CHALMERS

Energy Use in Hospital Wards

An Analysis based on Activity Related Key Performance Indicators

Master of Science Thesis in the Master's Programme Structural Engineering and Building Performance Design

JIMMY LYCKE

Department of Energy and Environment
Division of Building Services Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2012
Master's Thesis E2012:02

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ABSTRACT

The discussions about energy use have increased year by year everywhere in the society, and so also in the healthcare sector. But what is actually energy use in a hospital facility, and what affects it?

The typical way today to express the energy use is in kWh/m^2. The problem with a key performance indicator that is expressed as energy use in relation to a specific area is that it does not take into account the activity in the building. Even though the activity to a very high extent affects the energy use. The purpose with this project has been to analyse the variation between three different hospital wards with regard to the electric power of the equipment and the energy use. The aim has been to point out the need of including the activity when discussing energy use in hospital facilities.

This project has been carried out with a study of previous analyses within the field, an inventory of three hospital wards, interviews and discussions with experienced persons in the field. Persons like: the employees in the analysed wards, the department responsible for the medical technical equipment in the hospital and consultants and contractors with experience from design of hospitals.

The results show that independent on type of hospital ward, lighting and office equipment stand for a large amount of the energy use. Furthermore, when it comes to moderate and high technical intense hospital wards, also the medical technical equipment significantly affects the total energy use of the hospital. The conclusion that has been drawn is that it is not most optimal to discuss energy use of hospital facilities in terms of kWh/m^2; in some way the activity must be included.

Key words: Energy use, Medical technical equipment, Key performance indicators

Energianvändning i sjukhuslokaler
Analys baserad på verksamhetsrelaterade nyckeltal

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SAMMANFATTNING

Diskussionen kring energianvändning ökar år efter år i hela samhället, och likaså inom sjukvårdssektorn. Vad innebär egentligen konceptet energianvändning i ett sjukhus, och vad påverkar det?

Idag används allt som oftast enheten kWh/m^2 när energianvändningen skall beskrivas. Problemet med ett nyckeltal som endast uttrycker energianvändningen i relation till en specifik area är att verksamheten inte inkluderas på något vis. Detta trots att det är verksamheten i byggnaden som till stor del avgör omfattningen på energianvändningen. Syftet med projektet har varit att analysera variationen mellan tre olika sjukvårdsavdelningar med avseende på elektrisk effekt av använd utrustning samt dess påverkan på energianvändningen. Målet har varit att påvisa att det finns ett behov av att använda någon form av verksamhetsrelaterat nyckeltal för att uttrycka energianvändningen.

Projektet har baserats på studier av tidigare analyser inom området, en inventering av tre olika sjukhusavdelningar, intervjuer samt diskussioner med inom området sakkunniga personer. Personer med teknisk kompetens på sjukhusavdelningarna, avdelningen som ansvarar för den medicinsktekniska utrustningen på sjukhuset, konsulter och beställare med erfarenhet från sjukhusprojektering.

Resultatet visade på att oberoende av intensiteten av medicinskteknisk utrustning inom avdelningen så står belysning och kontorsutrustning för en betydande del av energianvändningen. För avdelningar med medelhög samt hög intensitet av medicinskteknisk utrustning så påverkar även den medicinsktekniska utrustningen energianvändningen avsevärd. Den slutsats som kunde bli dragen är att det inte är optimalt att diskutera energianvändning med nyckeltal i termer om kWh/m^2, utan verksamheten måste på ett eller annat sätt bli inkluderat då energianvändningen redovisas.

Nyckelord: Energianvändning, Medicinskteknisk utrustning, Nyckeltal

Contents

ABSTRACT I
SAMMANFATTNING II
CONTENTS III
PREFACE V
NOTATIONS VI

1 INTRODUCTION 1
- 1.1 Background 1
- 1.2 General aim 1
- 1.3 Method 2
- 1.4 Disposition of the thesis 2

2 THE CONCEPT OF ENERGY IN THE HEALTHCARE SECTOR 4
- 2.1 Definition of the activity in different hospital wards 4
  - 2.1.1 Definition of the activity in a low technical intense hospital ward 4
  - 2.1.2 Definition of the activity in a moderate technical intense hospital ward 6
  - 2.1.3 Definition of the activity in a high technical intense hospital ward 7
- 2.2 Indoor climate requirements in hospitals 9
  - 2.2.1 Requirements on the working environment in hospitals 10
  - 2.2.2 Requirements on air distribution systems in hospitals 10
  - 2.2.3 Requirements on heating and cooling systems in hospitals 11
  - 2.2.4 Requirements on water systems in hospitals 11
- 2.3 Previous analyses of the electric energy use in the healthcare sector 12
  - 2.3.1 Analysis of the electric energy use in hospitals 12
  - 2.3.2 Analysis of the cooling power in hospital wards 19
  - 2.3.3 Comments to previous analyses of the electric energy use in the healthcare sector 20
- 2.4 Experience from contractors and consultants regarding the concept of electric energy 21
  - 2.4.1 Experience regarding design of cooling systems in hospitals 21
  - 2.4.2 Experience regarding energy efficiency in hospitals 22

3 THE CONCEPT OF KEY PERFORMANCE INDICATOR 23
- 3.1 Key performance indicators related to the energy use 23
  - 3.1.1 Key performance indicators used at system level 25
  - 3.1.2 Key performance indicators used for the entire building 26
  - 3.1.3 Utilisation factor and utilisation time 28
  - 3.1.4 Factors that affects the energy use and should be included in a key performance indicator 29
- 3.2 Key performance indicators used in the healthcare sector 30

4 FIELD ANALYSIS OF HOSPITAL WARDS 31
4.1 Field analysis of a low technical intense hospital ward 31
4.2 Field analysis of a moderate technical intense hospital ward 34
4.3 Field analysis of a high technical intense hospital ward 36
4.4 Electric energy use in the analysed hospital wards 38

5 DISCUSSION AND CONCLUSIONS 41
5.1 Discussion 41
5.2 Recommendations regarding activity related key performance indicators 47
5.3 Conclusions 48
5.4 Suggestions of further investigations 48

6 REFERENCES 50

Preface

This thesis represents the final part of the Master's programme *Structural Engineering and Building Performance design* at Chalmers University of Technology in Gothenburg, Sweden. The project was carried out during the autumn 2011 at the Department of Energy and Environment at Chalmers University of Technology.

I would like to express my appreciation to all persons and companies involved in making this master's thesis possible. I am truly tankful for having the possibility to perform interviews, discussions and inventories. Moreover, for all the help I got with technical data of medical technical equipment. An appreciation to:

- All the involved employees at the analysed wards at Sahlgrenska University Hospital
- Christina Ekeroth, responsible for the medical technical equipment at the surgery ward at Sahlgrenska University Hospital
- Peter Thyberg, at the department responsible for all the medical technical equipment at Sahlgrenska University Hospital
- Sara Eriksson, Environmental Officer at the Environmental Secretariat in the region of Västra Götaland
- Hans Bjurbäck, Technical Property Manager at the department of HVAC and Energy at Västfastigheter, Göteborg
- Knut-Olof Lagerkvist, Business Development Manager at Västfastigheter, Göteborg
- Carl Martin, consultant at SWECO, Göteborg
- Rasmus Cagner, consultant at ÅF, Göteborg

Furthermore, I would like to express an extra appreciation to my supervisor and examiner at Chalmers University of Technology, Jan Gustén for all guidance and help during the project.

Göteborg, 2011-12-30

Jimmy Lycke

Notations

Roman upper case latters		Unit
A	Area	m^2
ATF	Air Transport Factor	kW / kW
Q	Annual heat energy	$kWh / year$
$\dot{Q}$	Heat power	kW
SFP	Specific Fan Power	$\frac{kW}{m^3/s}$
$SFPI$	Specific Fan Power for the Individual fan	$\frac{kW}{m^3/s}$
$\dot{V}$	Volume airflow	m^3/s
W_t	Annual electric energy	$kWh / year$
$\dot{W}_t$	Electric power	kW

Roman lower case letters		Unit
c_p	Specific heat capacity	$\frac{kJ}{kg/K}$
p	Pressure	Pa
q	Specific (on X) annual heat energy	$(kWh / year) / X$
$\dot{q}$	Specific (on X) heat power	kW / X
t	Temperature	$°C$
w_t	Specific (on X) annual electric energy	$(kWh / year) / X$
$\dot{w}_t$	Specific (on X) electric power	kW / X

Greek letters		Unit
η	Efficiency	$-$
ρ	Density	kg / m^3
τ	Time	$hours$
υ	Utilisation factor	$-$

1 Introduction

In this chapter an introduction to the project with its background and the general aims are presented. Also a presentation of the method that has been used to carry out this project is to be found in the late part of the chapter.

1.1 Background

No one could have missed all the discussions about energy efficiency, and that we must reduce the energy use in our buildings. The European Union decided in 2010 that the member countries until 2020 should reduce their total energy use by 20% compared to the 1995's energy use (Statens energimyndighet, 2011). In 2050 the reduction should be 50%. This work already has started in the healthcare sector (Västra Götalandsregionen, Sustainable Healthcare, 2011), but the issue is, what is actually energy use in hospitals, and what affects it?

Key performance indicators are used for different reasons in different contexts. In economical aspects it is maybe more known as financial ratio, and is often used in accounting to evaluate the economical condition of an organization (Nationalencyklopedin, 2011). It is also used in non-economical situations for instance to evaluate the number of working hours spent per produced product, the utilisation ratio of a machine in a factory or the energy use in buildings. Overall, the main reason of using a key performance indicator is to get an indicator of how efficient for instance a process, system or device is. A key performance indicator can for instance be used as a base when evaluating different alternatives for further investments or to evaluate how the energy use of a certain building stands in comparison to other similar buildings. It is of large importance that the key performance indicator is easy to use and that its content is simple to understand. Furthermore, it is very important to understand in what context a certain key performance indicator should be used.

Today when it comes to energy use in buildings, the typical way to express it is as kWh/m^2. The problem in many cases is that this key performance indicator does not take into account the activity in the building, which in a very high degree affects the energy use in the building. Obvious, if the operating time of the building increases, the energy use increases. If a building consists of an activity using large amount of equipment with high electric power and high utilisation time it uses more energy than a building with another activity that uses less equipment. Therefore, a key performance indicator that only takes into account the building area is not the most preferable.

1.2 General aim

The aim with this project was to analyse the difference in electric power from equipment used in three different kinds of hospital wards, one low technical intense, one moderate technical intense and one high technical intense. Also to analyse how the difference in medical technical equipment, both in terms of amount and in terms of utilisation time, affects the energy use within the wards, regarding the electric energy use and the energy use of the indoor climate system.

The results are in the very end used to point out the importance of including the type of activity in the building when discussing energy use.

1.3 Method

This thesis has been carried out with literature studies, field studies and discussion with consultants, contractors, different departments within the hospital and the department responsible for the technical equipment at the hospital.

First, literature studies have been carried out to identify what key performance indicators that are available and used today both regarding energy use, electric power and in the healthcare sector. Also a study of previous analyses of the energy use in hospital wards has been carried out.

The field studies were performed to analyse how much technical equipment that are used within three different hospital wards depending on the technical intensity of the ward. The analysis was performed in a general practise ward, a dialysis ward and a surgery ward. The study consisted of an inventory of the electric power used by lighting, office equipment, medical technical equipment, dining equipment and other technical equipment. To get the knowledge of the utilisation ratio of different equipment a discussion with the employees and the persons responsible for the technical devices in each ward took part.

The demands on technical devices, cleanness and patient secrecy in a hospital ward is for safety reasons very high, and therefore it is of large importance to act carefully and respectfully within the ward. Due to the demands, it has been restrictions in the accessibility within some of the wards; in these cases the department responsible for all the technical equipment at the hospital has been involved. Furthermore, no measurements of equipment have been done, due to the risk of disturb vital medical technical equipment. Instead a sensibility analysis was performed, where the variations of the medical technical equipment's utilisation time and its affect on the energy use was analysed.

To get the knowledge of how a hospital is designed, and what demands there are both regarding cooling power and energy, a discussion with a contractor and several different consulting companies has taken part. The discussions have been carried out both during interviews and during the seminary *Energieffektivt sjukhus – Framtidens möjligheter*.

1.4 Disposition of the thesis

Chapter 1: In the first chapter an introduction to the thesis with background and aims of the project is presented. Also a short presentation of how the work has been carried out is given.

Chapter 2: The concept of energy in the healthcare sector, and also different factors that affects the energy use in the hospital facility is to be defined in this chapter.

Chapter 3: A presentation of different key performance indicators that are used today can be found in the third chapter.

Chapter 4: In the fourth chapter a presentation of the results from the analysis of the field study of the three analysed hospital wards can be found. Also a sensitivity analysis of how the utilisation time and utilisation factor affect the energy use in the wards.

Chapter 5: The last chapter consists of an analysis of the results from previous chapters. The chapter ends with a discussion and conclusions of the results and also suggestions of further investigations within the field.

2 The concept of energy in the healthcare sector

In this chapter the concept of energy in the healthcare sector, and also different factors that affect the energy use in the hospital facility will be defined.

2.1 Definition of the activity in different hospital wards[1]

A hospital facility is built up of several different hospital wards. Every single hospital is unique, and therefore consists of different amount of wards, with different degree of technical intensity. Hence, a natural start would be to define what could be found in different kind of wards. In this report the wards have been divided into three different categories depending on the activity level and the technical intensity in the ward, as follows:

- Low technical intense hospital ward
- Moderate technical intense hospital ward
- High technical intense hospital ward

2.1.1 Definition of the activity in a low technical intense hospital ward

In all hospitals there are many different kind of wards with low technical intensity. A general practice ward is a good example of a ward with low technical intensity. It is a ward where the patients usually stay for observation during everything from one day to a couple of weeks. In this analysis the low technical intense hospital ward has been chosen to be a general practice ward with the focus on endocrine diseases. To the ward patients with diabetes related diseases, endocrine diseases and gastrology diseases come. The ward also takes care of patients that will get a liver transplantation and in some cases also patients with other medicine related diseases.

Normally in a general practice ward there is not a large amount of medical technical equipment. Usually the patient stays in the bed connected to drip, and in some cases also to an ECG-monitor to monitor the patient's heart activty. Therefore, the medical technical equipment found in these kinds of wards mostly consists of disinfection equipment, ECG-monitors, volumetric pumps and in some cases also air mattresses. An example of how a regular patient room in a general practice ward can look like is to be found in Figure 2.1.

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[1] The reference to Section 2.1 is the employees in the general practice ward, dialysis

Figure 2.1 An ordinary one-patient room in a general practice ward (Region Halland, 2011).

Due to the importance to avoid spread of bacteria within the ward, instruments and other equipment is disinfected. It is usually performed with special disinfection equipment, which is a “medical dishwasher”, and disinfects instruments and other equipment at really high temperatures. Typically the disinfection equipment is used in a very large extent. An example of typical disinfection equipment can be seen in Figure 2.2.

Figure 2.2 Two different kind of disinfection equipment that normally is used in general practice wards (Getinge AB, 2011 and Getinge Asia, 2011).

Since the patients in some cases are bedridden for weeks there is a risk of bedsores. To avoid that air mattress that changes the pressure from the mattress to the patients back is used. To control the amount and the speed of the drip that is given to the patients, a volumetric pump is used. The equipment described in this paragraph can be seen in Figure 2.3.

Figure 2.3 From the left: Volumetric pump connected to drip, ECG-monitor and air mattress on the top of a patient's bed (Management & Krankenhaus, 2011; MA Hospitalar, 2011 [1] and Danish Centre for Assistive Technology, 2011).

In general practice wards normally several patient rooms can be found, but also offices used by the doctors and nurses, treatment rooms and a kitchen. For that reason, the electric energy in the ward is also used by office equipment and dining equipment.

2.1.2 Definition of the activity in a moderate technical intense hospital ward

The moderate technical intense hospital ward obviously consists of more medical technical equipment than the low technical intense hospital ward. In this analysis a dialysis ward has been chosen to represent the moderate technical intense hospital ward.

Dialysis is a treatment method used of persons with reduced kidney function or that have lost a kidney. It is a process that uses an artificial replacement of the kidney, which removes waste and excess water from the blood system. There are two main types of dialysis treatment methods, hemodialysis and peritoneal dialysis, and these remove waste and excess water from the blood in two different ways.

