KPI’s energy consumption analysis of Isolation Rooms in Hospitals

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Abstract
The energy use of hospitals is among the highest of all building types. Within this specific group the academic hospitals, the high care hospitals, form a specific group with an even higher energy use. Given the necessity to reduce the energy demand, it is important to look for opportunities to reduce it without endangering the primary functions within hospitals. The HVAC energy reduction potential of isolation rooms in EMC is approximated using the Pareto analysis method, which enables to solve the majority of problems assessing the few major causes, called Key Performance Indicators (KPIs). Special focus was on the barrier function within the isolation concept of an intensive care unit. An energy management study in Erasmus Medical Center (one of the University Medical Centers that face challenges in defining energy reduction measures) revealed isolation rooms to be a large energy consuming healthcare function. This formed the starting point to define a framework which lead to long-term energy reduction in the complex building systems of UMCs.

Keywords – KPI’s, Pareto analysis, Energy reduction, Isolation rooms, Intensive Care units

Introduction
The world’s energy consumption raises concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts. Of this world’s energy consumption, 20-40% is used in the building sector of developed countries [1].

Energy reduction potential of University Medical Centres (UMCs)
Literature review shows hospitals to be one of the large consumers of energy in the building sector. Approximately 6% of the total energy consumption in the utility buildings sector is represented by hospitals’
energy consumption [2]. In the Netherlands, the healthcare sector consumes 1.64% of the energy consumption, of which 64% is consumed by UMCs [3]. Preliminary research revealed that UMCs have high potential for energy reduction in their heating, ventilation and air conditioning (HVAC) systems. However, if sustainability is considered, UMCs encounter problems in defining reduction measures and detecting inefficiencies due to the complex nature of their building, building systems and operational processes. Measures taken in order to reduce energy consumption or increase energy efficiency are often insufficiently founded, and guidelines, regulations and governance provide often only little guidance. Energy consumers, energy flows and energy wasting components are often unknown, resulting in uncertain parameters for sustainable energy reduction investments. The preliminary research concluded that energy management protocols require a framework, by which good practices can be established to support energy reduction.

**Energy consumption of the HVAC system**

HVAC systems consume approximately 50% of the total primary energy used in UMC buildings [4]. Operational optimization of these systems is not an easy task since many interrelated building parameters, building user characteristics and building services components influence the operation and performance of these large-scale HVAC systems. The main problems in the optimization process are the difficulties in detecting inefficiencies and intricate relations between the energy consumption and influencing parameters [5].

The majority of the research already performed on energy reduction in UMCs, was aimed on efficient generation of energy, compared to little research on the HVACs energy demand and supply (actual energy consumption), although its energy reduction potential. Awareness of user influences on HVAC systems is an important, but fairly unknown parameter of the demand [6].

Often there is not enough internal support for energy reduction, as hospital care providers are in lead in decision making and are reserved towards energy reduction and sustainability. On the other hand, they possibly do not have enough information and insight in the energy consumption. It is a challenge for the engineering working field to create this support. During energy reduction considerations, hospital healthcare providers need to be convinced that equal ‘patient safety’ can also be achieved with less energy. Additionally, this means that research on energy reduction requires engineers to take patient safety, as far as it is provided by the building systems, into account [7].
HVAC system in isolation rooms

One of the UMCs in the Netherlands that face challenges in reduction of HVAC energy consumption is Erasmus Medical Centre Rotterdam (EMC). This UMC is used as case study in order to define a framework towards efficiently management of energy reduction potential in UMCs. In order to constrain the complexity of the HVAC systems and its energy consumption, the large energy consuming functions of a smaller building complex: EMC Sophia (Children’s hospital of EMC) are identified in preliminary research. The complexity of defining energy reduction measures is performed by first focussing on the largest energy consuming functions. This largest energy consuming function was identified, analysing the energy intensity and the total energy consumption of the healthcare functions. The energy consumption per healthcare function was differentiated and ranked from the smallest to the largest energy consuming functions, taking the energy intensity (GJ/m²) into account, and project this intensity to the gross floor area.

The research revealed a high-energy reduction potential in isolation rooms (compared to other functions), as these rooms are high-energy intensive functions due to their high ventilation rates and continuous operation (energy intensity), and their amount of gross floor area.

Problem definition, relevance of problem and research

UMCs in general suffer from a lack of a consistent and homogeneous framework for energy reduction, due to complexity and diversity of their HVAC systems. Insufficient understanding of HVAC influencing parameters caused by a lack of systematic energy management, analysis of HVAC systems and knowledge about the energy demand and supply contribute to an ad-hoc approach of energy reduction measures, instead of desired long-term energy reduction. Systematically approaching the energy reduction potential in UMCs requires a consistent framework.

