KYMENLAAKSO UNIVERSITY OF APPLIED SCIENCES
Energy Technology / Automation Engineering

Mikko Suikkanen

METHODS OF ENERGY EFFICIENCY ANALYSIS

Bachelor's Thesis 2014

ABSTRACT

KYMENLAAKSON AMMATTIKORKEAKOULU
University of Applied Sciences
Energy Technology

SUIKKANEN, MIKKO	Procedure of Energy Efficiency Analysis
Bachelors thesis	27 pages + 4 pages appendices
Commissioned by	Kymenlaakso University of Applied Sciences
Supervisor	Arja Sinkko, Team Leader
Commissioned by	Step to Ecosupport
November 2014	

Keywords energy, energy efficiency, heat recovery, renewable energy sources

Ever since the Kyoto protocol, the environmental awareness has been a growing tendency. This new wave in politics has led to emission caps and emission trading scheme that try to inhibit the production of greenhouse gasses. The growing tendency towards energy efficiency has come to the point where everyone are demanding and marketing energy efficient solutions even if the concept of energy efficiency is poorly defined.

The aim of this research was to present quality control methods as a tool for optimization in energy use. This research is a part of work done in Step to Ecosupport project where different practices and ideas were tested and researched. During this project, a group of different types of buildings were audited. This gave wide perspective to energy efficiency in different processes.

This study is not complete nor final result but rather a solid base on which the future research can be based. This is not a manual because there are quite few actual “things to do”. Instead, this should be the direction of the future energy use.

TIIVISTELMÄ

KYMENLAAKSON AMMATTIKORKEAKOULU
Energiatekniikka

SUIKKANEN, MIKKO	Energiatehokkuusanalyysin Toimintamalli
Opinnäytetyö	27 sivua + 4 liitesivua
Työn ohjaaja	Tiimivastaava Arja Sinkko
Toimeksiantaja	Step to Ecosupport
Marraskuu 2014	

Avainsanat energia, energiatehokkuus, lämpö – talteenotto, uusiutuvat energialähteet

Energiatehokkuus on jatkuvasti nousussa oleva trendi. Ilmastosopimukset ja EU:n päästötavoitteet vaativat kasvihuonekaasujen vähentämistä. Silti ekotehokkaat energiaratkaisut ovat yhä toistaiseksi poliittinen pelinappula.

Energiatehokkuudella pyritään vähentämään energian kulutusta toiminnoista tinkimättä. Käyttämällä vähemmän energiaa tarvitsee sitä myös tuottaa vähemmän. Suomen energiasta yli puolet tuotetaan fossiilisilla polttoaineilla, jolloin säästö energian tuotannossa vaikuttaisi huomattavasti myös Suomen päästötavoitteisiin.

Energiatehokkuus toimintamallin keskeisenä ajatuksena on esittää laadunohjauksen käyttöä energiatehokkuus analyysissä. Tällöin energian kulutus ajatellaan ”virheenä”, joka koetetaan minimoida.

CONTENT

USED ABBREVIATIONS AND TERMS

COP	Coefficient Of Performance; ratio between electricity used and heat energy transferred
DMAIC	Define, Measure, Analyze, Improve, Control; The core thinking of six sigma quality management method
EEA	Energy Efficiency Analysis
ETS	Emission Trading Scheme
EU	European Union
INES	International Nuclear Events Scale; a scale to rank nuclear incidents by their severity and area of effect /3/
kW	Kilowatt; 1.000 W
LED	Light-Emitting Diode
PVT	Solar collector that generates photovoltaic electricity as well as collects thermal energy
R404a	Heat transfer substance; combination of R125, R143a and R134a
R717	Heat transfer substance; Ammonium
RCM	Reliability Centered Maintenance; quality control method
RCM, Streamlined	Lite version of RCM
Six Sigma	Quality control method; alternated writing 6 sigma
TPV	Solar collector that collects thermal energy as well as generates photovoltaic electricity
W	Watt, base unit for energy

PREFACE

Energy efficiency is a phrase that is used everywhere and many bachelors theses have been made about "how to improve the energy efficiency of xxx" but so far there has been no unambiguous explanation for term "energy efficiency".

While I do not claim to define the term thoroughly, this research still aims to make sense to this term as well as maybe to help others to identify, analyze and improve energy inefficient processes and working methods. Energy efficiency analysis is not and should not be treated as a specific tool, like a hammer, but rather as a way of thinking and doing things.

My personal gain from this study was enormous. What begun as yet another form of an audit, for the ice rinks specifically, grew into something quite different. When I started writing this paper, I never ever had heard about an idea of linking a quality management into energy efficiency. Nor had I ever thought about an idea of seeing all energy consumption as a fault, and use the tools of a quality control as a tools of an energy loss elimination. Personally, I could say I have grown along with my work, and thanks to this thesis, I even have started to view the things differently.

I wish to thank my colleagues and supervisor. You helped me to refine all the thoughts into coherent document. I also wish to thank my family for understanding me while I spent all my time writing this thesis. Your support was vital to me.

1 INTRODUCTION

In the beginning, the methods of energy efficiency analysis was going to be an energy efficiency study concerning ice rinks. As project proceeded, the ice rinks became a minor part of the research as focus moved into challenging energy consumers. This thesis was originally going to be a handbook for energy audit on ice rinks but it evolved into energy efficiency analysis overall.

Energy efficiency analysis is a tool that helps to understand where energy is spent and if the energy consumption is at the level it could be on this day with modern technology and information. It provides the means to control and improve the quality of the process. The purpose of this document is to help understand the process and meaning of energy efficiency analysis.

The need for this research rises from the political attitude and environmental protection. These facts have partially been a reason for Finnish-Russian joint project, Step to Ecosupport, which focuses on energy efficiency of public buildings. Continuation of this work will be Ecool -project. It is a Finnish project focusing on challenging energy consumers and good practices in energy efficiency analysis.

First, a short historical overview is presented explaining the use of energy as we know it today and why it is critical to control and reduce that use. Then the analysis is divided into smaller parts and explained in detail. Before conclusions, some real life case studies are presented where this analysis has been applied.

2 BRIEF HISTORY OF MAN AND ENERGY

Even the early caveman knew the secrets of fire. Ever since, the use of energy has been part of the life of mankind, be it wind power in sails or wind mills, hydro power in watermills or fire for cooking, heating or metal work. It had no major part in human life before the time of steam engine and industry, and at later stage the discovery of electricity.

2.1 The history of energy production in nutshell

With the discovery of steam engine in the beginning industrial age, the consumption of energy, usually in the form of coal, skyrocketed when compared to what it used to be in the earlier 18th century.

Another remarkable invention saw the light in the 19th century – electricity. Although this physical phenomenon had been known for centuries, it was not before this era that mankind could properly harness the secrets of electricity. Electrical engines, light bulb and countless other machines and products utilizing this new form of energy made growing demand for power plants to supply electricity.