Hemodialysis is the most common way to clean the blood; it is done with a machine called dialyzer that consists a filter that works as an artificial kidney. The blood is circulated outside the body through the dialyzer, where the waste and excess water is removed and then back in to the body. The hemodialysis is a process that takes about four to five hours to proceed, and has to be performed at least three days a week. In Figure 2.4 a patient during hemodialysis treatment can be seen.

*Figure 2.4 A patient gets hemodialysis treatment with a dialyzer (*Isioma Kidney Foundation, 2011).

Peritoneal dialysis is another way to remove waste and excess water from the blood system in the body. In this process the patient's peritoneal membrane is used as a filter to clean the blood. The peritoneal cavity is filled up with a sterile solution that is replaced four to five times during the day or night, and in this way the waste and excess water is removed from the blood.

The dialysis ward is very often built up in a similar way the general practice ward with several different patient rooms and also offices, treatment rooms and a kitchen. In the dialysis ward all the medical technical equipment used in the general practice ward can be found, equipment like disinfection equipment, ECG-monitors and volumetric pumps. However, the characterizing and most energy consuming equipment in this kind of ward is obvious the dialyzers and its purification system.

2.1.3 Definition of the activity in a high technical intense hospital ward

A high technical intense hospital ward characterizes by its large amount of medical technical equipment. Two good examples of wards in this category are surgery wards and radiology wards. Since different hospitals have different specialities, there is a wide variation in the number of high technical intense hospital wards between different hospitals. The analysed high technical intense hospital ward has been chosen to be a surgery ward with specialities in breast, endocrine, gastrointestinal, vascular and liver surgery and urology. Also kidney, pancreas, and liver transplant and advanced back, tumour and trauma surgery in orthopaedics. Since the surgery ward mostly consists of surgery rooms, and just a limited staff area, the study includes only an analysis of the surgery rooms.

A surgery room usually has a need of large amount of medical technical equipment. Depending on the type of surgery the equipment obvious varies a lot. But still, there are numbers of equipment that always are used independent on the surgery type. Equipment like operating table, operating lights, anaesthesia machine and warm air mattress, which can be seen in Figure 2.5. Furthermore, equipment such as pumps of different kind, surgery cart, medical warming cupboard, medical hotplate, monitors and computers are used.

Figure 2.5 Different equipment used during a surgery. From the upper left corner: Operating lights, operating table with a warm air mattress and anaesthesia machine (Pressbox, 2011; Kanmed, 2011 and MA Hospitalar, 2011 [2]).

To maintain good flexibility within the ward, most of the equipment is mobile. This makes it possible to use all the rooms for numerous different kinds of surgeries. Therefore, dependent on surgery type the rooms are occupied with different kinds of equipment. If there is an orthopaedic surgery there is a need for equipment like X-rays and special equipment used for sawing and drilling. The X-ray equipment used is normally a mobile C-arc, which is to be seen in Figure 2.6. When the surgery rooms instead are used for laparoscopy surgeries special laparoscopy equipment is used. An example of a surgery room during a laparoscopy surgery can be seen in Figure 2.7. Due to the fact that different surgeries have a need of different equipment, the technical intensity changes with the type of surgery.

Figure 2.6 A typical X-ray equipment used during orthopaedic surgeries is a mobile C-arc (Philips Healthcare, 2011).

Figure 2.7 Laparoscopic surgery room, with monitors, cameras and other equipment used (Wilson Hospital, 2011).

2.2 Indoor climate requirements in hospitals

The indoor climate in a hospital ward must satisfy both patients, employees and also be in line with the requirements of the activity in the ward. To create an indoor climate of good quality there are several different recommendations regarding air temperature, air humidity and air quality.

Since the hospital consists of several different wards, with different specialities, the requirements of the indoor climate differ within the building. According to ASHRAE, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, an appropriate temperature in a general practice ward is 21-24°C, due to the low metabolism of the patients. The relative humidity is recommended to be in the range of 30 to 60%. The demands on temperature and the relative humidity in a surgery room on the other hand are much higher. The temperature and the relative humidity should be possible to adjust and be easily readable by the surgical staff. To meet the requirements of some specialized surgeries the system should be design in a way such that it is capable of keeping a temperature of 17°C, and never exceed 27°C. The relative humidity in the room should be kept at a level of 30 to 60%.

2.2.1 Requirements on the working environment in hospitals

The Swedish Work Environment Authority has specified requirements on the working environment in hospital wards regarding for instance temperatures, ventilation and lighting.

According to AFS 2009:2 the temperature at the working place should be adapted to the working activity, and a heating system is preferable in all rooms where any working activity is performed. The recommended temperatures where the employee does sedentary work is 20-24°C during wintertime and 20-26°C during summertime. Additionally, the temperature should never fall below 20°C in any employee room. The working place should also be design in such way so that no discomfort due to draught occurs, and from experience this can be fulfilled if the air velocity is less then 0.15-0.20 l/s at normal indoor temperatures. Furthermore the requirements specify that the supply air should be supplied in a, for the working activity, sufficient amount of fresh air, and if necessary, the air should be preconditioned. It is suitable to place the intake of the outdoor air with regard to pollutions, temperatures and the exhaust air to reduce the risk of poor supply air quality.

The recommendation of the lighting says that it should be adapted to the working conditions and the requirements of the work assignment. It is also important to design the lighting so that no problems for the employee occur when moving between different areas of the working place.

2.2.2 Requirements on air distribution systems in hospitals

In a hospital ward the air distribution system is not only used to make sure that the indoor climate satisfies the persons in the hospital ward, but also to prevent spread of airborne contaminants. In Sweden today there are no requirements prescribed by the law of how the air distribution system should be design to avoid airborne contaminants. Instead, it is every single hospital’s responsible to design the air distribution system in such a way that no airborne contaminants occur (Svensk Förening för Vårdhygien, 2010).

The surgical area is the part that has highest demands on the indoor climate in a hospital facility. It is of major importance that the systems that serve the different areas within the surgical area are designed carefully, to minimize the concentration of airborne contaminants in the air. The air distribution system is not only used to minimize the airborne contaminants by removing contaminants during the surgery, but also to prevent an inflow of microorganisms from the surrounding areas and to clean the air in the room afterwards (Svensk Förening för Vårdhygien, 2010).

According to ASHRAE the most effective way to supply the air in a surgery room is from the ceiling with exhaust devices near the floor. An appropriate number of air changes per hour in a surgery room are 20 with a number of air changes of fresh outdoor air of four.

To prevent an inflow of microorganisms from the surrounding areas, there is a demand to have a positive pressure in the surgery rooms in comparison to the surrounding areas. The pressure is kept positive by supplying a larger airflow than the exhaust airflow. It is also a recommendation to have easily readable differential-pressure-indicating devices in the surgery room, to make the surgical staff aware of the pressure and if necessary change the airflows to keep the pressure positive in the room.

2.2.3 Requirements on heating and cooling systems in hospitals

Since there are requirements on the temperature in hospitals, there must be a possibility to guarantee that the temperature is kept in the right range. In a hospital there are several different internal heat gain sources, for instance patients, employees, lighting, office equipment and medical technical equipment. All these produce and emit heat to the ambient air, this heat surplus must in some way be taken care of to ensure the indoor climate to be satisfying for the persons in the building and be in line with the indoor climate requirements. Therefore, there will in many cases be a need of cooling during a large part of the year. Furthermore, there will be a need of a heating system in the building. It is used to make sure that the indoor temperatures can be kept even during the cold part of the year, and to make sure that the temperatures are in line with the requirements also when no internal heat gains are in the building. Today there are no requirements on what kind of heating or cooling system that should be used, it is instead up to the designer to choose an appropriate system to fulfil the indoor climate requirements.

2.2.4 Requirements on water systems in hospitals

The water distribution system in the building should be design in a way that no risk of Legionella occurs in the system (Svensk Föreining för Vårdhygien, 2010). The quality of the cold water must also fulfil the requirements from The National Food Agency (Livsmedelsverket, 2011). To be in line with these requirements the design of the water distribution system should fulfil following:

- The temperature of the hot water at every single tap must be at least 50°C.
- The cold water system should be designed in a way that no unwanted heating of the cold water occurs.
- Where circulation pipes are used, the return temperature must be at least 50°C.
- In water dispensers and water tanks the water temperature must have a higher temperature than 60°C.

- It is important to avoid the water to be stagnant in the pipes; therefore plugged pipes should be avoided.

It is of large importance that the system is design in such way that hot water, steam and heating always can be delivered. Therefore, there must a be sufficient amount of boilers to make sure that even though if one is taken out of service the remaining boilers are able to fulfil the function (ASHRAE, 2007).

2.3 Previous analyses of the electric energy use in the healthcare sector

Analyses of the electric energy use and the electric power in hospital wards are something that has not been performed in a very wide extent. Instead the main focus has been to analyse and find saving potentials at the building level, with for instance the building envelope and the air handling systems (Västra Götalandsregionen, Sustainable Healthcare, 2011). However, some analyses within the field still have been carried out, both regarding the electric energy use and the electric power in hospital wards, and will be presented below.

2.3.1 Analysis of the electric energy use in hospitals[2]

The total electric energy use in hospital facilities obviously depends on several different factors, for instance the building envelope, type of installations and also the type of activity in the building. Some hospitals deal with high technical intense healthcare, others with not that technical intense healthcare, which clearly will affect the use of electric energy within the building.

Statistics from 2010 of six different hospitals, or hospital areas, in the region of Västra Götaland have been analysed with regard to the electric energy use in relation to four different indexes, building area, DRG-index, number of full-time employees and number of treatments. Explanation to these indexes are to be found in Section 3.2.

The hospitals in the figures below are named with numbers from one to six, where:

- Hospital 1 is a University Hospital with a building area of approximate 600 000 m^2.
- Hospital 2 to 4 are Specialist Hospitals with an area of approximate 200 000 to 300 000 m^2.
- Hospital 5 and 6 are two smaller hospitals with an area of approximate 30 000 m^2, where hospital 5 is an Emergency Hospital and Hospital 6 is an Accidental Hospital.

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[2] The reference to Section 2.3.1 is the Environmental Secritary, Göteborg, 2011-12-08.

The typical way to express electric energy use today is in terms of kWh/m^2. In Figure 2.8 the electric energy use of these six hospitals can be seen in relation to their building area.

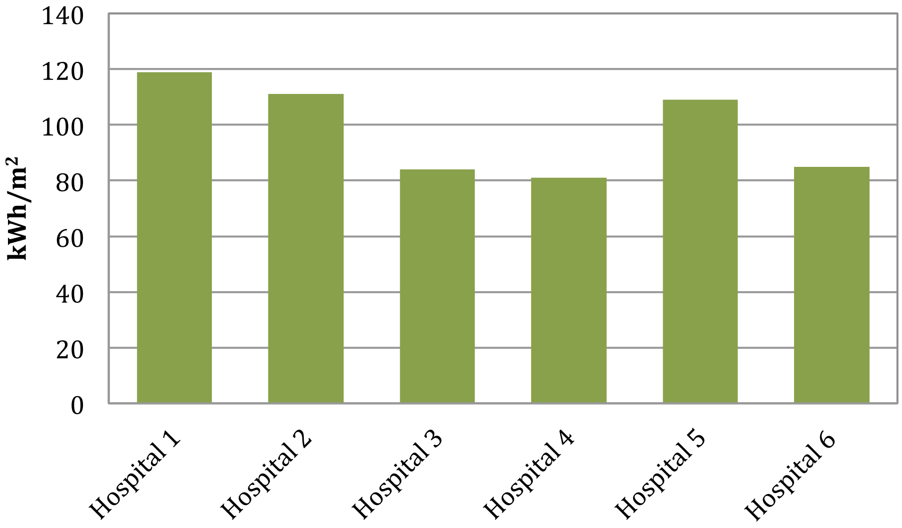

Figure 2.8 The electric energy use during 2010 in relation to the building area of six hospitals in the region of Västra Götaland.

When the electric energy use is related to the building area, as in Figure 2.8, hospital 3, 4 and 6 have the lowest values. If the electric energy use instead is sat in relation to another index, something that also includes the activity in the building, it shows another result of which hospital that has the lowest electric energy use. In Figure 2.9 to Figure 2.11, the electric energy use is sat in relation to three other indexes to demonstrate how the results can differ. The different indexes are discussed more in Section 3.2.

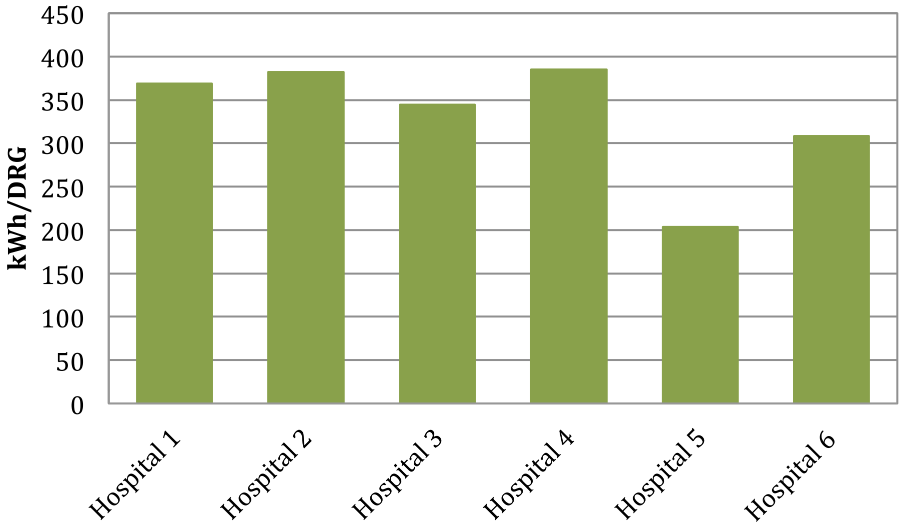

Figure 2.9 The electric energy use during 2010 in relation to the DRG-index of six hospitals in the region of Västra Götaland.

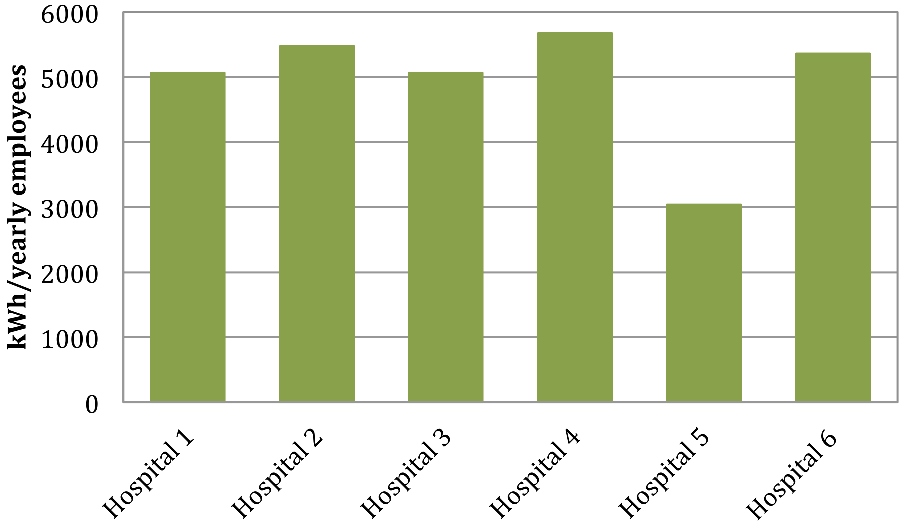

Figure 2.10 The electric energy use during 2010 in relation to the number of yearly employees of six hospitals in the region of Västra Götaland.

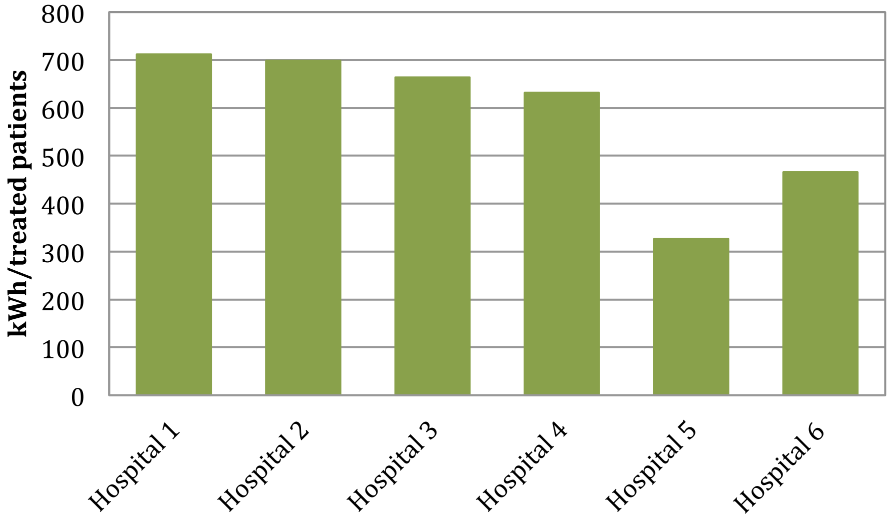

Figure 2.11 The electric energy use during 2010 in relation to the number of treated patients of six hospitals in the region of Västra Götaland.

