibrillator	201	59	260
Display	285	237	522
Electrocardiograph	56	15	71
Electroencephalograph	15	9	24
Electrosurgical Unit	291	29	320
Exam Chair or Table	595	179	774
Exerciser	68	7	75
Hemodialysis Unit	19	16	35
Humidifier	76	210	286
Incubator-Infant	0	68	68
Insufflator-Exsufflator	31	13	44
Irrigation-Distention System	44	0	44
Laser	59	9	68
Light source	426	123	549
Meter	2143	376	2519
Microscope	59	17	76
Monitor-patient	2462	2157	4619
Nebulizer	5	62	67
Nitric Oxide Delivery	13	42	55
Others	1005	341	1346
Patient Transfer Aid	80	0	80
Phototherapy	5	59	64
Positive Airway Pressure Unit	36	17	53
Pump-IV	2629	465	3094
Pump-Other	492	1193	1685
Recorder	147	62	209
Scale-Patient	180	124	304
Scanning Systems	156	56	212
Scope	487	148	635
Smoke Evacuation System	64	7	71
Surgical Tool	88	18	106
Tester	69	21	90
UPS	49	91	140
Ventilator	69	105	174
Warmer-Blood	164	34	198

Medical Device Category	SHC	LPCH	Total
Warmer-Patient	188	119	307
TOTAL	**14648**	**7372**	**22020**

The “Others” category includes devices that are few in numbers (~20 devices total or less), and/or are integrated systems that have multiple devices that can consume electricity separately (e.g., automated and integrated surgical system consisting of video display, probe, lighting system).

3.4 *Bed Inventories*

The electronic (rechargeable battery) hospital beds were counted separately from the medical equipment. SHC and LPCH had 548 and 137 beds, respectively.

3.5 *Power Consumption Measurements*

Our main objective was to quantify the aggregate power consumption of hospital medical devices. In addition to knowing what devices and how many of each device is present in the hospital, we also needed to measure the power consumption of a representative sample of devices. Ideally the power consumption measurements would be made during actual use of the devices. The power meters we used meet electrical safety standards but are not certified to a degree suitable to meet high patient safety requirements for use with devices providing a direct medical function. Either further internal safety testing or external safety certification would be needed to use these meters on devices providing medical care.

As a next best option, we collaborated with the biomedical engineering and clinical technologies (BME/CT) staff at SHC and LPCH to devise a methodology to measure the power consumption of medical devices during maintenance, calibration, and safety check procedures performed in various BME/CT shops in both SHC and LPCH. Each shop was provided with at least one time-series, data logging power meter[1] and a logbook for each meter. Technicians were asked to plug medical devices being serviced into a meter and record the date, time, specific information about the device (manufacturer, model, and description), and to check boxes indicating which power modes (charge, standby, and operation) the device was in during the metering period. Meters were configured to log power measurements in units of Watts and power factor values every ten seconds. Technicians were asked to make power measurements of devices for at least two minutes, which was often exceeded. Downloaded data were processed by averaging power measurements in each power mode for each device and noting the peak power measurement of each.

4 Results and Discussion

In all, power measurements of 130 individual medical devices were recorded representing 30 medical device categories (see Table 2). For the most part, technicians metered

[1] The WattsUp? PRO ES meters from Electronic Educational Devices were used in this study. http://www.wattsupmeters.com

devices that just happened to come in for maintenance. Toward the end of the metering campaign, we identified categories for which no measurements had been made and requested that BME/CT staff seek out and meter specific devices in these categories. While each medical device was clearly in an operating mode during the servicing/metering period, it was not clear if or when the device was in a standby mode. Time constraints prevented the technicians from going outside of their normal service and calibration procedures and intentionally putting devices in standby mode. Operating room technicians were provided with WattsUp meters, but participation was very low in these areas.

An initial concern about making power measurements during service procedures was that the devices would not be under the same load that they would be during actual use. Devices that operate with loads are put under simulated loads as part of their servicing and calibration procedures. For example, the output of a ventilator is fitted with different size flexible tubes to mimic the resistance of adult- and child-sized lungs.

The measurements provided valuable insight into the range of power consumed by devices in the same category and even among the same make and model of devices (see Figure 2). Ventilator-A and Ventilator-B are ventilators from two different manufacturers. The bars in Figure 2 are power measurements for different units in each manufacturer/model group, A and B. Manufacturer/model A ventilators had a wider range of operating power consumption than those of manufacturer/model B.