Even the mineral oil was known ever since 4000BC but it had no significant use apart for being refined to lamp oil. This changed with combustion engine and oil became major part of the modern, industrial civilization with Ford T-model, a car that anyone could afford. Since those days, oil has been the energy source that keeps the world running. /1/

Next major breakthrough in the field of energy came after the second world war. During this great strife, the German scientists had been working on atomic bomb. Americans perfected the design with well known consequences as well as turning it into power source. The nuclear power plants became a great success, not only because they made virtually no pollution but also because of cheap fuel. /2/

The Guardian has listed 34 significant nuclear accidents during the history of nuclear energy. One accident has reached the INES rating 7 (Chernobyl), one reached level 6 and four reached level 5 (one being Fukushima) /4/.

Yet it was not before Fukushima when the popular opinion started to turn against the nuclear energy. In the aftermath, Germany announced a plan to shut down its nuclear power plants in accelerated schedule.[1] This has resulted in increase in use of coal power plants. /5/ France have not made decision one way or another /6/

The modern age searches the answer for ever growing energy demand from fusion power and renewable energy sources, such as wind or solar power. There are several factors that have led mankind to look into these new alternatives.

2.2 Political attitude, also known as climate change

Growing pressure into environmental issues from general public led to Kyoto protocol in December 1997. It took effect February 2005. The aim of the protocol was industrialized countries to reduce the greenhouse gas emission by 5.2% compared to the emissions of the year 1990. The emissions have been growing at almost constant rate in spite of the protocol. /7/ /8/

As a response to Kyoto protocol, the EU started emission trading scheme in 2007[2]. /9/ The basic idea of emission trading is ”to reduce emissions where it is economically most feasible” /10/

The EU has also set goals for energy production and quality. These are:

- 20/20/20 – by the year 2020, 20% of energy should come from renewable sources, energy efficiency should be increased by 20% and green house gases should be reduced by 20%.
- 20/30/40 – by the year 2030, 27% of energy should come from renewable sources, energy efficiency should be increased by 30% and green house gasses should be reduced by 40 %.

1 Decision that has been criticized, for further reading see Potsdam Institute and University Leipzig study on the subject: https://www.pik-potsdam.de/members/knopf/publications/Knopf_Germanys%20nuclear%20phase-out.pdf

2 The EU ETS has been criticized for hampering the competence in Europe, for not having any major effect in carbon emission or for being implemented in wrong ways. In spite of this the EU ETS has been seen as one of the best tools in use these days: http://www.cccep.ac.uk/Publications/Working-papers/Papers/120-129/WP126-effectiveness-eu-emissions-trading-system.pdf

The EU directive concerning energy efficiency covering the production and the use of power in public and private sector came into power 4th of December 2012. This includes everyone and every mean to save energy or increase efficiency will help to achieve the aim. /11/

2.3 Energy efficiency and renewable energy sources

There are two ways of reducing emissions: use less energy or use less services that use energy. These are called energy efficiency and energy conservation. Energy efficiency should not be confused with energy conservation. In some cases, the use of less service is not a viable solution. For example, ice rink would not be able to sustain ice if the cold process is used only half the time.

Yet another solution for energy efficiency, especially when reducing the energy use is not an option, is to substitute energy production with renewable energy sources. Usually these include, but are not limited to:

- Photovoltaic, or solar electricity (PV)
- Solar collectors for heat (T)
  - surface collectors
  - tube collectors
  - also hybrid panels; PVT and TPV for heat and electricity production
    - PVT = Photo voltaic, Thermal; mainly produces electricity, also heat
    - TPV = Thermal, Photo voltaic; mainly produces heat, also electricity
- Wind turbines for electricity
- (Geothermal) heat pump

The use of wind turbines to produce electricity in Finland is common in large scale but seldom seen implemented locally. The windmills are restricted by Finnish law. Large scale plants (over 50kW) are prohibited near residential area. Additionally wind mill of any size need to fulfill some environmental restriction, noise and flickering for example. Wind mill will also require either building permit or action permit.

Heat pumps and geothermal heat pumps are quite common in residential areas and heat pumps are commonly used to cool office buildings. There are also systems that make use of exhaust air from air conditioning; exhaust heat pumps produce hot water and heat recovery systems warm up the intake air. /11/

These are examples of the renewable energy sources. These should be inspected separately in each case since there may be some limitations or benefits for using certain energy sources in certain cases. Most often these limitations include, but are not limited to location, energy storage or environmental issues.

In many cases, the use of renewable energy sources in small scale could be profitable in large scale. If decentralized power production would be more supported, it might be easier in the long run for Finland to meet the EU goals of 20/30/40. This way the installation and upkeep costs would be divided between users, and electricity would not have to be transferred over long distances thus causing less losses in transfer lines.

3 BASICS OF ENERGY EFFICIENCY ANALYSIS

Energy efficiency analysis (EEA) is a method to improve the process. It uses the same ideology as six sigma quality control method, more precisely DMAIC (Define, Measure, Analyze, Improve, Control). EEA is designed for the energy consuming processes. /12/

In this process, the energy consumption is seen as fault, and according to the philosophy of quality management the number of faults should be kept in minimum. High consumption is identified, isolated and divided into the most basic processes. These processes are studied one by one in order to find the means to improve them. The analysis is equally suitable to housing and office buildings as it is to industrial applications and processes.

3.1 Purpose of the analysis

Energy costs money, energy saved is money saved. This is the ultimate paradigm of economy. On the ecological side, the most green energy is the energy not produced. The environmental targets of the EU demand the change in the ways of energy consumption but consumers do not wish to downgrade their way of living.

There are already energy certificates for houses and home appliances, LED lights are displacing halogens and traditional light bulbs, zero-energy buildings are built. There are still many older buildings, industrial applications and processes. All these have to be upgraded to meet these new standards of energy use. EEA is a tool to make this happen.

3.2 Methods of the analysis

EEA can be divided into five distinguishing parts: defining the problem, gathering information, analyzing the information, improving the process and controlling the improvement.

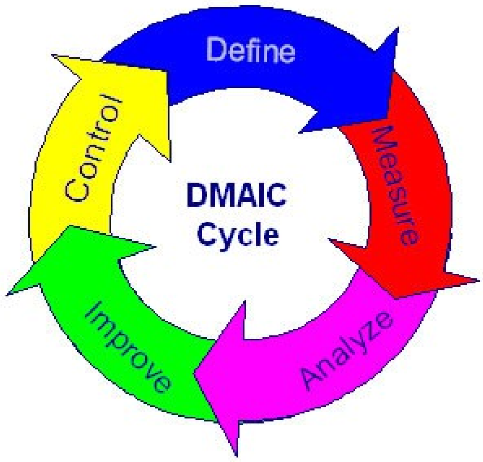

Figure 1: DMAIC; source: http://esselsolutions.com/strategy.asp

3.2.1 Defining the problem

During this first step, the whole picture is assessed and the overview of the system is under scrutiny. Defining the problem can be phrased into question ”why are we using so much energy?” or ”could this process be optimized to use less energy?”.

During the definition step, the problem (building or process) is seen as whole. The problem is analyzed and classified. For this, all the background data should be available including flow charts, consumption numbers and other relevant data. The clear overview of the target is required in order for problems to be defined accurately.

