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Report

Hospital Equipment and Energy Usage

Applied research by the Low Energy Hospitals Project, Norway

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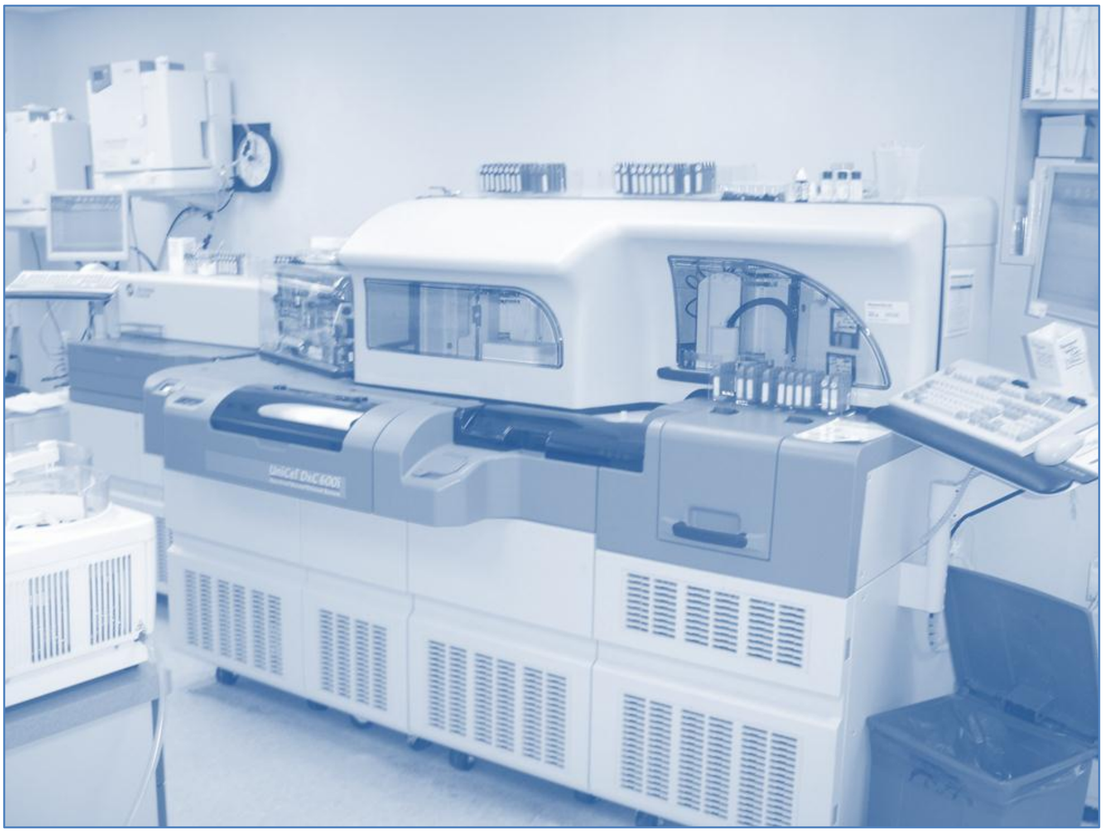

Report

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ABSTRACT

This project report describes how hospital users and their equipment affect the energy balance in hospitals, and suggests ways in which designers and equipment suppliers can help optimize energy performance while maintaining quality in the delivery of health services

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1 Background

The Low Energy Hospitals research project (2010- 2014) was funded by the Norwegian Research Council together with public and private sector partners. The project goal is to describe the ways in which future Norwegian hospitals could be designed for 50 % reduction in energy use, compared to recently completed hospitals. There are several ongoing Norwegian research projects studying how to make cold-climate buildings more energy-effective. These projects contribute to a growing body of valuable research on building envelopes and heating, ventilation and air-conditioning (HVAC) systems, but their research methods rely on a simplified view of user activity and user equipment. The Low Energy Hospital project concentrates only on hospitals, where energy-intensive user activity has a significant impact on whole-building energy performance.

User activity in schools and office buildings has well-understood consequences for artificial lighting and HVAC systems which maintain indoor climate comfort. In hospitals, it is the staff and patients use of equipment which places huge demands on electrical supply networks, chillers and ventilation. The physical construction of a hospital building and its HVAC systems is relatively well documented, but it is a more difficult task to get an overview of all equipment in a large, modern hospital and how this equipment is actually used.

This effort will hopefully fill some of the gaps in our understanding of how users and their equipment affect the energy balance in hospitals, and make it possible to suggest ways in which designers and equipment suppliers can help optimize energy performance while maintaining quality in the delivery of health services.

2 Why Study Equipment Energy Consumption?

Hospital designers and engineers are typically not aware of the energy demands and usage patterns related to most hospital equipment, with the exception of only a few large medical imaging units. Most other hospital-specific equipment is the domain of medical professionals, not engineers or architects. In large and complex hospitals, this lack of awareness can cause problems with sizing the electrical, heating and cooling needs, and missed opportunities for storing and recycling of waste heat. A literature survey in the first phase of the research project showed a large variation in assumptions about energy and power to lighting and equipment. Many designers were using standardized values borrowed from non-hospital building types.