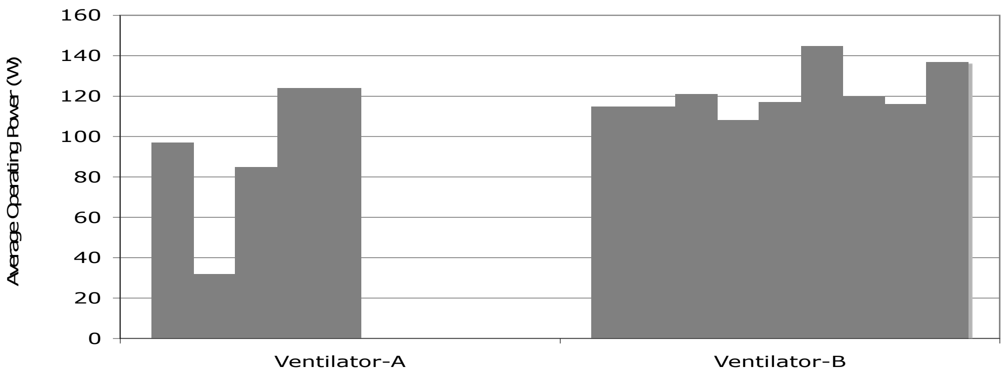

Figure 2. Average power measurements of two manufacturer's models of ventilators (A and B) showing the variation in A and the relative consistency in B.

4.1 *Comparisons of spot measurements to rated power*

Comparisons of actual device measurements with their rated powers were performed as part of the analysis. When possible, measurements for standby, normal operation, and peak power consumption were recorded. Table 2 below shows the device categories, the measurements, and their rated powers. In fairly broad terms, the rated power is in almost all cases higher than operating and peak power draw, but the magnitude of this difference depends on the category of equipment, and often varies from brand to brand.

Table 2. Measured and rated power by device category and specific brand/models in each.

Category	Spot measurements: standby, average, peak (W)	Rated power (W)
Airway Clearance	12, 233, 235	500
Anesthesia Unit	153, 302, 342	1440
Aspirator A	12, 20, 40	60
Aspirator B	NA, 115, 119	240
Autotransfusion	63,153, 75	NA
Bed A	20, 447, NA	NA
Bed B	30, 94, NA	NA
Circulatory Assist	NA, 4, 10	50
Computer-Infosys	NA, 24, 47	50
Defibrillator	NA, 29, 31	130
EEG	NA, 142, 143	NA
Exam Chair or Table	25, 150, 271	600
Exerciser	NA, 3, 6	NA
Hemodialysis Unit A	67, 87, 131	600
Hemodialysis Unit B	NA, 48, 51	NA
Hemodialysis Unit C	83, 504, 1574	1840
Humidifier A	12, 16, 147	185
Humidifier B	NA, 8, 10	NA
Humidifier C	NA, 40, 45	NA
Incubator-Infant	30, 308, 619	1035
Meter A	6, 16, 16	55
Meter B	NA, 7, 10	NA
Microscope	185, 602, 648	NA
Monitor-Patient A	8, 52, 53	145
Monitor-Patient B	2, 18, 19	NA
Monitor-Patient C	8, 38, 39	156
Monitor-Patient D	2, 5, 8	6
Monitor-Patient E	NA, 17, 17	161
Monitor-Patient F	NA, 49, 52	47
Monitor-Patient G	4, 37, 42	NA
Phototherapy	2, 42, 44	180
Positive Airway A	2, 126, 183	360
Pump A	NA, 8, 8	60
Pump B	NA, 193, 195	372
Pump C	7, 16, 18	14
Pump D	3, 41, 22	150
Pump E	NA, 15, 30	120
Pump F	NA, 57, 96	120
Scanning System	13, 945, 996	NA
Scopes	80, 250, 276	NA

Category	Spot measurements: standby, average, peak (W)	Rated power (W)
Smoke Evacuation	56, 876, 882	NA
Tester A	NA, 7, 7	NA
Tester B	168, 568, 1026	1920
Ventilator A	NA, 119, 207	NA
Ventilator B	NA, 58, 66	135
Ventilator C + UPS	NA, 35, 80	800
Ventilator D + UPS	71, 92, 194	800
Ventilator E + UPS	NA, 100, NA	800
Ventilator F + UPS	34, 164, 220	863
UPS	NA, 95, 109	660
Warmer-Lab A	1, 22, 94	NA
Warmer-Lab B	1, 19, 92	450
Warmer-Patient A	NA, 650, NA	792
Warmer-Patient B	46, 688, 826	1000
Water Purification A	4, 127, 272	570
Water Purification B	41, 132, 258	NA

4.2 *Impact of use of rated power in UEC estimation and hospital design*

The power measurements of medical devices show that rated power often exceeds measured operating power and measured peak power, as expected. This difference is often so large that using rated power as a proxy for measured operating power would lead to UEC errors in excess of a factor of two. This difference may also impact two major aspects of hospital facility design. First, the use of rated power for estimating cooling loads created by medical equipment plug loads may result in improperly sized and less than optimally efficient cooling system equipment. Second, receptacle electric service is required to be sized to satisfy a load representing all expected plug loads operating at rated power. With rated power often being significantly greater than typical operating mode power consumption, electric services may be wastefully oversized, although the safety aspect of this requirement does justify a conservative approach.