The problem usually emerges from either of two sources. One is that client acknowledges the problem and wishes to do something about it, the other is that the building goes under energy audit (or similar process) during which the problem is found.

3.2.2 Gathering the information

Before information can be gathered, the problem needs to be divided into individual faults. Each point, that may posses a possible fault, should be identified. The measurements should be planned for each of these points. Such point is not necessarily a single physical spot in the process but it may be a part of or maybe even a process of its own.

This preliminary planning should be done for each of these points. While information about the whole process is gathered preferably at one time, the key points need to be known forehand because it is not usually possible to measure every single variable in the process.

One final aspect to take into account when gathering the information is the correctness of the data. Also, the importance of the data should be a factor. Measuring data that has no meaning in the analysis can cause confusion during the analysis.

3.2.3 Analyzing the information

This is the most important part of the analysis process. If data collected is analyzed poorly or incorrectly, the data gathering has no use, and, improvements are very likely to be designed in wrong fashion, e.g. most likely being evaluated as profitable or non-profitable when in fact, the opposite is true.

There are several different processes for analyzing the information. Many methods for quality control are usable at this point. Typical ways to analyze the information include, but are not limited to comparing results to documentations, confirming that everything is working as designed, comparing results to earlier suspicions, confirming or rejecting the suspicions, identifying the high consumption points and focus on them.

3.2.4 Improving the process

Improvements are created separately for each of the points defined earlier. It is also possible that the data analysis reveal no known options for the point in question. Improvements may also include the changes in operating or using the process.

Similar solutions from earlier cases can be used as reference both when finding solutions and when justifying possible improvements to client.

3.2.5 Controlling the improvement

This is usually a neglected but never the less important part of the process. It involves the repetition of measurements as they were originally performed after the implementation of improvements. Measurements should be taken again three years after the last analysis.

The purpose of these measurements is to ensure that improvements are functioning as designed and there are no new sources of degeneration in the process. The information from the latest measurement can also be used to improve the process as it incorporates the process of analysis within it.

This step also provides research data for selected improvements. By gathering the control measurements and information, a resource base can be built. It can be used as a source for possible improvements implemented in similar cases in the future or as comparison data for control measurements.

4 METHOD OF ENERGY EFFICIENCY ANALYSIS

The main points in EEA are information gathering and analyzing. Gathering the information is by itself a quite critical part since the accuracy of the information and its relevance contribute directly to analysis. Nevertheless, the information analysis is undeniably the most important part.

The main difference between EEA and energy audit is that energy audit is a systematic list of steps to do. EEA is an analytic approach where the whole energy consumption of the target is opened and studied with various methods.

In Finland Motiva Oy offers information, solutions and services about energy efficiency for public administration, corporations, municipalities and consumers. It is former Energiansäästön palvelukeskus, founded 1993, which became a government owned corporation in 2000. Motiva has produced practices for energy audit[3] as well as audit procedures for cold processes[4]. /13/

---

3 http://www.motiva.fi/toimialueet/energiakatselmustoiminta/tem_n_tukemat_energiakatselmukset/energiakatselmus_kaynnistamisesta_seurantaan

4 http://www.motiva.fi/files/3097/KYTE-analyysi_Kylmajarjestelmien_energia-analyysimalli.pdf

Here the main point is on six sigma, RCM (Reliability Centered Maintenance) and FMEA (Failure Mode and Effects Analysis) but other quality management tools are equally well suited for EEA.

4.1 Defining the problem

The problem definition is the first phase in analysis process. During this phase, the preliminary data is either provided by the client (consumption numbers) or gathered by other means (common knowledge, building database and other similar sources)

This phase is about outlining what the problem is. This “sketching” can be done in numerous ways, for example by using streamlined RCM or FMEA, or both. The definition of the problem formed in this point is detailed in later phases. /14/

4.1.1 Streamlined RCM based defining

When applying RCM based defining model, the preliminary information is placed into table. Using this table, a sample graph is formed. This graph will help in dividing the problem into parts.

The bar graph is based on consumption numbers, either documented or measured. For example:

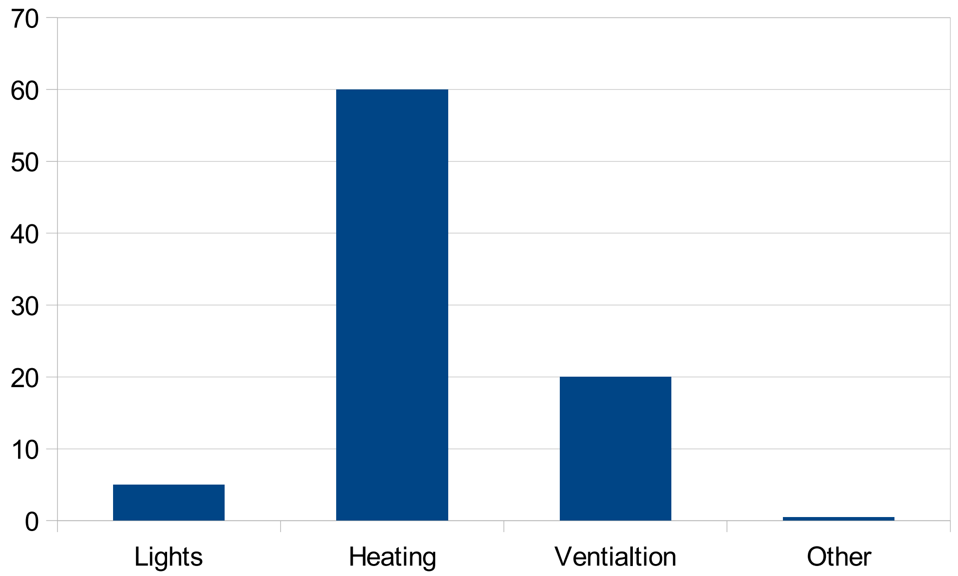

Figure 2: RCM example chart; source: KyAMK EnergyLab

From this graph we can identify that 90% of all energy is used by heating and ventilation. Thus, the effort should be concentrated on these. Saving 20% in the ”other” yield less result than 1% in heating.