In this research the ‘Pareto analysis’ method, as known in other fields, is used as a guideline for the development of an energy reduction framework for UMCs. In order to define this framework as a step towards guided HVAC energy reduction in UMCs, EMC is selected as case study. EMC is a compact UMC, includes all healthcare functions, provided in a good cooperation during preliminary research, and already has knowledge and experience on this topic. As EMC is continuously under construction, EMC Sophia is used as case study, as this part of the building complex is not under construction during this research. A defined framework enables a
present and future (systematically) energy reduction in EMC, and other UMCs or buildings with complex HVAC systems.

The motivation for energy reduction in EMC is to pursue a good company governance that enables ‘long-term’ energy reduction instead of ad-hoc measures. UMCs in general are driven by consciousness of a rising trend in energy consumption. They encounter a growing energy consumption, which combined with the forecasted rising costs of energy, result in significant higher energy costs. As well as awareness of prevalent and increasing environmental problems (climate change, CO₂ emissions, etcetera) to which their energy consuming activities contribute. All UMCs participate in the ‘Meerjarenafspraken 3’ (MJA3), a covenant to achieve 2% energy efficiency per year.

**Methodology**

The Pareto analysis, also known as the 80/20 rule, assumes that: the majority of problems (80%) can be identified by a few major causes (20%), or 80% of the problems can be solved with 20% of the effort. This analysis method is often used in decision-making issues, or in solving complex problems in for example the industrial engineering. An example of a proven applicability of the Pareto Analysis is found in, where the stem making in a lamp production process is responsible for more than 87% of the total defects [8]. Other examples are:

- 80% of the complaints of clients is a result of 20% of the products or services;
- 20% of the products or services resulting in 80% of the profit;
- 20% of the system failures cause 80% of the system problems.

Figure 1 illustrates this Pareto analysis, in which the required effort (causes) is plotted against the solutions (problems) [9]. According to this definition of the Pareto analysis, the hypothesis has been formed that the Pareto analysis was also applicable to energy reduction. Where the Pareto analysis identifies the few major causes that result in the majority of energy consumption problems. If improvements, in for example energy reduction, are made for individual systems and there is no defined basis, the energy still consumed would produce disappointing results (as the ongoing concerns on energy reduction). A Pareto analysis is a useful tool to draw attention on concerns, and target the most important problems that affect the energy consumption. The analysis identifies problems and rates the influencing parameters, resulting in the most important parameter to focus on first. “It is normally easier to reduce a tall bar by half than to reduce a short bar to zero.
Significantly reduce one big problem, and then hop to the next”, as cited by [11].

Fig. 1 Methodology based on the Pareto-analysis. Majority of problems (80%) can be identified by a few major causes (20%) [9]

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<td>2. Identify the root causes of each problem (RCA)</td>
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Fig. 2 Basic steps of the Pareto analysis. Step 2 includes the Root Cause Analysis (RCA)

Figure 3 illustrates a Pareto diagram applied on the energy reduction problem of this research. On the x-axis the problems which causes the energy consumption, and on the y-axis the energy consumption. The 80% value line illustrates 80% of the energy consumption, which is assumed to be
caused by 20% of the problems. If primary problems are identified, the problems can be solved by defined corrective actions.

**Pareto diagram**

![Pareto diagram](image)

Fig. 3 Pareto diagram projected on the energy problem. Primary problems are differentiated and are rated to their energy consumption. The dotted line indicates the 80/20 rule: 80% of the energy consumption can be solved with 20% of the influencing parameters.

If the primary problems are solved, the same technique can be used in a new Pareto analysis, in which again new primary problems can be distinguished (continuous improvement). The Pareto analysis includes six basic steps, as illustrated in Figure 2.

**Step 1 and 2: Identify problems and root causes of problems**

Main problems of energy consumption are indicated using data based on calculations, observations, interviews and reports. The cause-effect of these problems can be identified by a RCA, which defines the nature of the problems. The RCA includes defined basic steps:

1) Collect data: Systematically collect data and notify the problem. Determine for how long this problem has been occurring. Determine the frequency (quantify) and the impact (if the problem will not be solved) of the problem.

2) Define and classify possible causes: Identify how and under what conditions the problems arise, and identify what other problems arise if these identified problems are solved.

3) Define root causes: Define the causes that induce the problems and define their correlation.
Step 3, 4 and 5: Rank, score and group problems (prioritization)

Identified problems are ranked to importance, scored and grouped together. An example of ranking in a financial approach, is the gravity of the problem concentrating on the organizational costs. If the main cause of the organizational costs are customer dissatisfaction (group), the focus is on the number of complaines.