The figures above indicate that the result is very much dependent on what the electric energy use is related to. The hospitals that were in the lower range in Figure 2.8 did not turn out to have the lowest energy use when it was related to another index. Instead hospital 5 turned out to have much lower energy use in Figure 2.9 to Figure 2.11.

2.3.1.1 Analyses of the electric energy use in hospital wards

Skåne Energy Agency did in 2004 an investigation of the use of electricity in three dental centres, two healthcare centres and one hospital ward. The common part in these wards is that they do not have any markedly amount of medical technical equipment. The aim with the report was to find out how the electricity was divided between different equipment in different wards, and to find saving potentials of the usage of electricity.

They have chosen to express the electric energy use as specific electricity use in relation to the area, and also in relation to the number of beds or the number of treatment rooms, which can be seen in Figure 2.12 and Figure 2.13. The conclusion from the analysis was that lighting stood for the largest amount of the electric energy use in all the wards. As much as 38-50% of the total electric energy use, was consumed by lighting. The second largest electricity consumer was the office equipment.

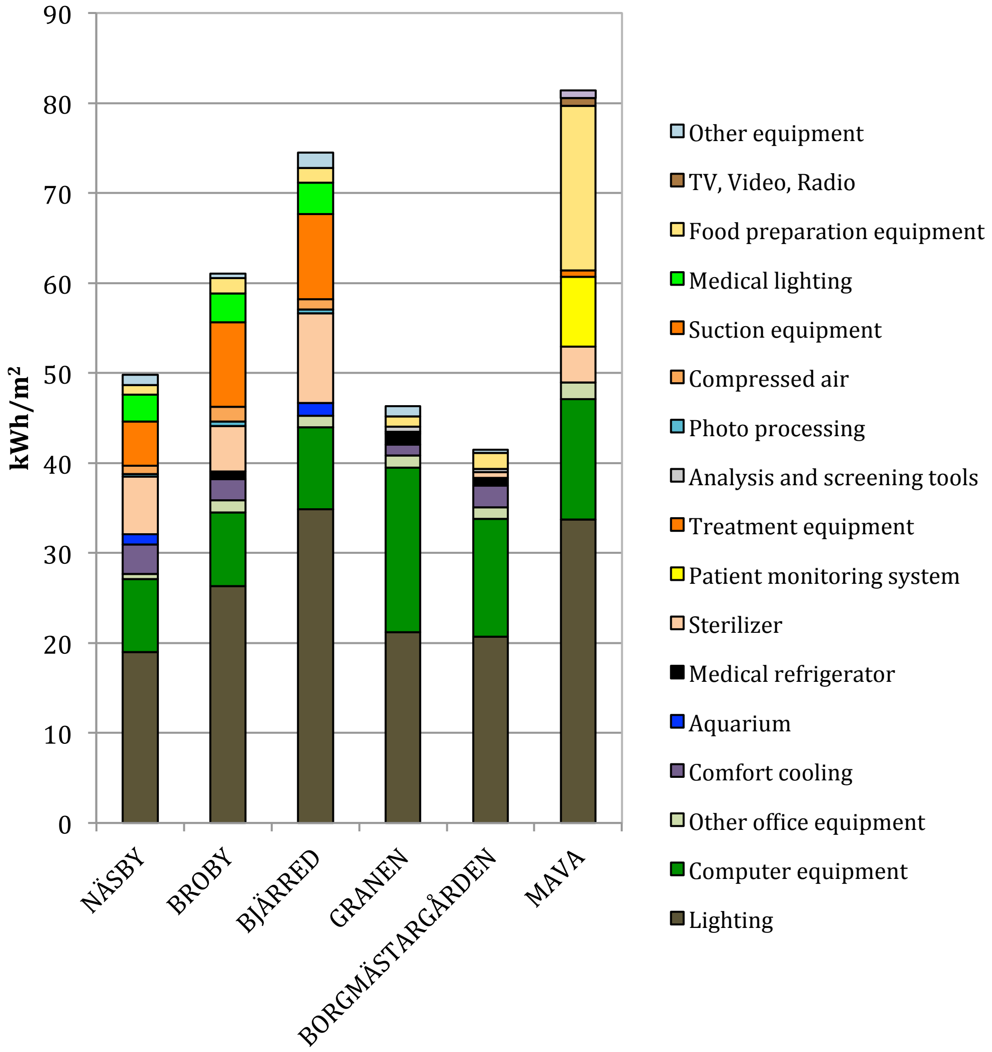

Figure 2.12 The figure shows how the electric energy use is divided within six different healthcare wards. Näsby, Broby and Bjärred are dental centres, Granen and Borgmästargården are healthcare centres and MAVA is a medical emergency ward (The figure is based on the reference: Drakenber, B., Kjellman, A., 2004).

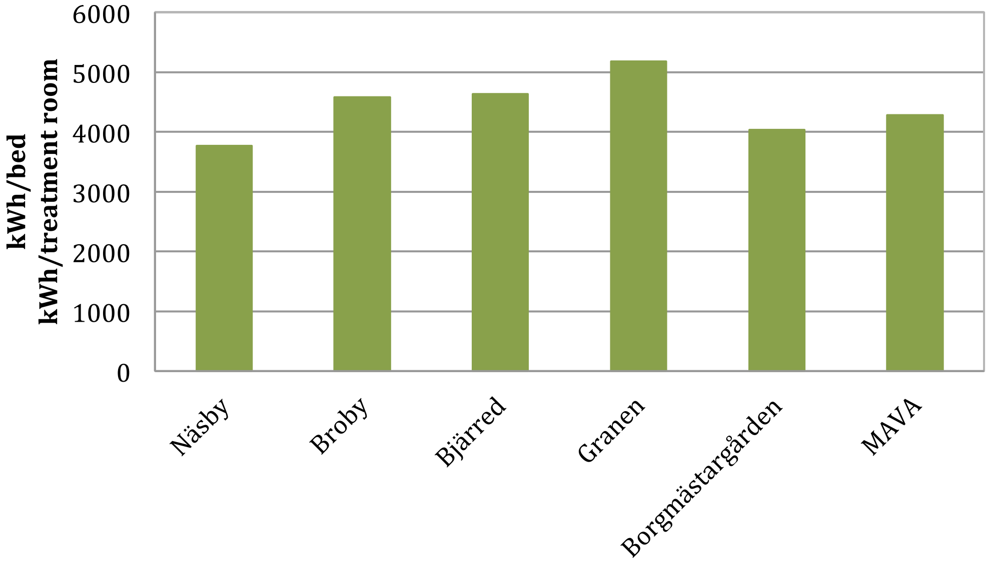

Figure 2.13 Electric energy use in six different healthcare wards. Näsby, Broby and Bjärred are dental centres, Granen and Borgmästargården are healthcare centres and MAVA is a medical emergency ward. The electric energy use is in all cases sat in relation to the number of treatment rooms except from at the medical emergency ward where it is sat in relation to the number of beds in the ward (The figure is based on the reference: Drakenber, B., Kjellman, A., 2004).

Two years later, in 2006 The Environmental Secretariat of the region of Västra Götaland, did an investigation of the electric energy use in healthcare wards. They have chosen to categorise the healthcare wards into three categories, low electricity intense, moderate electricity intense and high electricity intense. How the analysed wards are categorised can be seen in Table 2.1.

Table 2.1 The table shows how the nine analysed wards have been categorised dependent on their electricity intensity.

Low electricity intense	**Moderate electricity intense**	**High electricity intense**
General practice	Dental care	Surgery Intensive care units Recovery rooms
Child psychiatry	Orthopaedics Rehabilitation General practice	Orthopaedics Radiology department Emergency Medicine
Psychiatry Dental care		Emergency Medical services
Office		

The report presents the results of the distribution of the electric energy use between different equipment within in each type of ward. Independent of electricity intensity, lighting stood for the largest amount of electric energy use, which can bee seen in Figure 2.14. Which corresponds to the results from the analysis Skåne Energy Agency did. Furthermore, in hospital wards with high electricity intensity also the medical technical equipment stands for a markedly amount of the electric energy use, in the analysed wards approximate 25%. This indicates that in these types of wards the medical technical equipment affects the electric energy use significantly.

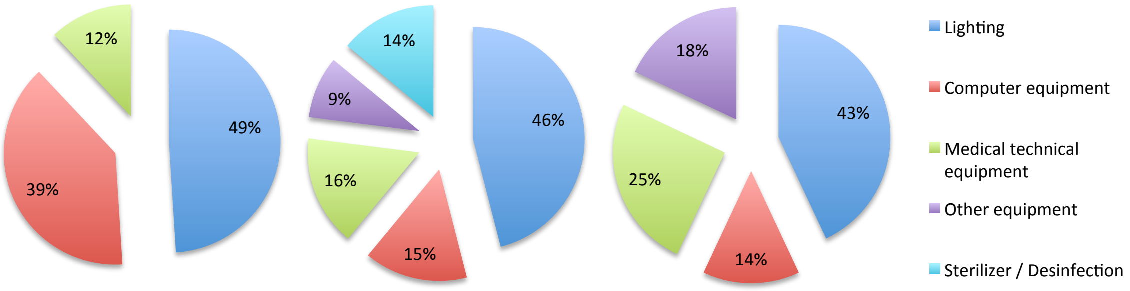

Figure 2.14 The distribution of the electric energy use in the analysed wards. From left: Low electricity intense hospital ward, moderate electricity intense hospital wards and high electricity intense hospital wards (The figure is based on the reference: Bjurbäck, H., Estéen M., 2006).

The report also presents results from measurements of the specific electric energy use in each type of ward. The average specific electric energy use in the different categories varied between approximate 40 kWh/m^2, year and 105 kWh/m^2, year and is to be seen in Figure 2.15.

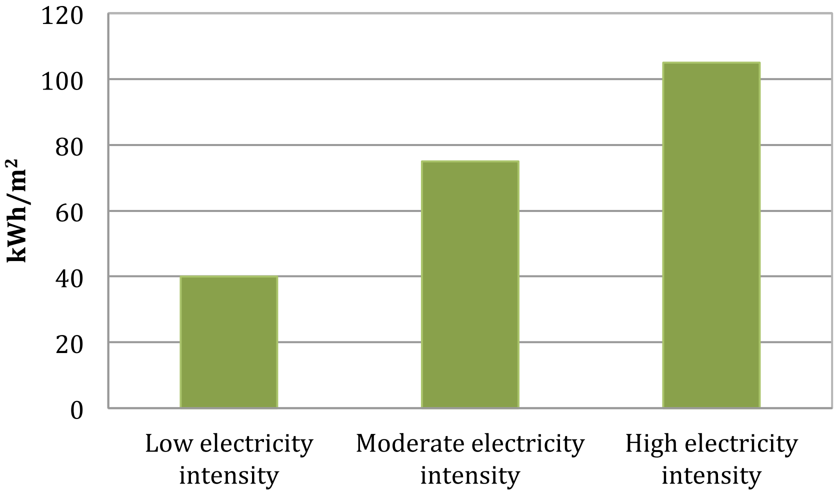

Figure 2.15 The average specific electric energy use in the analysed wards (The figure is based on the reference: Bjurbäck, H., Estéen M., 2006).

The conclusion in the report was to some point based on the results from the report that Skåne Energy Agency did in 2004, but also on their own measurements from hospital wards at Södra Älvsborg Hospital. The result was similar to what Skåne Energy Agency came up with in 2004; the conclusion was that lighting was the largest energy consumer and that the second largest was the office equipment. This report also included an investigation of wards with high electricity intensity, which the other one did not. The conclusion was that in these wards also the medical technical equipment could stand for a large amount of energy used for electricity. Additionally a deeper study of the radiology department at Södra Älvsborgs Hospital was performed. The aim was to analyse to how large extent the medical technical equipment affects the total energy use in a high electricity intense hospital ward. The result was that in wards with high electricity intensity single equipment could stand for a very large part of the total electricity use. In this case the X-ray equipment stood for 10% of the total electricity use in the entire building.

During the years 2006 and 2007 the Swedish Energy Agency did an investigation of 159 hospital facilities in Sweden. The aim with the investigation was to update the statistics of the energy use in the country, and the main focus was to study how the electric energy was used within the building.

The report deals with subjects as:

- Electric energy use in different room types.
- Distribution of the electric energy use between different kind of equipment in a hospital.
- Usage of different light sources.
- Electric power used by lighting in different building types.

The report presents that the average electricity use of 69 hospitals in Sweden was approximate 92 kWh/m^2, year, where nearly 46% of the total electricity use was connected to the activity related electricity. In Figure 2.16 the average distribution of the activity related electricity in the hospitals is to be seen.

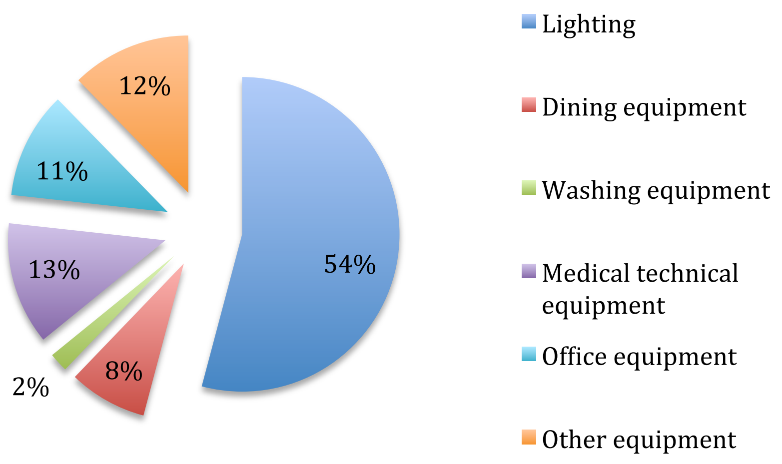

Figure 2.16 The average distribution of the activity related electricity use in 69 hospitals in Sweden during the years 2006 and 2007 (Statens energimyndighet, 2008).

The results presented in the report of the total energy use have been expressed in two ways, either in relation to the specific area or in relation to the number of full-time employees. In the discussion part of the report they mention that this may not be the best way to express the energy use, and that there is a need for a better or a complementary index to make the comparison of the energy usage of healthcare facilities complete.

2.3.2 Analysis of the cooling power in hospital wards

In 2008 a Bachelor thesis at Chalmers University of Technology was carried out. The focus of the report was on the real need of cooling power compared to the design cooling power in a new healthcare building at Sahlgrenska University Hospital in Göteborg.

The report presented the design cooling power need to be 50 W/m^2 in the building, and that the real theoretical need for cooling power was as much as 109 W/m^2 at one of the analysed floor, see Figure 2.18. However, what is important to have in mind is that this value is the theoretical maximum, and no consideration has been taken to the fact that in the real case everything is not in operation at the same time, and some of the equipment may only be used in very short periods. Nevertheless, the report gives an idea about the electric power in these types of hospital wards, and that it varies a lot dependent on the type of ward.