In the beginning, all these energy uses are seen as ”faults” that need to be corrected. During the later phases, these blocks are dicided into smaller parts. First, all the required energy use is excluded. For example, the heating block could be something like this:

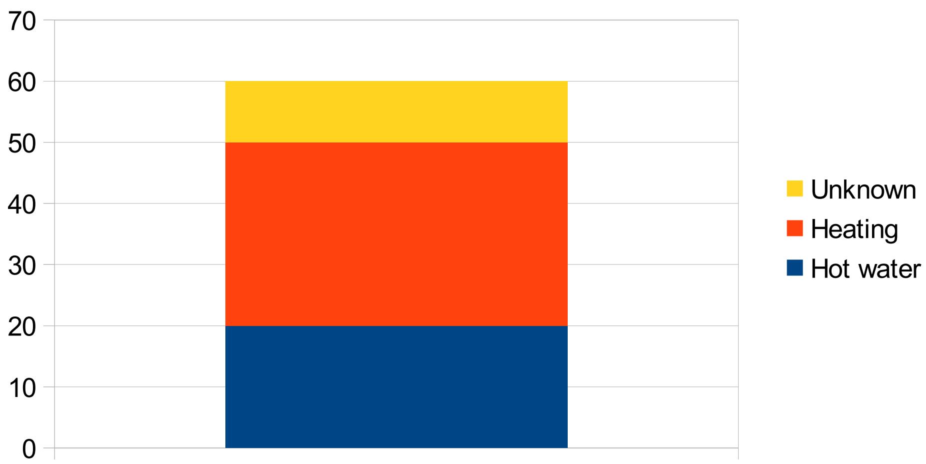

Figure 3: Heating example in detail; source: KyAMK EnergyLab

This reveals that 50 units out of 60 goes to designated use but there are still 10 units of unexplained energy use. These 10 units are presumably wasted in one or more locations in the process and this should be eliminated as far as possible.

After this elimination of ”waste energy”, focus can be shifted into improving the heating or hot water component of the heating block. This process can be repeated as many times as seen fit during the EEA.

4.1.2 FMEA based defining

FMEA is a method to catalog and categorize possible sources of faults. In this method, all the possible sources of energy loss are listed, the possibility and severity of energy loss is estimated for each source and possible solutions to improve each item is suggested.

This is not a defining model per se, but rather a civilized guess what the faults in the process may be. These guesses are based on documented information as well as personal experience. For example:

Item	Energy loss	Probability	Solution
Ventilation	High	Low	Exhaust heat recovery; in-out heat exchanger
Sewage	Moderate	High	Sewage heat recovery
Condence heat from cooling unit	Low	Confirmed	Heat recovery

Similar table helps to identify the possible spots of problem and gives a preliminary list of possible improvements. Later, it may be found out that these improvements are already implemented in which case it is good to measure how well they work.

4.2 Identifying problem points

Problem identification is a process of studying the system, measuring the key values and interviewing users and operators. In DMAIC model, this identification phase is part of the process from defining to measurement and analyzing.

In the defining phase, the identification outlines the areas of energy consumption as mentioned in chapter 4.1. Identifying becomes more important during measurement. Without knowing what to measure and why, it is hard to narrow down the area of study and single point of fault is difficult to identify. The basic idea is to divide the areas of energy consumption formed in the defining phase into smaller parts.

After preliminary work, it is time to become acquainted with the target. Site must be visited in order to get flow charts and system specifications and other detailed information about the target.

It is common practice that someone from staff (operator, caretaker, any other applicable person) who has knowledge of the target gives a tour around the premises showing all the machines, heat exchangers, ventilation and other equipment that are part of the current study. The tour usually includes interviewing staff, photographing equipment and other similar information gathering tasks.

This information is used to divide the defined problem into smaller parts and to help identify and focus the problem points. These problem points will later be used as measurement points. Another way to define measurement points is the energy audit method produced by Motiva. This audit outlines the most basic measurements that have to be made.

The measurement is important part of the work but analyzing is even more important. The same fact applies to the identification. If the fault is poorly identified, or not identified at all during the measurement, it may still present itself when measurement data is analyzed.

Identifying problem points is a ongoing process. In other words, it is not uncommon to discover yet another point to measure and inspect.

4.3 Collecting data

Information about the problem at hands can be gathered from several sources:

- Interviewing users and staff
- Gathering information from system monitor
- Measuring the key points, measurement data from system
- By making first hand observations

This information is used to divide the problem into smaller parts. Information gathering is divided into two parts: interview and measurement. These are not rigid rules that must be applied in a certain sequence but rather two different methods used in analysis.

4.3.1 Interview

Information gathering begins with basic information: name and address of the target, the purpose of the building, area and volume, history of energy consumption (water, heating, electricity) and other applicable information.

It is also advisable to try to talk with the operators and users personally. They usually hold the “hidden knowledge” about how things work or what is not working properly. It is vital that this information can be found and documented since this is invaluable first-hand experience and it is almost never documented in any form.

There is a form to collect basic data in appendix 1. This form, when properly filled, provide most of the information required in the beginning apart from the consumption figures. This form can be filled by the client, in advance if possible, or it can be used as a basis for the interview during the first meeting.

Next phase is to acquire drawings and schematics of the system. These are needed in order to understand where the system may waste energy and to provide the measurement points used in the study later.

4.3.2 Measurement

Measurement requires a measurement plan (see appendix 2). The measurement plan describes the process: what is measured, from where, the aim of the measurement and if measurement is destructive or non-destructive (i.e. is there a need for a sensor to be placed under insulation).

Figure 4: Destructive sensor placement;
source: KyAMK EnergyLab

The measurement period is also critical. While it is not harmful to have a too long measurement period, it is still suggested that time is kept to minimum. All the variables affecting this particular measurement point have to be able to be identifiable.

Typical things to consider:

- Weather/outside temperature, for example:
  - Air cooling units
  - Ventilation/fresh air
  - Solar thermal radiation
- The duty cycle of the equipment, for example:
  - Motor running 24/7
  - Air conditioning in use when room temperature rises above certain level
- Effects of the users
  - If they do what is the utilization rate
- Other aspects depending on location and process

The idea is to acquire as many different situations recorded as possible (e.g. while in use, while not in use, hot outside, cold outside and other similar situations). This will give better overview of how the process performs in this specific part and if it matches the designing.

Typical values to measure include, but are not restricted to:

- Temperature
- Flow rate
- Electricity; quality and quantity
- Pressure

Figure 5: Bad sensor placement; source: KyAMK EnergyLab

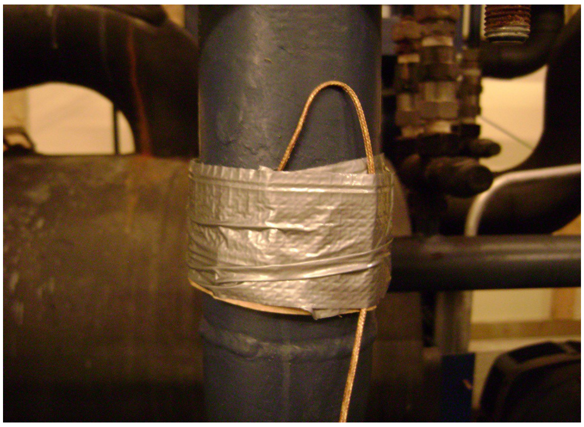

Figure 6: Better sensor placement; source: KyAMK EnergyLab

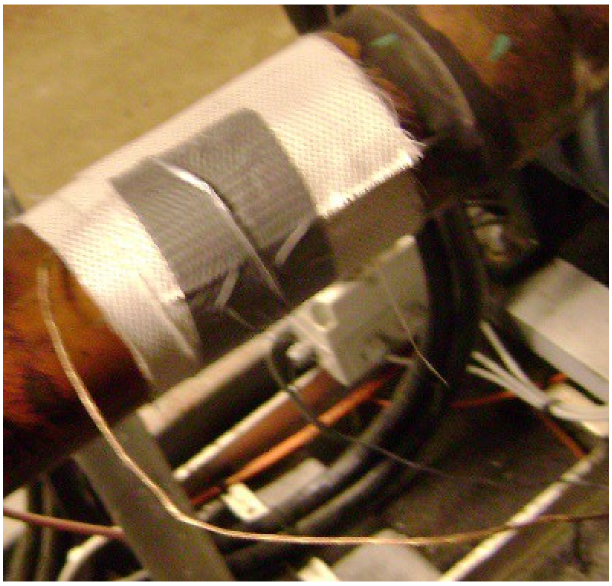

Figure 7: Sensor placement with heat insulation;

source: KyAMK EnergyLab

Figure 8: Sensor placement with heat insulation and insulation from room air;

source: KyAMK EnergyLab

4.4 Analyzing the data

A basic analyzing method is to compare measurement data to original assumptions and technical data of the object. This will open up most of the cases and measurement reveals the amount of energy wasted, if any.