One of very few initiatives we have found aimed at more energy effective equipment is from the NHS in England saying that; "In order to meet the energy saving targets, the NHS has therefore highlighted in its energy strategy that when making procurement decisions, consideration should be given to the energy performance of medical devices and equipment by taking into account whole life energy costs in contracts and purchases of new and replacement equipment."[1]

Analysis of energy data from the country's newest, large university teaching hospital in the Oslo area (Ahus) showed that electricity consumption was 163 kWh/m^2 per year. This represented almost 40 % of the whole-building energy use. Waste heat from the use of electrical energy in equipment must be removed from the room, leading to a large annual energy consumption of cooling energy, even in the cold Norwegian climate.[2]

[1] NHS Purchasing and supply agency, Protocol Energy efficiency assessment for electrical medical devices CEP08037 February 2009

[2] Robert Martinez1, Tarald Rohde2, Kåre Kallmyr1, Dag Horne1, Nina Høstvang Melby1 og Jon Vårdal1, Sidsel Jerkø2, Trond Thorgeir Harsem1, Energibruk i sykehus, status over energikrevende funksjonskrav og faktisk forbruk knyttet til bygg

There are few published articles dealing with electricity consumed by hospital equipment. Some of our many questions were: how much equipment is present in a hospital, how energy-intensive are they? Is the equipment being used in an energy-efficient way, and how can the equipment be designed or used for increased efficiency?

Recent studies have estimated a large potential for energy efficiency of user equipment in homes and offices. One study[3] of devices and equipment commonly used in U.S. homes and businesses, concludes that "these products, with more than 2 billion in use, consume more energy each year than many large countries use to power their entire economies", and "that these devices could be made to use 40–50 percent less energy with existing technology". In US the Northwest Energy Efficiency Alliance have, with the help of Betterbricks, produced equipment purchasing guidelines for hospitals.[4] In their Hospital energy benchmarking guidance, the Lawrence Berkeley National Laboratory concludes that facility size is the most important determinant when it comes to energy consumption, but also points to what they call miscellaneous equipment and plug loads as important energy consumers.[5]

In the US, the Energy Star logo certifies that equipment satisfies a level of energy-efficiency for products.[6] In Europe the similar EU Ecodesign[7] directive also regulates the energy performance of building equipment such as lighting, circulation pumps, ventilation fans and water heaters. The directive is now turning its attention to more specialized user equipment such as food-preparing equipment and office imaging equipment. It is not hard to imagine future Ecodesign rules for hospital autoclaves and diagnostic imaging equipment as well.

2.1 Trends in equipment energy use

There is one final reason to look more closely at equipment energy loads. Installed equipment energy density in kWh per m^2 is increasing due to increased processer capacity, more screens and screen area and advances in treatments which require new electrical diagnostic equipment.

Advances in the design building of building envelopes and HVAC systems are helping to reduce the yearly specific heat (in kWh/m2) lost through facades and ventilation exhaust. But the increased amount of waste heat from hospital equipment is, however, driving up the yearly specific mechanical cooling demand in core hospital areas. The combined effect of increased electrical consumption and increased cooling demand means that equipment has a very large impact on the whole-building energy accounting, even in cold climate hospitals." .

3 Classification of hospital equipment

Equipment is divided into four main categories in hospitals in Norway. They are:

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og utstyr og muligheter for energieffektivisering, Fra 1ste fase av prosjektet Halvering av energibruken i sykehus finansiert av Norges forskningsråd i samarbeid med prosjektets partnere, Norconsult 2011-11-21, 1:Norconsult, 2: SINTEF

[3] Sameer Kwatra, Jennifer Amann, and Harvey Sachs, Miscellaneous Energy Loads in Buildings, Research Report A133,American council for energy efficient economy, Washington, June 2013

[4] Betterbricks, The commercial initiative of the Northwest Energy Efficiency Alliance, Energy efficient equipment purchasing guidelines for hospitals – version 1 (updated January 2010)

[5] Singer, Brett C, Hospital Energy Benchmarking Guidance – Version 1.0, Lawrence Berkeley National Laboratory, LBNL Paper LBNL-2738E, 03-31-2010

[6] www.energystar.gov

[7] EC Commission Ecodesign Directive 2009/125/EC

- User equipment
- Building equipment
- ICT equipment (Information,computer, telecom)
- Furniture : this category is not in scope because it does not involve energy use) part of our analyses.

3.1 User equipment

User equipment is divided into medical technical equipment (MTE), and non-electrical surgical instruments household equipment and different sorts of trolleys used in operation theatres and laboratories. In terms of total number of units, most of the equipment other than MTE and household equipment does not use electricity.

In the sub-category MTE we find the category of medical imaging equipment (MIE) which includes equipment such as Magnet Resonance tomography imaging (MRI), Positron emission tomography (PET), Computer Tomography (CT), X-ray and fluoroscopes for diagnosis. These are large, expensive items housed in special rooms, usually with hookups for water cooling to supplement air cooling. In biochemical laboratories we also find large analyzing equipment.

The other sub-category of smaller medical technical equipment (sMTE) is a much longer and more varied list including monitors, analyzers and many therapeutic devices. These are smaller air-cooled equipment distributed in many rooms throughout the hospital. These devices have short startup times and draw much less power, but many of these units are in use throughout the day. sMTE devices constitute a large number in a large hospital. An ultrasound apparatus is strictly speaking an imaging device, but shares many of the characteristics of sMTE and is therefore grouped under this category.