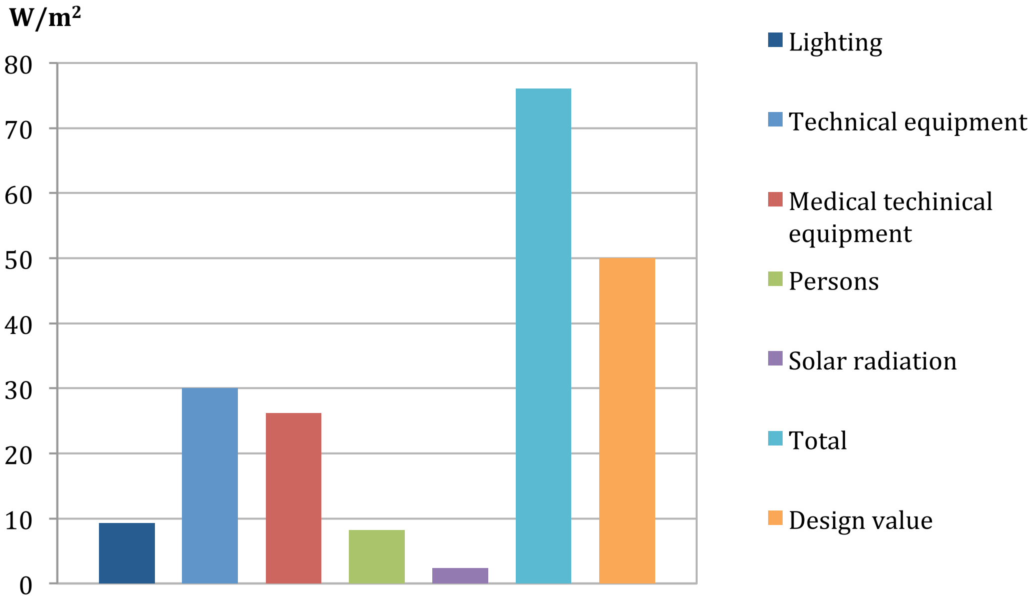

Figure 2.17 Theoretical need for cooling power at the first analysed floow in the new healthcare building at Sahlgrenska University Hospital in Göteborg (The figure is based on the reference: Backman, E., Eliasson, E., Johansson, P. Lindström, P., Thollander, J., 2008).

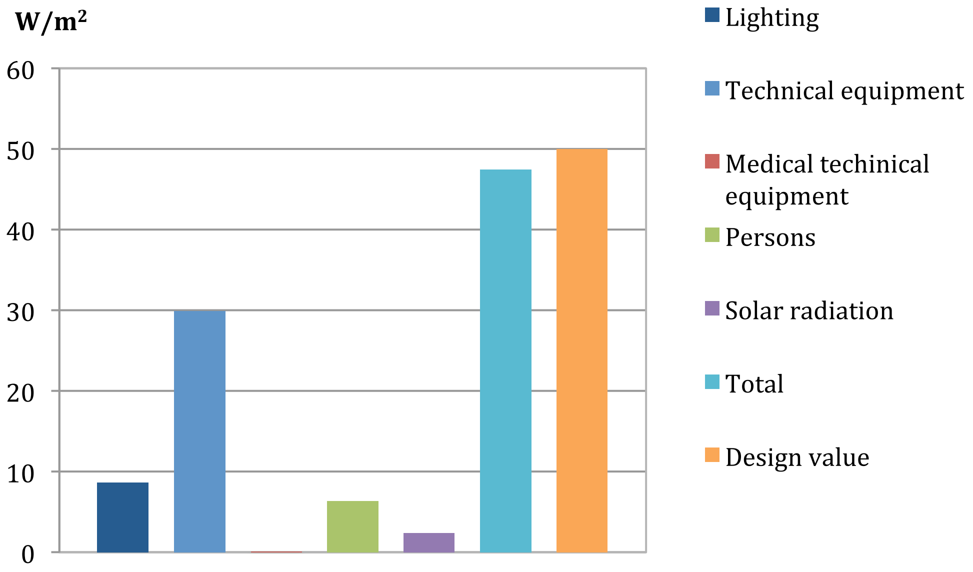

Figure 2.18 Theoretical need for cooling power at the second analysed floor in the new healthcare building at Sahlgrenska University Hospital in Göteborg (The figure is based on the reference: Backman, E., Eliasson, E., Johansson, P. Lindström, P., Thollander, J., 2008).

As seen in the figures above the largest electric power can be found at medical technical equipment and technical equipment, such as computers, TV and food preparation equipment.

2.3.3 Comments to previous analyses of the electric energy use in the healthcare sector

The reports from the region of Skåne, the region of Västra Götaland and the Swedish Energy Agency all pointed out that lighting was the largest electric energy consumer, even though the Bachelor Thesis showed that the lighting was in the lower range of the electric power. This illustrates that even though an equipment has a low electric power it still can be the largest electric energy consumer. Furthermore, there is equipment with very high electric power that still not affects the electric energy use significantly, due to the fact that its utilisation time is very low. Although, when it comes to the design of the cooling system, it can in many cases be designed to take care of those power peaks, even though these may not last for a long time. This shows the importance to understand the difference between electric energy and electric power, and that they affect the system in different ways.

The result in the report from the Swedish Energy Agency is given as energy use in relation to the building area, but also in relation to the number of full-time employees. One of the conclusions in the report is that there is a need of a better representative index to express the energy use in relation to, neither the building area or the full-time employee is good enough, in some way the healthcare given must be included to give a representative information about the energy use.

2.4 Experience from contractors and consultants regarding the concept of electric energy

In this section experience from different consultants and contractors is presented. Experience regarding the concept of electric energy and design of cooling systems in hospitals.

2.4.1 Experience regarding design of cooling systems in hospitals

Today there are usually no specific requirements of how to design the heating, cooling and air distribution system in hospitals; instead it is up to the designer to choose an appropriate system to live up to the requirements on the indoor climate. Therefore it varies from case to case how the system is designed. Some companies prefer cooling with air, others with cooling beams. However, even though the cooling system differs between different companies, the problem to know the amount and what kind of equipment that is used in different wards is the same for all the companies. The manufactures are not that interested to help with technical data before their products have been ordered, which is usually in the late end of the design phase. Therefore it can be hard to design the system with a good accuracy, and it is more and more common that the consultants contract lasts one or two years after the building is sat in use. The reason is to optimise the system when the equipment is known and they know how the building will be used.

Today the healthcare sector does not set any requirements regarding energy efficiency of the medical technical equipment, and therefore also no requirements of the type of cooling system in the equipment. The consequence is often that the equipment has some sort of air-cooling, which emit the heat surplus to the ambient air. The result is that there is a large cooling demand in high technical intense hospital wards. But the owners of the hospitals are today working with this subject, to make it possible to include demands on the energy efficiency of the medical technical equipment.

When designing the cooling system, a qualified assumption of the number of persons and equipment and its utilisation time in the ward is performed. From these conditions, the quality and location of the building, and the requirements on the indoor temperature the cooling system is designed. In Figure 2.19 experience from different consulting companies regarding the cooling power in three different wards can be found, unfortunately the cooling power in the surgery ward is from one company only. Although, it can be seen that there is a variation of the cooling power between different companies, it differs approximate 20% from the maximum to the minimum values in both the general practice ward and the dialysis ward.

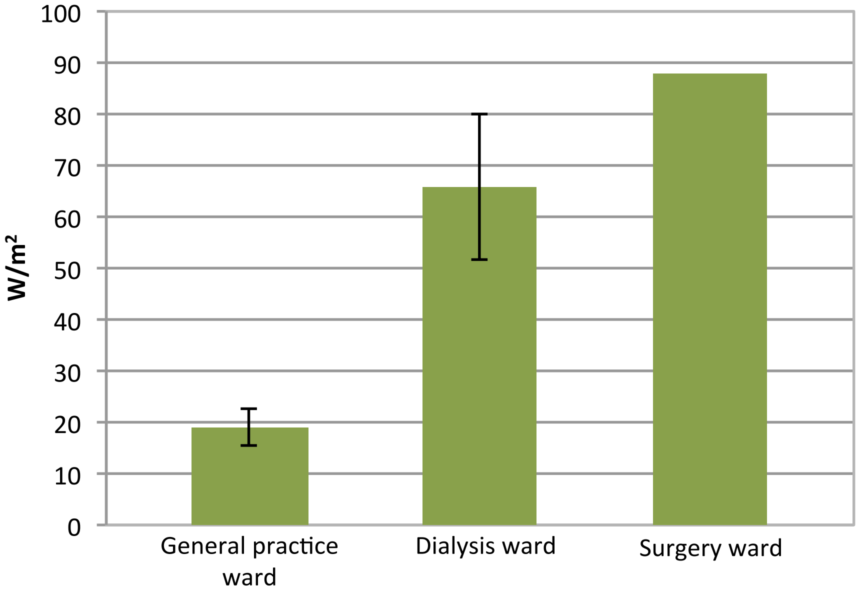

Figure 2.19 Cooling power in a general practice ward, a dialysis ward and a surgery ward. The columns show the average value, and the error bars symbolise the variation of cooling power between different companies.

2.4.2 Experience regarding energy efficiency in hospitals

In the building sector when dealing with all different kind of contexts the comparison with a specific area is wide spread. It may be a really suitable way to express for instance the construction price or the construction time. As mentioned before in the report, when it comes to comparing the energy use between buildings it is not that simple. Hence, the energy use is very much connected to the activity in the building, which makes it hard to get an accurate and useful value of the energy use when it is compared only with a specific area. The opinion that many persons within the branch do have is that there is a need of a complementary key performance indicator, when discussing energy use in hospitals. During the seminar *Energieffektivt sjukhus – Framtidens möjligheter* the question "How suitable is it to express the energy use related to the building area?" came up several times and the answer was mostly that it is not that suitable, but since everything else in the branch is expressed in that way, it is an easy way to express it. And the same answer was given during discussion with different companies afterwards as well.

Another problem is that there is a lack of accurate data about the equipment used in different wards, and also about the difference between different wards; too few studies have been performed within the field. But there is an investigation starting up in 2012 of all hospitals in the region of Västra Götaland, which is a great opportunity to further work within the field.

3 The concept of key performance indicator

The definition of key performance indicators is presented in Section 1.1. In this chapter key performance indicators related to the energy use are presented. In the late end of the chapter key performance indicators used in the healthcare sector is to be found.

3.1 Key performance indicators related to the energy use[3]

The design of a building can be done in several different ways, one better than the other. To get an idea of which systems are more suitable than others, considering the energy use, there must be a way to evaluate different systems, or to make an evaluation of the entire building. There are today numerous different key performance indicators that are used for these purposes, indicators that are used to:

- Evaluate different climate systems or devices in a building during the design phase.

- In the design phase to make sure that the entire building and all its installations is in the right range of energy use.

- Compare the energy use between different buildings.

- Evaluate the energy use of a building to the entire building sector.

To evaluate different systems, or the energy use of the entire building with key performance indicators, it is important to compare the energy use in a relation to something that is common for all the buildings or all the systems. What it should be in relation to is not always obvious; it depends of the purpose of the key performance indicator. It can for instance be in relation to the heated area of the building, the design airflow or the design heat surplus.

In the table below some different key performance indicators of the design of different systems or the entire building are listed:

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[3] The reference to Section 3.1 is Jagemar, 1996.

Table 3.1 The table shows different key performance indicators used in different state of the design phase (Jagemar, 1996).

Design phase	**Key performance indicator**	**Unit**
Design of the air distribution system Design of the duct system, air handling units and fans.	Design fan electric power per design airflow	$\frac{kW_{electricity}}{m^3/s}$
Design of the air handling system Choice of components and its controlling. The electricity includes all components as fans, pumps, cooling machinery etc.	Design electric power per design airflow	$\frac{kW_{electricity}}{m^3/s}$
	Design heating power per design airflow	$\frac{kW_{heat}}{m^3/s}$
	Annual electric energy per design airflow	$\frac{kW_{electricity}/year}{m^3/s}$
	Annual heating energy per design airflow	$\frac{kW_{heat}/year}{m^3/s}$
	Utilisation factor	-
	Utilisation time	$hours/year$
Design of the entire building Includes lighting, office equipment, heating, cooling and air distribution systems.	Design electric power per specific area	$\frac{kW_{electricity}}{m^2}$
	Design heating power per specific area	$\frac{kW_{heat}}{m^2}$
	Annual electric energy per specific area	$\frac{kW_{electricity}/year}{m^2}$
	Annual heating energy per specific area	$\frac{kW_{heat}/year}{m^2}$

3.1.1 Key performance indicators used at system level

At system level, the key performance indicator can be used for instance to compare different air distribution systems or different heating systems. It is used as an indicator of which system that can be the most suitable in a certain project. Or in the same way, it can be used at device level, to indicate which is the most suitable fan or pump. A key performance indicator that is commonly used to express and compare the efficiency of air distribution systems is the Specific Fan Power, SFP. The SFP-index takes into account the system size and is defined by the total electric power needed for all the fans in the system divided by the design airflow of the entire building, which is the largest of the supply and the exhaust airflow. Therefore the SFP-index makes it possible to compare large air distribution systems with small air distribution systems. The Specific Fan Power is defined as:

$$SFP = \frac{\dot{W}_t^{Supply} + \dot{W}_t^{Exhaust}}{\dot{V}_{Design}} \quad , \quad \left[\frac{kW}{m^3/s}\right] \tag{3.1}$$

Where:

$$\dot{W}_t^{Supply} = \frac{\dot{V}_{Supply} \cdot \Delta p_{tot}^{Supply}}{\eta_{tot}^{Supply}} \quad , \quad [kW] \tag{3.2}$$

$$\dot{W}_t^{Exhaust} = \frac{\dot{V}_{Exhaust} \cdot \Delta p_{tot}^{Exhaust}}{\eta_{tot}^{Exhaust}} \quad , \quad [kW] \tag{3.3}$$

The SFP-index is very suitable to use for systems with constant air volume, CAV-systems, but when it comes to systems with variable air volumes, VAV-systems, it is not that accurate, due to the fact that the airflows vary. Instead of using the maximum airflow as operating condition, it is common to use 70% of the maximum airflow to calculate the SFP-index for a VAV-system.

There is also a possibility to use the SFP-index for individual fans, and is then called Specific Fan Power for the Individual fan, SFPI. It is defined as the required fan electric power divided by the transported volume airflow. This is a key performance indicator that can be used to compare individual fans against each other, but should not be compared with the SFP-value. The Specific Fan Power for the Individual fan is defined as:

$$SFPI = \frac{\dot{W}_t^{Individual\ \ fan}}{\dot{V}} \quad , \quad \left[\frac{kW}{m^3/s}\right] \tag{3.4}$$

What should also be mentioned is that the SFP-index is not suitable to use for exhaust-only systems, instead the SFPI-index should be used, due the fact that these systems only consist of one fan.

Another key performance indicator also related to the air distribution system is the Air Transport Factor, ATF. This parameter quantifies the design heat surplus divided by the required fan electric power to remove the heat surplus, where the heat surplus is equivalent to the cooling power of the air. The Air Transport Factor is given by:

$$ATF = \frac{\dot{Q}_{Heat \quad surplus}}{\dot{W}_t^{Supply} + \dot{W}_t^{Exhaust}} \quad , \quad \left[{}^{kW}\!/_{kW}\right] \tag{3.5}$$

Where:

$$\dot{Q}_{Heat \quad surplus} = \dot{V} \cdot \rho \cdot c_p \cdot (t_{Room} - t_{Supply}) \quad , \quad [kW] \tag{3.6}$$

$$\dot{W}_t^{Supply} = \frac{\dot{V}_{Supply} \cdot \Delta p_{tot}^{Supply}}{\eta_{tot}^{Supply}} \quad , \quad [kW] \tag{3.7}$$

$$\dot{W}_t^{Exhaust} = \frac{\dot{V}_{Exhaust} \cdot \Delta p_{tot}^{Exhaust}}{\eta_{tot}^{Exhaust}} \quad , \quad [kW] \tag{3.8}$$

3.1.2 Key performance indicators used for the entire building

To evaluate if the building’s energy use is in the right range, or to compare different buildings against each other there are several different key performance indicators used for these purposes. What is worth to have in mind is that the building sector uses the relation to specific areas very often, in many different contexts, and also when expressing the energy use. Therefore when discussing key performance indicators of the entire building it is mostly about energy use, electric power or heat power in relation to a specific area.

Key performance indicators related to a specific area can be expressed in several different ways. To be able to use them in the right way, it is important to understand what is included in the different key performance indicators. Some commonly used key performance indicators are:

- The area specific power used for
    - Electricity
    - Heating

- The area specific energy used for
    - Electricity
    - Heating

3.1.2.1 The area specific power and energy used for electricity

The area specific power and energy used for electricity can be divided into design electricity requirement of the entire building and design electricity requirement of the climate system.

- In the building the electric power or the electric energy use of following posts are included:
    - Lighting
    - Office equipment, such as computers, printers etc.
    - Activity related technical equipment
- The climate system includes the electric power or the electric energy use of following posts:
    - Fans
    - Cooling machinery and their pumps etc.
    - All pumps used in the heating and cooling system
    - Equipment used in the controlling system

It is important to have in mind that all the equipment in a typical case is not in operating at the same time. Therefore, the maximum value of the electric power is normally not of that large interest when designing for instance the cooling system. As an example, studies have been done in several different office buildings, with the result that only 40-50% of lighting and computer equipment was in use at the same time.