When analyzing the data there is one thing to be kept in mind: Heat transfers from hot to cold, never the opposite way.

Good way to view the consumption figures of the target is by comparing them to another, corresponding target. This way the deviations can be seen in correct context. When these differences in consumption are identified the points of possible improvement are also determined. This reference target may be one of the old cases.

When comparing the consumption figures it pays to keep the whole picture in mind. The reason for difference in one point may be caused by some other difference, e.g. the efficiency of the cooler is partly dependent on the refrigerant and its temperature (see 5.2.1 Case: ice rinks).

4.5 Improvements

After the analysis of the problem is completed, the solutions can be created. These may include, but are not limited to, following methods

- Altering the way of behavior
- Heat recovery
- Using renewable sources, like wind, sun or biomass
- Renewing the old and aged equipment

First, all of the solutions are listed. For each of them the following steps are done: equipment required for each solution is listed with their cost. If required by client or seen applicable the cost of the work is also listed. Estimation of energy saving, both in energy and in cash, is made. In this point the cost for the client of that particular energy saved is used.

The solutions, or improvements, are collected into a list stating the method, cost and repayment period for each improvement. Later in the report these improvements are explained in detail. The customer has always the final word over implementing these suggested improvements.

5 ANALYSIS IN PRACTISE

Here are presented some examples of what kind of typical characteristics targets may have and then there are some real life examples of targets of EEA.

Also, a brief overview of targets with some typical characteristic is presented. These characteristics are not exclusive. A swimming hall, for example, can be both a target with high electricity consumption and a target with high water consumption.

These typical characteristics are explained with relation to real life targets that have been analyzed during the Step to Ecosupport -project.

5.1 Typical targets

These are qualities shared by similar targets. Therefore, these qualities can be identified and studied in detail, and this knowledge can be later used at the targets that share these qualities.

Four different qualities are listed here: cold process, ventilation and air conditioning, high water consumption and high electricity consumption.

5.1.1 Targets with a cold processes

Typical targets with cold processes are factories, food processing industry and ice rinks. The common factor with all these is the need for cold for different purposes. In almost every case, the cold is produced in the same way: by utilizing a compressor process.

A compressor process works in four stages:

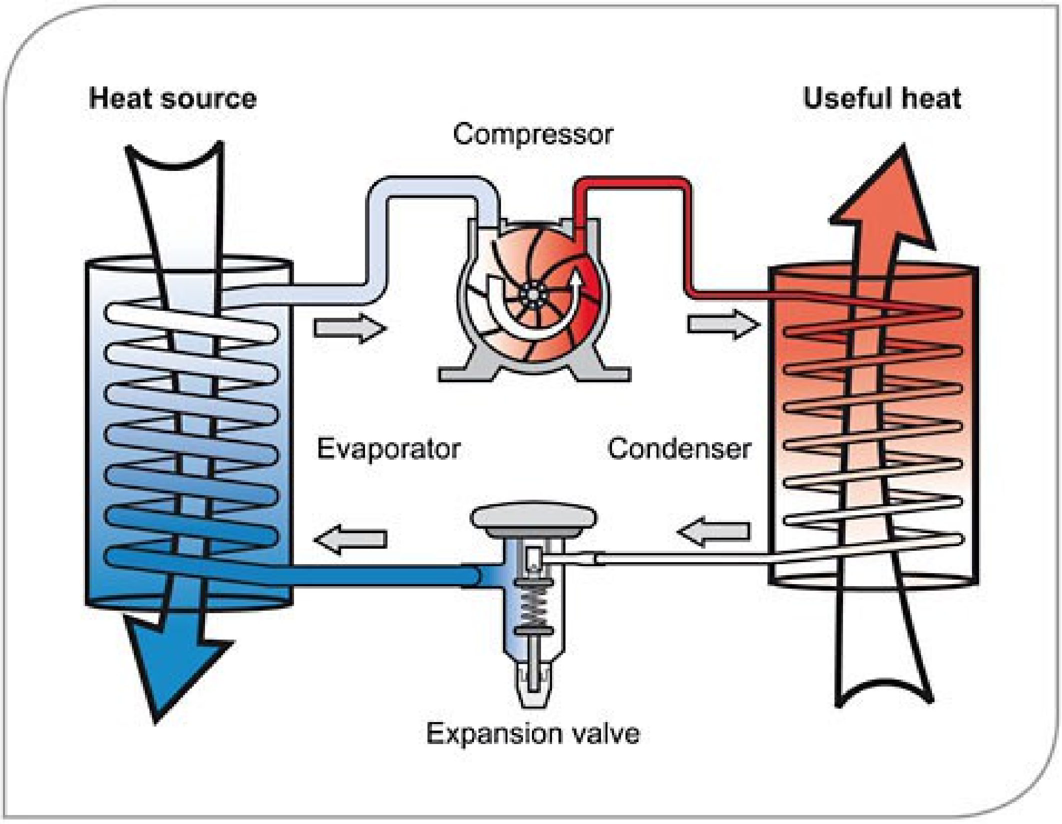

Figure 9: Compressor process;
source: www.veoliawater2energy.com/en/references/heat-pumps

First, the compressor compresses the refrigerant to make it hotter. Then, the refrigerant flows through condenser which is a heat exchanger. In the condenser, the heat energy from the refrigerant is transferred into secondary flow. In this process, the hot gas cools down and liquefies.

After the substance is cooled down, it flows through expansion valve. Here the pressure is lowered and the substance expanses. This causes it to cool down, even to temperatures below 0 ºC. This cooled refrigerant flows through the evaporator, which is another heat exchanger. The cold substance ”gives away” the cold, i.e. it receives the heat energy from the secondary flow which cools down. In this process the cold liquid heats up and gasifies.

When evaporating, the refrigerant receives the heat energy from its surrounding. When condensing, it gives the heat energy away. This process is usually called a heat pump process. It can be used to produce hot, cold or both.

Every time with the cold processes there are two things to be inspected:

1. Economic production of the cold

This may seem self explanatory. The following items should, however, be paid closer look. First, the temperature of the cold. This should not be colder than required. If not required, the cold produced should not be freezing.