3.2 Building equipment

Building equipment is typically autoclaves, decontaminators, washing machines, ventilated hoods, fume cupboards, safety cabinets etc.. Much of this equipment has traditionally been integrated in the buildings walls and floors, and integrated with the buildings HVAC systems such as heating supply and the ventilation ductwork for air exhaust.

3.3 ICT equipment

More and more MTE includes also ICT devices, but the category ICT equipment here is defined as freestanding computers, screens and servers in server rooms without direct clinical functions.

Server rooms are an especially large consumer of both electrical and cooling energy in modern hospitals. Reducing the energy use ICT equipment is an established research field and is not in focus for the equipment studied within the Low Energy Hospitals project. Heat recovery from server rooms is, however, an important theme when designing the hospital energy supply systems.

4 Method

The method used is gathering data from existing databases owned by the hospitals involved and the ICT responsible department of the South-East Health region. The databases have registered the different equipment types being studied and the floor area of the hospitals. With the data of floor areas we have the data of both net and gross area in m^2.

Some typical hospital-areas are chosen for more thorough studies to make the results relevant for most hospitals (chapter 6.2)

Registrations from each area are done by on-site personnel under guidance of research personell and by measuring the use of electricity in switchboards on the specific time, mid-week at 10-11 am.

To transform the results to hospital figures we have used earlier registrations at another hospital in South-East Health region.. This hospital is newer and has more possibilities to divide between electrical and thermal energy.

4.1 Data Collection and Analysis Methods

Three types of data were collected; equipment inventory, equipment usage, power and energy consumption.

4.2 Equipment inventory data

Detailed room-level equipment usage data for MTE were collected from the country's 500 bed national hospital (Rikshospitalet), now part of Oslo University hospital (OUS), via responses to questionnaires that were distributed to key-personnel. Equipment inventory data came from the hospital's database of all purchased medical-technical equipment (MTE). Data of autoclaves/decontaminators/ventilated benches (BE, so-called 'building equipment') were collected from the hospitals technical division. The data for desktop ICT equipment were delivered from the health regions unit responsible for ICT.

A total of 18, 700 electrical medical technical equipment (MTE) units were registered. The number of desktops and portable units, including screens, were 11, 400. In the category of building equipment (BE) there were 46 biological safety cabinets, 85 decontaminators and 17 autoclaves.

The equipment database showed the rooms where each item was located, and the room areas where also available. Excluded from the analysis due to lack of data were 'household equipment' like refrigerators and dishwashers. For each equipment type, the average power level in continuous use and in standby (where available) was determined based on the supplier's information. This analysis provided a picture of installed electrical equipment power.

Ultra freezers were not included in the survey. The reason is that these units must be turned on continually and not measureable.

4.3 Equipment usage data

Due to the size and complexity of a large university hospital, it was decided to focus our efforts on the following typical hospital-areas:

- The radiology department
- Operation 1 with 8 surgical units
- The ICU for the thorax department, 11 beds
- One bed ward, the Heart medicine department;
- The laboratory of biomedical chemistry
- The surgical outpatient and day treatment department.

The reason why we selected these departments is that these are typical areas in all large hospitals. We further assume that the use of equipment in these departments does not differ too much between hospitals. Results for the biomedical chemistry laboratory may be generalized for other hospitals, but cannot be applied to other laboratory types such as microbiology, pathology and immunology; these have different equipment and/or usage patterns.

Questionnaire answers from all the above departments helped to determine the actual inventory of medical equipment, how it is used and when it is used. For the questionnaire survey, the staff were asked to record usage levels for each of the equipment types in their department; was it running 24 hours 7 days a week, only daytime or to what extent was it used evenings, nights and weekends? They also answered questions on how the equipment was turned on/off; was it manually, automatically, did it go automatically to a stand by position or was it never turned off?

4.4 Equipment and department power and energy data

For each of the departments listed above, actual electrical power from the switchboard rooms were measured. This was done during the peak activity time in a hospital from about 10 am to noon. In the switchboard room of the biomedical chemist laboratory, the measurements were logged at 1 minute intervals for an entire week to compute corresponding energy use. Total hospital energy use data were collected from Akershus university hospital (Ahus) on the outskirts of Oslo.

Ideally, we would have preferred to have both energy data and the equipment data from the same hospital, but the older "Rikshospitalet" (the former national hospital) did not have detailed energy metering. To compensate and correct for this, we measured actual daytime electrical power levels in many of the treatment areas at "Rikshospitalet". Power levels to that hospital's ICT rooms were not available for measurement.

5 Results and analysis

The results are presented in the following paragraphs. First we present the number of equipment units and types registered for the hospital and for each department. Then we describe the profile of how the equipment is used and present the activity profile of each department during a day and a week. We then present the area of each department of which we have registered the use of energy at certain time of the day and for the biomedical laboratory a whole week. In the last paragraph we discuss what implication the use of equipment may have on heating/cooling demands and on ventilation air supply.

5.1 The departments analyzed

Professionals from each of the departments helped us register the usage activity of all their medical technical equipment; this was also a quality check on the initial equipment database. This cross-checking showed that some equipment that was no longer in use, was still in the database and also that some equipment in use were not registered.

For the Radiology department we chose two switchboard rooms in the east part of the department, covering most kinds of equipment except angiography. The two switchboard rooms in the surgical out-patient department covered that entire department.