The area specific power used for electricity is given by the total electric power in the building divided by the specific area, as follows:

$$\dot{w}_t = \frac{\dot{W}_t}{A^{Heated}} \quad , \quad \left[{kW}/{m^2} \right] \tag{3.9}$$

The area specific energy use for electricity is defined as:

$$w_t^A = \frac{W_t}{A^{Heated}} \quad , \quad \left[\frac{kWh/year}{m^2}\right] \tag{3.10}$$

3.1.2.2 The area specific power and energy used for heating

In the same way as for the area specific power and energy used for electricity, the area specific power and energy used for heating can be divided into the design heating demand in the building and in the climate system as follows:

- In the building the heating power and the energy used for heating of following post are included:
    - Domestic hot water
- In the climate system the heating power and energy used for heating of flowing posts are included:
    - Heating coils in the air distribution system
    - Heating terminals used in the building for instance radiators and convectors

The area specific power used for heating is given by the total heating power in the building divided by the specific area, as follows:

$$\dot{q} = \frac{\dot{Q}}{A^{Heated}} \quad , \quad \left[{}^{kW}\!/_{m^2}\right] \tag{3.11}$$

The area specific energy use for heating is defined as:

$$q^A = \frac{Q}{A^{Heated}} \quad , \quad \left[\frac{kWh/year}{m^2}\right] \tag{3.12}$$

3.1.3 Utilisation factor and utilisation time

In some cases it can be useful to express how much a system or a machine is in use, and how that affects the energy usage. Two key performance indicators that are used to define the degree of utilisation of a system are the utilisation factor and the utilisation time.

The utilisation time is expressed as the number of hours during a year the system is running. The utilisation factor is expressed as the ratio between the utilisation time and the run time of a system, as follows:

$$\upsilon = \frac{\tau_{Utilisation}}{\tau_{Run}} \quad , \quad [-] \tag{3.13}$$

As an example how the utilisation time affects the area specific electric energy use at different area specific electric power can be seen in Figure 3.1.

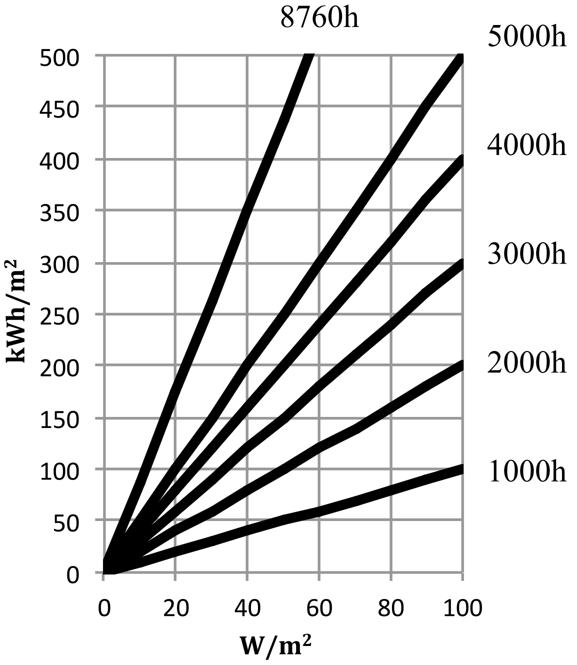

Figure 3.1 The relation between the electric energy use and the area specific electric power and its utilisation time.

3.1.4 Factors that affects the energy use and should be included in a key performance indicator

The energy use in a hospital facility depends on several different factors; one of the perhaps most obvious is the location and the quality of the building, how appropriate the building envelope and the heating, ventilation and air-conditioning system, the HVAC-system, are designed. Other factors that affect the energy use are the electric power of the equipment used in the facility and also the utilisation factor and utilisation time of the equipment. The equipment in the facility does not only affect the electric energy used by the equipment, also it affects the size and energy use of the

HVAC-system. Due to the fact that the HVAC-system for instance has to take care of the heat surplus from equipment, which is often related to the equipment's electric power.

Some of the factors mentioned above are highly related to the number of patients. One of the perhaps most obvious factor is the utilisation time and in some cases also the number of medical technical equipment. Typically, to treat more patients, the medical technical equipment has to be used in a wider extent, which normally both affects the electric energy use and the energy use of the HVAC-system. Other equipment is not related to the number of patients in the same extent, equipment like lighting and office equipment.

3.2 Key performance indicators used in the healthcare sector

As in all sectors also the healthcare sector follows up statistics over the years, comparing the healthcare between different regions and evaluate that the healthcare given is in line with the budget. To make this possible they use several different key performance indicators. It is key performance indicators that express the average treatment time of a patient, number of treatments per year, number of fulltime employees in either a certain department or at the hospital overall.

Another indicator, or classification system that often is used is an indicator that describes the mix of patients in different hospitals, and is often used to make it possible to compare the quality and the cost of the healthcare in different hospitals. The indicator that is described is called Diagnostic Related Groups, DRG (Socialstyrelsen, 2011).

4 Field analysis of hospital wards

Three different hospital wards have been analysed to study the difference in electric power and electric energy use. To distinguish the complexity in the healthcare and between different wards, the wards have been selected due to their intensity of technical equipment. The analysis consisted of a study of lighting, technical equipment, office equipment and medical technical equipment. It has been carried out by an inventory of the wards where the maximum electric power and standby electric power of the equipment have been studied. Furthermore, to get the knowledge about the utilisation ratio of the equipment a discussion with the employees at the ward has taken part. This has been the basis to an approximation of the total electric power during operation at daytime and nighttime.

In the figures presented in this chapter, five different categories are to be found. The categories and what is included are:

- **Lighting** – consists of all the lighting in the wards.
- **Office equipment** – consists of computers, printers, copying machines, fax machines and projectors.
- **Technical equipment** – consists of TVs.
- **Medical equipment** – consists of all the medical technical equipment in the wards. In this post also the disinfection equipment and medical refrigerators are included.
- **Dining equipment** – consists of dishwashers, stoves, fridges, freezers, microwave ovens and coffee machines.

4.1 Field analysis of a low technical intense hospital ward

The analysed low technical intense hospital ward was chosen to be a general practice ward. It is a ward that mostly takes care of patients that are not in a critical condition; instead they are usually bedridden and need to be under observation. The analysed ward had a total area of 1150 m^2; with a total capacity of 25 patients spread over eight one-patient rooms, three two-patient rooms and three three-patient rooms. The average treatment time of a patient is five days, which equals to 1825 patients per year.

In the general practice ward only a small amount of medical technical equipment is used, equipment like disinfection equipment, volumetric pumps and ECG-monitors. In Figure 4.1 it can be seen that the medical technical equipment still stands for approximate 30% of the total electric power in the ward, the reason is that the disinfection equipment uses very high electric power. The largest post of the maximum electric power does the dining equipment stand for, which is mainly caused by the stoves, which have a very high maximum electric power, up to 10 kW.

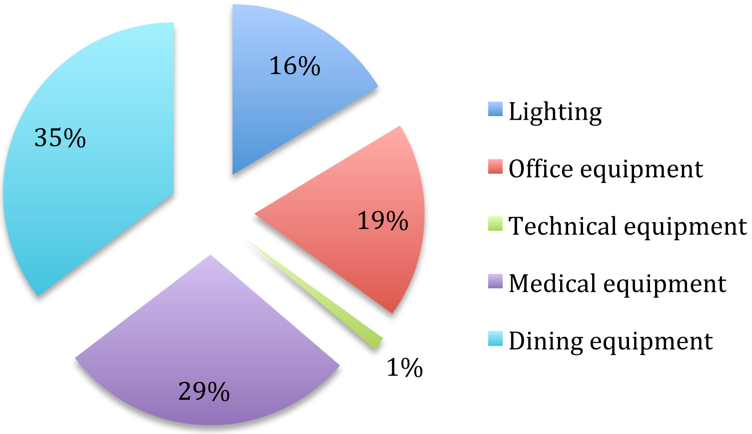

Figure 4.1 The distribution of the maximum electric power the equipment used in the general practice ward.

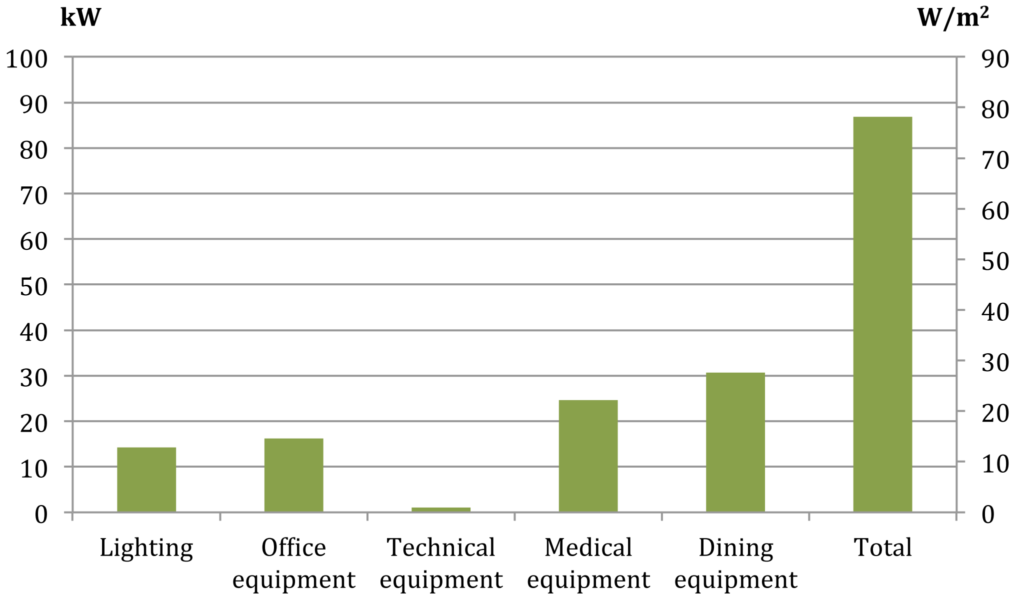

Figure 4.2 The maximum electric power of the equipment in the general practice ward.

Figure 4.2 shows the maximum electric power of all the equipment in the ward, in other words, the electric power when all the equipment is operating at the same time at their maximum electric power. Normally the equipment does not use its maximum electric power; neither do all the equipment be used at the same time. Therefore, it is more interesting to know the operating electric power. After discussion with the employees about the utilisation ratio of the equipment in the general practice ward theoretical operating electric power during daytime and nighttime was carried out, and can be found in Figure 4.3 and Figure 4.4.

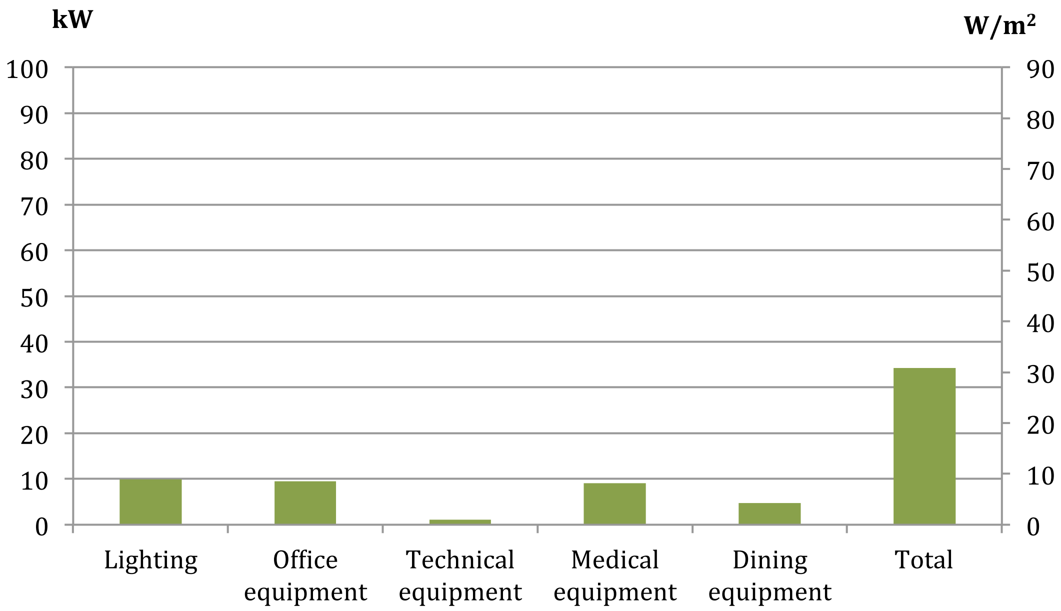

Figure 4.3 Theoretical operating electric power of the equipment used in the general practice ward during daytime.

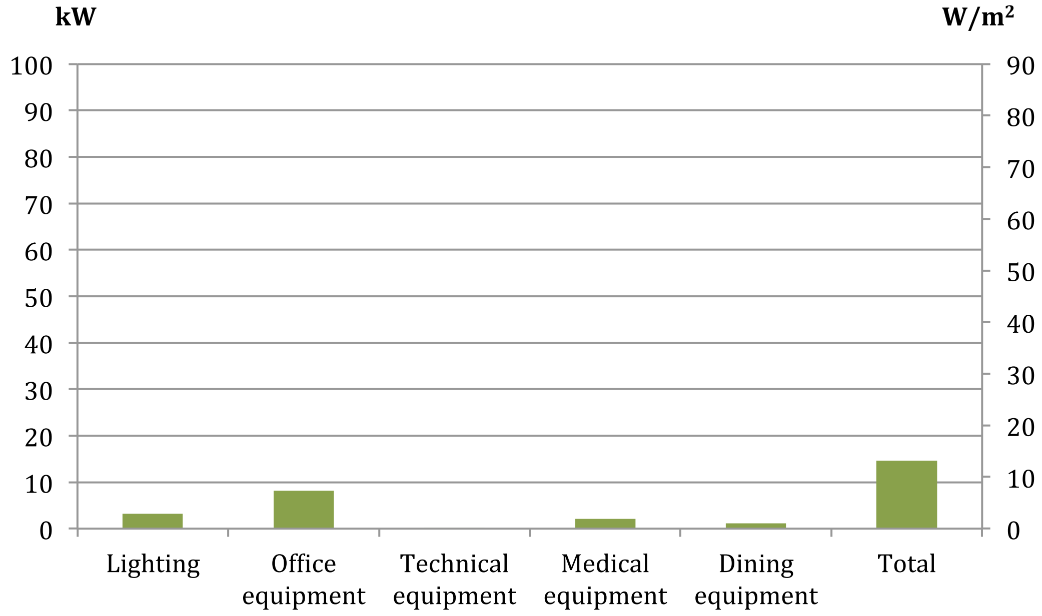

Figure 4.4 Theoretical operating electric power of the equipment used in the general practice ward during nighttime.

As seen in the figures above the total theoretical electric power during daytime and nighttime differ from the maximum electric power. The posts that differ most are medical equipment and dining equipment. During the daytime-case the total theoretical electric power is approximate 40% of the maximum electric power, and for the nighttime-case the value is approximate 17%.

4.2 Field analysis of a moderate technical intense hospital ward

The analysed dialysis ward had a total area for approximate 1150 m^2 with 25 beds and treats approximate 30 to 40 patients every day, or approximate 14 600 patients per year. The department takes care of both emergency patients and patients that return there three times a week. The ward has eight rooms with one to eight beds in each.

The basic medical technical equipment that is used in the general practice ward is also used in the dialysis ward. Medical technical equipment like disinfection equipment, volumetric pumps and ECG-monitors. The difference between the wards is that in the dialysis ward, medical technical equipment like dialyzers and its purification system can be found. Therefore, the maximum electric power in the dialysis wards is divided in another way, the medical technical equipment stands for as much as 54 % of the maximum electric power, as seen in Figure 4.5 and Figure 4.6.

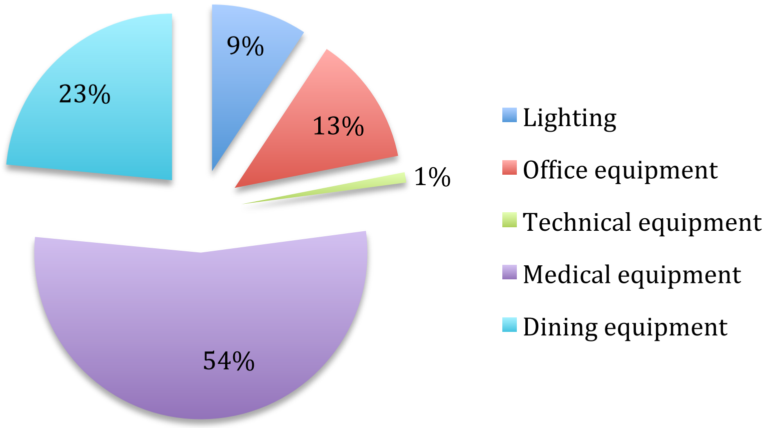

Figure 4.5 The distribution of the maximum electric power the equipment used in the dialysis ward.