Second, if it is possible to produce cold by other means. Is it possible to utilize free cooling (i.e. to use outside temperature for cooling) or if there is another process that requires heat and can give cold in exchange.

2. Proper utilization of the condense heat

The cold process never “produces” cold, it simply moves heat energy from one place to another. When generating cold lots of excess heat energy is to be utilized for some other purpose, such as for heating or to heat hot water.

In short, it could be said that producing cold generates excess heat, and producing heat generates excess cold. This ”byproduct” should be put into a good use in order to reduce energy consumption.

5.1.2 Targets with a ventilation and an air conditioning

Typical targets with the ventilation and the air conditioning are schools, offices and other areas where people work or live. In case of the ventilation, there are some aspects that have to be taken into account.

A fresh air flow is required to keep the CO_2 quantity below the acceptable level. This flow may cause some energy dissipation due to difference between outside and inside temperatures. This is true during the summer (loss of the cooling) and the winter (loss of the heating).

A typical way to counter this dissipation is to use heat exchanger between the exhaust and the fresh air flows, and using the exhaust either to cool or heat the inflow. Certain caution should be exercised: if the exhaust is cooled too much during the winter (i.e. outside temperature is below 0 ºC), there is danger for ice building up. The condense water in exhaust air may freeze in ventilation and cause ice forming in the shaft. In this case there must be a defrost system or heat recovery must be tuned, maybe even shut down.

5.1.3 Targets with a high water consumption

Typical targets with a high water consumption are kitchens, laundry rooms, washing rooms and swimming halls. In these cases, the key factors to analyze are is heating of water and if the heat could be recovered. It is also advisable to find out if it is possible to recycle or reuse water.

In most of the cases, the water is heated by the machines that use it, and there is no secondary use for the waste water. A waste water heat recovery is usually the only viable procedure.

5.1.4 Targets with a high electrical consumption

Typical targets with a high electrical consumption are swimming halls, pumping stations and similar facilities with large motors. The main cause for the high electricity consumption are usually pumps, motors or ovens. Other sources could include server rooms or similar facilities.

In many cases, the consumption of an electricity cannot be reduced, except by renewing the equipment. However, the equipment usually produce waste heat that may be recoverable. In the case of the pumps, especially if flow is closely controlled, changing the throttle valve to the frequency converter can save a great deal of energy.

Some attention should also be paid to the lights and the light source. By changing the old lamps to newer or to LED, some of the energy consumption can be reduced.

In case of LEDs, or energy saving bulbs, the effect on reactive electricity is less studied. If the lights are changed to the LED lights, the quality of electricity should also be measured. If the share of the reactive electricity rises too high, it must be compensated or the electricity provider will charge extra.

5.2 Case studies

These are the real life examples of what can be wrong, what can be right and what can be improved. These targets were analyzed during the Step to Ecosupport -project. The identified problems are explained with the possible solutions.

5.2.1 Case: The ice rinks

The ice rink meets the characteristics of a target with the cold processes. For a case target, there were two quite different ice rinks under study. The ice rink in Karhula is an example of things gone horribly wrong, the ice rink in Hamina is an example of things done right.

The fact that makes comparing these two cases interesting is that they both were in use a part of the year (8-9 months) and this was later changed to continuous use (12 months a year). The change was significant: in Karhula the consumption of district heating energy doubled while in Hamina the consumption of electrical power was halved.

The fundamental problem in Karhula is, the ice rink simply is not designed for continuous use. It has been built on an artificial ice instead of being constructed as a genuine ice rink.

Another major difference is the refrigerant. In Karhula, R404a is used and in Hamina R717, or ammonium. Ammonium can be compressed more thus it becomes hotter than R404a. The cooling will be more effective because the temperature difference with the outdoor air is greater. This improves the COP (efficiency) of the compressor. In addition, the exhaust heat from the ammonium can be used for heating and to produce the hot water in conjugation with the district heating.

The air cooling has proved to be problematic in Karhula. The minimum temperature is limited by the temperature outdoors. During the summer the outdoor temperature can rise as high as +35 to +40 ºC, and the system is designed to have a +25 ºC return temperature. This causes the need for an additional cooling with the booster unit. The booster is also used to produce additional heat for hot water.

One solution for the inadequate cooling power could be the use of ice from the ice resurfacer. For this, a some kind of collection pool with a heat exchanges for the ice would be needed. Another solution could be the change of the refrigerant, but this would require the change of the equipment as well.

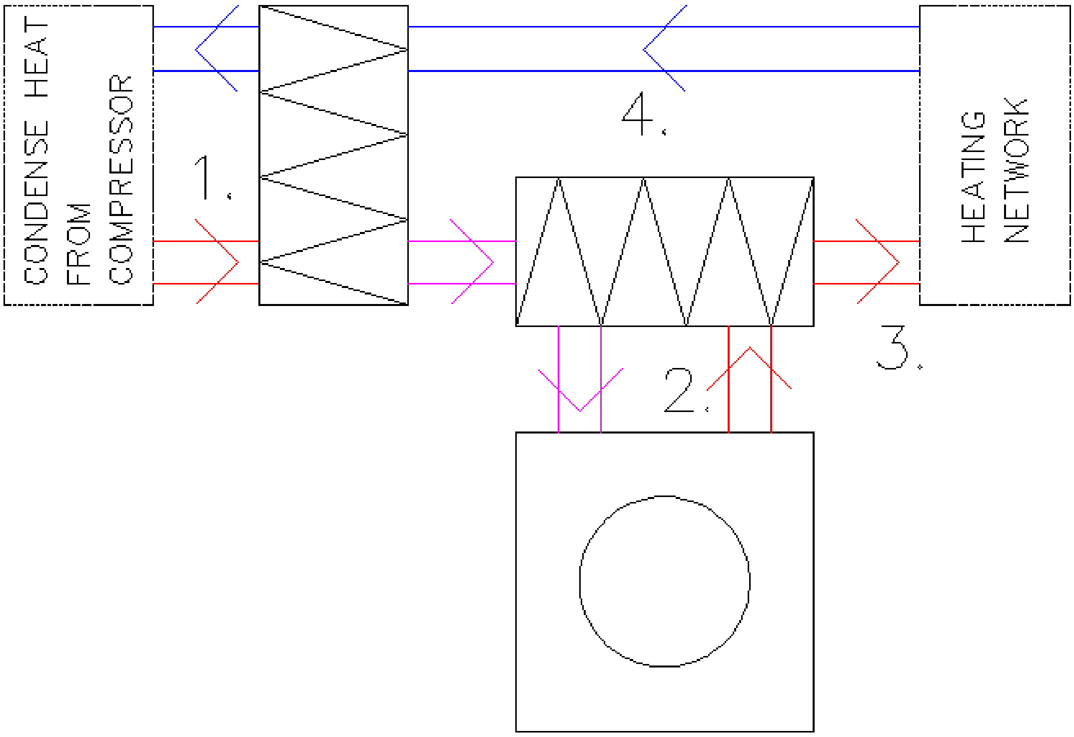

Figure 10: Heating cycle of Karhula;
source: KyAMK EnergyLab

The heating of the building is implemented with water circulation. The colors of the lines express the designing temperatures: condense heat from compressor (1) pre-heats the return line of the heating circulation (4). This is heated with district heating (2) into desired temperature (+55ºC) (3) before used for heating again.