The national hospital (Rikshospitalet) has three surgical units and one day-surgery unit. We measured electrical power to what is called surgical unit 1 serving the thorax, heart surgery, gastro surgery and transplantations. The two switchboard rooms covered the whole unit.

The ICU where we registered the usage pattern of their MTE was the thorax unit which has 11 beds. The switchboard room for that unit also covered the children's' surgical ICU.

The last unit studied was the biomedical chemist laboratory, and the switchboard room from which we measured electrical power covered about 2/3 of that department’s floor area. The university part of this area was not covered by our investigation.

Table 3 shows the area covered by each of the switchboards. The definition of net and gross area used in the table is described in the footnote at the bottom of the page.

Table 1 Area which the switchboard room covered[8]

Department	Switchboard room	Net area	Gross area
Radiology	D2.2901	921	1 457
Radiology	D3.2901	1 042	1 648
Surgical out-patient	D4.1901	1 350	2 136
Surgical out-patient	D4.1926	500	791
Surgical suits	D2.4901	1 014	1 604
Surgical suits	D2.4926	567	897
ICU	D1.4927 and D1.4926	650	1 028
Cardiology	C1.3901	771	1 163
Biochemical chemist	B2.2901	1 118	1 593

5.2 When is it activities in the departments analyzed?

An earlier report[9] from this research project concludes that the time of activity and the intensity of that activity varies a lot in a hospital. Most of the areas is in use during ordinary office hours for the five working days of a week. Only some areas is in full use 24 hours / 7 days a week. The project registered how many percent of the day staff that was on duty evenings, nights and in weekends.

Results showed that staffing levels at bed wards was reduced to 20/30 % in the evening and to 10/15 % at night. For radiology the evening shift was 18 % of the dayshift, at night it was close to zero and in the daytime on weekends it was 7 %. For the laboratory of medical biochemistry it is 7 % in evenings, 3 % at nights and 13 % on daytime in weekends.

Table 2 describes activity in terms of equipment usage. The usage pattern is similar to what was found looking at staff schedules, but with some important exceptions. In the laboratory of medical biochemistry as much as 40 % of the MTE is running 24/7. Laboratory equipment is left running unattended; probably to avoid delays with restarting and calibrating the equipment after it has been turned off. The percentages presented in table 2 for radiology are when the different radiology laboratory rooms are in use.

Table 2 When is the MTE in use, Medical biochemistry and Radiology, registration 2013

		Weekdays			Weekends		
	24/7	**Daytime**	**Afternoon**	**Night**	**Daytime**	**Afternoon**	**Night**
Medical biochemistry	40,2 %	38,50 %	10 %	10 %	2,10 %	0,80 %	0 %
Radiology	n.r.	93,50 %	25,80 %	22,60 %	38,70 %	25,80 %	3,20 %

The Cardiology ward runs 24/7 but the activity varies a lot. When patients are under constant monitoring, about 25 % of the related medical technical equipment (MTE) is used 24/7. At the time of responding to the questionnaire, the ward did not have any such patients, which explains why only 2-3 % of the MTE was is use. Under normal conditions, according to the answers, 24 % of the MTE is used in daytime, 10 % is seldom used and 13 % is hardly used at all.

n.r.: not reported

[8] Net area is functional area inside the rooms. Gross area is the whole departmental area including corridors, walls and technical rooms, but not shafts, intestinal floors and technical towers.

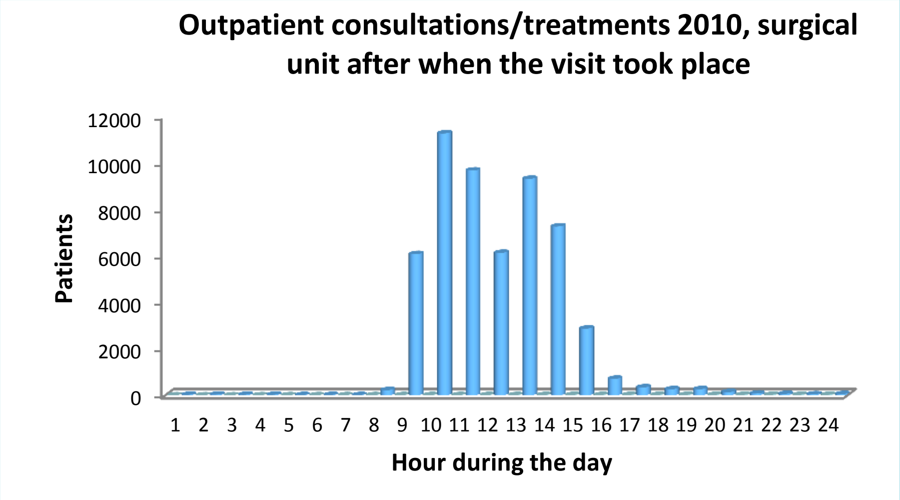
[9] Rohde, Tarald, Brukstid for areal i sykehus, SINTEF notat, 06.07.2011

The equipment in the surgical suites is active while the suite is used. The suites in this hospital have presence detection sensors, and analysis showed that over the course of one week (weekdays) the suites were used for 70 % during daytime afternoon, and 20 % were in use during night.

The ICU is running 24/7, but the activity varies. We visited the ICU to register activity and found that 4 of 11 beds were not in use, among them the isolation room, and they had only one respiratory patient. We were told that normally they had 260 day/night with ECMO[10] in a year. When we visited there were 3 infusion pumps in use, but they had capacity for up to 10 such pumps.