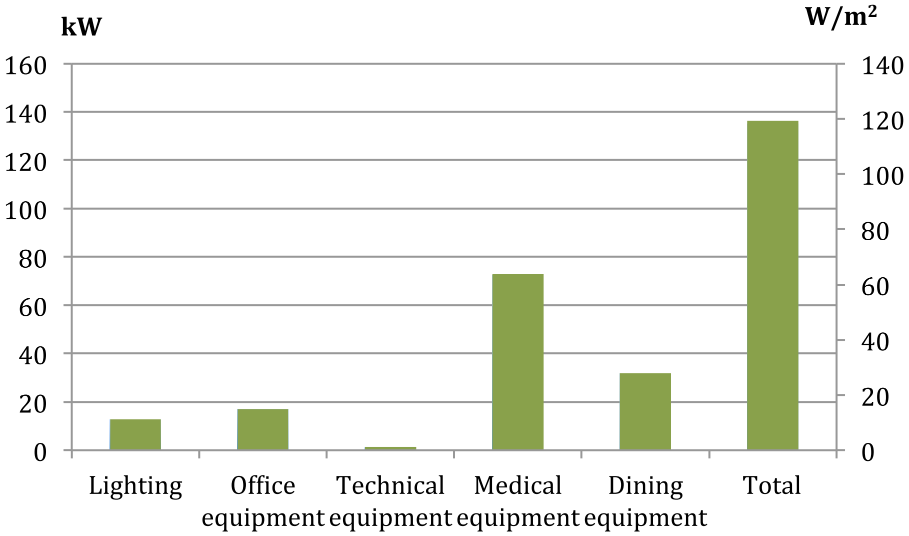

Figure 4.6 The maximum electric power of the equipment in the dialysis ward.

In the same way as in the general practice ward theoretical operating electric power of the equipment in the ward during daytime and nighttime was carried out after a discussion with the employees at the dialysis ward. During the daytime-case the theoretical electric power is approximate 60% of the maximum electric power. The same value for the nighttime-case is approximate 15%, as seen in Figure 4.7 and Figure 4.8.

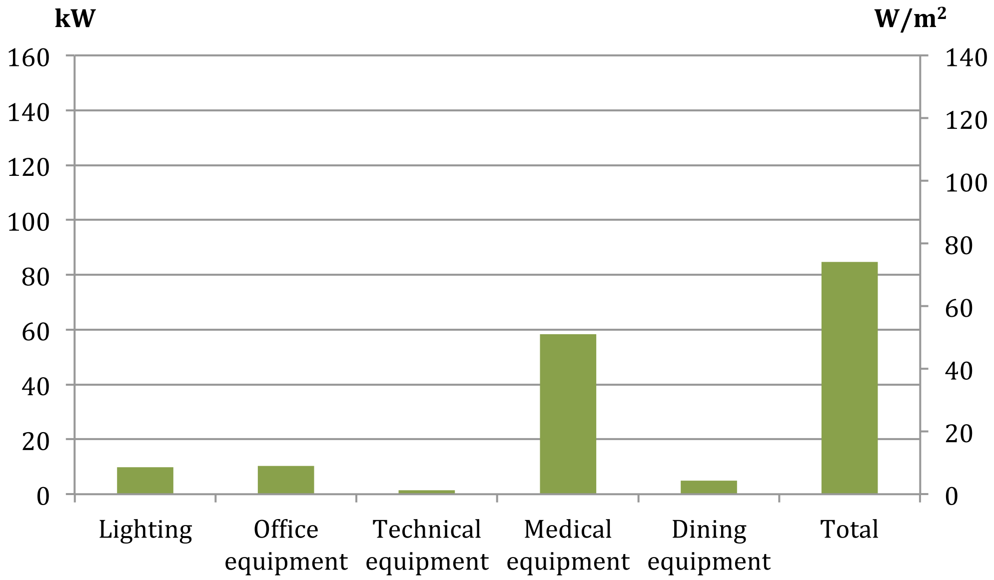

Figure 4.7 Theoretical operating electric power of the equipment used in the dialysis ward during daytime.

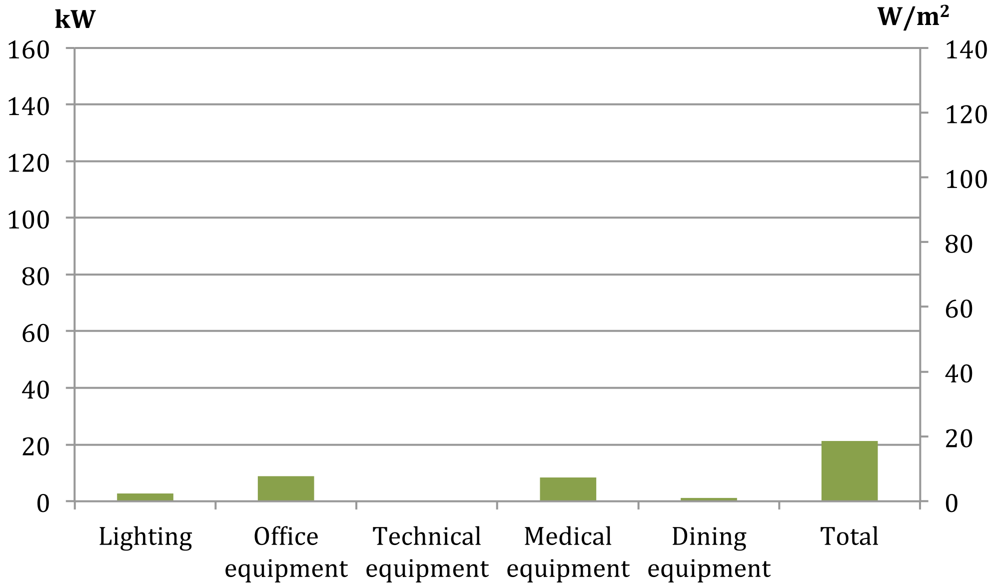

Figure 4.8 Theoretical operating electric power of the equipment used in the dialysis ward during nighttime.

4.3 Field analysis of a high technical intense hospital ward

The analysed high technical intense hospital ward was a surgery ward with a total of 14 surgery rooms with an approximate size of 34 m^2 each. These are used for planned surgeries as well as emergency surgeries. All the 14 rooms are usually in use all the time during the day, and approximate two during nighttime. During a year the surgery ward treats close to 5000 patients, and depending of the type of surgery it can take everything from an hour up to over 10 hours per surgery. Obviously, the equipment differs with the surgery type, but generally there is a need of much special medical technical equipment. The results presented below are based on equipment used during orthopaedic surgeries and laparoscopy surgeries.

The distribution of the maximum electric power in the surgery ward differs from the low and moderate technical intense hospital ward as seen in Figure 4.9, approximate 90% of the maximum electric power is from medical technical equipment.

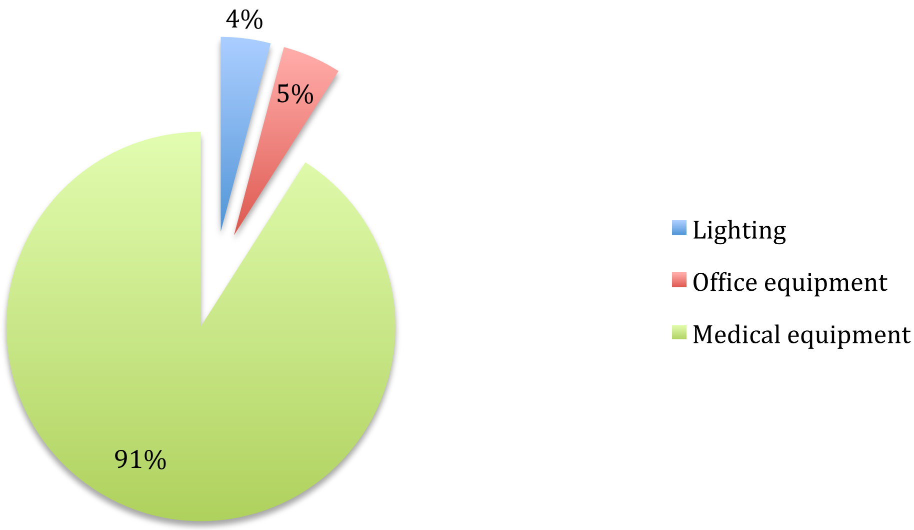

Figure 4.9 The distribution of the maximum electric power the equipment used in the surgery ward.

In Figure 4.10 the maximum electric power of the equipment in the surgery ward is shown; it can be seen that the total maximum electric power is close to 500 W/m^2. The maximum electric power is the electric power when all the equipment is in use at the same time, and the probability of that happening is very small. After discussion with the employees at the surgery ward a theoretical operating electric power during daytime and nighttime was carried out. In Figure 4.11 the electric power for daytime can be found, and it can be seen that the total theoretical electric power is approximate 190 W/m^2 or approximate 40% of the maximum electric power. The nighttime-case is to be found in Figure 4.12 where the total theoretical electric power is close to 50 W/m^2 or 10% of the maximum electric power.

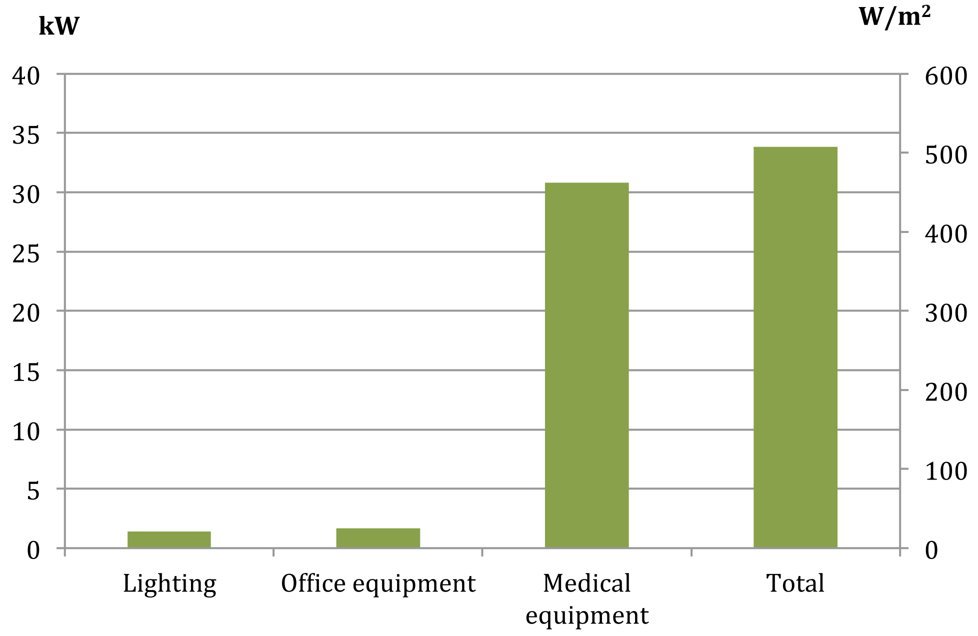

Figure 4.10 The maximum electric power of the equipment in the surgery ward.

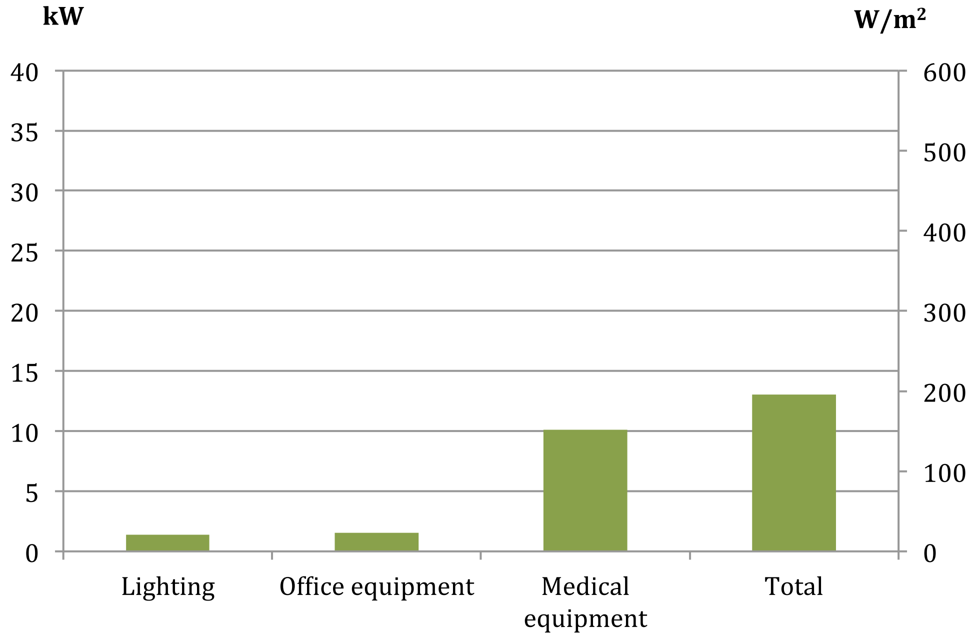

Figure 4.11 Theoretical operating electric power of the equipment used in the surgery ward during daytime.

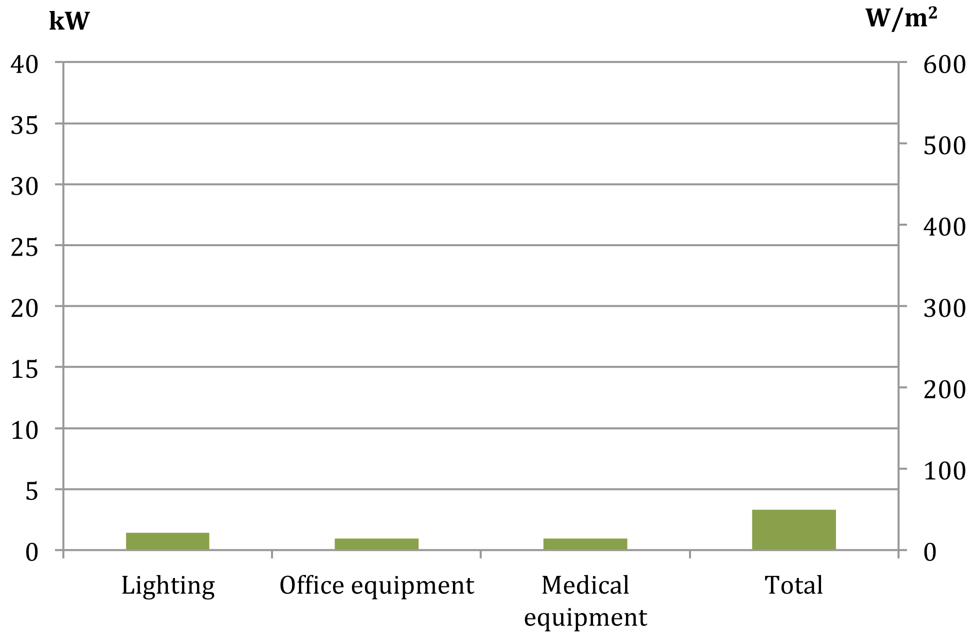

Figure 4.12 Theoretical operating electric power of the equipment used in the surgery ward during nighttime.

4.4 Electric energy use in the analysed hospital wards

In the previous section the variation of the electric power between the wards was presented. Also how the theoretical operating electric powers stood in relation to the maximum electric power. The electric energy use is obvious affected by both the operating electric power and also the utilisation time of the equipment. In this section a sensibility analysis of how the medical technical equipment in each ward, depending on the utilisation time, influences the total electric energy use.

According to the employees in the wards, the computers are never shut down, even though many of the computers are not in use during nighttime. Furthermore, since the wards are in operating during nighttime as well, the lighting is always on, but with reduced electric power during nighttime, which could be seen in Figure 4.4, Figure 4.8 and Figure 4.12. To analyse the influence from medical technical equipment at the total electricity energy use, a simplified study has been carried out for four different cases. The medical technical equipment is sat to operate 2 hours, 4 hours, 8 hours and 14 hours during daytime. The electric energy used for lighting, dining equipment and office equipment is sat to operate with constant electric power according to Figure 4.3, Figure 4.7 and Figure 4.11 during 14 hours at the day and Figure 4.4, Figure 4.8 and Figure 4.12 during 10 hours at night.