The factor that made this inoperable during summer, was the return line (4) to be in a higher temperature of the return line compared to the condense heat from the compressor (2). In reality, the circulation was heated with the district heating, and that was used for heating in circulation and the excess was transferred into the condense circulation, and to the outdoor air cooling unit. Possible solution for this would be to cut off the district heating during the summer.

The last problem, learned from the operators, is that the concrete slab on which the ice is made suffered from damages caused by ground frost. This was a reason for ice having to be melted for repairs shortly before analysis took place.

The only problem in Hamina that was identified was that the condense heat was wasted during summer because there is no more use for the heat energy. The possible solution for this could be a connection to the district heating network.

Karhula ice rink	
Problem	Solution
The district heating vented to the air cooler	Cut off the district heating during summer; a HVAC automation to control the use of the district heating
Increased use of the district heating	As above; return to part of the year -usage
Insufficient cooling power	The use of the ice from the ice resurfacer for cooling; change of the refrigerant
Hamina ice rink	
Problem	Solution
Excess heat energy with no use	Connection to district heating network

5.2.2 Case: The office building

The office building meets the characteristics of a target with the ventilation. Students from KyAMK had performed an energy audit earlier for the building. The real estate manager requested an additional research about the use of the solar power for electricity or heating. In addition to this, the use of condense heat for producing the hot water was examined.

The building is in two parts: the older, original office building which is three stories high and newer addition, a six stories high tower. Both sections have their own gas boiler for heating and hot water heating as well as separate air conditioning units with cooling unit.

The case of using condense heat from the cooling unit is a concept that only works for the old part. This is because the condense heat is too cold to be used for heating, and the new part has practically no hot water consumption (a measurement of $40m^3$ in a year 2013, the data provided by the real estate manager). For the old part of the building, this proved to be a viable solution. The repayment period would be less than ten years, in the most optimistic calculations under five years.

The case of using solar collectors for heating and hot water had two major problems.

1. The price of the collectors
2. Size and location of the storage tank

First, the price of the collectors is feasible for the purposes of replacing part of the natural gas used for the heating and the hot water, the rest of the system causes the installation to become too expensive to be economically feasible improvement.

Second, the storage tank has designing volume of 50-100 liters per square meter of the collector surface. If the solar power would be properly utilized for hot water production in the old part, the collectors would require an area of $190m^2$. This translates into a storage tank volume of 10-20 m^3. The only location for the tank would be outdoors. While is is plausible location, and collectors would provide enough heat to keep the tank molten trough the winter, the complexity of the design became a severe obstacle.

The case of using solar panels for electricity suffered the same drawback as the collectors: the cost of the panel is simply too high compared to savings via electricity production.

Office building	
Problem	Solution
The photovoltaic energy	Not feasible, the price of panels is too high
The solar thermal energy	Not feasible, the installation is too complex and the overall price too high
The use of a condence heat to preheat the hot water	Feasible, installation simple, requires some automation, less than 10 years repayment period

5.2.3 Case: The swimming hall

The swimming hall meets the characteristics of both a target high water consumption and a target with high electrical consumption. The swimming hall is a textbook example of a difficult target to analyze. The requirements for the operation are such that the improvements are hard to define.

Before becoming acquantainted with the case, there were few ideas based on preliminary data gained. These included the heat recovery from the waste water and the heat recovery from the exhaust air. All of these methods drafted were already in use in the target.

During the preliminary visit, it was noticed that the filter circulation flow is controlled by the choke valve. During the winter, while the outdoor pool is not in use, the flow is choked. This causes a loss in the pumping power, therefore the loss of the electricity. The control methods of this kind should be avoided nowadays, instead a frequency controller should be used. Apart from this, the only thing to do was to perform measurement and analysis by Motivas energy audit.

Tight restrictions placed by the regulations and the operation of the swimming hall makes it difficult to identify any plausible energy saving methods in the process. Possible methods are the heat recovery from the waste water and the heat recovery from the exhaust air. Also, the control methods and values of the pumps should be inspected. One fact to keep in the mind is the exhaust air in swimming hall is moist. If the exhaust air is cooled too much, there is a risk of freezing unless preparations are made to prevent this.

Swimming hall	
Problem	Solution
The heat recovery from the waste water	Already implemented, measure the efficiency
The heat recovery from the exhaust air	Already implemented, measure the efficiency
The circulation flow controlled by the choke valve	Replace the valve with a frequency converter

6 CONCLUSIONS

The use of the energy is ever rising tendency. While waiting for a some perpentual energy source, that will save the earth and the mankind, the other actions must be taken. While increasing the part of renewable energy in the power production is a good thing, it is even better to lower the use of energy.

The greenhouse effect and the climate change have led to change in the political attitudes. This has created different goals and agreements to reduce the GHG (Green House Gas) emissions. The major share (80%) of these emissions come from the energy use, and nearly half (46%) of this comes from the energy industry.

Since the share of the renewable energy is growing slowly due to the price and local resistance, the best way to reduce the GHG emissions is to reduce the use of energy.

Even if there is the energy audit, it still only meets the needs of the legislators. While most of the energy wasting can be controlled with the energy audit, it still may miss many faults in the system. The analytical aproach of the EEA tries to understand the use of energy as whole, and to analyse the weak points in the process or the building.

The quality is the key to reduce the emissions. The quality is a part of our everyday life, as well as part of the production or the consumption of the consumer goods. While it may be difficult to alter the behavior of man, it is still possible to alter the way our buildings and processes consume energy.

This work is not even close to be finished. In fact, this is just the first step on the long road of implementing quality thinking into energy efficiency. There is still a great deal of work to be done. In this paper, the quality concept is barely touched. There is a need for a quality management tools to be converted into energy efficiency tools.

The energy efficiency philosophy is a way to make more out of the same amount of energy previously used. The problem with the energy efficiency is that it seldom is explained in detail. By appyling a quality management philosophy to the energy audit procedures, we can create a method for the energy efficiency thinking, that will help us to reduce the use of energy in the current living, and help us achieve a greener life tomorrow.