The ICU also had capability for 24-hour dialysis, so at the time of our visit the ICU equipment usage was probably below average. Beside each bed there is a column for equipment with 24 electrical sockets and on top of that an additional 6 sockets installed in the wall. This gives an indication of the electrical capacity,

Figure 1 describes the activity in the surgical out-patient clinic. The first patients arrive around 9 am, there is a peak in activity at 10/11 am and then activity falls quickly after 2 pm, and after 5 pm it is closed.**Figure 1 The activity during a day in a surgical out-patient department, 2010**



5.3 Number and type of equipment

Table 3 shows the vast number of equipment units, drawing electrical power or not, in a large teaching hospital. This hospital is a highly specialized university hospital, but we have not studied the university departments. This explains why the number of medical equipment units in the target departments for this study is low relative to the total number. Also, there are a lot of smaller equipment types that are centrally stored and not distributed to the different departments on a steady basis; infusion pumps are an example of this practice.

There are two kinds of equipment we have not registered: Ultra-freezers were not studied because we already know that they must run continuously. The other type of equipment not registered was common household equipment such as refrigerators, coffee machines, dish washers etc..

[10] Extracorporeal membrane oxygenation (commonly abbreviated ECMO) is an extracorporeal technique of providing both cardiac and respiratory support oxygen to patient.

Table 3 Number of equipment registered for the hospital and for the departments studied.

	All hospital	Departments studied	Studied as percent of all
Medical technical equipment	18 678	930	5,0 %
Decontaminators	295	85	28,8 %
Autoclaves	70	17	24,3 %
Ventilated benches	320	46	14,4 %
ICT	11 411	2 236	19,6 %

5.4 The user profile of the medical technical equipment (MTE)

With the help of personnel at the departments and at the Medical Technical department we collected usage data on the departments' MTE. The registrations were done on a weekday in the middle of the day. The result is presented in table 4.

In the operation department it is equipment in the surgical suites that was registered. Stainless steel trollies, tables and surgical equipment are part of MTE, even though they do not use electrical energy; that is why the total number of equipment units is so high. That also explains the high percentage of this kind of equipment in the radiology department. Most equipment using energy in the surgical suites are turned on when the suit is in use. In paragraph 6.2 we discussed the activity profile of the departments we have studied.

Cardiology is a ward which,in some periods, monitor patients around the clock. Most of their MTE is oriented towards that kind of patients, but at the time of data collection they had no such patients. Most wards are a place for patients waiting for investigations and treatments done elsewhere in the hospital. Then we must explain why measurements showed relatively high use of electric energy on the ward, compared with treatment parts of a hospital[11]. One likely explanation is the amount and intensity of "household" activities demanding electrical energy on these wards. At the National Hospital they serve hot food to the patients from specialized serving trays keeping the food warm. In addition they have the traditional ward kitchen with industrial type refrigerators, dishwasher, coffee machines and the like, and of course ICT equipment, copy machines and TV-like monitors.

It is also interesting to see that the use of MTE in the ICU ward was quite low. The reason for that we have already discussed. At the time we registered they had only one patient on respiratory equipment and four of eleven beds were not in use. So even in a unit you would expect was running close to full capacity 24/7, there will be a great range in electrical equipment usage from an average day to a peak day.

The low usage-percentages of MTE in the outpatient department are as expected. Different patients will need different examinations and treatments, and as a result they will be directed to different rooms with different equipment. Even in a hospital with national duties, the patient population is not big enough to use most of the available and varied equipment types at the same time. This result highlights the importance of powering down unused equipment for energy efficiency in this area.

The rate of MTE in active use is higher in the radiology department. Even higher usage levels were recorded in the laboratory for medical biochemistry. Here the activity in daytime resembles that of an industrial production line. The table 4 describes great differences between the different types of departments as to how the MTE is used.

[11] Data collection recorded at Akershus University (“Ahus”)hospital in 2012

Table 4 The use of medical technical equipment in six departments at the National hospital in Oslo, 2013.

	Surgical outpatient department	ICU, thorax	Cardiology ward	Radiology	Lab: medical biochem.	Operation dept - thorax
Equipment in use	24,5 %	32,3 %	2,6 %	51,5 %	76,2 %	
Turns off manually after use	93,1 %	1,6 %	68,4 %	29,9 %	30,1 %	
Turns off automatically	2,0 %	0,0 %	0,0 %	7,2 %	2,9 %	
Turns to stand by	0,0 %	17,7 %	0,0 %	14,2 %	15,1 %	
On battery, loading	4,9 %	9,7 %	18,4 %	0,9 %	0,4 %	6,5 %
Must always be turned on	0,0 %	19,4 %	0,0 %	1,5 %	39,3 %	3,2 %
Not using energy	0,0 %	1,6 %	0,0 %	63,1 %	0,0 %	45,2 %
Runs 24 hours 7 days a week	0,0 %	1,6 %		0,0 %	40,2 %	
Component of other equipment		14,5 %		7,9 %		

Table 4 shows the difficulty in recording the ways in which different equipment types are turned off. The sum of different ways of doing that should be 100 % and are not, particularly not for the ICU. The reason is that some answers are connected to the equipment used at the time of registration. The main conclusion is that equipment must still be turned off manually by the users. Almost no equipment is turned off automatically after a specific time of not being in activity, and only a very small portion has a “standby” mode.