4.3 *Energy consumption of hospital MELs*

An estimate of the aggregate energy consumption of medical equipment can only be made with knowledge of the power levels a device uses in each mode and how much time each device spends in each of its power modes (e.g. off, standby, charging, and operation, see Figure 1).

For medical equipment, we have spot metered data of selected devices to provide power level information, but we have no direct measurements of time in each power mode. To indirectly estimate the time in each power mode of selected medical devices, two physicians were interviewed regarding typical use patterns, observations of power state when not in use, and standard hospital procedures. Estimated activity data are shown in Table 3. These estimates are rough because they are based on the activity pattern estimates of physicians rather than detailed measurements. These data are the best available at this time for the activity of non-imaging medical equipment in hospitals, however, and they provide a way to estimate the magnitude of energy used by these device categories. For other equipment (e.g. computers and MRI machines), we used power consumption and activity data collected in other MELs studies or from published reports. For the purposes of this analysis, the SUH and LPCH inventories are combined.

Table 3 Estimated fraction of devices in use and estimated fraction of time in power mode for selected device categories.

	% of Devices		% of Time in Mode for Used Devices		
Device Category	In Use	Not In Use	On	Low Power	Off
Infusion Pump	80%	20%	83%	0%	17%
Sphygmomanometer, Fixed	80%	20%	13%	0%	87%
Sphygmomanometer, Portable	80%	20%	2%	0%	98%
Pulse Oximeters, Portable	80%	20%	5%	0%	95%
Pulse Oximeters, Fixed	80%	20%	60%	20%	20%
Physiological Monitoring System	80%	20%	80%	0%	20%
Aspirators, Wound	80%	20%	10%	0%	90%
Defibrillator-Pacemakers, External	95%	5%	0%	100%	0%
Hemodialysis Unit	90%	10%	1%	24%	75%
Feeding Pump	80%	20%	90%	0%	10%
PCA Pump	80%	20%	0%	90%	10%

The activity data in Table 3 was combined with the spot power measurements in Table 2 according to the method shown in Figure 1. Table 4 shows estimated unit energy consumption (UEC) for metered devices, annual aggregate energy consumption (AEC) for that specific device make and model, an estimate for the AEC of makes and models not metered, and an estimate for the device category AEC. In addition, the annual unit standby energy consumption (USEC) is shown to highlight cases where the UEC is significantly made up of standby energy use. In MELs energy analysis, it is common to have measured data on just a subset of the devices of interest. Estimates of the energy parameters are made for similar devices that were not measured. In these cases, we used the most conservative standard technique for these devices, which is to use the lowest UEC in the category as the UEC estimate for devices not metered. We did not make estimates for any device categories for which we did not have measured power data or physician provided activity estimates.

Table 4 Estimated annual unit standby energy consumption (USEC), unit energy consumption (UEC), aggregate energy consumption (AEC) by device model, and AEC by device category for selected device categories.

Device Category		USEC (kWh)	UEC (kWh)	AEC by Model (kWh)	AEC by Category (kWh)
Aspirators, Wound	Model 1, Category Total	39	57	3,000	3,000
Defibrillator-pacemakers, external	Model 1	130	130	16,000	
	Est. of other models			7,400	
	Category Total				**23,000**
Feeding Pump	Model 1	6	130	15,000	
	Est. of other models			16,000	
	Category Total				**31,000**
Hemodialysis Unit	Model 1	170	200	3,300	
	Model 2	110	110	500	
	Model 3	170	180	1500	
	Category Total			**5,300**	**5,300**
Infusion Pump	Model 1 (multi)	4	110	3,200	
	Model 2 (multi)	4	120	14,000	
	Model3 (multi)	4	270	180,000	
	Model 4 (multi)	4	210	11,000	
	Est. of other mult-syringe models			5,400	
	Model 5 (single)	4	120	18,000	
	Est. of other single-syringe models			81,000	
	Category Total				**310,000**
PCA Pump	**Model 1, Category Total**	26	26	**3,200**	**3,200**
Physiological Monitoring System	Model 1	14	350	85,000	
	Model 2	9	140	30,000	
	Est. of other models			55,000	
	Category Total				**170,000**
Pulse Oximeters, fixed	**Category Total (Est)**	19	84	**53,000**	**53,000**
Pulse Oximeters, portable	Model 1	43	46	2,900	
	Est. of other models			2,100	
	Category Total				**5,000**
Sphygmomano-meter, fixed	Model 1	0	8	530	
	Est. of other models			5,600	
	Category Total				**6,100**

Some device categories in Table 4 consume large amounts of energy and some consume quite small amounts. This diversity in energy use and, in particular, the existence of large energy consuming categories suggests a need for more detailed information on the energy consumption of these smaller medical devices. Determining the aggregate energy use of all medical MELs in the hospital was not possible based on the data we collected, but it appears likely that hundreds of additional MWh (in addition to the hundreds of MWh shown) are consumed annually by other small medical devices for which we do not have complete data in our case study hospitals.