The results from the low technical intense hospital ward can be seen in Figure 4.13. As seen the medical technical equipment stands for a small amount of the electric energy use in the low intense technical hospital ward, instead the main part comes from lighting and office equipment.

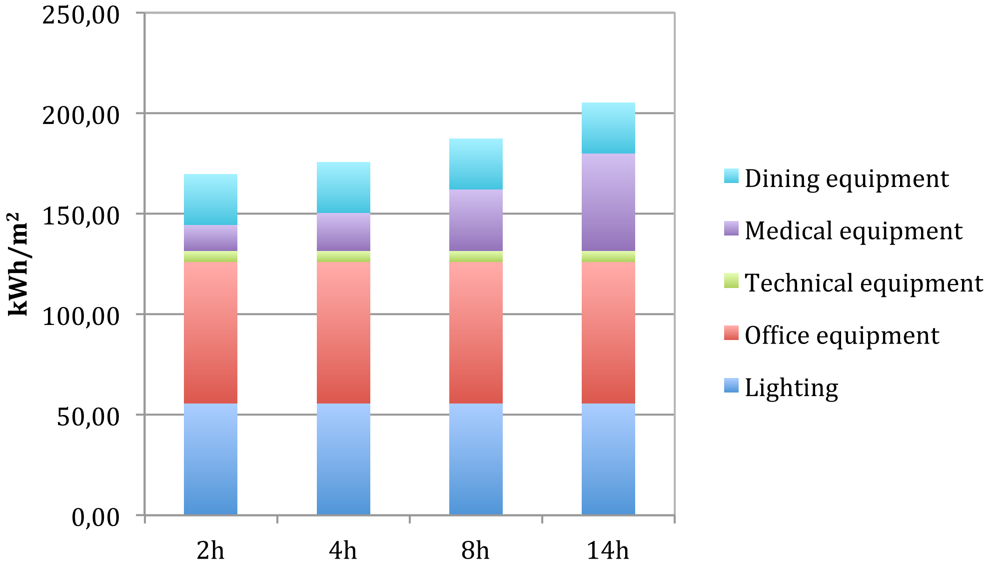

Figure 4.13 Theoretical electric energy use in the low technical intense hospital ward. The medical technical equipment is operating 2, 4, 8 and 14 hours according to Figure 4.3. The other equipment is operating constant 14 hours in according to Figure 4.3 and 10 hours in according to Figure 4.4.

In the moderate technical intense hospital ward the medical technical equipment has a much larger influence of the electric energy use in the ward, as seen in Figure 4.14. The typical utilisation time of the medical technical equipment in a dialysis ward is approximate four to five hours per day. In that case the medical technical equipment stands for 40% of the total theoretical electric energy use within the ward, and with a higher utilisation time the total electric energy use increases significantly.

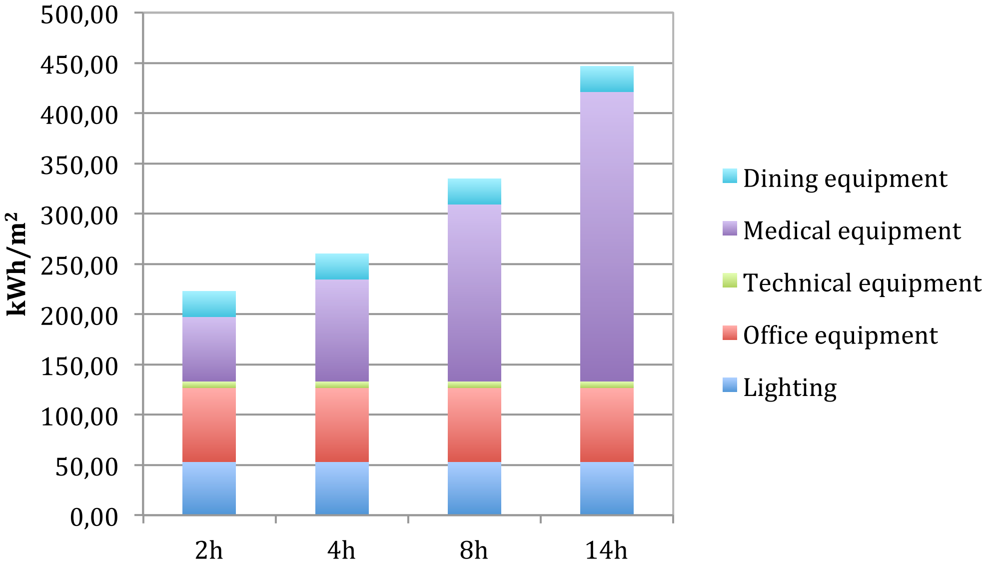

Figure 4.14 Theoretical electric energy use in the moderate technical intense hospital ward. The medical technical equipment is operating 2, 4, 8 and 14 hours according to Figure 4.7. The other equipment is operating constant 14 hours in according to Figure 4.7 and 10 hours in according to Figure 4.8.

Since the surgery ward is even more technical intense, the electric energy use obvious will be even more highly related to the utilisation time of the medical technical equipment. In Figure 4.15 the theoretical electric energy use for the four different cases is shown. According to the employees in the surgery ward, the utilisation time of the X-ray equipment varies from 2 up to 30 minutes per surgery when the equipment is used. Therefore, the energy used by the X-ray equipment is showed separately with an error bar in Figure 4.15. Although, the results indicate that the energy use in a surgery ward very much depends on the utilisation time of the medical technical equipment.

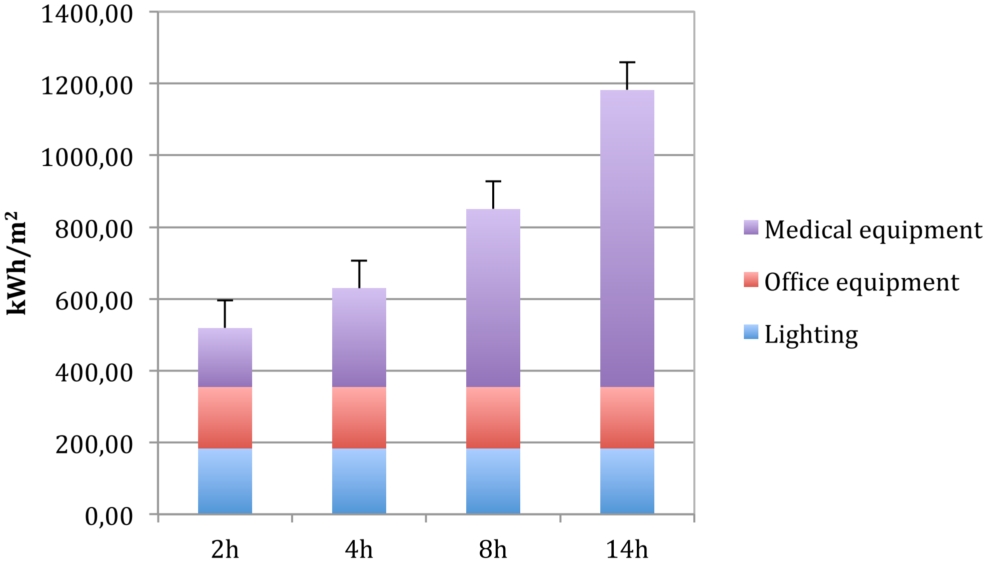

Figure 4.15 Theoretical electric energy use in the high technical intense hospital ward. The medical technical equipment is operating 2, 4, 8 and 14 hours according to Figure 4.11. The other equipment is operating constant 14 hours in according to Figure 4.11 and 10 hours in according to Figure 4.12.

5 Discussion and conclusions

In this chapter a discussion of the results from the field studies is presented, also recommendations regarding activity related key performance indicators are given. In the late part of the chapter conclusions and suggestions of further studies is to be found.

5.1 Discussion

The analysis points out that there is a very wide range of the electric power dependent on the type of hospital ward. The maximum electric power in the moderate technical intense hospital ward was approximate 150% of the maximum electric power in the low technical intense hospital ward. In the high technical intense hospital ward, the same value was 630%. This large difference was mostly caused by the difference in medical technical equipment. Since the high technical hospital ward deals with much more advanced healthcare, it obviously needs more advanced medical technical equipment, which also is seen in the results from this analysis. Furthermore, the results indicate that independent on the type of hospital ward, lighting and office equipment stands for a similar amount of electric power and electric energy use in all wards.

In Figure 5.1 the maximum electric power in the analysed wards are collected. Since some of the equipment has an utilisation time of as little as 30 hours per year, which is equal to 5 minutes per day, the maximum electric power is not of significant interest from an energy point of view. Instead the operating electric power is more interesting. After discussions with the employees in each ward theoretical operating electric power have been carried out. In Figure 5.2 and Figure 5.3 these theoretical operating electric power during daytime and nighttime can be seen. The results of the theoretical operating electric power turned out to be approximate 40 – 60% of the maximum electric power during daytime and 10 – 20% during nighttime. These 10 – 20% mostly consists of office equipment and lighting that is not turned off during nighttime, but also from standby electric power from medical technical equipment.

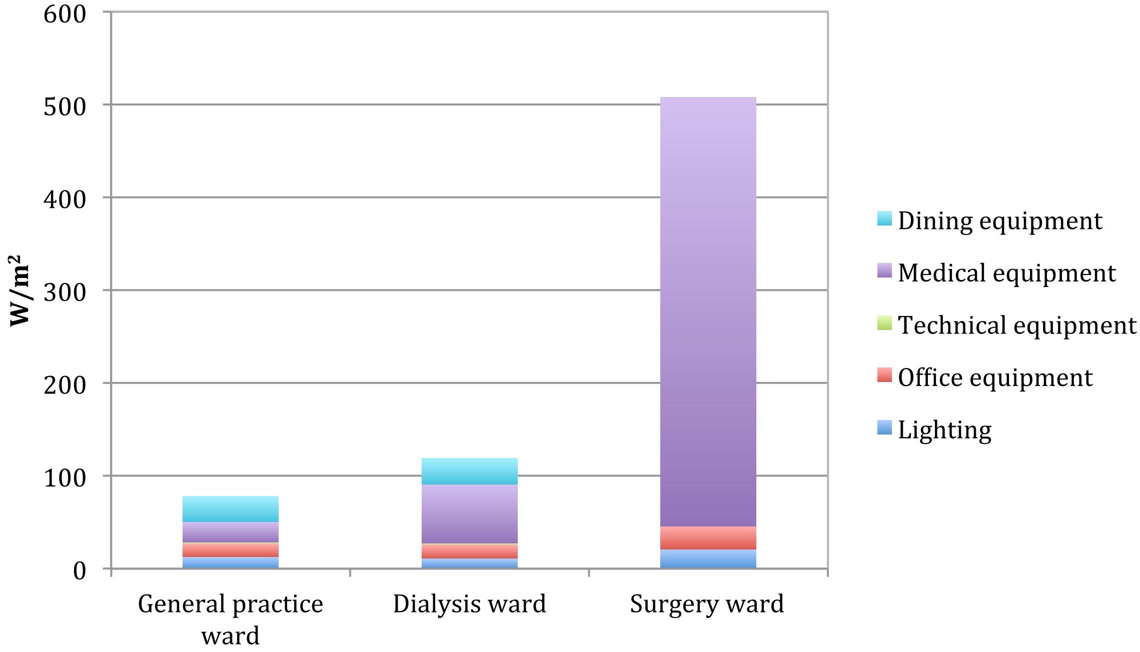

Figure 5.1 The maximum electric power of the equipment in the three analysed wards.

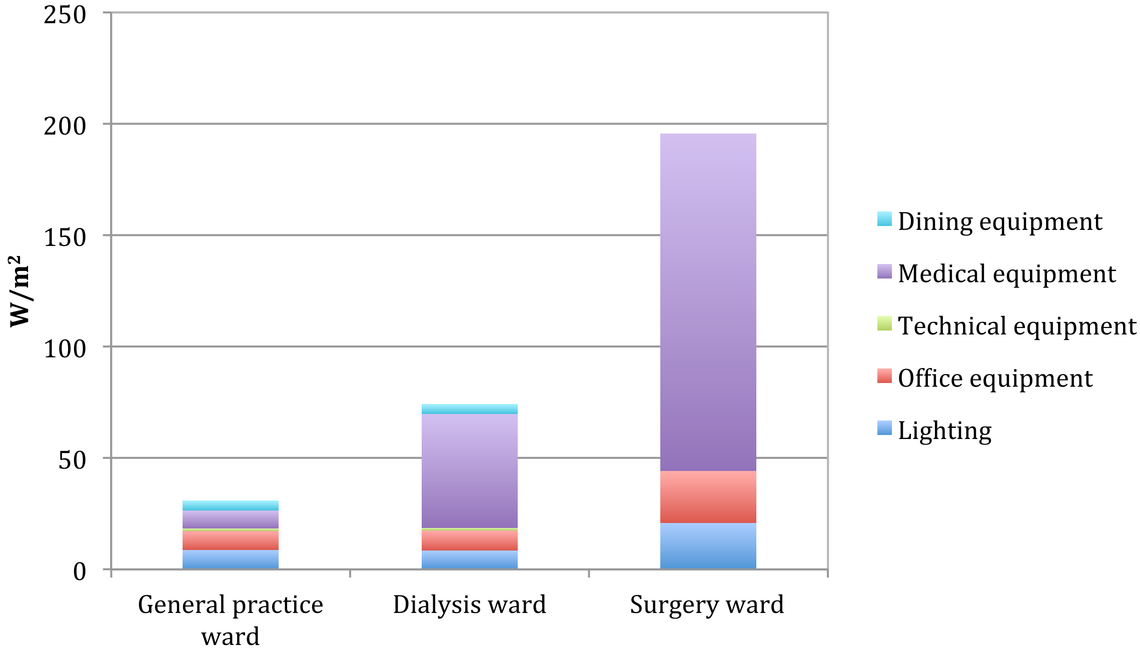

Figure 5.2 The theoretical operating electric power of the equipment in the three analysed wards during daytime. Note the difference in vertical scale from previous figure.

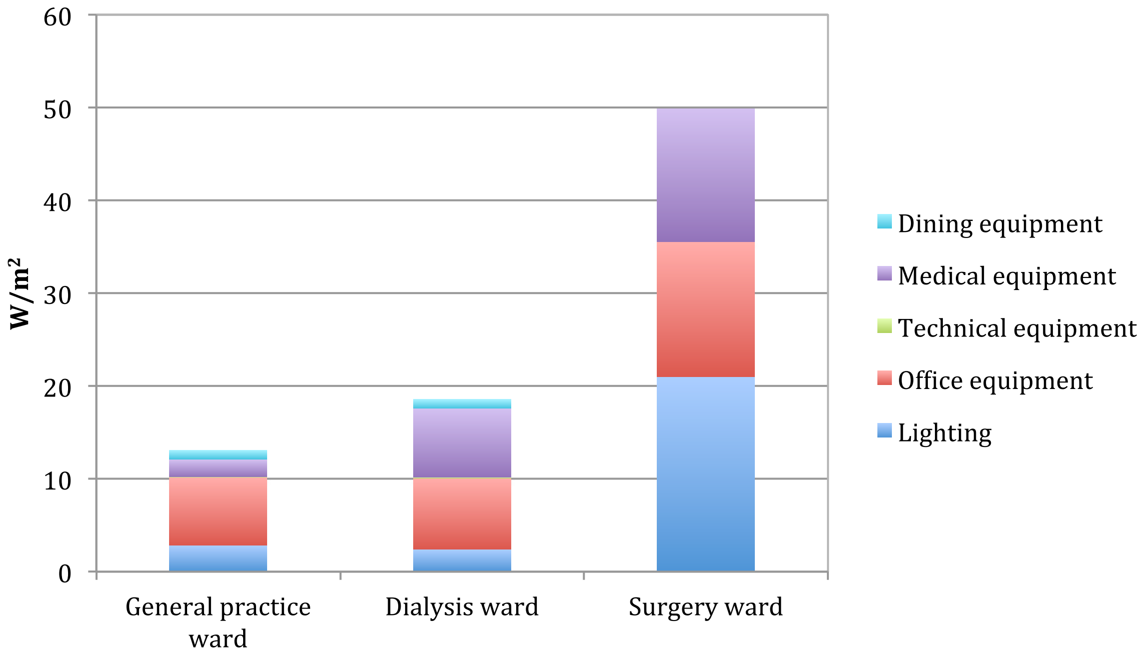

Figure 5.3 The theoretical operating electric power of the equipment in the three analysed wards during nighttime. Note the difference in vertical scale from previous two figures.