Particularly for the ICU and the medical biochemistry laboratory, a large portion of the equipment is reported as must be turned on 24/7. For radiology this percentage is low, reflecting the reality that most of their large equipment seldom is turned off. The reason for that is the time it takes to prepare the equipment for active use.

5.5 Electrical power to hospital areas

Measured electrical power, at weekday at peak activity time (10 AM), is shown in the table 5 in terms of specific power per m^2. The area definition includes corridor but not technical area such as shafts or technical rooms. These results confirm the large electrical and heating load caused by equipment. Another interesting result is that full area lighting consumes less than one-third of the power to equipment on an average day. This is in contrast to the standard values used by the country’s building energy codes[12], which has power consumption for lighting in working hours the same as for equipment.

[12] NS3031:2011 table A2

Table 5 Power intensity in W/m² based on measurement done in our selected departments

Switchboard number	Room number	Department	Equipment W/m²	Light W/m²	SUM W/m²	SUM without imaging eqpt W/m²
D202	D2.2901	Radiology	20	12	32	24
D203	D3.2901	Radiology	101	8	109	18
D104	D4.1901	Outpatient surgical	12	13	25	25
D108	D4.1926	Outpatient surgical	23	18	41	41
D406	D2.4926	Surgical suites west	32	8	41	41
D405	D1.4926	ICU	18	7	25	25
D402	D2.4901	Surgical suites east	51	13	64	64
C301	C1.3901a	Cardiology ward	12	8	20	20
B202	B2.2901a	Biochemical chemistry	36*	9	45	45
All			**35**	**10**	**47**	**33**

* *Combined light and equipment measured at 45 k, and split here using data from related areas*

Power readings at 1 minute intervals in the lab area were used to calculate energy use during a typical full week (7 days), which were then extrapolated to an entire year and divided by floor space.

The result shows the high energy intensity of equipment and lighting in this area, 356 kWh/m².

Table 6 Energy used in medical biochemistry laboratory, one week 2014, switchboard room B2.2901a

Circuit	kW (avg.)	kWh/year	kWh/(m² year)
Priority equipment and lighting	15	129 549	116
Low priority equipment and lighting	20	170 966	153
Equipment on UPS circuit*	11	97 162	87
SUM	**46**	**397 676**	**356**

* *Datalogger error ; estimate is based on power measurements over a shorter period.*

Measured energy in Table 6 is about 50% higher than that which can be calculated based on the users information about equipment usage and the momentary power readings. One possible explanation is that lighting in this area is on nearly continuously and not energy efficient. Lighting could not be measured separately on this switchboard.

Based on measured power and reported usage patterns for equipment in the studied department areas, we can make a rough estimate of the daytime energy intensity of equipment at about 90 kWh/m².The energy intensity for entire hospital area including normal bed wards will be somewhat lower; it should be the goal of further study to investigate power intensity in normal bed wards and other areas.

As a comparison, Norway's building code uses a standard figure of only 47 kWh/m^2 for evaluating energy consumption in hospitals.[13] This figure is low, at least for the areas in question, and yet is still being used by some hospital planners and designers in preliminary estimates.

In Scandinavia, Swedish hospitals are probably the most energy efficient, but compared to US west coast hospitals all Scandinavian hospitals are very energy efficient, using close to half the energy per square meter as hospitals in the northwest of US[14]. It is therefore a challenge to reduce energy use further without affecting healthcare service quality.

If one were to include electricity to pumps and fans, estimated at least 40 kWh/m^2, then we see that only electrical energy intensity for laboratory areas can reach 400 kWh/m^2.

5.6 Analysis of electrical energy consumption to small MTE

Analysis of energy consumption data from the country's newest, large university teaching hospital in the Oslo area (Ahus) showed that electricity consumption was 163 kWh/m^2 per year. This represented almost 40 % of the whole-building energy use. Splitting up the electrical energy in one of the studied hospitals, we estimated that artifical lighting accounted for 35 % of this electrical energy, 20% went to pumps and fans accounted for 20%, and the remaining hospital equipment accounted for 45%..

A 2009 study from the USA estimates that between 20 and 25% of a given facility's overall (electrical) load is due to medical equipment.[15] This lower proportion reflects American hospitals greater overall electrical load due to air conditioning. Another American study estimated that equipment "plug loads", or devices plugged into wall outlets, accounted for 6 to 18 percent of total energy use in hospitals.[16]

A study[17] from the UK showed that medical equipment uses only 17 kWh/m^2 based on total hospital area, out of a total electrical supply of 155 kWh/m^2.

Smaller MTE such as console-based ultrasound apparatus have typical yearly energy consumption of about 1600 kWh each, but there are often more than 20 such units in a central hospital, giving a total yearly consumption which is comparable to a typical CT device. Patient monitors, laboratory analysers, chromatographs, centrifuges, incubators, dialysis devices, localized patient heating devices etc. have various power levels and usage patterns drawing an estimated average of about 0,3 kW each for an estimated 5000 hrs/year, but with only a 50% recycling of waste heat from inefficient water-circuit heat recovery units.