As the first comparison case for medical MELs energy use in the hospitals, we estimated the energy use of computers in the facilities. The time in mode percentages, 70% on, 25% low-power, and 5% off, are estimates based on Lawrence Berkeley National Laboratory's (LBNL's) commercial MELs research and the extended working hours of the hospital. The annual energy consumption of each device type has been estimated based on LBNL measured field data in commercial buildings and the values are presented in Table 5. Computers consume more energy than any single category of medical equipment in our small sample, but there are many medical MELs categories for which we have no data. Just the ten categories of medical devices for which we have estimates are about two-thirds of the computer total, and it is likely that small medical devices in aggregate consume far more than computers in a typical hospital.

Table 5. Computer inventory quantities and power consumption, and aggregate energy use estimates.

Device Type	Count	Average Operating (W)	Average Low-power (W)	Total Consumption (kWh/yr)
Low-profile Desktops	1927	65	3	780,000
Notebooks	579	40	2	140,000
Other	10	100	3	6,200
Total	**2516**			**930,000**

The second comparison case is to an MRI machine. MRI machines are often a primary subject of concern for medical equipment energy consumption because individual devices consume significant amounts of energy. Based on data collected by Koenigshofer et al. (2009), an example MRI consumes an estimated 270 MWh annually when considering both direct electricity use and chilled water use. In aggregate, infusion pumps in our example hospitals consume more energy, and this further highlights the need to address the energy use of small devices in hospitals.

5 Future Work

A major obstacle we encountered was not being able to meter medical device power consumption during actual use. The measurements of actual medical device power consumption that we made are informative, but the pattern of use of each type of device is key to understanding how to improve the energy performance of those devices. Being unable to install power meters in-line with the power cords of medical devices in the hospital prevented the measurement of critical activity data. We propose the creation of a non-intrusive current monitor that clamps onto a power cord and provides estimates of relative current levels in the cable. The key feature of this activity sensing method is that it would only touch the outside of the power cord and would not interfere with the function of the device. This sensing method appears to be the best method of acquiring usage pattern activity data of electrical devices in sensitive locations such as patient areas in hospitals.

Additional data needs to be gathered on the power consumption levels of similarly capable equipment. This will enable robust estimates of the energy savings opportunities available through efficient procurement practices in hospitals. Our study shows that the energy consumption of small equipment is important to consider, but we did not collect broad enough data on enough devices to suggest the savings opportunity available today.

6 Summary and Conclusions

Based on the general approach used for miscellaneous loads in other commercial buildings, we developed a framework for quantifying power and energy consumption rates of medical equipment and miscellaneous electrical loads in hospitals. We worked collaboratively with staff from Stanford University Hospitals and Clinics and the Lucille Packard Children's Hospital to identify, understand and overcome challenges in adapting techniques for equipment inventory, use and power consumption data collection in the hospital environment.

Tracking systems used to ensure regular maintenance and calibration of diagnostic and treatment devices were used to quantify the prevalence of these devices. We made the first estimates of annual unit energy consumption for small medical devices based on measured power levels and activity levels estimated by medical professionals. These estimates clearly show a need for more data on these devices' energy use and a new focus on improving their energy efficiency.

We identified barriers to direct equipment monitoring in hospitals. These include (1) concerns about placing any device (e.g. a logging power meter) in-line with the power supply to any device used for patient care, (2) the fact that many medical devices are mobile and moved frequently for use in different areas of the hospital, creating logistics issues with recovering any metering device, and (3) patient privacy concerns that increase the logistical costs of researchers gaining access to verify equipment inventories and install even non-invasive activity monitors.

Several alternative approaches were developed in an effort to obtain data on medical equipment energy use. We developed a protocol for hospital biomedical technicians to acquire data on power consumption during standby, operating and peak power modes. Data were obtained for roughly 130 individual devices covering roughly 30 device categories. We gathered time in power mode estimates by interviewing physicians on typical usage patterns of medical equipment in different hospital environments.

This work clearly shows that small medical devices in hospitals consume a significant amount of energy, but the total energy use of these devices is unknown and difficult to quantify. We observed that more than one manufacturer sells devices that perform nearly identical functions, and some devices consume less energy to provide a particular function than others. Therefore, it is likely that increased information on the energy use of small medical equipment could have a significant impact on hospital energy use by motivating efficient procurement specifications and, in turn, encouraging the manufacture of more efficient medical equipment.

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