REFERENCES

/1/ Fanchi John R., 2005, Energy in the 21st Century, p. 1-23 [10.11.2014]

/2/ Fanchi John R., 2005, Energy in the 21st Century, p. 54-58 [10.11.2014]

/3/ International Atomic Energy Agency, The International Nuclear and Radiological Event Scale (INES); [WWW] http://www-ns.iaea.org/tech-areas/emergency/ines.asp [4.11.2014]

/4/ The Guardian, Nuclear power plant accidents: listed and ranked since 1952; [WWW] http://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank [4.11.2014]

/5/ World Nuclear Association; [WWW] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Germany/ [4.11.2014]

/6/ energy post, The French disconnection – How to reduce the nuclear share in France's energy mix; [WWW] http://www.energypost.eu/french-disconnection-reduce-nuclear-share-frances-energy-mix/ [4.11.2014]

/7/ KyotoProtocol – Toward Climate Stability; [WWW] http://www.kyotoprotocol.com/ [4.11.2014]

/8/ Olivier Jos G.J., Janssen-Maenhout Greet, Muntean Marilena, Peters Jeroen A.H.W, 2013, Trends in Global CO2 Emissions: 2013 Report; [PDF] http://edgar.jrc.ec.europa.eu/news_docs/pbl-2013-trends-in-global-co2-emissions-2013-report-1148.pdf [24.9.2014]

/9/ European Comission, Climate Action; [WWW] http://ec.europa.eu/clima/policies/ets/index_en.htm [24.9.2014]

/10/ YouTube; Autohor EUClimateAction, The EU Emission Trading System explained http://www.youtube.com/watch?v=yfNgsKrPKsg [24.9.2014]

/11/ O'Keefe Phil, O'Brien Geoff, Pearsall Nicola, 2010. The Future of Energy Use; p. 171-230 [4.11.2014]

/12/ Promaint, 2009, Kuntoon perustuva kunnossapito; Kunnossapidon julkaisusarja – n:o 13, p. 74 [3.11.2014]

/13/ Motiva, Motiva Oy; [WWW] http://www.motiva.fi/motiva_oy [4.11.2014]

/14/ Promaint, 2009, Kuntoon perustuva kunnossapito; Kunnossapidon julkaisusarja – n:o 13, p. 76-77, 128-132 [3.11.2014]

APPENDIX 1 **BASE INFO SHEET FOR A BUILDING**

Building

Name			Type
Address			
Built	Renovated	Expanded	
Total Area		Area of level	
Level count		Building volume	

Contact info

Real estate manager		
Name	Phone	eMail
Maintenance		
Name	Phone	eMail
Machine responsible		
Name	Phone	eMail

Heating

☐Oil	L / year	☐Wood chip ☐Pellet ☐Natural gas	m^3 / year
☐Electricity ☐District heating	kWh / year	☐Other	Consumtion

Water

Measurement point	Consumption
1.	
2.	
3.	
Total	

Cooling

Cooling power (kW)	Electrical power (kW)
Utilising condensing heat	
Target	Energy (kWh / year)

Air Conditioning

Machine	Service area	Control ☐Auto ☐Man	Setpoints	Exhaust heat recovery ☐Plate ☐Rotary ☐Fluid
Age	Maxim air flow (m^3)	Fresh air flow (m3)	Fresh air temperature	

Machine	Service area	Control ☐Auto ☐Man	Setpoints	Exhaust heat recovery ☐Plate ☐Rotary ☐Fluid
Age	Maxim air flow (m^3)	Fresh air flow (m3)	Fresh air temperature	

Machine	Service area	Control ☐Auto ☐Man	Setpoints	Exhaust heat recovery ☐Plate ☐Rotary ☐Fluid
Age	Maxim air flow (m^3)	Fresh air flow (m3)	Fresh air temperature	

Illumination

Light source	Amount	Power

Electricity

Provider	Main fuse (A)	Yearly consumption (kWh)
Billed active power kWh / year	Billed reactive power kWh / year	

As an attachment include following consumption figures on monthly level from previous three (3) years

- Electricity
- Water
- Heat

APPENDIX 2. **MEASUREMENT AGREEMENT**

As part of energy efficiency analysis some measurements must be made from various parts of the system. Measurements are performed according to previously created measurement plan that has been accepted by the client. Measurement equipment is installed by analyst.

The responsibility of client is to take care that measurement equipment stays intact and unharmed. If measurement is to be repeadet due to lack of clients effort then the client is to pay all the expenses caused by travel, acoomondation and food.

Analyst will install the equipment and is responsible for that they cause no obstruction to client. Power cables must also be placed in such way that they will cause no hazard or obstruction to clients normal activity. Installation of the quipment must be made in such fashion that damaging is not possible without outside influence.

Thermometer A		Thermometer B	
Sensor 1		Sensor 1	
Sensor 2		Sensor 2	
Sensor 3		Sensor 3	
Sensor 4		Sensor 4	
Thermometer C		Energy and power quality analyzer	
Sensor 1			
Sensor 2		Extension cords	
Sensor 3			
Sensor 4			

Signatures

Client **Analyst**

Date and place

Attachment: Measurement plan

Attachment to measurement agreement: Measurement plan

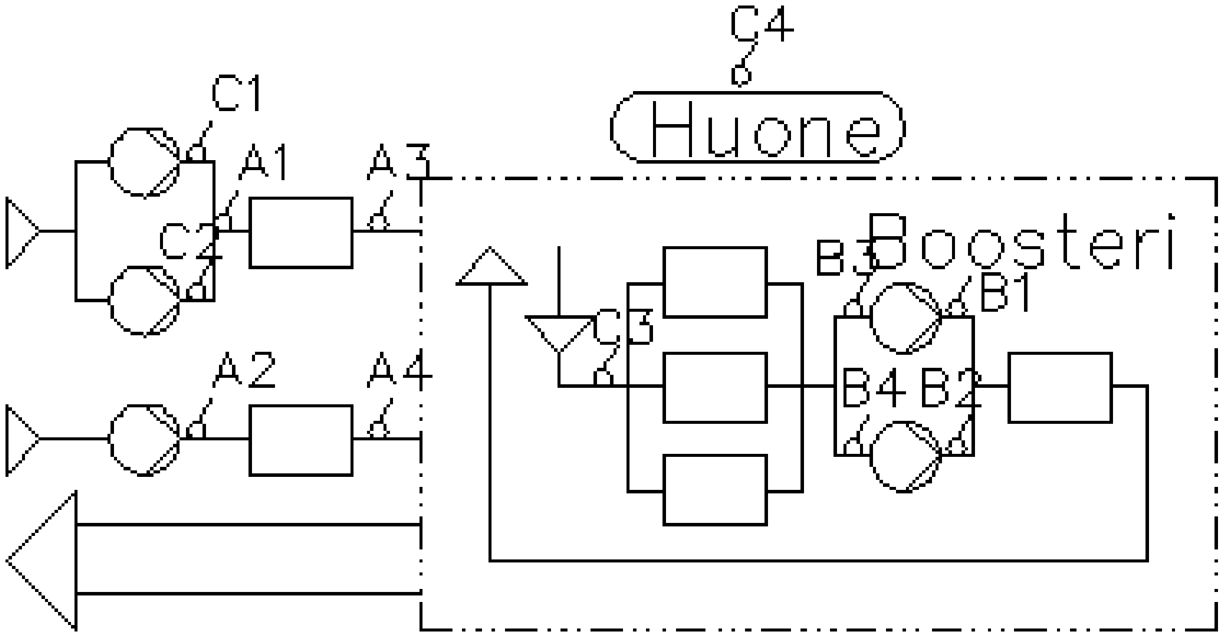

Figure 11: Example of measurement plan; Measurement plan of booster unit in Karhula ice rink; source: KyAMK EnergyLab