In Section 2.4 the experience regarding design of hospitals from different consulting companies was discussed. In Figure 5.4 the cooling power from the companies is compared to the theoretical operating electric power in the wards. As seen in the figure the cooling power is lower than the theoretical operating electric power in all wards. In the high technical intense hospital ward the cooling power is approximate half of the theoretical operating electric power. What should be mentioned is that the cooling power is from one consultant company only. With the same deviation as in the case with the general practice ward and the dialysis ward, the value can differ with approximate 19 W/m^2, which also is shown in Figure 5.4. Normally it is not a significant problem that the cooling power is lower than the electric power in the surgery ward. The temperature is allowed to rise a bit during the surgery and the heat surplus in the surgery room is afterwards extracted with the air distribution system when the surgery is over. Therefore, the cooling system is usually not designed to take care of the very highest peak of the internal gain.

The difference in cooling power between the different consulting companies could also be of interest. It turned out that the cooling power in a dialysis ward differs as much as 30 W/m^2. But since these values are from real projects, the reason for the difference could be that there were different conditions in the wards, with different internal heat gains. Although, the difference both regarding the theoretical operating electric power and the cooling power, and the difference between the companies, indicates that there is a problematic in the knowledge about the equipment in different wards.

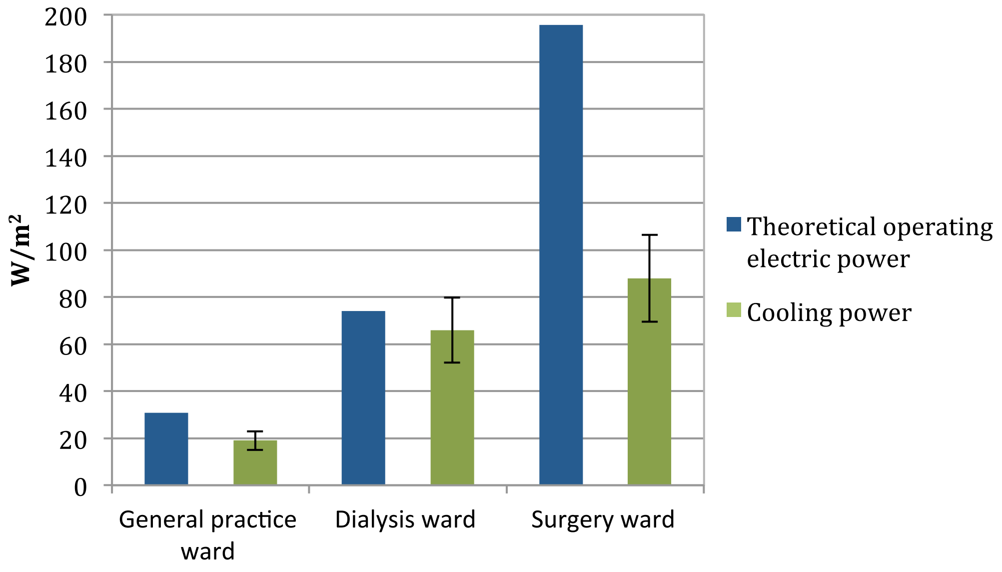

Figure 5.4 The theoretical operating electric power of the equipment compared with normally used cooling power in the three analysed wards. The error bars represent the variation in cooling power between different companies. Due to the lack of information from consultant companies, the error bar at the surgery ward is an approximation with the same deviation as in the other analysed wards.

In Chapter 4 the electric energy use of the three analysed wards was presented. It could be seen that there was a difference in the behaviour of the electric energy use depending on the technical intensity in the wards. In the low technical intense hospital ward, the electric energy use was only slightly affected by the medical technical equipment and its utilisation time; instead the main part consisted of the electric energy used by lighting and office equipment. Which also coincide with the results from the previous analyses carried out by Skåne Energy Agency, The Environmental Secretariat of Region Västra Götaland and the Swedish Energy Agency. But, the more medical technical equipment used in the ward, the more related the electric energy use was to the utilisation time of the medical technical equipment, which all can be seen in Figure 5.5.

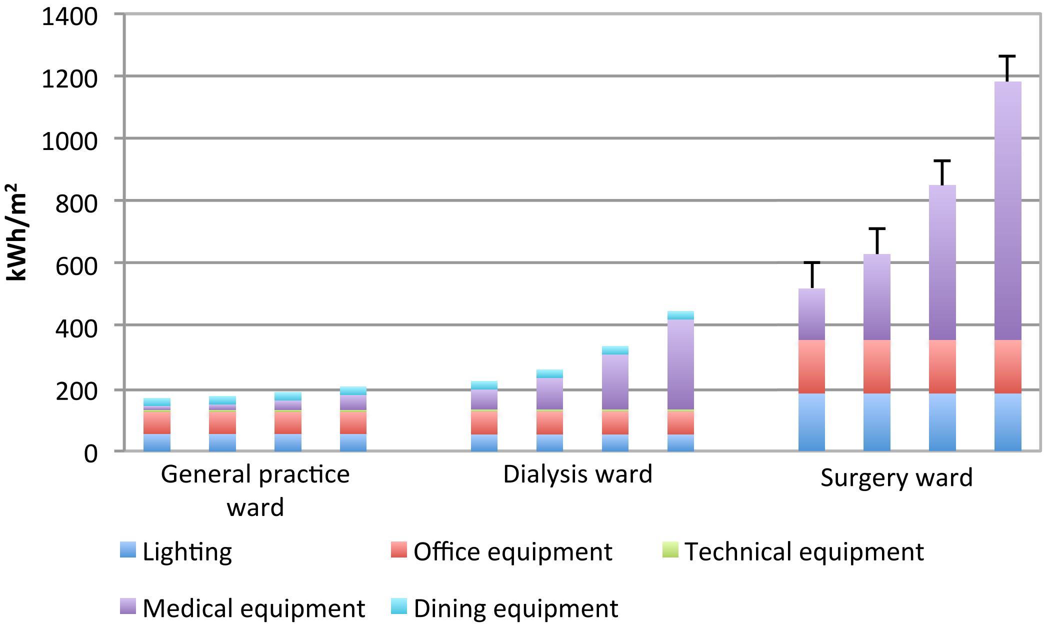

Figure 5.5 Theoretical electric energy use in the analysed wards at four different utilisation times, 2 hours, 4 hours, 8 hours and 14 hours of the medical technical equipment. The error bars that can be seen on the bars at the surgery ward represent the extra electric energy use when the X-ray equipment is used.

These results indicates how highly related the electric energy use is to both the utilisation time of the medical technical equipment, and also the type of ward and its technical intensity. This illustrates the importance of including the activity when discussing energy use in hospital facilities, due to the very large variation in wards between different hospitals.

In Section 2.3.1 four different figures were shown of the variation in electric energy dependent on what it was related to. The same results can be seen Figure 5.6, but in this case presented as percentage of the average electric energy use of these six hospitals. This comparison really points out how the result can differ dependent on what the energy use is sat in relation do. Extra attention should be paid to hospital number five. When the electric energy use is related to the building area, it has approximate 110% of the value of the average hospital. When the electric energy use instead is related to the number of treated patients during the year, it has less than 60% of the value of the average hospital. The reason to why the energy use is high when it is related to the building area but low when it is related to the number of treated patients could for instance be that they do utilise their building to a higher degree, and have a more efficient way to handle the flow of patients.

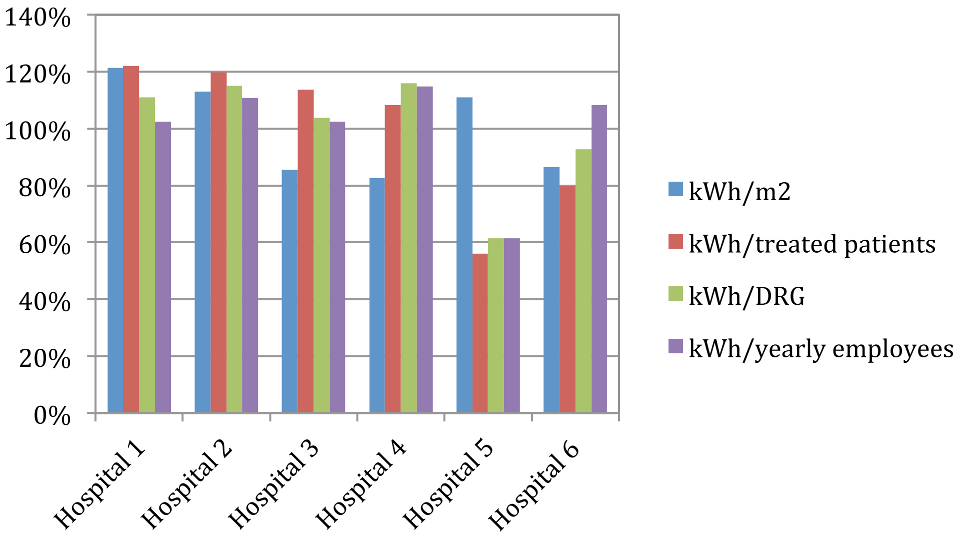

Figure 5.6 The electric energy use of six different hospitals sat in relation to four different indexes, the building area, number of treated patients, DRG-index and yearly employees. The result is presented in relation as percentage of the average energy use of the six hospitals.

Besides the result of how the electric energy use of the entire hospital varies dependent on what it is related to, the result of the electric energy use in relation to the specific area and number of treated patients in the analysed wards has been illustrated in a similar way in Figure 5.7. When the electric energy use is related to the specific area, the electric energy use is increasing with the technical intensity of the ward. When the electric energy use instead is related to the number of treated patients, the result is the opposite; the electric energy use is decreasing with the technical intensity. This indicates how highly related the energy use is to both the type of ward, and also the number of treated patients.

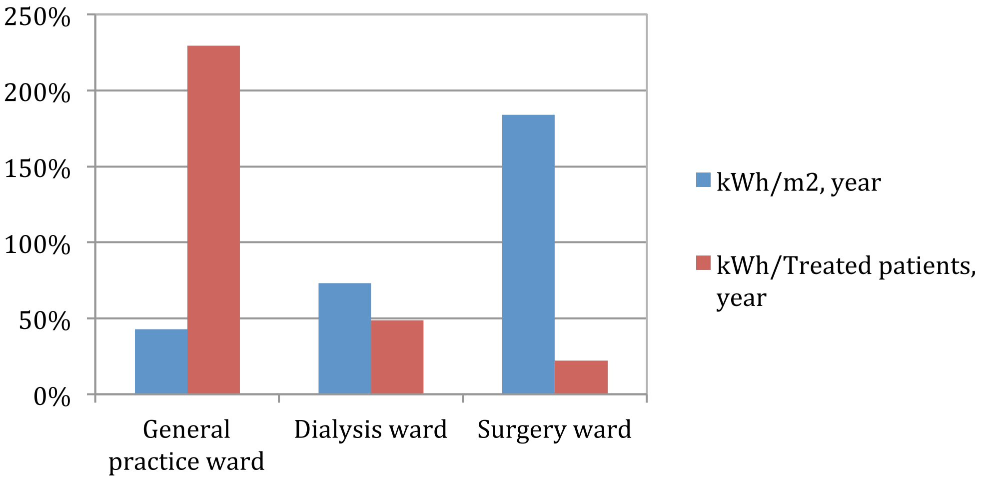

Figure 5.7 The electric energy use in the three analysed hospital wards in relation to two different indexes, the specific area and the number of treated patients in the ward. The number of treated patients in the general practise ward are 1825, in the dialysis ward 14600 and in the surgery ward approximate 5000 per year. The result is presented as percentage of the average electric energy use of the wards.

It has been seen how the electric energy use in three wards differs. When it comes to the total energy use of the hospital also the energy used by the HVAC-system must be taken into account. In Chapter 2 the requirements of the indoor climate in the different wards were presented, it could be seen that there was a wide range in requirements between the wards. The highest requirement was found in the surgery ward when in the other parts of the building there were more moderate requirements. Since the highest requirements were found in the high technical intense hospital ward, there is a need of a system that can supply more and cleaner air, and also a larger heating and cooling system. Therefore, it is obvious that this ward also will have the largest effect on the energy use of the HVAC-system.

5.2 Recommendations regarding activity related key performance indicators

In spite of that this analysis is based on a study of relatively few wards, the results show that the medical technical equipment does stand for a large amount of the electric energy use, and also the total energy use, especially in high technical intense hospital wards. During the seminary *Energi*effektivt *sjukhus – Framtidens möjligeheter* (Västra Götalandsregionen, Sustainable Healthcare, 2011), it was mentioned that the contractors are working to include requirements on energy efficiency of the medical technical equipment. But no attention was paid to what could be included in these requirements. In the high technical intense hospital ward it is not only a large amount of medical technical equipment, the highest demands on the indoor climate is also found there. Therefore, it is important to have in mind that it is not only the equipment's electrical energy use that affects the total energy use, but also the climate system in the ward. Factors that could be of interest to include in these requirements are of course low electric energy usage, but also requirements how the heat surplus is taken care of, in other words what kind of cooling used.

Most of the key performance indicators that have been discussed in Chapter 3 were expressed either in relation to a specific area or the design volume airflow. This is the typical way of how these are expressed today. That may work very well when it comes to buildings that have an activity that is similar in all the buildings within their category, as residential buildings, schools or offices. As an example, office buildings, it does not matter what kind of office building, they are all generally occupied during working hours and have similar equipment independent the occupying company. But, it has above been pointed out that in a hospital building it is not that simple. The energy use is very much connected to the activity, with other word what kind of healthcare that is given in the facility and the operating hours of the hospital. Therefore, there is a need of including these factors when discussing energy use in hospitals.

Since the building sector prefers to express most of the information in relation to a specific area, that should be the main expression also for the energy use. But, to give a more accurate information also complementary expression should be added, where for instance the number of treated patients is included or another index that includes the activity. The main focus in a hospital building must be to have a low energy usage to a high level of healthcare, not a low energy use divided over a large building area.

5.3 Conclusions

The results indicate that independent of type of ward, lighting and office equipment stand for a very large amount of the electric energy use. Furthermore, in moderate and high technical intense hospital wards, also the medical technical equipment significantly affects the total electric energy use.

These results denote that during the design phase, the low technical intense hospital ward can be handled as any typical commercial facility. Hence, most of the equipment found and used in these kinds of wards are lighting and office equipment. In the moderate and the high technical intense hospital ward there is another situation. In the moderate technical intense hospital ward the equipment with high electric power, characterises by relatively short utilisation time. Even though this equipment does not have a very long utilisation time it still contributes to a large part of the total electric energy use in the ward. Moreover, it contributes to the energy use of the HVAC-system. Hence, the HVAC-system has to be designed to be able to take care of the power-peaks that the equipment creates. The high technical intense hospital ward characterises by its intensity of advanced equipment with high electric power. This equipment affects to a large extent the electric energy use in the ward, additionally to a wide degree the energy use of the HVAC-system, to keep the indoor climate in line with the requirements.

During the phase when aims for the energy use are formulated, in projects with new production as well as in refurbishment projects, it is essential that these aims are realistic. This analysis points out the need of activity related key performance indicators. It is not obvious what key performance indicator that is most suitable, in Figure 5.7 it could be seen how the energy use decreased with technical intensity when the energy use was related to the number of treated patients, and the opposite when it was related to the building area. Therefore, to get an accurate value more than one key performance indicator should be used when the energy use is expressed. Furthermore there is a need of further improvement and development of activity related key performance indicators that include the building area, the flow of patients and the complexity of a healthcare facility.

Due to the reasons mentioned above, it is not optimal to talk about the energy use of the entire hospital without mentioning anything about the activity in the building. The energy use in a hospital is too much related and dependent on what kind of wards and theirs utilisation time it consists of. Therefore, it is more preferable to divide the hospital into different categories. In this report, the difference has been presented for three different cases. This is a start, but a more refined partitioning of the hospital would be desirable, to get an even better accuracy in the results.

5.4 Suggestions of further investigations

Since there is a lack of information about the medical technical equipment used in different wards, I would like to suggest that further studies are performed. Some factors that would be of interest to study more in detail is how the real operating electric power stands in relation to the maximum electric power of different equipment, but also the real utilisation time of different kind of equipment.

Further on, I would like to suggest that the work with a refined partitioning of the hospital is carried out. To analyse more in detail the difference between different wards. And also, to work further on with a system of how to present the energy use with a key performance indicator that also takes the activity into account.

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