5.7 Electrical power and energy to large medical imaging equipment (MIE)

Large medical imaging equipment (MIE) includes equipment such as Magnet Resonance tomography imaging (MRI), Positron emission tomography (PET), Computer Tomography (CT), X-ray and fluoroscopes for diagnosis.

The Radiology department studied at the national hospital has several large imaging units with high power ratings. At the time of our measurement, the MIE in the area served by switchboard D3.2901 consumed 95 kW (CT+MR), for an area of 1042 m^2. The calculated energy intensity for MIE is therefore 91 W/m^2. This figure is close to that stated by the Green Guide to Healthcare (USA), a

[13] Norwegian Standard NS3031:2011, table A.1

[14] Burpee, Heather; McDade, Erin; Comparative Analysis of Hospital Energy Use - Final Draft Report, Academy of Architecture for Health Foundation, University of Washington, 2013-02-04

[15] Healthcare Design 9/28/2009

[16] Consortium for Energy Efficiency. "Commercial Building Performance: Healthcare Facilities." 2005. Available at http://www.cee1.org/com/bldgs/hc-fs.pdf.

[17] Healthcare energy targets - Healthcare engineering, IMechE 2003, using DETR data from 1999)

LEED-based certification tool, in which imaging process loads are estimated at 86 W/m^2 based on only the treatment area where the equipment is located.

Data on energy consuming by medical imaging equipment from another, but smaller teaching hospital in the Oslo area (Ahus) showed direct annual electrical energy consumption of about 520 000 kWh/year. Indirect cooling utility consumption means that total energy is approximately 625 000 kWh/year assuming 80% recycling of waste heat. The hospital area is 120 000 m^2 which puts total specific energy consumption for large MIE at about 5,2 kWh/m^2 , based on total hospital area.

Full and standby power drawn by large medical imaging equipment was studied and published[18] by the authors earlier in the project. Siemens Healthcare, one of the research project partners, assisted with high resolution power measurements on a range of their own equipment. The results from that investigation showed a high standby power level, especially for the MR machine. It has a maximum power of 40 to 45 kW during the procedure, and in standby mode the power is approximately 17 kW. During night-time when the MR equipment is turned down to the lowest possible level it is still using almost 20% of maximum power, in our case the machine consumed 9 kW.

5.8 Cooling and ventilation demand

Waste heat only from equipment on a typical workday morning, amounts to 35 W/m^2 on average for these areas. Lighting adds another 10-11 W/m^2. These areas are usually not placed along the periphery of the building, which means that only a small fraction of the 47 W/m^2 will be lost through the building envelope. The remaining 40-45 W/m^2 must be cooled by a combination of ventilation and local room cooling units, all year round. This cooling utility energy must therefore be added to the direct electrical energy consumed by medical equipment to estimate the true energy and climate footprint of all MTE, large and small.

It is important to pinpoint that peak equipment loads will of course be higher than this, and must be combined with loads from sunlight and persons in the room before calculating maximum summer cooling demand

6 Recommendations for Hospital Designers, Equipment Suppliers and hospital employees

6.1 Hospital designers

This study shows that standard values in the buildings codes for calculating energy performance are much lower than actual values, at least for the treatment areas of large modern hospitals. Designers are therefore urged to use different power and energy intensity values, depending on the hospital area. They are also urged to make use of the room equipment database to further refine their sizing for HVAC cooling.

Designers of HVAC technical systems should strive to recycle as much as possible of the waste heat generated by medical equipment. The percentage of waste heat which may be recycled for use in other parts of the building or in domestic hot water heating depends on the design of the heating- and cooling system, and also on the location of the particular medical equipment. Water cooled devices have higher recycling rate, as condenser heat from the ice-water chiller can be easily routed to other applications. The Low Energy Hospital has newly published guidelines for heat-pump designs which optimize energy production by moving heat between areas, and by enabling seasonal storage of excess heat in boreholes, a big advantage for cold climate hospitals. Design rules of thumb and potential

[18] IFHE Conference Paper June 2011, “Medical Equipment and Trends in Energy Consumption” , Martinez et al.

energy benefits for hospitals using seasonal energy storage are described in the author's paper[19] for the ASHRAE Cold Climate Conference in 2012.

Waste heat removed by air-cooling is more difficult to control and recycle. Best practice for ventilation air heat recycling in most building types is with rotating heat wheels, which allow up to 85% heat recovery. This technology, however, allows some leakage of exhaust air and moisture into the incoming air stream and therefore cannot be applied in areas of a hospital where there is a contamination risk. For such areas one must use other methods with lower recycling rates, from 50% to 70% depending on the application.

The Low Energy Hospital has newly published guidelines for which areas can safely use high efficiency rotating heat wheels.

Hospital planners and architects should consider grouping of medical equipment wherever possible to allow more effective, enclosed air-cooling design. Phase Change Materials (PCM) are a promising innovation which can absorb heat emitted from air-cooled large MIE and thus avoid shock cooling demands to such rooms.

6.2 Recommendations for equipment suppliers

Our measurements suggest that large medical imaging equipment (MIE) accounts for less than half of the energy consumption related to all medical equipment in acute hospitals, and a much smaller percentage when all hospital types are considered. The relatively lower share of energy consumption for large medical imaging equipment is due to the fewer number of devices, more limited duty schedules, and higher heat recycling rates due to water cooling systems

Still, energy to MIE is significant, and further research is recommended for suppliers of large imaging devices to reduce scan times, lower standby power level, introduce hibernate functionality, shorten start-up times, and expanded use of water cooling instead of air cooling. Suppliers of smaller medical equipment should implement energy-saving measures for the ICT components in their devices, especially power-save modes for screens. Functions which can be handled by networked ICT devices such as printing should be decoupled from the medical equipment.