Step 6: Take action (corrective actions)

As the problems are identified, an action plan with improvement actions can be formulated in order to solve the problems.

Case study definition for testing the hypothesis (Pareto analysis)

The case study (EMC) as used for testing the Pareto analysis is revealed in this paragraph. First a description of EMC and EMC Sophia is given. Secondly, the preliminary research on the function that has most potential for energy reduction (isolation rooms) is shortly described. EMC is, with 345,000 m² in size, the largest UMC in the Netherlands [12]. EMC is constantly changing; it is currently being rebuilt and renovated. As EMC Sophia (the children’s hospital of EMC), is least susceptible to change throughout the research, this research focuses on this building complex. Figure 4 designates an overview of EMC and EMC Sophia. The steps of the Pareto analysis were followed in the study.

Differentiate energy consumption to functions

The first step for accessing the energy reduction potential in EMC was defining a case study. This case study was defined through differentiation of energy consumption to functions, and was performed in preliminary research. The large scale and complexity of the HVAC systems in EMC was not a manageable situation, and needed to be addressed on a smaller scale. Therefore, preliminary research outlined the energy consumption of different healthcare functions in EMC Sophia. The outcome of the preliminary
research were the energy intensity and the total energy distribution per healthcare function. The research revealed the healthcare function with most potential for energy reduction: isolation rooms.

**Key Performance Indicators**

In order to efficiently define potential energy reduction measures in EMC, KPIs of energy consumption in isolation rooms were defined. The Pareto analysis was assumed to be a useful method for defining these KPIs.

*Step 1 and 2: Identify problems and identify the root causes of each problem*

The first step of the Pareto analysis identified the problems (energy consuming parameters) of the large energy consuming HVAC systems in isolation rooms. In this first step, hand calculations and simulations were used. The root causes of the problems were analysed using a Root Cause Analysis (RCA), a well-known method used in the second step of the Pareto analysis.

*Step 3, 4 and 5: Rank, score, group problems*

The energy influencing parameters were broken down and grouped into five prospective (use influences, setpoints, building, system operation and external influences). The prospective including the parameters were scored and rated using a probability-impact analysis. A high probability and large impact means a high energy reduction potential. The outcome of this analysis were KPIs (user presence and occupancy, room temperature and air changes per hour (ACH)), which represented the focus of the research on corrective actions.

**Corrective actions**

The corrective actions were part of step 6 of the Pareto analysis. An action plan was described in which improvement actions on the KPIs (user presence and occupancy, temperature and ACH) were determined and formulated. Corrective actions resulted in a useful solution of energy reduction. Alignment of the actual system operation to the users energy demand, potentially leads to energy reduction. In order to determine the magnitude of this energy reduction potential, a building simulation model was used. The quantified user influences and their related system operation as specified in the corrective actions of the previous step, were used as input for the building simulation model and defined the theoretical energy demand. The outcome of this simulation was compared to the energy consumption of the actual HVAC operation, for which the same simulation model was used. Input of the actual HVAC operation in the simulation model was obtained from field measurements.
The large scale and complexity of the HVAC systems in EMC is not a manageable situation, and needs to be addressed on a smaller scale. The Pareto-analysis is a practical way of identifying causes of problems, and it encourages analysing and organizing. It is proven to be a successful systematic approach in for example economic aspects [10]. The analysis encourages to identify the primary causes that need to be addressed to resolve the majority of problems. Once the predominant causes are identified, a root cause analysis (RCA) can be used to identify the root causes of the problems (continuous improvement analysis). A RCA is a systematic approach for defining the nature of problems. The RCA is a part of the second step in the Pareto analysis. The energy consumption of EMC Sophia is differentiated to functions, see figure 5 and figure 6. Two large energy consuming functions are marked as important functions to focus on: both surgery rooms and isolation rooms consume, overall (GJ) and per square meter (GJ/m²), significantly more energy than other healthcare functions.

Fig. 5 Local heating, cooling and fan energy demand per healthcare function/m² respectively total energy demand per ealtcare function [GJ]in EMC Sophia. Surgery (SR), bedroom (BR), intensive care (IC), treatment and examination room (Tr. & exam.), assessed using Vabi Elements building simulation

Conclusions

The Pareto analysis is assumed to be a useful method for research on energy reduction potential in buildings with complex building systems, which need a systematic approach (energy reduction in UMCs). This hypothesis was tested using the case study as described. This case study is selected according to a differentiation to functions, in which the largest energy
consuming function (based on energy intensity and total energy consumption) is designated to approximate the HVAC system energy reduction potential in EMC, and to test the Pareto analysis. The Pareto analysis was found to be a useful approach for future research on energy reduction potential of other functions in EMC, UMCs or other buildings with large and/or complex HVAC systems.

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