Both Siemens and GE Healthcare, two of the largest suppliers of equipment in this category, have stated goals for energy efficiency improvements. GE has previously committed to reducing energy consumption of new ultrasound products by 25 percent by 2012[20], and they have also set up projects working for equipment energy efficiency.[21]

On the other end of equipment complexity, there are many household items in hospitals which can be made more energy effective, especially dishwashers and other hot water devices.

6.3 Recommendations for hospital employees

6.3.1 Buying equipment

The majority of large medical imaging equipment (MIE) devices are in use only during day time, at most during a period lasting 10-14 hours per day, With few exceptions (MR), these devices can be entirely powered off outside of standby hours, but tend to have long start up times which restrict this energy-saving practice.

[19] Balancing Act - Using Hybrid Heat Sources to Avoid Permafrost and Optimize Heat Pump Systems in Cold Climate Hospitals, Martinez et al, ASHRAE 2012.

[20] GE - Press-Releases - GE Healthcare and Medical Device Industry Commit to Reducing Energy Use of Ultrasound Products.htm

[21] Medical and process equipment efficiency, Pilot Credit 3. LEED Pilot Credit Library, July 2010, A Prescription For Energy Efficiency.htm

Green procurement practices and energy certifications such as BREEAM and LEED should be more demanding of the energy performance, especially on standby power, of medical equipment.

It is especially important for procurement specifications to call for “power management” functionality in all equipment which draws more than 100 W. This functionality should include standby mode, hibernate mode, fast start up, auto screen shutoff, screen dimming. Buyers should look for models with this functionality, and should ask for the highest Ecodesign energy mark for equipment in those categories.

High power consumption of medical equipment incurs hidden investment costs which are typically not accounted for in lifecycle analysis. Larger dimensions for transformers, uninterruptible power supply and other components of the in-house electrical network are additional costs which can be eliminated with lower-power specifications. This aspect is not elaborated upon in this paper, but should be kept in mind when facing investment decisions.

6.3.2 Using equipment

Hospital administrators can consider energy monitoring systems (EMS), tied to the central building automation system (BAS) for medical equipment, and establish good energy management practices, with clear accountability and support from top hospital administration. A modern EMS will provide important energy alarms and job order follow-up functions to help technical staff control energy usage without it being an additional burden.

Automatically timed electrical power circuits for non-critical equipment should be introduced, starting in laboratory areas. Automation of electrical sockets, marked with separate colour and with LED status indicator, can provide great savings in many areas.

Another suggestion is to establish hierarchy where equipment such as printers which are subordinate to other main equipment will be powered down when the main device is powered down.

Finally, it is important that buyers specify, designers build, and staff use many more low-level energy meters, especially energy meters down at the switchboard level.

One interesting result of our investigation was that apart from the large equipment in the radiology department and in the medical biochemistry laboratory, most of the MTE that could be manually turned off was, in fact, turned off when not in use. The ICT equipment, however, was not generally turned off when not in use.

7 Conclusions and suggestions for further research

The main conclusions from this study are:

- Equipment in hospitals is a major contributor to whole-building energy consumption; real energy use is much greater than standard values recommended in the building codes for energy calculation, at least in Norway.

- Equipment usage patterns, outside of lab areas, shows great variability between night/day and weekday/weekend.

- Staff generally turn off MTE equipment when not in active use. But MTE with long startup time is generally not turned off, and these units have also high standby power levels as well.

- Newer hospitals such as the national hospital (Rikshospitalet) have very few occupancy sensors apart from inside the operation theatres. This limits the design potential of demand control for lighting, heating/cooling and ventilation energy.

- The electrical network architecture does not adequately separate loads for lighting equipment, making it difficult to monitor and control energy use.

It should be possible to reduce the energy consumptions considerably without compromising patient treatment or safety. The main recommendations for improved energy efficiency are:

- Equipment purchasing is focused on price, functionality and service costs, but not energy; this should be a criteria used in Lifecycle Cost calculations prior to purchasing. It is especially important for procurement specifications to call for "power management" functionality in all equipment which draws more than 100 W.

- Hospital planners and architects should consider grouping of medical equipment wherever possible to allow more effective, enclosed air-cooling design

- MTE purchasing databases contain much information about the equipment (vendor, when bought, the connection to other equipment, where placed etc) , but this information cannot be directly used for optimal design of the HVAC systems. The potential of using this database as a tool for optimal design should be investigated.

This study was difficult to accomplish, with relatively few existing references; we consider our study as a starting point for more work on energy use of equipment in hospitals.

- It should be the goal of further study to investigate power intensity in normal bed wards and other areas.

7.1 Hospital equipment energy in a wider perspective

In a wider perspective, even high-power medical equipment can give a net overall energy benefit if early diagnosis reduces the length and complexity of a patient's later treatment.

Digital systems which replace older analogue devices save water previously used in film processing and hence lifecycle energy.

Telemedicine technology in particular shows promise for reducing transport energy costs.

These aspects are difficult to quantify but should also be considered when evaluating lifecycle costs of medical equipment.

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